THE

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OF THE

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THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant. —*Novum Organum, Præfatio.*

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Page 52, line 13 from bottom, and page 53, explanation of Fig. 3, *delete* "(reversed)."

Page 88, note §, *for* "Bristowe" *read* "Bristow."

Page 119, explanation of Fig. 1, line 3, *after* "stone" insert "*l*."

Page 120, line 7 from foot, *after* "except" add "*Trophon clathratus* and."

Page 123, line 2 from foot, *for* "of" *read* "as."

THE

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Vol. XLIV.

1. Note *on the so-called* "Soapstone" *of* Fiji. By Henry B. Brady, Esq., F.R.S., F.G.S. (Read November 9, 1887.)

[Plate I.]

Soon after the cession of the Fiji Islands to the British Crown, some ten or twelve years ago, it was determined by the authorities to remove the government offices from Levuka, a flourishing settlement on the little island of Ovalau, to some locality on one of the larger islands of the group. The site chosen for the new capital was Suva Point, a promontory on the south coast of Viti Levu, commanding a considerable bay or harbour to the west, and rising on the land side to an elevation of 300 or 400 feet. How far the geological aspects of the question were taken into consideration it is needless now to inquire; we may confine our attention to the fact that the area selected presents certain peculiar and interesting features in respect of its superficial deposits.

I visited the islands in 1874–5, but owing to repeated detentions, there and elsewhere, the result of quarantine regulations, the rainy season had already set in before permission was given to land, and at Suva I was in consequence unable to do any great amount of field observation. The geological features of the localities have, however, been described by a competent naturalist, Mr. Horne, in the following terms:—

"In Viti Levu and Vanua Levu, sedimentary or limestone rocks are found on all the mountains. Where absent, denudation, it is conjectured, has been the cause . . . . At Suva the strata on the sides of the slopes lie at a greater or less angle, while on the top of the slopes the strata assume a somewhat horizontal or unconformable position. This would point to the presumed unconformable strata either having been deposited after the formation of the other strata, or, what is more likely, these are the top of the folded strata, *i. e.* the strata forming the slopes, and from their horizontal position better preserved from denudation. This rock in many places is soft, and crumbles when exposed to the air. It is smooth and very slippery when wet or polished, and is locally known as *Soap-stone.* In other places it is hard, brittle, and shattered to the size of road macadam, often rough from coralline and other sands, pieces of shells, &c., being imbedded in it. These may be noticed on descending the cliffs from the native village of Tamavua to the river, and again at the native town of Kaluba, on the river of the same name, between Suva and the Rewa. At Tamavua and Kaluba the cliffs are about 300 feet in height. At the last, the river has cut down through this soft rock, and now flows over a bed of hard agglomerate"*. To this I may add, from particulars furnished by my friend Mr. H. Reeve, late of the Government Survey and Public Works Department at Suva, that the superficial deposits referred to extend from a point about twelve miles west of Suva to the valley of the Rewa River, which must be about as far in the opposite direction, and from the sea-coast to a height, in one place at any rate, of 700 feet, at a distance of three or four miles inland; more commonly, however, they are not met with at a greater elevation than 250 feet. The thickness of the deposit, of course, varies in different localities. Borings for water have generally shown that it rests on a sort of coral-limestone.

From a practical standpoint, that is to say, as a foundation for roads, in a region where harder material is not readily accessible, or for buildings, the objectionable qualities of the deposit are not overstated by the author above quoted. The inhabitants of Suva complain that in the rainy season their roads are so deep in soft, sticky mud as to be almost impassable, whilst in hot dry weather they are tormented by ceaseless clouds of irritating dust.

Deposits of very similar nature occur in many of the islands of the Pacific, and typical specimens of the so-called "Soapstone" exhibit precisely the same physical characters as some of the softer rocks described by Dr. H. B. Guppy in his excellent memoir on the recent calcareous formations of the Solomon Group†. They belong to the first division of Dr. Guppy's classification, namely, "rocks which, being largely composed of volcanic *débris* mixed with the tests of Foraminifera, Pteropods, and other Molluscs, have a composition very similar to that of the volcanic muds at present forming around oceanic islands in the Pacific," and containing "both pelagic

* 'A Year in Fiji,' by John Horne, F.L.S., London, 1881, pp. 165, 166.

† "Observations on the Recent Calcareous Formations of the Solomon Group, made during 1882–4," by H. B. Guppy, M.B., F.G.S., Surgeon H.M.S. 'Lark.' Trans. Roy. Soc. Edinb. vol. xxxii. pp. 545–581, pls. cxliv., cxlv. (1885).

and bottom forms of Foraminifera." Further, this Suva deposit corresponds pretty closely to the first subsection of the class referred to, which includes "friable rocks, containing from five to twenty per cent. of carbonate of lime, and displaying to the eye only the white specks of minute Foraminiferous tests with a few of macroscopic size, such as *Cristellaria cultrata* and *Nodosaria soluta*, Molluscan shells being rarely observed."

The Suva deposit, in its typical condition, is exceedingly friable and easily disintegrated. It varies in colour from nearly white to dark grey, generally speckled more or less with minerals of darker hue. Under the microscope it presents the characters of a fine siliceous mud, with crystals and grains of augite, hornblende, felspar, and sometimes magnetite, together with sparsely scattered tests of Foraminifera. Its chemical composition varies within certain limits, but may be roughly stated as about 50 per cent. silica; 18 per cent. alumina; 5 or 6 per cent. lime and magnesia; a variable quantity (from 3 to 8 per cent.) ferric oxide; and 16 per cent. water; with a small proportion of alkalies, chiefly potash. The lime and magnesia exist mainly, if not entirely, in the form of silicates, and the rock gives off no appreciable quantity of carbonic acid on treatment with acids.

Intercalated with beds of this typical description are layers of a white and also of a lilac or purplish tint, differing somewhat from the rest in physical characters. The whiter variety is harder and more compact, and gives a more or less conchoidal fracture. Treated with water, it is easily broken up into small angular lumps, but does not readily disintegrate further. Its chemical composition does not differ materially from that of average samples of the common variety. It contains rather less alumina, iron, and silica, somewhat more lime and magnesia (a portion existing as carbonate), and a larger percentage of combined water.

The dark-coloured, lilac, or purplish bands resemble an exceedingly fine sandstone, though by no means uniform in texture. This sort is hard and difficult to disintegrate. A fragment, on analysis, yielded nearly 60 per cent. silica and 20 per cent. alumina. Microscopical sections revealed a few pelagic Foraminifera, but were otherwise devoid of organisms.

In addition to the foregoing, the deposit contains small veins of iron-pyrites.

My attention has been chiefly devoted to the common, grey, friable rock which forms the bulk of the deposit, and especially to its microscopic fauna. Material of this description cannot be studied with advantage by means of transparent sections. Thin slices of geological deposits even less cohesive than these may readily be made by hardening the material in the first place with a resinous varnish, in the manner described by Mr. Pearcey*; but microscopical sections of the Suva rock, so prepared, were chiefly serviceable in showing

* Proc. R. Phys. Soc. Edinb. vol. viii. p. 296, pl. 11. Mr. Pearcey has been good enough to prepare sections of these and some similar rocks for me by his method.

how large a proportion of impalpable mud it contained as compared with organic constituents.

The only satisfactory method of treatment in such cases is to soften the material in water and wash on a fine sieve, proceeding in exactly the same way as with a sample of the recent sea-bottom. Three samples of the Suva deposit have been so examined. In all of them the proportion of residue remaining on a sieve of 120 meshes per linear inch was extremely small, and consisted mainly of Foraminifera with a few Ostracoda.

I. Light-grey rock from a cutting on the shore-road close to the sea-level.

II. Similar material, of rather lighter colour, from an elevation of 100 feet or more.

III. Nearly white, somewhat harder and more compact specimen, from an intermediate point.

So far as the Microzoa are concerned, the first two present no important differences—none that might not be observed in dredgings from the recent sea-bottom, taken at similar depths a little distance apart. Of Foraminifera they have thirty-six species in common. The whiter sample, No. III., differs from the others in the comparative absence of *Lagenæ* and *Nodosarinæ*; and appears, from both positive and negative indications, to have been deposited in somewhat deeper water. In all three there is a remarkable scarcity of arenaceous forms. Subjoined are a few notes on the rarer and more interesting species, together with a complete list of those furnished respectively by the samples above described.

6. Haplophragmium rugosum, d'Orbigny, sp. (Pl. I. fig. 2.)

"Lenticulae minusculae petrefactae, calcareae nempe aut siliceae," Soldani, 1798, Testaceographia, vol. ii. p. 110, pl. 26. fig. N.

Robulina rugosa, d'Orbigny, 1826, Ann. Sci. Nat. vol. vii. p. 290. no. 21.

Lituola rugosa, Parker, Jones, and Brady, 1871, Ann. & Mag. Nat. Hist. ser. 4, vol. viii. p. 242. no. 117, pl. 9. fig. 31.

The only arenaceous Foraminifera found were two specimens, about $\frac{1}{60}$ inch (0·4 mm.) in diameter, of Nautiloid contour, depressed at the umbilicus, and with thin rounded margin, but bearing little external evidence of segmentation. The interior of the test appeared, in section, to be constructed very much after the manner of such forms as *Haplophragmium pseudospirale*, Will., sp., that is to say, roughly subdivided by aggregations of sand-grains, but without any regular or definite septa.

The specimens under notice may, I think, be referred to a species founded by d'Orbigny on a figure in Soldani's 'Testaceographia,' *loc. cit.*, from a fossil occurring in the later Tertiary deposits of Coroncina, near Sienna.

Under the name *Haplophragmium acutidorsatum* (Jahrb. d. k.-ung. geol. Anstalt, 1875, vol. iv. p. 10, pl. 1. fig. 1), von Hantken figures a similar form from the lower Tertiaries of Hungary. This, however, appears to differ from the specimens above described in its comparatively regular and complete septation.

7. Textularia quadrilatera, Schwager.

A clear-shelled compressed variety of *Textularia*, with four sharp or carinate edges, first described by Schwager from specimens occurring in a deposit of very similar nature to that under notice in the Nicobar Islands. It is abundant in some of the Post-tertiary material collected by Dr. Guppy in the Solomon Islands. As a recent species it is not uncommon in the South Pacific, at depths of over 400 fathoms; in shallow water I have only record of its appearance at one point, Humboldt Bay, Papua, 37 fathoms.

10. Spiroplecta annectens, Parker & Jones, sp.

Only one or two broken specimens of this rare and peculiar form were met with. The 'Challenger' dredgings furnished recent examples from two localities, both in the region south of Papua, depth 129 fathoms and 155 fathoms respectively.

18–21. Pleurostomella, spp.

The genus *Pleurostomella* is represented by four species, possibly all the well-characterized forms at present known; and it is noteworthy that two of these were first obtained by Dr. Schwager from the Nicobar deposit before referred to. Of three of the species, *Pl. alternans*, *Pl. brevis*, and *Pl. rapa*, the known recent distribution is very limited. All of them were observed in the 'Challenger' material from the Ki Islands, 129 fathoms; *Pl. alternans* also in a dredging at 2075 fathoms, in the Low Archipelago; and *Pl. brevis* (by Mr. Pearcey) at 1950 fathoms, in the Southern Ocean. *Pleurostomella subnodosa* was met with sparingly at four 'Challenger' stations in the South Pacific and South Atlantic, ranging from 1375 to 2350 fathoms.

26. Ehrenbergina bicornis, sp. nov. (Pl. I. fig. 3.)

Test subspherical, regularly biserial, earlier portion helicoid; margin entire; armed with two stout spines, one at each side, directed outwards. Longer diameter about $\frac{1}{30}$ inch (0·8 millim.).

This is a curious modification of the Cassiduline type, somewhat allied to *Ehrenbergina hystrix*, the short scattered spines of which are replaced by two long processes, one at each lateral margin, protruding at right angles to the longer diameter of the shell. The segmentation is exceedingly regular, and the septal lines are scarcely, if at all, depressed.

Ehrenbergina bicornis occurs in two out of three samples of Suva material; and I have also recently found it in the chalky deposit from New Ireland, described by Prof. Liversidge *.

27. Ellipsoidina ellipsoides, var. oblonga, Seguenza. (Pl. I. fig. 1.)

Ellipsoidina oblonga, Seguenza, 1859, Eco Peloritano, Anno v. ser. 2, fasc. 9.

* Geol. Mag. 1877, dec. 2, vol. iv. p. 529.

Ellipsoidina ellipsoides (pars), Brady, 1868, Ann. & Mag. Nat. Hist. ser. 4, vol. i. p. 338.

It was particularly gratifying to meet with this form, the representative of a genus for which I have been searching nearly twenty years, and hitherto known only by specimens obtained by Prof. Seguenza from the Miocene rocks in the immediate vicinity of Messina. I may add that I have also had the good fortune to find the typical form, as well as the elongated variety, in some of the soft deposits collected by Dr. Guppy in the Solomon Islands. With respect to the somewhat anomalous structure of the test, I have at present nothing to add to what has already been written on the subject.

34. Nodosaria longiscata, d'Orbigny.

Nodosaria longiscata, d'Orbigny, 1846, For. Foss. Vien. p. 32, pl. i. figs. 10–12.

Nodosaria arundinea, Schwager, 1866, Novara-Exped., geol. Theil, vol. ii. p. 211, pl. v. figs. 43–45.

Nodosaria arundinea, Sherborn & Chapman, 1886, Journ. R. Micr. Soc. ser. 2, vol. vi. p. 747, pl. xiv. figs. 28, 29.

Some misunderstanding has arisen in connexion with this species from its insufficient illustration by the figures in the "Vienna-Basin" monograph. Through the ever-ready kindness of Herr Karrer, of Vienna, I have had the opportunity of examining a number of the original d'Orbignyan specimens, and I find that the tapering of the segments towards the distal end, which has been regarded as a distinctive feature, is at most exceedingly slight and often cannot be detected at all; indeed some of the shells are quite undistinguishable from the figures given by Dr. Schwager from Kar Nicobar specimens. The species occurs in the soft deposits of the Solomon Islands as well as in those of Fiji, and the same variability within certain limits may be noticed in all.

51. Polymorphina sororia, Reuss.

Only one or two examples, and those in the fistulose condition.

52. Uvigerina pygmæa, d'Orbigny.

The elongate, elegant variety figured in the 'Challenger' Report, pl. lxxiv. figs. 13, 14.

57–60. Sagrina, spp.

Sagrinæ are abundant in these deposits and show a tendency, especially noticeable in *S. virgula* and *S. raphanus*, to become completely Nodosariform.

73. Sphæroidina ornata, sp. nov. (Pl. I. fig. 4.)

Test spherical or subspherical, slightly excavated at the umbilicus; consisting of an involute spire, of which about four chambers are visible externally, the ultimate segment occupying nearly one half of the exterior convolution; surface beset with small, irregular, convex prominences, except in the region of the aperture, which is marked with radiating grooves or furrows; aperture obscure, crescentiform, situated in a depression at the inner margin of the terminal segment. Diameter $\frac{1}{50}$ inch (0·5 millim.).

This is a somewhat obscure organism, but it may, I think, be safely referred to the genus *Sphæroidina*, though differing in point of superficial ornament from any species hitherto described. Only two specimens have been met with. It is possible that the minute shells described provisionally under the name *Discorbina pulvinata* ('Challenger' Report, p. 650, pl. 88. fig. 10), which exhibit very similar surface-markings, may represent the immature condition of the same species; whether this be so or not, however, can only be determined from the examination of a larger number of specimens than are at present forthcoming.

75. Truncatulina mundula, Brady, Parker, & Jones.

A compact, neatly constructed variety of *Truncatulina*, described and figured in a recent memoir on some Foraminifera from the Abrolhos Bank (Trans. Zool. Soc. Lond. 1887, vol. xii. pt. 7, pl. xlv. fig. 25, in the press). Morphologically it is a near ally of *Truncatulina Haidingerii*, but is less stoutly built and has nearly double the number of segments in each convolution; the periphery is usually sharp, and the sutures on the superior face are marked by a certain amount of thickening of the shell-wall. Its nearest isomorph is *Pulvinulina Karsteni*.

On the Abrolhos Bank it is common at 260 fathoms, but the form is by no means rare in tropical seas.

It may be here observed that the specimens assigned in the Table to *Truncatulina Haidingerii* and *Tr. Akneriana* do not in either case present quite the typical characters of these species, as portrayed in d'Orbigny's "Vienna-Basin" monograph. The differences, however, are in comparatively trifling details, and not sufficient to demand separate specific treatment.

The remains of a few Ostracoda were found associated with the Foraminifera, but they were for the most part imperfect and otherwise in poor condition. These have been examined by my brother Dr. G. S. Brady, who writes as follows concerning them:—"Some, if not identical, approach very closely certain of the 'Challenger' species. In fact no doubt there is *Krithe producta*, a common recent species in the southern hemisphere; and there are valves which may be referred with some little reservation to *Cythere dictyon* and *Cythere arata*; but this is all that can be said."

Turning now to the question of geological age, there need not, I think, be the slightest hesitation in assuming the Post-tertiary origin of the deposits under consideration. Of the ninety-two species of Foraminifera which have been identified, eighty-seven are forms still living in the neighbourhood of the Pacific islands; whilst the remaining five, two of which are new to science, are all extremely rare, and from one cause or other may easily have been overlooked hitherto in the examination of recent dredgings.

The depth at which the deposit may originally have taken place can only be determined approximately. Comparing the list of species with similar lists compiled from material collected on the 'Challenger' Expedition at various Pacific stations within the tropics, it is found to include several forms not recorded from depths of less than 129 fathoms, and certain others of which the minimum depth is about 150 fathoms; besides a few, relatively unimportant, so far as our present purpose is concerned, which are best known from much deeper water. Nevertheless, judging from its general facies, the Rhizopod-fauna is one that I should expect to find in a deposit forming at from 150 to 200 fathoms (more rather than less) in the neighbourhood of any of the volcanic islands of the Pacific.

Post-tertiary Foraminifera of Suva, Fiji.

	I.	II.	III.
1. Biloculina bulloides, *d'Orb.*	*	*	
2. —— depressa, *d'Orb.*	*	*	
3. Miliolina seminulum, *Linn.*, sp.	*	*	*
4. —— venusta, *Karrer*, sp.	...	*	
5. Planispirina celata, *Costa*, sp.	*	*	*
6. Haplophragmium rugosum, *d'Orb.*, sp.	*		
7. Textularia quadrilatera, *Schw.*	*	*	*
8. Verneuilina pygmæa, *Egger*, sp.	*	*	*
9. Bigenerina capreolus, *d'Orb.*, sp.	...	...	*
10. Spiroplecta annectens, *P. & J.*, sp.	*		
11. Gaudryina pupoides, *d'Orb.*	...	*	
12. Clavulina communis, *d'Orb.*	*		
13. Bulimina Buchiana, *d'Orb.*	*		
14. —— inflata, *Seg.*	*	*	*
15. Bolivina punctata, *d'Orb.*	...	...	*
16. —— Hantkeniana, *Brady*	*	*	*
17. —— limbata, *Brady* (?)	...	*	
18. Pleurostomella subnodosa, *Rss.*	*		
19. —— alternans, *Schw.*	*	*	*
20. —— brevis, *Schw.*	*		
21. —— rapa, *Gümb.*	*		
22. Cassidulina crassa, *d'Orb.*	*	...	*
23. —— calabra, *Seg.*, sp.	*	*	*
24. —— Bradyi, *Norm.*	*		
25. Ehrenbergina serrata, *Reuss*	*	...	*
26. —— bicornis, n. sp.	*	...	*
27. Ellipsoidina ellipsoides, var. oblonga, *Seg.*	*		
28. Chilostomella ovoidea, *Rss.*	...	*	
29. Lagena hispida, *Rss.*	...	*	
30. —— lævigata, *Rss.*, sp.	*	*	
31. —— marginata, *W. & B.*, sp.	*		

Post-tertiary Foraminifera of Suva, Fiji (continued).

	I.	II.	III.
32. Lagena Orbignyana, *Seg.*, sp.	...	*	
33. —— plumigera, *Brady*	...	*	
34. Nodosaria longiscata, *d'Orb.*	...	*	*
35. —— mucronata, *Neugeb.*, sp.	...	...	*
36. —— farcimen, *Sold.*, sp.	*		
37. —— consobrina, *d'Orb.*	*	*	
38. —— ——, var. emaciata, *Rss.*	*	*	
39. —— radicula, var. annulata, *T. & B.*	*		
40. —— hispida, *d'Orb.*	*		
41. —— obliqua, *Linn.*, sp.	*	*	
42. —— perversa, *Schw.*	...	*	
43. Rhabdogonium tricarinatum, *d'Orb.*, sp.	*		
44. Cristellaria obtusata, *Rss.*	...	*	
45. —— variabilis, *Rss.*	...	*	
46. —— rotulata, *Lamk.*, sp.	*	*	
47. —— cultrata, *Montf.*, sp.	*	*	*
48. —— acutauricularis, *F. & M.*, sp.	*		
49. —— cassis, *F. & M.*, sp. (?)	*		
50. Polymorphina angusta, *Egger*	*	*	
51. —— sororia, *Reuss.*	*	*	
52. Uvigerina pygmæa, *d'Orb.*	*		
53. —— tenuistriata, *Rss.*	*	*	*
54. —— porrecta, *Brady.*	...	*	
55. —— asperula, *Czjz.*	*		
56. —— ——, var. ampullacea, *Br.*	*		
57. Sagrina nodosa, *P. & J.*	...	*	
58. —— virgula, *Brady.*	*	*	*
59. —— dimorpha, *P. & J.*	*	...	*
60. —— raphanus, *P. & J.*	*	...	*
61. Globigerina bulloides, *d'Orb.*	*	*	*
62. —— ——, var. triloba, *Rss.*	...	*	
63. —— dubia, *Egger*	*	*	*
64. —— sacculifera, *Brady*	*	*	*
65. —— conglobata, *Brady*	*	*	*
66. —— æquilateralis, *Brady*	*	*	
67. Orbulina universa, *d'Orb.*	*	*	*
68. Candeina nitida, *d'Orb.*	*	*	
69. Pullenia sphæroides, *d'Orb.*, sp.	*	...	*
70. —— obliquiloculata, *P. & J.*	...	...	*
71. Sphæroidina bulloides, *d'Orb.*	*		
72. —— dehiscens, *P. & J.*	*	*	*
73. —— ornata, n. sp.	*		
74. Discorbina Bertheloti, *d'Orb.*, sp.	*	*	*
75. Truncatulina mundula, *B., P., & J.*	*	*	*
76. —— Ungeriana, *d'Orb.*, sp.	*		
77. —— Wuellerstorfi, *Schw.*, sp.	*	*	*
78. —— Akneriana, *d'Orb.* (?) sp.	*	*	*
79. —— Haidingerii, *d'Orb.*, sp. (?)	*		
80. —— culter, *P. & J.*, sp.	...	...	*
81. Pulvinulina concentrica, *P. & J.*	...	...	*
82. —— lateralis, *Terq.*, sp.	*		
83. —— umbonata, *Rss.*	*	*	

Post-tertiary Foraminifera of Suva, Fiji (continued).

	I.	II.	III.
84. Pulvinulina Menardii, *d'Orb.*, sp.	*	*	*
85. —— patagonica, *d'Orb.*, sp.	*	*	*
86. —— crassa, *d'Orb.*, sp.	*	...	*
87. —— Micheliniana, *d'Orb.*, sp.	...	...	*
88. —— pauperata, *P. & J.*	*	...	*
89. Rotalia Broeckhiana, *Karrer*	*		
90. —— Soldanii, *d'Orb.*	*	*	*
91. —— orbicularis, *d'Orb.*	...	...	*
92. Nonionina umbilicatula, *Montag.*, sp.	*	*	*

EXPLANATION OF PLATE I.

Fig. 1. *Ellipsoidina ellipsoides*, var. *oblonga*, Seguenza, magnified 40 diameters. *a*, lateral aspect; *b*, apertural end; *c*, diagram of longitudinal section.

2. *Haplophragmium rugosum*, d'Orbigny., sp., × 75 diam. *a*, lateral aspect; *b*, peripheral aspect.

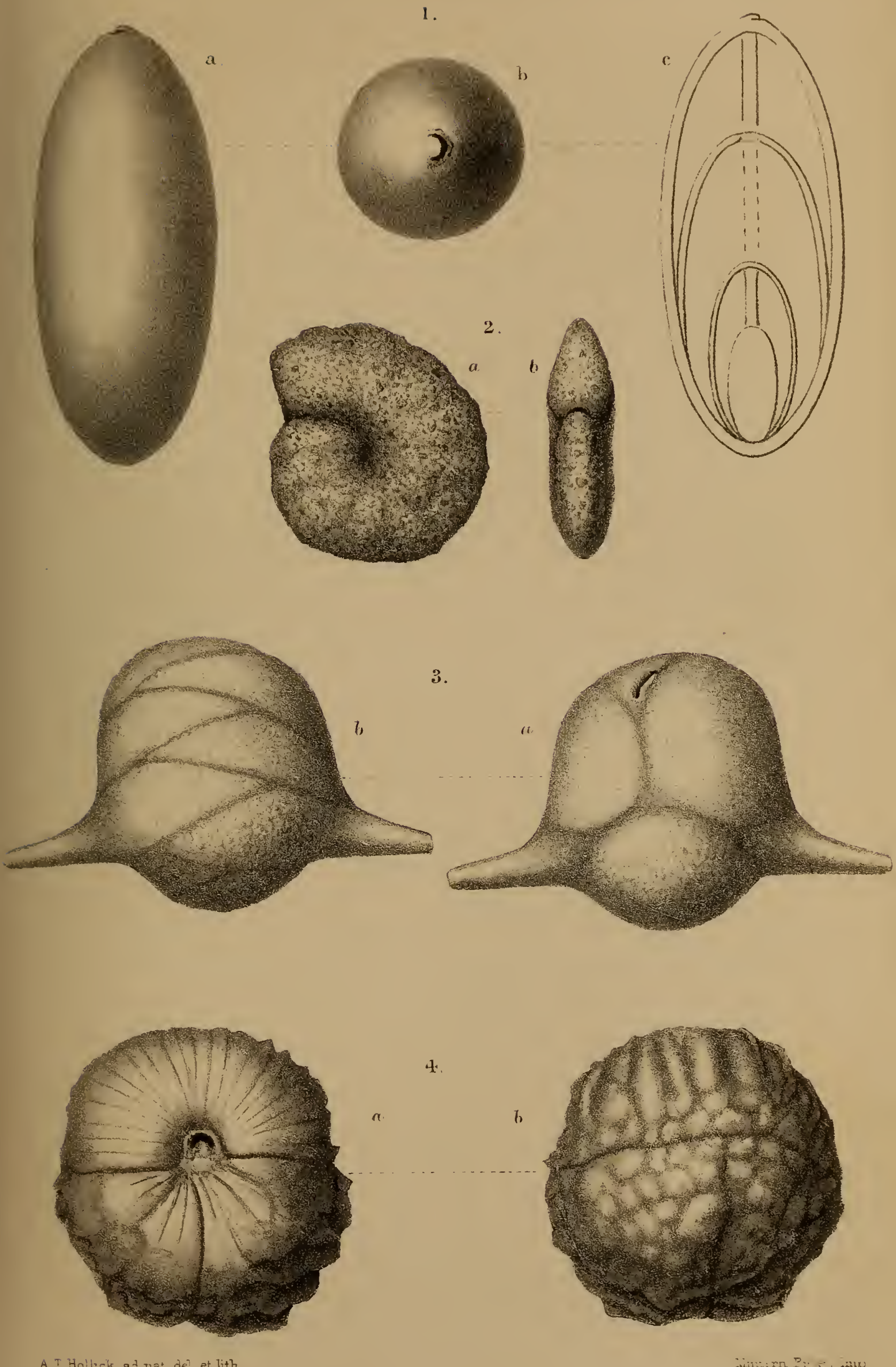
3. *Ehrenbergina bicornis*, sp. nov., × 50 diam. *a*, apertural aspect; *b*, reverse side.

4. *Sphæroidina ornata*, sp. nov., × 75 diam. *a*, apertural aspect; *b*, reverse side.

Discussion.

The President hoped that this paper might be regarded as one of the first-fruits of travels undertaken by the Author for the purpose of investigating the interesting deposits of this nature.

Prof. Rupert Jones agreed that this was a valuable instalment of work to be expected. The peculiar Foraminifer specially mentioned by Mr. Brady (*Ellipsoidina ellipsoides*, var. *oblonga*, Seguenza) must have connexions, so that, as the Author had intimated, the interest attached to it was not yet wholly worked out.



A. T. Hollick ad nat. del. et lith.

Mintern Bros. Imp.

POST-TERTIARY FORAMINIFERA-FIJI.

2. *On some* Results *of* Pressure *and of the* Intrusion *of* Granite *in* Stratified Palæozoic Rocks *near* Morlaix, *in* Brittany. By T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read November 9, 1887.)

[Plate II.]

In my paper on the "Structures and Relations of some of the Older Rocks of Brittany"* I briefly referred to the slaty rocks in the neighbourhood of Morlaix. As the main object of my journey was to study the older and, presumably, Archæan rocks of Brittany, only a moderate amount of time was devoted to those of later date, and not many specimens were collected. These, however, have proved of unusual interest; so I venture to offer a few remarks upon them to the Society, because, as I anticipated, they seem to throw some light upon the history of the genesis of certain crystalline schists.

The rock beneath and in the immediate neighbourhood of Morlaix consists of alternating bands, differing in texture and colour †. The grey material, at the time of deposition, was evidently a fine-grained silt or earthy sand, the dark a carbonaceous mud. The layers of the former commonly do not exceed an inch in thickness, and are often less; the others are frequently more; but extremely thin, more or less lenticular streaks of the one material are occasionally interlaminated with the other. Both are cleaved, the sandy band imperfectly, the dark band very completely. Commonly the planes of cleavage and stratification coincide, and then the rock has a compressed appearance; but minor folds and "wriggles" are frequent, so that the "stripe" is cut by the cleavage-planes at very different angles. In these cases the change in amount and direction of the cleavage, the thickening of the sandy bands before a thrust, their attenuation along a line of strain, in short all the usual pressure-phenomena in banded rocks are exceptionally well exhibited. Indeed, though my opportunities of study have not been few, I never saw finer examples. It was often difficult to make progress by the side of the rude terrace-walls which support the gardens towards the outskirts of the town, so interesting were the structures in the rough blocks of which they are built. A cleavage-face in one of the darker bands has a slightly micaceous lustre, exhibits, in short, a "sheen surface." It is also wavy, being marked by a number of flat "puckers," the crests being parallel, though not quite straight lines. The specimen which I brought away (I obtained it in a roadside cutting near the river, north of the town) shows four of these

* Quart. Journ. Geol. Soc. vol. xliii. p. 301.

† It was considered to be Devonian by the French geologists, but Dr. Barrois has recently informed me that the fossiliferous Devonian occupies a fold to the south of Morlaix, the rock to the north of it, and perhaps that to the south (those mentioned in this paper, which are lithologically identical), being Cambrian.

bands, and the direction of the folds is practically the same in each, making an angle of about 70° with the boundary of the band.

We have, in short, in the Morlaix district, those satiny slates, approaching phyllites, which are commonly found in regions where suitable materials have been exposed to intense pressure, as, for instance, parts of the Ardennes, Devon, and the Alps.

On examining the rock under the microscope (Pl. II. fig. 1), we find the grey bands mainly composed of granules of quartz, and flakes of a mica varying from almost colourless to a pale yellow-brown or buff tint, among which are occasionally scattered granules of darker colour, sometimes associated in clusters. The quartz grains are not very definite in outline; they occasionally exceed ·001″ in diameter, but are more commonly about that size or a little less. Usually they are free from mineral enclosures, but sometimes envelop a tiny flake of mica. Near the edge, or where one of the above-mentioned darker films occurs, the mica flakes have a distinct tendency to be parallel with the surfaces of the layer; but generally it is difficult to detect any definite orientation. The occasional granules appear to be sometimes ferruginous or earthy matter, sometimes carbonaceous; in one or two cases they resemble specks of epidote *. The mica flakes, more especially where they begin to dominate, are occasionally quite ·002″ in length, but commonly they are about ·001″ long, and often much less.

The dark bands consist chiefly of flakes of light-coloured mica with granules of earthy and carbonaceous material, sometimes so thickly interspersed that it is difficult to obtain a perfectly clear definition of the constituents, and with occasional specks of clear quartz, which here and there predominate. This, of course, occurs where the black band is interrupted by a sandy film, just as the sandy bands are interrupted by black films. The cleavage-planes are defined by rude dark lines. Careful study shows that the micaceous constituent is arranged in a series of wavelets, the general surface of which is at a high angle with the cleavage-planes, so that the latter structure is a strain-slip cleavage †.

A specimen taken from a small quarry south of the town (on the Huelgoat road) shows the two last-named structures still better. Here the sandy bands are wanting. The dark rock exhibits yet more distinctly this "incipient foliation," as we may term it; the surfaces are waved, and there is frequently a very distinct strain-slip cleavage, making, with their general direction, angles

* Here, however, as in all the instances to follow, I have not endeavoured to make a precise investigation into the exact nature of these less definite substances, for two reasons. One, that my eyes always feel the effects of a prolonged use of high-power lenses; the other that my purpose is to endeavour to follow up the history of the rock, and for that the identification of the less definite constituents is immaterial. Moreover an excellent study of the effects of contact metamorphism in Brittany already exists in an elaborate paper by Dr. Barrois, "Sur le granite de Rostrenen, ses apophyses et ses contactes" (Ann. de la Soc. Géol. du Nord, t. xii. p. 1). I have therefore, as far as possible, confined myself to details which appeared to have a distinct "historical" significance.

† As stated in my Presidential Address (Quart. Journ. Geol. Soc. vol. xlii. Proc. p. 95) I use this phrase as the equivalent of "Ausweichungsclivage."

which vary from 60° to nearly 80°. In this case also I believe the flakes are in the general direction of the original bedding.

I found a similar double structure in slates which I have examined from the Torcross district, and from other localities where the rocks have undergone exceptional folding, the result presumably of exceptional pressure; but it is by no means present in all slates. One specimen from Torcross does not show it, others do.

The question then arises, Is this incipient foliation in any way connected with contact-metamorphism? In several of the cases which I have examined from other localities there is not the slightest reason to suspect the presence of any igneous rock. It is true that in the example just described the crag exhibits at no great distance two dykes of felstone or micro-granulite, each about 4 or 5 feet thick. These, however, produce little appreciable alteration in the slate with which they are in contact. It is *very* slightly indurated, but its colour is unchanged. Moreover I have examined a junction specimen microscopically. The mica flakes are very slightly larger and a little more clearly separated from the quartz than in the other specimen, but the difference is hardly more than may be seen in some parts of the latter, while one or two little bits of slate, actually included in the igneous rock, are practically unaltered *. The slate also shows strain-slip cleavage, the planes of which are abruptly crossed by the igneous rock, and obviously existed prior to its intrusion. There can, then, be no doubt that these dykes have nothing to do with the incipient foliation. Possibly, however, tiny flakes of mica may have been, from the first, important constituents of the rock? No doubt flakes of mica frequently enter into the composition of muds which are subsequently converted into slates, but, after a very careful study of these and other specimens, I am forced to conclude that here the mica has not the usual appearance of fragmental scales, but appears to have been developed *in situ*. To this subject I shall have to return; for the present it will suffice to have established that the incipient foliation and the strain-slip cleavage were anterior to the intrusion of the dykes, and in no way connected with contact-metamorphism.

Let us now examine some specimens from the south of Morlaix, where intrusions of granite are common and indubitably affect the adjacent rocks. I collected a series from a partially quarried crag at a distance of 8½ kil. on the Huelgoat road. They occur thus, enumerated in descending order:—(1) Banded micaceous schist; (2) Dull grey quartzite; (3) Banded micaceous schist, like (1), but looking rather more altered, and in some places containing a mineral resembling andalusite; (4) Rather silvery micaceous rock with imperfectly developed prisms or oval spots of a similar mineral, generally lying parallel with the surface of apparent foliation; (5) A dark brownish somewhat spotted and somewhat micaceous rock, not definitely foliated. The quartzite was much the thinnest

* The rock (at the margin) is a micro-porphyritic quartz-felsite. The way in which it has been "injected" into cracks in the slaty rock shows that it must have then been quite in a fluid condition.

of these beds, being about a couple of feet. Of the others I did not keep any record, as the exact thickness was immaterial. I have no doubt a mass of granite is very near (5), but it had not been exposed in the quarry; there was, however, a vein visible by the roadside at a distance of about 10 yards.

Of these specimens No. 1 at once reminds us of the banded slate already described. There are the same alternate bands of dark and light rock, but with this difference, that the former has become a solid, faintly-foliated mass, the latter, also solid, exhibits a foliation due to the presence of small wavy laminæ of rather silvery mica. The larger as well as the smaller mineral layers are waved and crumpled, and exhibit in places indubitable remains of a strain-slip cleavage; but its surfaces have become soldered together, though sometimes the fracture of the rock indicates that they are still planes of imperfect coherence. No one who examines the rock in the field or even, I think, in a hand specimen, can for a moment doubt that here we have the normal Morlaix rock, after it had undergone a certain series of mineral changes. A portion of No. 3 is almost identical with No. 1, but one of its dark layers obviously contains andalusite or a kindred mineral.

Under the microscope the lighter-coloured part of these rocks consists mainly of the following minerals:—quartz, two micas, one colourless, the other varying from pale olive-colour to a fairly deep brown inclining to olive, a granular or slightly fibrous mineral, occurring in rather cloudy patches, and black granular spots, rods or plates, which are probably sometimes iron-oxide, sometimes graphite. The quartz and the mica form (as one sees in the hand specimen) alternating bands, commonly from about ·02″ to ·04″ thick (Pl. II. fig. 2). In short, at the first glance, the slides cut from this rock resemble those from an ordinary fine-grained mica-schist, such for instance as we obtain at Holyhead in Anglesey. The quartz occurs in grains, rather irregular in outline and variable in size, the larger rarely exceeding ·03″ in diameter. The majority, however, are only about ·002″, and most of the grains are near the one size or the other. The quartz is clear and seems free from enclosures other than mineral, but little flakes of mica (colourless or nearly so) are interspersed, and perhaps intrude into the smaller grains and are included in the larger. Thus, one of the quartz bands, when regarded by ordinary transmitted light, appears to be rather thickly sown with tiny flakes, rods or granules of minerals, chiefly mica; sometimes, however, a grain is also outlined by flakes of mica. This mineral, when it occurs in the bands, is very commonly in flakes about ·01″ long. There are clearly two distinct varieties—one colourless, but giving brilliant tints with the polarizing apparatus, no doubt a hydrous soda- or potash-mica; the other olive-brown rather than umber or sienna-brown, no doubt a ferro-magnesian mica. The variations in colour very probably are partly due to subsequent mineral change. The fibrous mineral occurs associated with the mica in cloudy patches (in No. 1 only). At the first sight it rather resembles a matted mass of minute fibrolite; but after examination with high powers, I incline to consider it only an aggregate of very minute flakes of colourless mica. The old lines of the strain-slip cleavage are occupied by a filmy brownish mica associated with opacite; the flakes of this lie roughly along the planes and are wavy, sometimes almost intertwined, like a section of an imperfectly twisted cord.

It is evident that these rocks have been not only stratified but also much disturbed, subsequent to stratification, though prior to a large part of their alteration. We have the usual waving, arching, and puckering of the diverse mineral layers; we have even the trace of a strain-slip cleavage, as above described; but in places where the bands of mica are forced into sharp angular folds there is no sign of the nipping, creasing, or tearing which are familiar to everyone who has examined foliated rocks which have been subsequently subjected to folding by pressure. The mica flakes are well developed; true, they are sometimes interrupted thus /\, sometimes bent thus ∩ at a sharp fold, but in each case the flakes are well developed, as though they either had been formed, or had grown larger, and perfected their outline on the spot. The latter, I have no doubt, is the true explanation. The rock, after undergoing severe pressure, resembled in its incipient metamorphism those first described. The results of the intrusion of a molten mass set up further chemical action, caused both destruction and construction. The residual detrital stuff yet remaining in the rock—the "dirt," we may call it—was obliged to make itself useful; silica went to enlarge quartz granules, some of the ferruginous compounds produced magnetite, hæmatite, limonite, or other iron salts; and magnesian or alkaline earths went to aggrandize the micas already existing or, in some cases, to form new flakes; carbonaceous matter perhaps sometimes was oxidized, sometimes became graphite. Thus the result of the action of a mass of heated rock on a rock previously banded has been to produce a very fair imitation of an ordinary fine-banded mica-schist. Differences between these will be presently noticed.

The crystalline grains of andalusite in No. 3 are of moderate size, from about ·3″ by ·1″ downwards. Under the microscope they are seen to be associated with quartz, brown mica, ferrite, and opacite. The last two are abundant enough to give a rather dusty look to the mineral; they traverse the crystals in bent or wavy bands, obviously indicating the direction of the (contorted) original stratification; and the somewhat "crippled" outline of the crystals intimates that their full development has been interfered with by the banded structure of the rock.

In order to eliminate the effects of the puckering, I examined a specimen from another locality on the same road, about 7 kil. from Morlaix. This is a fine-grained, somewhat micaceous rock, looking rather like an altered greywacke, with a much less clearly marked foliation, which presumably corresponds with an original bedding and shows no puckering. The general character of the rock is very similar, except that it is rather distinctly foliated. The mica is chiefly brown, and rather more commonly outlines the quartz grains, which are a little larger, but which contain abundant enclosures of the mica. Needles, possibly of sillimanite, are abundant, especially piercing into the quartz grains; there are a few grains of tourmaline, one or two of epidote, and perhaps a tiny garnet or two. Iron-oxides as usual. Here, then, as has been said, the mica is both disseminated and to some extent aggregated in bands, but these have at most been compressed, not puckered.

No. 2 is a quartzite containing numerous microliths of mica. Its grains are often about ·04″ in diameter, but smaller occur; they are irregular in outline. Flakes of white (rare), brown and greenish mica, perhaps sometimes of a chlorite, granules of ferrite and opacite, and one or two possibly of epidote, are scattered over the field. The rock obviously is a quartzite, but there is this peculiarity:—In an ordinary quartzite mineral inclusions are comparatively rare and obviously were present in the materials of the original sand. Adventitious or accidental minerals usually occur between the constituent quartz grains, and not seldom the distinction between the original grains of the sandstone and the secondary quartz which has made it a quartzite can be observed. But in this rock from Brittany there is no sure indication of an original nucleus, for the little mica flakes are constantly included in the grains. Now and then a whole granule or an inner space in a grain seems comparatively free, and one or two also of such grains are cracked, as I have seen happen with quartz grains which have been exposed to heat; but generally the mica is so uniformly disseminated that either the rock must originally have been a very fine-grained one, or its constituents must have been reduced to such a plastic condition that a large amount of molecular movement became possible.

Nos. 4 and No. 5 may be more quickly dismissed, as they are nearer types which have already been noticed. The former rock consists largely of mica (chiefly the rich brown variety so characteristic of contact-metamorphism) and small granular quartz. The rock is foliated, but not banded, the mica flakes being parallel with the original stratification, and the bed itself less disturbed (where it is exposed) than the other, so that here there is little "waving" and no strain-slip cleavage. There are the usual vaguely defined spots of granular andalusite, associated with quartz and a little mica, and here and there a more perfect crystal. No. 5 is a similar rock, the chief difference being that the andalusite is better developed, and fairly complete crystals are common. They are practically colourless, and frequently occur in cruciform twins. Evidently the granular stage represents an arrested development. If the mass were kept long enough with the requisite environment the separated granules of andalusite would draw together, "elbowing aside," as it were, most of the quartz and mica (though sometimes these cannot be expelled, but must be incorporated), so as to form well-developed crystals.

I may remark here—what, no doubt, has often been observed before—that the difference in the mode of occurrence of the varieties called chiastolite and andalusite is singular. Typical chiastolite generally occurs at a considerable distance from the intruding mass, where the body of the rock is comparatively unaltered. It is excellently developed in a matrix which is almost unchanged. Everyone will remember that on approaching the intrusive granite of Skiddaw, as the slaty rock becomes more crystalline by the development of mica and andalusite, the chiastolite disappears. Its regular and well-developed crystals are replaced by vaguely defined spots of granular andalusite, which does not "purge" itself from the associated quartz and mica till we come quite close to the coarsely crystalline granite. This is the case in Brittany (not to mention other places); here also the best-developed long prismatic crystals with the peculiar internal structure occur (as at Chapel du Mur and St. Brigette) in a comparatively not much altered matrix; indeed at the latter place corals may still be recognized in a rock which contains crystals of chiastolite more than an inch long*. I call special attention to this as indicating the importance of environment; for, so far as we can tell, there is no essential difference in the materials of the rock itself.

I have thus traced the development of a rock which may not unfairly be called a mica-schist, though it is a peculiar one. It is composed of quartz and mica, it is truly foliated, it is extremely difficult to identifiy any grain as an original constituent. But it is not identical with one of the banded mica-schists from a district where all the rocks are metamorphosed, where we suspect, and perhaps can prove, that they are of Archæan age. The distinction would be recognized at a glance by any one familiar with the two types. Apart from certain mineral peculiarities, not unimportant, well known to those who have made a study of "contact-metamorphism," there is the marked feature of the general dissemination of mineral enclosures throughout the granules in the quartzose bands. If now we take a banded schist which has not suffered seriously from subsequent pressure (not always very easily found, but still to be obtained by patient searching), we find that the quartz grains, as a rule, are remarkably clear, mica or other minerals only occurring between them in positions where, in a tolerably clean sandstone, there would be flakelets of fragmental mica or earthy matter. If, however, the banded schist has been exposed to considerable crushing, there is sometimes an approach to the structure of the Brittany rock, due to a mechanical admixture of the constituents, as they crush, shear, and slide under great pressure. I have, in my collection, cases of this last from both Anglesey and the Alps; still even here the distinction between the two kinds of schist can be recognized by a practised eye.

At the same time, to refer to words of my own, these specimens concerning whose history we have some knowledge, illustrate, though they do not elucidate, those whose history is a matter of conjecture. Once they consisted of stratified sand and mud, and in the bands of

* I am indebted to my friend the Rev. E. Hill for this information and for specimens.

each material there were stratulæ of the other; pressure, apparently acting first roughly at right angles to this banded structure, caused certain mineral changes, and gave rise to an incipient metamorphism, even an "embryonic" foliation. Further pressure crumpled up the beds, producing corrugation of the mineral bands, and in some cases "Ausweichungsclivage," possibly also continuing a little further the mineral change. Still the detrital origin of the rock remains indubitable, and (what is very important) the original stratification can be clearly recognized, and no new mineral-banding is introduced as the result of pressure. Then the temperature of the mass is raised by the intrusion of igneous rock; much more considerable mineral changes take place, the minerals already existing are enlarged, new minerals are formed, the old divisional planes are soldered together, the whole mass is consolidated and rendered crystalline *. Still a perfectly normal schist has not been produced. Why? I think we may express the chief reason in a homely way by saying that Nature has baked or stewed her pudding in too "quick" an oven. The element of time is wanting; the process of segregation and development, though for a while intense, has been too soon arrested; a longer time at a somewhat lower temperature would, I believe, have allowed of a more complete separation.

It is remarkable that the process of contact-metamorphism seems very unfavourable to the formation of a felspar. The analyses which have been made and are often quoted indicate that though the ordinary muddy sediments are commonly not rich in potash or soda, these substances are frequently present in sufficient amount to form some felspar; but in these rocks we get quartz, mica, and an alumina-subsilicate (chiastolite or andalusite), we may perhaps get garnets, but not felspar. I have, indeed, read of its occurrence, but though I have examined a good many specimens, I never saw an indubitable felspar, and I know that some of the instances which have been quoted are more than dubious.

But, whatever be the explanation of this peculiarity, the cases which I have described seem in my opinion to justify the following inferences; that the foliation in certain mica-schists is a record of an original stratification of the materials; that these rocks were once composed of stratulæ of sand, silt, and mud; that the foliation is a record of the original bedding, and that the latter, though it may be affected and sometimes even obliterated by subsequent mechanical, followed by chemical, alterations, can in many cases be readily recognized, and can be distinguished from the cleavage-foliation and pseudostromatism † caused by these changes. Further, the inference seems reasonable that these normal schists, early in their history, have passed through an environment different in some important respects from that of indubitably Palæozoic rocks—different, at any rate, in this, that whole regions instead of very restricted areas were similarly and simultaneously affected.

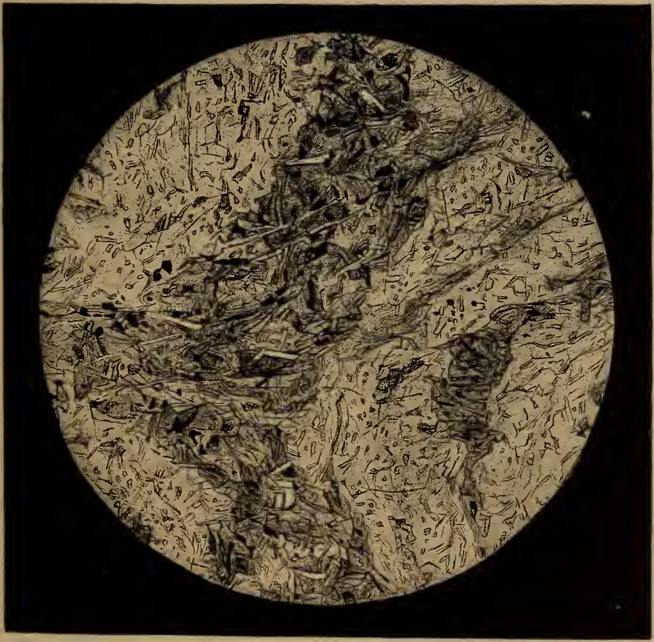
* Compare thew to microscopic sections on Plate II.

† For definition of this term, see my Address, Quart. Journ. Geol. Soc. vol. xlii. Proc. p. 65.

1.

x 27.

2.



x 27.

Felix Oswald del. F. H. Michael lith.

Mintern Bros. imp.

PRESSURE AND CONTACT ALTERATION
OF STRATIFIED ROCKS.

Seeing, then, that the rocks thus affected by "regional metamorphism," in the full and complete sense of that term, are proved to be, in many cases, pre-Cambrian, and that in no case has the asserted Palæozoic age of such rocks been satisfactorily determined, it seems reasonable to infer that their environment at the time of change was one which has rarely, if ever, recurred, and that it is possible to state the "uniformitarian" doctrine so unguardedly as to lead to conclusions which are not warranted by the facts of nature.

How far, then, may we take foliation as an indication of original stratification? Certainly not in all cases. I have already called attention to some instances requiring a different interpretation, but I believe that the distinction of these is often possible. When I am able to lay before the Society the full results of my work in the Alps last summer, which I trust will be before the conclusion of the present session, I have good hopes of advancing nearer to giving an answer to this question.

EXPLANATION OF PLATE II.

Fig. 1. Banded Phyllite from near Morlaix. ×27.

Represents the interbanded quartzose and darker micaceous layers, as described in the text (p. 12), the latter predominating in the drawing. The "embryonic" foliation can be seen running diagonally across the drawing from about N.N.W. to S.S.E., but much waved and puckered; the upper dark band shows distinctly the lines of the strainslip-cleavage running about N.N.E.

Fig. 2. Effect of contact-metamorphism on a banded phyllite from the road to Huelgoat, 8·5 kil. from Morlaix. ×27.

Represents the interbanded quartzose and micaceous layers, as described in the text (p. 14), the former predominating in the drawing; the greater size of the flakes of mica and granules of quartz throughout and the diminished opacity of the darker band are indicated. This part of the slide does not show the "soldered-up" lines of strainslip-cleavage, which, however, may be seen in another part.

(For the Discussion on this paper, see p. 45.)

3. *On the* Position *of the* Obermittweida Conglomerate. By Prof. T. M'Kenny Hughes, M.A., F.G.S. (Read November 9, 1887.)

On the south-west side of the little valley of the Mittweida, within an easy drive from Annaberg, about 25 miles south of Chemnitz, and twice that distance south-west of Dresden, there is a remarkable section which seems to show a strong conglomerate, crushed, it is true, but otherwise not much altered, intercalated among the gneiss and mica-schist which cover so large an area in that part of Saxony. It is therefore of some importance to inquire how far it would be possible to admit other explanations of the section than that which seems at first sight to be the obvious inference, and to consider whether an examination of the rocks in the field and a comparison of the mode of occurrence of other similar conglomerates render it possible to explain away the apparent interstratification of the conglomerate and gneissic series.

I am indebted to Professor Credner, not only for much information on the subject, but for references to previous writers. The first notice seems to be that of Dr. Sauer, of Leipzig *, under whose guidance I visited this locality a few years ago, and whom I take this opportunity of thanking for much kind attention.

The occurrence of this conglomerate is indicated on the Geological Map of Saxony and in the section given in its margin †.

Professor Justus Roth, of Berlin, wrote a paper ‡ upon these conglomerates in 1883, and afterwards referred to them in his work on General and Chemical Geology §, published in Berlin in 1887.

Von Hauer referred to this rock as only something like a conglomerate. As Prof. Roth did not allow that the gneisses were of sedimentary origin, he, of course, could not admit that the so-called pebbles were included rolled fragments, but referred them to concretionary action.

Several geologists, Dr. Sauer amongst them, have tried to get over the difficulty by suggesting that the conglomerate was altogether newer than the gneiss, and that it has been folded and faulted in. So that my friend Professor Credner, not without justice, remarks that we should not now put this explanation forward as a mere hypothetical solution of a difficulty without offering some facts in support of the view; yet I venture, at my friend Professor Bonney's request, to offer my impression of the section.

* "Ueber Conglomerate in der Glimmerschiefer-Formation des sächsischen Erzgebirges," Zeitschrift f. d. ges. Naturwiss. Band lii. 1879, p. 706.

† Geolog. Special-Karte von Sachsen, Masstab 1·25000, Section Elterlein, nebst zugehörigen Erläuterungen.

‡ Sitzungsberichte der kgl. Preuss. Akad. der Wissenschaften zu Berlin, 1883 (Physikal.-mathem. Classe) xxviii. 14 Mai.

§ Algemeine und Chem. Geologie, ii. Band, p. 428. Berlin, 1887.

As we travelled from Annaberg south-west we crossed various types of gneiss and mica-schist, and at Schlettau had an opportunity of examining a continuous though shallow section in a road-cutting. Different names, such as Plattgneiss, &c., are given to the massive or fissile, coarse or fine varieties, names which are convenient for lithological description, but did not appear to be of much classificatory value. South-west of Schlettau these beds are covered by Oligocene deposits capped by columnar nepheline basalt; but the valley descends into the underlying schistose series, which here contains thick beds of white saccharoid crystalline limestone. This limestone is very irregular, probably owing first to the plications of such hard bands in the yielding schists, and, secondly, to decomposition facilitated by the comminution of portions of the limestone. I had to take on trust the connexion between these schists and gneisses and the beds seen east of the stream at Obermittweida, but I saw no reason to question the information that they belonged to the same series.

At Obermittweida, however, the section became more complicated (see fig. p. 22). Near the forge, on the east of the stream, there was a coarse large-flaked Muscovite-schist associated with gneissose rocks. Along the valley in which the little stream ran the sequence was interrupted, and I saw no similar rocks immediately west of it.

Ascending the hill west of the stream, we first came to a grey felspathic granular rock, in which there was an apparently superinduced schistosity. In this were scattered pebbles of felsitic and quartzose rock, which soon became so numerous that the rock was obviously a coarse conglomerate.

I am unable to state whether a precisely similar sequence may be seen at other points along the outcrop. There was nothing in a single traverse, except the character of the rocks, to suggest that there was any faulting or folding of the conglomerate and associated beds. I did not notice that the top of the section in the conglomerate resembled the bottom, as if it were a repetition of the same set of beds. But the conglomerate was an irregular deposit, and may well have varied in thickness and character within short distances. Moreover, it was not clear that we saw the base of it on the side next the stream. In the conglomerate were fissile sandy beds which, even where crushed, were quite unlike the mica-schists which cropped out above and below.

There was plenty of room for, and strong probability of, a fault along the valley below the section.

On the whole I was inclined to believe, from an examination of the rock in the field, that the conglomerate might belong to quite newer beds caught in a sharp synclinal fold.

The line of reasoning which has led me to the conclusion that the conglomeratic series is folded and faulted into the gneisses is briefly as follows:—

The character of the two rocks, that is of the gneissic series and of the beds associated with the conglomerate, is so different that I am unwilling to admit that they can both belong to one series and have been subjected to similar conditions.

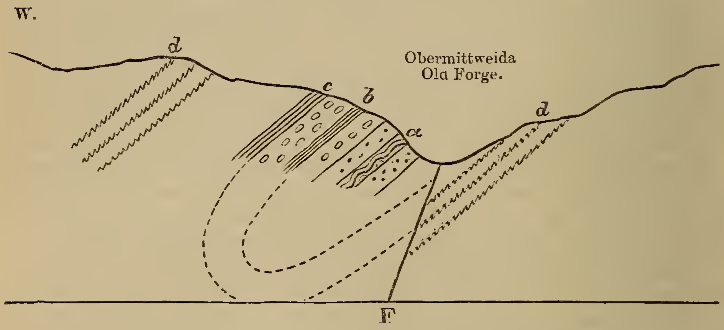
The absence of any passage from one to the other.

The identification of both series with others known to be discordant to one another.

The analogy of similar foldings-in of newer rocks so as to produce on the surface the effect of a true sequence.

In illustration of my remarks, I subjoin a section across the valley

Diagram Section across the Valley at Obermittweida.
(Length of Section 200 yards.)



a. Crushed rock.
c. Micaceous flaggy rock.
F. Fault.
b. Micaceous Sandstone.
d. Mica-gneiss.

at Obermittweida. I did not observe any such repetition of similar beds as would justify the assumption thas we saw the whole of the infolded conglomeratic series. I should expect to find that the conglomerates might be repeated somewhere in the bottom of the valley, but that in the line of this section they were cut out by a fault. The crushed rock (*a*) between the two gritty bands seen near the bottom of the section may perhaps be the centre of the fold.

The micaceous sandstone (*b*) between the two bands of conglomerate is exactly like some of the beds in the conglomerate at the base of the Cambrian of Bangor.

The micaceous flaggy rock (*c*) above the conglomerate seen highest up the hill is quite unlike the mica-gneiss (*d*) seen in the wood above or on the east side of the valley below. It is more like what might be called a mica-arkose. If this be included in the conglomeratic series there is no junction seen between that series and the gneissic series.

An examination of the section showed me that there was no passage from the one to the other, and that there was room for such folds and faults as would most easily explain the occurrence of the conglomeratic series, if for other reasons it could not be included among the gneisses.

Then a traverse across the gneissic series of the adjoining district showed a similar sequence to that with which we are familiar in other areas of Archæan rocks. A selection from the Pyrenees and from Wales, from rocks referred to the Archæan, can hardly be distinguished from those of Saxony *. The common gneiss, the mica-gneiss, the limestones are almost identical. So far as there is any value in what I have called syntelism, it is clear that we have a similar sequence in all these districts. If this be so, we may just remark that these types of Archæan rock are not the highest, and conglomerates are less likely to be found associated with them than with such newer rocks as those I have named the Bangor Series.

In the next place I observe that the character of the conglomeratic series is quite different. We cannot conceive of those gritty pebble-beds having originated in the same manner, or having subsequently undergone the same vicissitudes as the muscovite-schists and granitoid rocks seen on either side of them. We turn, therefore, to other areas and ask whether we have any parallel case where the overlying fragmental beds have a general resemblance to the rocks of doubtful age and origin from which they, by their position, might be supposed to be derived. We are fortunate in Wales in being able to examine basement beds of newer series (Cambrian) in which there has not been much deformationof the constituents by mechanical action, while within twenty miles we find the same beds violently cleaved and the included pebbles drawn out almost beyond recognition. We find among the locally varying beds of the Cambrian of North Wales a rock very similar in character to the conglomerate of Obermittweida, and, in a closely adjoining area, the equivalent rock squeezed so that the included pebbles are crushed and flattened.

Let the accidents which happened to the conglomerate of Llanberis or of Borthwen, in Anglesey, affect such a bed as the conglomerate of Bangor Station, and we should have a rock identical in all essential points with that of Obermittweida. In both we have pebbles of felsitic and granitoid rock, either crowded together or occurring scattered through a grey matrix, which sometimes weathers into an irregular and granular surface, as if from the development of the rolled fragments in the felspathic paste, and sometimes is gritty from the predominance of the siliceous constituents of the granitoid rocks. As from the nature of the case we must often have what may be called a granite-arkose, a mica-gneiss-arkose, or a schist-arkose, so we may have many a portion of any newer series made up so directly of the constituents of the underlying rocks as to resemble them in superficial characters. But generally a wide search reveals the derivative character of the newer beds.

* Collections from the three districts mentioned were exhibited at the meeting and are now in the Woodwardian Museum at Cambridge.

Of the catching and preserving of newer rocks in inverted or isoclinal folds there are abundant examples in our own Highlands, as well as in the Alps, and I need only refer to the sections drawn by Favre, Renevier, Heim, and many others.

In the light of the knowledge gained in Wales, the Obermittweida conglomerate appears to be best referred to a newer series than the gneisses among which it occurs; to be similar to those gneisses, only in so far as it has derived its material from them; to owe the deformation of its included pebbles, to the mechanical action of which there is abundant proof in the district, and its mode of occurrence to the faults and folds which accompanied that action.

(For the Discussion on this paper, see p. 45.)

4. *On the* Obermittweida Conglomerate, *its* Composition *and* Alteration. By T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read November 9, 1887.)

The series of specimens from Obermittweida entrusted to me for examination by Professor Hughes is a remarkably fine one. All those of the conglomerate are of a fair size, some weighing several pounds, and are carefully selected so as to show the nature both of the matrix and the included pebbles; there is also a piece of the neighbouring gneiss. The pebbles are, in form, both well rounded and subangular. Some of the smaller fragments, indeed, occasionally seem to be little, if at all, worn, while the larger, in three specimens at least, are true pebbles. Two of them are full three inches in diameter. More than one kind of rock is present. The matrix also varies from a rather coarse-grained micaceous grit, to a hard tolerably uniform rock, in which the individual constituents can barely be detected by the unaided eye. It is of a purplish-brown colour, and has evidently been subjected to a pressure definite in direction, which has produced, especially around the included pebbles, an incipient cleavage. These divisional surfaces are coated with a filmy mica, producing what I have already termed "sheen surfaces." As is usual, they bend round the pebbles, like the husk around a nut, so that the presence of a concealed pebble is often indicated by a "varnished" ovoid swelling on the surface of the mass. The matrix, though clearly fragmental in origin, suggests that a certain amount of metamorphism *in situ* has taken place, and in this respect it reminds one of that of the Huronian conglomerate, which I have examined at Sudbury (Canada).

The gneiss has a superficial resemblance to this matrix, but is rather more distinctly micaceous. Foliation is not very strongly marked; the specimen brought exhibits neither a distinct mineral banding nor a marked fissility.

In my study of these rocks I have not attempted to identify with precision every microlith either in matrix or pebbles. My purpose has been to investigate, as far as possible, the history of the rock, and to see what light it throws on the subject of metamorphism *.

As it happens, my own collection, both of fragmental rocks of considerable geological antiquity and of schists, gneisses, and other rocks usually called metamorphic, is a rather large one; and to the examination of these and of specimens kindly lent by friends I have of late years devoted much time. I have also a fair series of rocks in which the changes have been mainly due, in the one case to

* It is the less needed because the rock has been the subject of an elaborate study by Dr. A. Sauer (Zeitschr. gesammt. Naturwissenschaften, Halle, 1877), to whose courtesy I am indebted for a separate copy of his paper. The rock also is noticed by Dr. J. Lehmann, 'Enstehung der altkryst. Schiefergest,' ch. vii.

mechanical causes, in the other to the action of intrusive igneous masses; so that I may venture to speak with some confidence as to the usual characters of metamorphic and hypometamorphic rocks.

Microscopic examination of the gneiss* shows it to consist of quartz, in rather small grains, felspar, occurring occasionally in larger, but very irregularly bounded grains, mica, brown, pale-olive green, and colourless, and garnets, with some rods, flakes, and imperfect crystals of black iron-oxide. The quartz is clear and calls for no remark. The felspar does not exhibit any twinning structure, is in moderately good preservation, and commonly includes flakes of mica, small garnets, and sometimes granules of quartz. The larger flakes of brown mica occasionally include small crystallites, sometimes, I think, quartz, sometimes perhaps apatite. The olive-coloured mica is clearly only the result of alteration of the brown. The colourless mica, as usual, gives rich tints with crossed nicols. The garnets, generally about ·003″ diameter, are practically colourless, but often so full of dusky granular inclusions as to be darkened when looked at with a low power. The sections prove them to have a well-developed crystalline form. There is no very definite mineral-banding, but the mica, especially the white, tends to be arranged in irregular wavy lines, imparting to the mass a moderate degree of foliation. Study of this and of the rock generally, leads me to the conclusion that it has undergone a certain amount of mechanical disturbance at a rather remote epoch. Lithologically, the rock resembles one of the gneisses, which, in the Alps, occur rather low down in the succession which I, in common with many other geologists, believe to exist, though still by no means at the bottom of the series.

Matrix of Conglomerate from Obermittweida, showing well-developed mica flakes associated with quartz (the white ground of the figure). × 140.

The matrix of the conglomerate is almost wholly composed of three minerals, quartz, felspar, and mica, of which the first and

* *d* in Prof. Hughes's section, p. 22.

third are far more abundant than the second. It is, of course, not very easy to settle where fragments are to end and matrix is to begin; but we may, I think, say that the quartz constituting the latter occurs in angular or subangular grains, in diameter from about ·025″ (even these being sometimes compound grains) downwards to less than ·001″; but here it becomes quite impossible to say whether one is dealing with original or secondary granules. The felspar is in similar grains, in good preservation but not common: much of it resembles orthoclase, but plagioclase may be identified; other grains exhibit the vein-like association which may be seen in microcline, perthite, &c. The mica is of two species, but most of it is of a strong olive-brown colour, markedly dichroic, changing from a rich olive-brown to a pale buff tint; the individual flakes do not generally much exceed ·003″ in length, and are very commonly about this size, though not seldom less. The flakes are often associated. The other mica is colourless. The constituents exhibit a slight tendency to parallelism; but there are no marked indications of "squeezing," not, indeed, so much as I should have expected from the macroscopic aspect of the blocks. The quartz grains are generally rather clear; the most frequent enclosures are small films of pale olive-coloured to white mica; so far as I have observed, fluid-cavities with bubbles are neither large nor numerous. While the fragmental character of these quartz grains cannot be doubted, they do not exhibit quite the ordinary appearance of fragments in a sandstone or greywacke. In these the boundaries are sharp and definite, the distinction often being accentuated by interstitial material, which will be quite as accurately defined by designating it "earthy dust," as by any more high-sounding appellation. Of this material, so abundant in many greywackes, the residue of decomposed felspar, comminuted mica, and the like, there is here little to be seen. Where two fragments of *clean* quartz have been in contact, the grains are united with a rather wavy boundary, as in many pure quartzites; and in the place of the above residue we have tiny mica-flakes, mostly brownish in colour, imbedded in quartz; the latter mineral being sometimes continuous with one of the larger grains. I have not been able to distinguish the precise boundary line of the original fragments, but think they have been only slightly increased in size by secondary quartz.

The way in which the mica is disposed in the rock leads me to regard it as to a considerable extent an original constituent, but here also a change has taken place. The sections of the flakes have not the ragged outline, especially at the ends, common with derivative micas in a clastic rock, but resemble those in an undisturbed gneiss or granite, or in a rock affected by contact-metamorphism, giving abundant rectilinear sections, which are rhomboidal in form (see fig.); very minute flakes of colourless mica are sometimes associated with the other, and also occur in the felspar fragments, which, however, are on the whole in good preservation. One or two quartz grains contain hexagonal prisms, which may be apatite, and there are probably one or two fragmental garnets.

The pebbles and other larger fragments in the Obermittweida conglomerate consist, as may be seen with the unaided eye, of various kinds of rocks; some have evidently been derived from more than one species of holocrystalline rock, others from fine-grained quartzose clastic rocks. In the slides which I have examined, 6 in number, I recognize the following:—granitoid rock 3 varieties, mica-schist 1, quartz-schist 4, quartzite 2, hälleflinta ? 2.

Of the granitoid rocks the coarsest (a pebble about 3″ diameter) consists of quartz, felspar, and mica; the felspar (chiefly orthoclase with some plagioclase) is in fair perservation, but the crystals are often broken across, slightly displaced, and at the edge have a somewhat crushed appearance. The quartz occurs in "nests of grains," and as chalcedonic quartz in cracks in the felspar &c.; the mica, of a rich brown colour, but becoming greenish by alteration, together with a little colourless mica, also occurs in nests of flakes about ·01″ long. The rock appears to me to have undergone considerable mechanical disturbance, which has cracked the felspar crystals and the original quartz grains, and has crushed the mica flakes, affecting especially the latter two; and that then a certain amount of recrystallization and recementation has taken place. This, however, has not produced any definite orientation in the fragments. It has made it difficult to pronounce as to the true nature of the original rock, but I incline to regard it as a granite rather than a gneiss.

Another specimen consists of quartz, of rather decomposed felspar (2 species) and a very little dull olive-coloured mica. Here also I suspect some mechanical modification of the original rock, so that it is hard to say whether it is from a vein-granite or one of those granitoid bands which we meet sometimes among rocks apparently not of igneous origin. I incline, however, to the former view.

The quartz-schists are exceedingly fine-grained rocks containing a fair proportion of brown mica. The quartz grains and the mica flakes do not as a rule exceed about ·001″. One has rather more mica, and in it the materials are more parallel in arrangement than in the other. The mica-schist is a little coarser and has more mica than quartz. It is a brown mica more or less changed to green, the structure being moderately foliated. The quartzites are coarser rocks, the grains being near ·01″ in diameter; they call for no special remark beyond the fact that the quartz grains are rather full of cavities containing small bubbles, and there is here and there a flake of a green mineral, chlorite or altered biotite. I believe these to be true quartzites, but two or three smaller fragments more resemble a vein-quartz. The rock to which I have given the vague name hälleflinta has a ground-mass consisting apparently almost wholly of very minute granules of quartz of somewhat chalcedonic aspect, associated with still more minute microliths of brown mica; in this are occasional larger quartz grains, not seldom in aggregates of four or five, nests of flakes of brown mica, and felspar crystals, whole or broken. The general aspect of this rock recalls to my mind those hälleflintas of Treffgarn and Roche Castle, for long so great a puzzle, and it is possible that, like some, at least, of these, we may have before us here old and altered volcanic glasses.

Two specimens *, from what Prof. Hughes describes as the inner part of the fold, are especially interesting†. One resembles a greenish grit, with marked "sheen surfaces"; part of the slab is composed of very minute materials, looking like a kind of argillite or "indurated silt," the rest of small fragments, which evidently are much compressed and elongated; the rude cleavage-faces in the latter are more "sheeny" than the more level faces in the former; the finer-grained part consists mainly of granules of quartz and minute flakes of greenish, nearly colourless mica; the coarser part of grains of quartz, of felspar (less common), of flakes of greenish and sometimes white mica, with little fragments of a fine-grained quartz-schist, of quartzite or vein-quartz, and of a darkish mica-schist, not so coarsely crystalline as the gneiss described above, but more so than any part of the matrix. Here, although the fragmental character of the rock is indubitable, no part, from the coarsest to the finest, seems to be in the condition of an ordinary Palæozoic greywacke. The edges of all the quartz fragments are more or less ragged, the mica flakes are generally more regular in outline than is usual in a greywacke, even when it has undergone compression, and the smaller quartz granules form a kind of "paste" in which the mica seems to be imbedded, more as described in the case of the contact-metamorphism at Morlaix. In regard to the larger quartz grains, I feel sure that I occasionally detect enlargement. Altogether I cannot doubt that this is an altered greywacke, and think the alteration cannot be wholly the result of pressure-metamorphism. The second specimen is a schistose micaceous rock, much corrugated, with a micaceous sheen on the surfaces of all the laminæ displayed on fractures, but not composed of flakes distinguishable with an ordinary lens. When I examined it macroscopically, I felt uncertain whether it would prove to be simply a "pressure-schist," like one of those from Morlaix, or would resemble one of the more minutely crystalline schists of Anglesey or of the uppermost group of the Alps. It had, however, a rather more "crystalline" aspect than I have yet seen in any Palæozoic argillaceous rock, when affected by pressure only. This proves to be the case on microscopic examination. The principal constituent is a mica, varying from pale olive-green to colourless, but usually tinted, with interstitial quartz. The mica flakes are often about ·007″ in length, but many are smaller. There is also a fair amount of a mineral, more distinctly green, in somewhat irregular scales, often associated, which has little, if any depolarizing action, and is no doubt one of the "viridite" group; besides this we have ferrite and opacite in variable amounts, the former some-

* This paragraph has been inserted since the paper was read. The specimens which it describes, owing to an accidental misunderstanding, were not seen by me until the evening when Prof. Hughes's paper was read; they also appear to me of considerable interest. He exhibited at the same time some specimens of crystalline rocks (gneisses, or schists, and a marble) from the district near Obermittweida; these, I may remark, were such as, from my experience in other districts, I should have expected to find associated with, or not far from, a gneiss such as that which occurs at Obermittweida.

† See figure on p. 22; the first is (*b*), the second (*a*) of Prof. Hughes's section.

times appearing as if it stained the mica, sometimes, especially in a more quartzose stratula, like a residuum of an "earthy dust." Now and then I find a granule of quartz, looking very like the indication of an original fragment. A quartz vein occurs in the slide, posterior in date to both foliation and corrugation. I have compared this rock with the most extreme instance of pressure-metamorphism in my collection. Molecular rearrangement is more complete in the former, and the mica flakes in it are about double the size of those in the latter. The Obermittweida rock might be matched with some of the Anglesey schists (*e.g.* from Holyhead Island) or with exceptional specimens from the uppermost group in the Alps (an average specimen, so far as I know, is more coarsely crystalline). I cannot doubt that it was once a sediment, and that, even if pulverized mica was an important original constituent in this sediment, subsequent molecular changes have seriously modified its structure and given it a crystalline aspect. Were these changes the result of the pressure which has produced the corrugations, and, occasionally, an incipient "strain-slip" cleavage? To discuss this question would require a lengthy digression, which, after all, would be unsatisfactory, because some of the reasons depend on the results of personal experience, which can hardly be formulated, so I content myself with observing that, while I will not venture to speak positively, I incline to the opinion that the rock had undergone considerable molecular changes before it was corrugated. These modifications, of course, might belong to different stages in a continuous disturbance; but I am disposed to regard them as separated by a not inconsiderable interval of time.

My study of this series of specimens from Obermittweida leads me to the following conclusions:—

(1) That the matrix of the Obermittweida conglomerate has been derived largely from the detritus of a biotite-granite or fairly coarse biotite-gneiss, and that a good deal of the felspar has by some means or other been sifted out, so that, chemically, the rock approaches more nearly to the composition of a quartz-mica- (biotite-) schist.

(2) That the pebbles are derived from a variety of rocks, some of which may have largely contributed to the matrix, but others to no great extent.

(3) That the structure of some of these included fragments is not that which we generally find in the older part of the Archæan series.

(4) That the matrix of the conglomerate has undergone a certain amount of metamorphism, so that it may now be regarded as truly crystalline, an amount comparable with that which we often find produced by intrusive masses of granite (I do not, however, consider this a case of contact-metamorphism).

(5) That while the mass has undergone some pressure, to which probably some mineral change is due, I am unable to attribute to it the principal alteration, *i. e.* this appears to me something more than an ordinary case of "pressure-metamorphism," the matrix exhibiting

even rather fewer symptoms of having been squeezed than I should have expected from the macroscopic aspect of the blocks.

The amount of metamorphism in the rock is more than I have been accustomed to see in Palæozoic grits *, or even in those generally supposed to be a little older than the Cambrian series †. I should conjecture that the Obermittweida conglomerate was Archæan, but should not assign it to a remote period in that series. Still, in the present state of our knowledge, it would be unsafe to do more than conjecture. Be this as it may, I think it far more likely that the conglomerate beds are much newer than the gneiss, mentioned in the beginning of this paper, than that they are in true chronological sequence with it. I have had the opportunity of examining, both in the field and with the microscope, cases of these supposed sequences, and have always found the appearance of transition to be illusory, due to the fact that the later formation is so largely composed of fragmental material derived from the earlier, and that the effects of subsequent pressure have obscured the break between them, have produced sensible modifications of both rocks, and so have brought about a delusive appearance of forming parts of one and the same group of strata.

(For the Discussion on this paper, see p. 45.)

* I do not here take into consideration quartzites like that of Loch Maree; for a clean sandstone is evidently readily changed to a quartzite, but the development of mica, other than the most microscopic, is less easy.

† I refer to the sedimentary rocks underlying the basement pebble-beds of the Cambrian in North and South Wales.

5. Notes on a part of the Huronian Series in the Neighbourhood of Sudbury (Canada). By T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read November 9, 1887.)

During my visit to Canada in 1884, I had the opportunity, through the liberality of the Directors of the Canada Pacific Railway, of examining more minutely than is possible to the passing traveller the geological structure of a part of the route over which the line had recently been constructed. I had further the great advantage of being accompanied by Dr. Selwyn, the Director General of the Geological Survey of Canada, to whom I record my most grateful thanks, not only for advice and guidance on the spot, but also for information and specimens subsequently supplied. The study of these has brought out some peculiarities which I think may help to render more precise the term Huronian, and throw some light on general questions of metamorphism *.

On the Canada Pacific Railway, the Laurentian series, which has been traversed for nearly 240 miles †, comes to an end near a little station called Wahnepitae. The last rock seen is highly crystalline, an eclogite or garnetiferous hornblendic gneiss, which apparently dips at a rather low angle towards the S.E. Hard at hand is a river, on the opposite side of which rises an ice-worn range of low rocky hills considered to be the Huronian. The valley is believed to follow the line of a fault. The latter rock is mainly composed of quartz and felspar, with but little mica, though occasional thinnish bands of a fissile mica-schist occur. It is much jointed, and appears to have a flaggy bedding, reminding me in its general aspect of parts of the Highland "eastern gneiss," in Glen Docherty (that is, where the crushing is less conspicuous), or of the schistose series on the south side of Porth Nobla, Anglesey. The dip of the apparent bedding is rather more to the east and is slightly steeper than that of the Laurentian; but the difference both in direction and amount is not

* In my Presidential Address to the Geological Society (Quart. Journ. Geol. Soc. vol. xlii. Proc. p. 81) I gave a very short account of this region; but since then I have studied more minutely all the specimens noticed, as well as a series of slides cut from specimens sent to me by Dr. Selwyn in the spring of the present year. A description of part of the region will be found in Sir W. Logan's 'Geology of Canada,' pp. 50–52, 55. It is shown in the beautiful geological map of Canada published by the Survey in 1886, and is noticed in a paper by Mr. Irving in the fifth Annual Report of the Geological Survey of the United States (1883–4). This general survey of the North-American Huronian rocks, which embodies some most important observations by Professor Van Hise, should be studied by everyone who wishes to obtain a good idea of the Huronian rocks. Our conclusions in many respects seem likely to agree; but I may venture to say that my own were formed quite independently. His lucid statement of the problem presented by the Huronian could not be surpassed.

† This is roughly measured along the railway in a straight line, avoiding one or two outlying patches of Lower Palæozoic strata; the Laurentian zone is not far off 200 miles broad. There are, however, frequent patches of drift.

great. The zone over which rock of this character is exposed in some cuttings is not wide,—less than a mile, for at that distance outcrops of a rock distinctly fragmental are exposed. This may be described as a dark quartzite, at times rather flaggy, having a filmy greenish mineral, like a varnish, developed on the divisional planes. In parts the clastic structure is very distinct, the fragments from ·25″ downwards usually very slightly projecting on weathered surfaces, but there are occasional larger fragments of a grey granitoid rock up to about 2″ in diameter, subangular in form. Rock of this character, varying from the finer to the coarser varieties, continues for about ten miles till we reach the clearing where stands the village and railway junction of Sudbury.

Beyond Sudbury a dark quartzose rock, something like that seen on the opposite side of the village, but even more compact and schistose, occurs in the first cuttings. Then the rock assumes a rather streaky or porphyritic aspect, but on weathered surfaces is seen to contain small fragments less than ·5″ in diameter, the ground-mass being occasionally slightly schistose. There is a considerable thickness of this rock, my specimens being labelled "about ½ mile from Sudbury." After a time the rock becomes more coarsely fragmental (about ¾ mile from Sudbury), the fragments now showing very distinctly on a weathered surface, by a slight bleaching, some looking rather like a felsite, others more like a holocrystalline (? gneissose) rock; they are often from 1″ to 2″ in diameter, sometimes larger. Next (about 1 mile) comes a coarse breccia, looking rather like an agglomerate, the fragments often 8″ or 12″ in diameter; these are of a compact felsitic rock, containing ill-developed elongated prisms, about ·5″ long, very dark green in colour, like badly crystallized hornblende, the matrix in all the cases being apparently a more or less fine-grained quartzite, sometimes rather schistose. Quartzite without fragments now succeeds for a time. Then comes (about 1½ mile) another group of fragmental rocks (the matrix being crowded with subangular fragments); these are a slightly reddish-grey rock, resembling a microgranulite with dark green spots, gneissose and schistose rocks, and a greenstone or possibly chlorite-schist. The matrix occasionally had an ashy, sandy look, reminding me of some of the so-called quartzites of Blackbrook, Charnwood; sometimes it was the usual quartzose rock. Near the point where we turned back, about 1¾ mile from Sudbury, the fragments (this being apparently low in the series) were of smaller size in rather regular layers, the stratified arrangement being very conspicuous on weathered surfaces, where the fragments were bleached. The dip was generally throughout at a moderate angle, say 10° to 20°, roughly to the S.E. I was informed that this is the usual dip of the whole region, the observations varying from E.S.E. to S.S.E. *

* Possibly the rocks noticed in this paragraph may belong to the (lower) "slate conglomerate" of Logan's section, p. 56; but if the Limestone be thin or wanting here, the upper conglomerate also may be present: still, according to the dip, we were descending in the series; and I feel very uncertain about the correlation of these beds with the less altered conglomerates nearer Lake Huron, specimens from which are mentioned later.

The rocks forming the eastern zone of this "Huronian" region (the doubtful belt west of Wahnepitae station) must be passed over rather briefly; not because they are deficient in interest, but because their exceptional difficulty obliges me to speak of them with great hesitation. Their distinction in the field from the typical Laurentian is obvious; their special difficulty was not realized at the time, so that I only took specimens from two localities. That from the first (eastern) mass of rock referred to Huronian, the appearance of which in the field has already been noticed, when examined under the microscope is seen to consist chiefly of quartz, felspar, and a brownish mica. The quartz occurs in rather elongated irregular grains, is fairly clear, but contains occasional films of mica; occasionally there is a grain-like spot of chalcedonic quartz. The felspar exhibits the striping of plagioclase and the cross-hatched structure of microcline. The mica occurs in small but fairly well-defined flakes, lightish brown, sometimes inclining to greenish, and (especially in the smaller separate flakes) almost colourless *. The rock certainly exhibits a fragmental structure with secondary reconstruction. Is it, then, a rather fine-grained gneiss, modified by pressure, or an arkose of similar materials in which rather marked reconsolidation has occurred? Pressure indubitably has acted, as may be seen by the occasional cracking of the felspar and the strain-shadows which sweep across the quartz grains. I incline, though not without hesitation, to the former view, and to consider that, as in Scotland, an important fault has brought up some of the more fine-grained rock of the Laurentian series, and in so doing has given it a pseudoclastic aspect.

The constituents of the specimen from the western side of the belt are very similar to the above. In the field I took it for a variety of a fine-grained quartzite, but, though under the microscope there is indubitably a structure suggestive of a clastic origin, I am doubtful whether this is not really a member of the Archæan series modified by subsequent pressure. There has certainly been mineral change in either case, and until more evidence is obtained I think it safer to state the alternatives. It contains some small crystals, generally aggregated, of a dark olive-brown, almost opaque mineral, probably a very ferruginous mica or chlorite.

After this we enter a region where our hesitation is at an end, and microscopic examination confirms the impression formed in the field that (excepting some unimportant intrusions of a basic igneous rock) we are dealing with a series of clastic origin. I have already described the general succession in this region †. Time will be saved if in noticing their microscopic structure, I group them lithologically as follows:—

(A) Ordinary quartzites. Quartzites containing conspicuous fragments. Fine-grained schistose quartzites.

(B) Agglomeratic or conglomeratic rocks.

* It contains some crystalline grains, often aggregated, of a mineral granular in texture, varying from a golden-brown colour to all but opaque, perhaps an impure sphene or rutile.

† See also Logan, p. 52, for one more detailed in a neighbouring district.

(A) *Quartzites.*—These rocks vary in colour from almost white to grey. The recognizable fragmental grains are commonly from about ·005″ to ·025″ in diameter. The rock consists of quartz, with occasional felspar (fragmental), and mica (variable in amount).

The grains of quartz are generally clear, though microlithic enclosures and exceedingly minute cavities do occur. The slightly ragged outline of the grains, and the way in which they are (so to say) fused one with another and with the matrix, prove to my mind that there has been secondary enlargement; but to what extent I cannot determine, for I have not been able to distinguish (as one sometimes can) the true boundary of the original grain. From their general outline I believe them to have been formerly angular. Chalcedonic quartz is also present, sometimes interstitially, sometimes in aggregates, and this occasionally may also be an original constituent. The felspar fragments exhibit in some cases the striping of plagioclase and the cross-hatched structure of microcline; it is possible that these also have been enlarged. The mica, which occurs in scales from about ·002″ or ·003″ downwards, is light brown in the darker, colourless or almost so in the lighter quartzites. Their well-formed outlines indicate that, even if there has been a nucleus of detrital origin, they have developed their present boundaries *in situ*.

Passing now to the quartzites with marked fragments—altered pebbly sandstones—we find that their matrix strongly confirms the view just expressed (specimens from about one mile west of Wahnepitae to one mile east of Sudbury Station). Brown mica is more abundant, the flakes are larger, often about ·005″, and occasionally

Fig. 1.—*Matrix of Conglomerate from the Sudbury District, showing well-developed mica flakes associated with quartz (the white ground of the figure).* ×140.

even more in length, excellently developed, but without any definite orientation (fig. 1). Smaller films of white mica are intermingled variably with quartz (probably interstitial)*. The larger quartz grains in the matrix are usually compound, consisting of several granules rather polygonal in outline, and sometimes containing between them tiny flakes of brown mica.

The fragments in this altered conglomerate, east of Sudbury, are interesting; those examined in this rock are more or less rounded in outline and light grey in colour. They consist of quartz, felspar, and mica (brown and white), but the condition of these minerals is peculiar. Broadly speaking, their association resembles that of a moderately coarse granite, but the quartz on examination proves to be not in single, or almost single, grains of fair size, but a mosaic, like a honeycomb, of different granules, among which occur, very sparsely, flakes of mica and earthy granules. The felspar has almost lost not only all definite external form, but also to a great extent its characteristic internal structure. Flakelets of white mica and specks of quartz are developed in large patches over most parts of the crystals, insulated portions only here and there remaining comparatively untouched, and exhibiting sometimes the parallel lamination of plagioclase, at others possibly the structure of microcline, while others may be orthoclase; nay, at times, even the larger clusters of polygonal quartz appear to have been developed in the heart of a large grain of felspar. The process of alteration seems to be as follows:—First a bit of the felspar assumes a 'dusty' aspect; next some tiny flakes of mica and a granule of quartz segregate; then the latter enlarges, as it were pushing back the mica, which forms an irregular ring round the grain (fig. 2). Then two or three grains

Fig. 2.—*Development of Quartz and flakes of Mica in Felspar Crystals.* (The mica is indicated by the outlined flakes, the quartz is dotted. In the upper part of the diagram the larger mass of quartz is beginning to show the "mosaic" structure.) × 27.

grow together, generally expelling the intervening mica, so that at last the felspar crystal is replaced by aggregated patches of quartz and of microscopic mica. It is singular that while, from the general appearance, one would be prepared to accept some of the quartz in

* Crystalline grains of black iron-oxide and of a dark granular mineral are present.

the slides as an original constituent, all of it, on applying the polarizing apparatus, breaks up into the above-described mosaic of separate crystalline grains. The change of the felspar is not always as above described; in some cases it is replaced by microscopic white mica and occasional interstitial quartz in the more usual manner. Dark brown mica occurs in the slide, occasionally in isolated flakelets, but commonly in aggregated patches of these, and there is, as usual, a little iron-oxide. It can, I think, hardly be doubted that these fragments were once a fairly coarse granite or granitoid gneiss, and that their present aspect is due to subsequent change. If so, it is interesting as indicating a very considerable freedom of molecular movement during the change, for the position of the constituents must sometimes have been altered by quite ·01″. I cannot but conclude that spots of quartz ·025″ in diameter have formed in the heart of felspar crystals, so that some of the constituents have been pushed aside for half that distance, and I believe that some, at least, of the larger patches have been thus formed. If I am right in inferring that formerly the quartz and the brown mica were in grains sometimes approaching ·1″ in diameter (and this the size of the felspar crystals, still occasionally discernible, appears to justify), then it would seem as if all the constituents had undergone a crystalline modification so as to form aggregated groups of smaller crystals *.

Was, then, the alteration of the fragments anterior or posterior to their inclusion in this conglomerate? As the matrix of the latter is altered, we might reasonably expect some marked change to have occurred in the fragments; but inasmuch as the matrix contains numerous small fragments (associations of from 3 to 6 or 7 granules) of the "mosaic" quartz, and two or three fragments, still recognizable, of the modified felspar, there can be no doubt that these changes occurred anterior to the formation of the conglomerate, so that we have here a case of "Pre-Huronian" alteration.

With this group I include a fine-grained schistose rock (occurring just west of Sudbury Station), which, though quartzose, is evidently less rich in that mineral than the rocks belonging to the great series already described. Assuming these to be altered sands and gravels, this would represent a more silty or earthy stratum. When examined microscopically, the latter rock is found to consist almost wholly of granules of quartz seldom exceeding ·002″ in diameter, and flakes of a micaceous mineral, commonly slightly larger, sometimes approaching near ·01″. Some of the quartz grains look as if they were fragments, but I expect the majority have been formed *in situ*. There are a few granules of magnetite scattered about. There is a slight, but only a slight tendency to banding in the arrangement of the constituents, and the flakes of the micaceous

* I have sought to calculate the proportion of silica which would be set free in converting a crystal of average orthoclase into quartz and potash-mica. Supposing none of the constituents removed, the quantity of silica set free would be nearly $\frac{4}{10}$, so the result would be about $\frac{4}{10}$ free quartz, and $\frac{6}{10}$ mica; but in reality a considerable percentage of the alkali is not needed to form an ordinary mica, and has probably been removed, so that the actual percentage of free quartz in the resulting compound would be rather higher.

mineral have not a well-marked parallelism. This mineral is in part of a pale olive or brownish-olive colour, in part colourless. The latter is the ordinary white mica, giving bright tints with crossed nicols; the former is variably dichroic, giving only low dull tints, and is probably an altered brown mica. Distinct dichroism is often exhibited as a cloudy spot in a flake, when the remainder is feebly dichroic. This rock has some resemblance to one of the fine-grained mica-schists, but it is by no means identical with them. I have many typical specimens of the latter, such as occur in Anglesey, in the upper group of schists in the Alps, &c., from all of which this one differs, often very markedly.

Macroscopically similar to the above, except that some light-coloured specks are detected on close examination, are two specimens sent by Dr. Selwyn, one labelled "Sudbury," the other "Between Sudbury and Vermillion river." Under the microscope, the ground-mass is generally similar to the above, except, perhaps, that there is not quite so much mica, and a larger proportion of it is the colourless species. Many of the dark grains are rather prismatic in form, and on applying a high power, appear to be a yellowish mineral, blackened, often almost wholly, with opacite. The mica does not exhibit any orientation. The spots are rudely rhomboidal in form, and consist mainly of quartz granules with some mica, variable in quantity, and rather irregularly dispersed. The second specimen has only varietal differences, but here there is a rather well-defined border of white mica (chiefly) in the outer part of the rhomboidal "spot." The structure suggests that these may once have been separate crystals, and I think it possible that the rock was either a volcanic glass or tuff, containing crystals of felspar, in which both ground-mass and crystals have subsequently undergone a rearrangement of their constituents.

(B) Proceeding next to the remarkable group of breccias (for the fragments are more commonly angular than rounded) which occur at intervals for certainly more than a mile along the railway west of Sudbury, we find, as stated above, considerable variety in their mineral character. It was impossible for me to bring away materials for an exhaustive study, so I secured a few of the more remarkable specimens. The first, about half a mile from Sudbury, is a compact grey rock, with pale-coloured spots of rather irregular form, which weather to a pale cream-colour. In the field one could say no more than that it might once have been a rather peculiar porphyritic trachyte, but that it rather resembled a true breccia, where bits of a compact lava were imbedded in a somewhat quartzose, very fine-grained matrix. Under the microscope it appears to be a mosaic of irregular grains of quartz and felspar; in what proportion it is difficult to say, but the former certainly predominates, and in it are scattered rather irregular flakes of a brownish or greenish mica, occasional larger grains, commonly associated, of quartz, and grains of felspar with ragged outline, as if they had once been larger and had been corroded by the matrix. Hence, even after microscopic examination, one cannot venture to speak positively of the nature of the rock; its structure resembles that of some devitrified felstones; also, though more coarse, that of the Treffgarn hälleflinta.

Bearing some resemblance to this, but more distinctly fragmental (it contains a yellowish fragment, about $1\frac{1}{4}'' \times \frac{1}{3}''$, together with some little bits), is a small specimen sent by Dr. Selwyn, labelled "1 mile W. of Sudbury." The matrix consists of granules of crystalline quartz and the usual brown or greenish-brown mica, with occasionally a larger grain of quartz or of felspar. I have little doubt that all the constituents, if not developed *in situ*, have been enlarged, but I cannot detect the original boundary of any one. The fragments contain but little mica, and chiefly consist of granules of quartz much smaller than in the matrix, with rather more ferrite scattered among them. The slide includes a portion of the larger fragment and some of the smaller; all can be distinguished, but they are, as it were, "fused" into the matrix.

The next set of fragments are of a grey-speckled crystalline rock, which often occurs of large size and in great abundance. The matrix exhibits a structure identical with that just described, but the grouped quartz grains therein are rather larger in size, while the felspar-crystals are all larger and more distinct. These certainly give one the idea of being encroached upon by the matrix, as their actual outlines are so very irregular, and occasionally there appears a kind of intrusion of the matrix, but there is not, as one would expect, any appreciable amount of white mica formed. There are, however, in the slide, some yellowish mineral granules, and an occasional larger yellow-grey grain, which may be an alumina silicate. On the whole, then, I think it highly probable that these have once been a porphyritic rhyolite, though they have been subsequently greatly altered by molecular rearrangement.

The fragments with the dark hornblende-like crystals have a similar matrix, but it seems to contain more felspar; at any rate the "dusty" look of a considerable proportion of the granules indicates clearly the position of what is, or has been, this mineral. There is also more ferrite, opacite, or an impure chlorite (?) scattered about the slide than in the other cases. We find the compound grains of quartz and the porphyritic felspar in the condition already described. The supposed hornblende proves generally not to be a perfect crystal, but an irregularly outlined group of associated flaky grains of hornblende or chlorite (some a very dark indigo-green, others practically opaque) "clotted" together, with occasional interspersed quartz-grains. Where these flakes are cut transversely they show cleavage, are dichroic, and extinguish either parallel or at small angles with the cleavage. There is, however, in one slide a fairly perfect crystal, which is undoubtedly hornblende, and on the whole I am disposed to refer most of the granules to this mineral rather than to one of the chlorite group. The pale-brown mineral, looking like granules of gum, mentioned above, is not uncommon here. It would therefore appear probable that this rock also may be of igneous origin, but changed like the other.

The last to be described are the breccias (less coarse) at the greatest distance, all $1\frac{3}{4}$ mile from Sudbury; these, in the field, especially when weathered, as Dr. Selwyn pointed out, have a marked resemblance to beds of volcanic ash. The matrix has a general similarity to that of the schistose rock described above, except that the mica flakes (brownish or greenish, possibly in some cases a chlorite, and white in variable proportions) are rather larger, and the rock, as a whole, is nearer to a typical mica-schist. The fragments have a general structure resembling that described above, but the mosaic structure is less strongly defined, and there is, in one case, much more mica, especially white. They are not porphyritic, as in the other instances.

I travelled over the great belt of the Huronian, mapped as extending for more than 70 miles from Sudbury *, as far as Pagamaseng (59 miles), where the track ended at the time of my visit, but could only examine the rocks here and there, and then hastily. Still as the train went very slowly, and I was in an open van, I could form some notion of their general character. I believe that Laurentian gneiss is brought up by faults two or three times, the intervening and dominating rock being Huronian, interrupted occasionally by intrusive masses of granite, syenite, or diorite. It is, however, hardly worth while my transcribing notes gathered on a hasty traverse. I will merely say that near the east end of Geneva lake is a grand conglomerate which contains blocks of a grey granite-like rock, passing westward into a dark-grained slaty rock, interstratified with a grey quartzite distinctly banded with quartz-pebbles. Near Vermillion River I obtained an ordinary greywacke. At High Falls, on the Oneping (25 miles from Sudbury), we cut through a mass of fragmental rock like a volcanic ash, which is worth notice. The finer matrix is almost opaque, a very dark dust; the smaller fragments are quartz (not abundant) and altered felspar or devitrified glass. The larger have probably been a moderately acid glass, sometimes vesicular, the cavities being now occupied by a pale chloritic mineral, the matrix being partly microcrystalline, partly a mass of small felspar crystallites, with occasional groups of pale actinolite. The zonal arrangement of some of the evitrification-structures suggests that the changes have taken place *in situ*†.

The remaining specimens in my collection, not from the above line of section, and almost all given to me by Dr. Selwyn as typical varieties of the Huronian group, may be classified as follows:—

(1) Rocks little altered. These are grits, the fragments evidently being waterworn. One (from an island on Lake Huron between Delormine and Boulanger locations) contains in a rather earthy matrix fragments of three distinct varieties of lava: one is a very character-

* Measured on the map, Sudbury is about 12 miles by the railway from the eastern boundary of the Huronian, but the railway is here running about W.S.W. The total breadth of the Huronian belt, as mapped, is probably nearly 80 miles, measuring in a N.W. direction, the prevalent dip being roughly S.E.

† I obtained a specimen thus: the guard kindly jumped off the train as it was going along, and picked up a block for me! I mention this to show that the pace of a "construction" train on a new line gives more opportunity for geological observation than do modern expresses.

istic andesite, the others, more compact, are probably the same species; these are perhaps even better preserved than the fragments in the volcanic grits of Charnwood Forest. With them are two fragments of a granitoid rock, one of which has its quartz in compound streaks, *i. e.* exhibits a gneissic structure, probably the result of pressure, but anterior to the detachment of the fragment. Another (from the east end of the same island) consists of rather similar materials, but the volcanic rock is more basic, containing a considerable amount of viridite and chlorite, and the granitoid fragments (the commoner) indicate very curiously the results of fracture, under pressure, and recementation. A third (between Upper and Lower Rapids, Vermillion River, C.P.R.) consists of rather angular fragments of quartz and felspar, and of flakes of altered brown mica, evidently the detritus of an old granitoid rock, where the proportion of the materials has not been very much changed by drifting. Another (between Spanish and Sable Rivers, C.P.R.) has an argillaceous matrix, with a few scattered grains of quartz, but contains a comparatively large fragment of a rock which has the structure of a true granite rather than a gneiss. The last (Campment d'Ours*) is crowded with fragments, andesite or porphyrite (4 varieties), granitoid rock, and a fine-grained gneiss, with marked foliation. The matrix also is obviously the detritus of the above materials, chiefly of the second. That rock, it may be remarked, contains much microcline, and exhibits a structure characteristic of the granitoid gneisses so common in the lower part of the Laurentian series.

(2) The next group has undergone changes like and about equal to those described in the Sudbury district. White quartzites, from between Serpent River and Algoma Mills, *i. e.* about 8 miles from Lake Huron, on a line branching from Sudbury, and from between Sable and Spanish Rivers, C.P.R.† These have clear quartz grains imbedded in a colourless micaceous "paste," in which is sometimes a darker mica and iron-oxide. This is more abundant in the second (darker) specimen.

Lastly is a very interesting rock. The ground-mass consists of micas, greenish and colourless, in well-defined flakes from about ·002″ to ·004″ long, associated rather irregularly with granules of clear quartz, generally of less diameter, and some grains of opacite, in which occur somewhat oblong spots consisting chiefly of white mica and granular quartz, the mica being to a large extent collected about the edges. I suspect that this rock was once a microporphyritic igneous rock, probably an andesite or quartzless trachyte, subsequently changed.

With these rocks may be included a grey limestone (from Echo Lake, some distance east of Sault Ste. Marie), the outside of which is weathered very curiously into a sort of ridge and furrow‡.

* An island at the east end of the narrow channel between Lake George and North Channel on Lake Huron.

† These, according to Logan, come well above the great conglomerates. So also does the well-known "red-jasper conglomerate."

‡ Undoubtedly No. 5 in the series given by Logan, p. 56. Here, as in another place, it divides an upper from a lower mass of conglomerates. Here a thickness of 300 feet is assigned to it.

Macroscopically it is compact in structure, looking very like an argillite or felstone; under the microscope it is found to be a rather minutely crystalline granular dolomite, containing occasional granules of quartz, flakes of white and brownish mica (with probably one or two grains of tourmaline), with hæmatite and opacite, and occasional rather earthy-looking granules, chiefly occurring in streaky bands and causing the peculiar weathering. All the minerals look as if developed or completed *in situ*, so that the rock is a little more altered than would be supposed from a macroscopical examination; still I feel doubtful whether to class it with these or with the former group.

There are some igneous rocks of interest associated with those above described; but as they have no bearing on the questions discussed in this paper, I pass them by without further notice. I may, however, mention that when at Pagamaseng, a specimen was given to me of a rock (diabase) containing in porphyritic crystals the variety of anorthite called huronite. This was first described from specimens of the same rock occurring as boulders near Lake Huron. My specimen also came from a boulder near Pagamaseng, but I was afterwards informed by Dr. Girdwood that the rock had been formed *in situ* at no great distance from the settlement.

The results described above may be thus briefly summarized:—

(1) Putting aside rocks indubitably of igneous origin, and certain others the position of which is not clear, the Huronians of the Sudbury region obviously form a series separated from the Laurentian by a long interval of time. Though here and there among them rocks may occur the structure of which, inconspicuous from the first, has been yet more obscured by subsequent micromineralogical change, the majority are obviously of fragmental origin, and we need not hesitate to claim for them a place among the stratified rocks, so that these will carry the other less definite cases with them.

(2) Among the rocks in this region at present referred to the Huronian, two groups may be distinguished. One, where the alterations of the matrix are comparatively slight, merely such micromineralogical changes as are common in the older Palæozoic rocks, such as the deposit of secondary quartz, the partial micatization of felspars, the formation of viridite, &c.; another, where the changes are more strongly marked, where the enlargement of fragments, the generation of mica (especially of brown mica), has taken place on a larger scale, so that the original clastic character of the rock, though still to be discerned, is less obvious, and in the case of the smaller constituents it is often difficult to decide whether they are clastic or endogenous.

(3) This distinction must indicate either (*a*) that selective metamorphism has produced marked effects, viz., that diversity of material has led to different results being produced by one and the same cause, or (*b*) that we are dealing with a series of great thickness, the deposition of which occupied a very long time, so that the lower beds are more altered than the higher, or (*c*) that under the name Huronian two distinct series are included. I am well aware that in

structural and mineral changes much depends upon the constituents of a rock. Under certain circumstances, such minerals as epidote, chlorite, viridite, hydrous white mica, quartz, &c., readily form; a clean sandstone, for instance, is readily cemented into a quartzite, the calcareous constituents of a rock will crystallize, while the argillaceous are absolutely unchanged. But making all allowance for this, and confining my attention to the finer portion of the detrital materials, I find them in the case of the latter group more altered (especially where brown mica is developed) than I have ever yet seen in any Palæozoic fragmental rock, even the oldest, or even in the typical "Pebidian" of this country, except when affected by contact-metamorphism. Hence, I think, our choice lies between the second and third hypotheses, and, as at present advised, I incline to the latter; viz. that two distinct groups, of which, at any rate, one is Pre-Cambrian, are included under the name Huronian.

(4) It is a curious coincidence that fragments of lava bearing a general resemblance to those which in Great Britain are found, certainly or presumably, rather below the level which appears to be the natural base of the Cambrian series (*i. e.* in the so-called Pebidian), should occur so abundantly in a formation which also seems to be the record of a late phase in Archæan history—one of the concluding chapters of the volume.

(5) It seems also worth note that many of the fragments have assumed structures characteristic of Laurentian rocks, such as the peculiar "intermediate" structure, neither normal granite nor normal gneiss,—or a somewhat foliated structure, resulting from mechanical, followed by chemical change,—prior to the formation of these conglomerates. Also that certain other important changes, apparently of a somewhat segregatory nature, had taken place in other rocks, possibly of igneous origin. The occurrence, too, of fragments of a true schist, similar to those met with in old conglomerates elsewhere (*e. g.* Charlton Hill, Salop) and not at all unlike one which I obtained *in situ* near Straight Lake, is also interesting as showing that ordinary schists and gneisses, of comparatively fine-grained structure, existed at that period as well as granitoid rocks.

(6) The changes which have taken place in the more altered "Huronians" show that a gneiss might conceivably result from the alteration of a felspathic greywacke or a mica-schist from a muddy sandstone, so that it is possible for a series of banded gneisses and schists, of moderate coarseness, to have been produced by the metamorphism of a sedimentary series. Other specimens, however, indicate the possibility of certain gneisses and certain schists being due to the metamorphism of rocks originally igneous.

(7) While in the case of some of the fragmental rocks there is reason to believe that the mineral changes in the included fragments occurred prior to their being detached; others (which seem originally to have been very compact, possibly porphyritic lavas) appear to have undergone a change together with the matrix in which they are imbedded. It is possible that these breccias may be of volcanic origin, at any rate it appears probable that from "trachytic" mate-

rials quartz-mica rock has been developed, which, however, differs (chiefly in the absence of foliation) from a normal mica-schist.

(8) The evidence of these Huronian rocks, so far as it is positive, is in favour of the theory which regards the more coarsely crystalline gneisses and schists as produced, as a rule, only in early Archæan times; and so far as it is negative, it is against the theory which regards them as metamorphosed sediments of Palæozoic or even later age, because we find in them an approach, though an incomplete one, to the structure of crystalline gneisses and schists, and this approach is nearer than I have yet found in any rock indubitably Palæozoic*.

Postscript.—A common thread of thought and purpose runs through these three papers; they form a kind of trilogy; may I, then, be allowed to point the moral in a brief epilogue?

The first illustrates the effects of pressure on Palæozoic sediments; the result is micro-mineralogical change only, the production of tiny films of mica, of specks of secondary quartz, an enlargement probably of clastic granules of the same. Thus a microfoliation only is produced, which, strange to say, appears to be parallel to the original stratification and independent of the pressure which has subsequently cleaved the rock. If the temperature of a mass, thus modified, be considerably raised by the intrusion of igneous rock, further and more active chemical changes occur, the minerals already microscopically present grow larger, while others are produced. The result is a moderately good imitation of one of the fine-grained mica-schists.

The next paper illustrates the changes in a fragmental rock of unknown geological age, which has certainly been compressed, which may have had its temperature raised, though not by intrusive igneous rocks, and in which considerable change has been produced; the result, however, in this case also does not quite accord with a typical fine-grained mica-schist, though in one instance it comes very near to it.

In the last case we are dealing with rocks, certainly of great antiquity, which I suppose all would admit to be, in the main, Pre-Cambrian. Here we find changes very similar to those last described; these also have not produced typical gneisses and crystalline schists, and they further distinctly testify that when they were formed, such rocks already existed, and mineral changes occurred, seemingly with more facility than in later days. To what conclusions these results point, it is needless to suggest to a careful reader.

* This paper was completed (except for two or three trivial details) last August. Since my return to London in October, I have had the opportunity of reading the most valuable paper by Prof. R. S. Irving, "Is there a Huronian Formation?" (Amer. Journ. Sci. vol. xxxiv. pp. 204, 249, and 365). We appear to have arrived independently at very nearly the same conclusion. I think, however, that the Sudbury rocks exhibit, as a group, rather more alteration than those from the vicinity of Lake Huron, as described by him, and as confirmed by the specimens sent to me by Dr. Selwyn. Possibly the Sudbury rocks may be a slightly older group, the equivalents of his "iron-bearing (Animiké) series," p. 216.

Discussion.

The President remarked that the relations of foliation to stratification and cleavage would receive much illustration in the study of incipient crystallization in rocks. It was only possible to understand the origin of great changes by finding out what took place in cases of smaller change.

Dr. Geikie coincided with the President's views of the importance of beginning the study of metamorphosis by investigating the process of smaller changes. He hoped before long to lay a contribution to this subject from the north-west of Scotland before the Society. The Obermittweida conglomerate reminded him of some crushed Cambrian conglomerates in Scotland, where there is a passage from crushed conglomerates and sandstones into mica-schist.

Mr. Rutley said that one of the Morlaix rocks represented in the diagram resembled, in microscopic character, some of the slate from Boscastle in Cornwall. He was much interested in the evidence of transition between the two rocks figured in the diagrams. He thought the enlargement of crystals might in some cases give rise to pressure. He then, with reference to the Sudbury rocks, noticed the occurrence of some similar characters in certain Huronian rocks from Michigan.

Rev. E. Hill said he had seen the Morlaix beds, and described the locality. The age of the rocks might be determined with fair certainty.

Mr. Marr said the mode of occurrence of the Obermittweida conglomerate was in boat-shaped patches that looked like the loops of overfolded synclinals. The fossiliferous rocks of Saxony are unfortunately found at a distance, but at Hof, in Bavaria, and in the Bohemian basin primordial beds are found. Dr. Reusch considered the Obermittweida rocks very like Silurians near Bergen.

Mr. Bauerman had also been at Obermittweida and thought that Prof. Hughes's view was a fairly probable one of the structure of an obscure section.

Prof. Hughes, in reply, said he did not insist on the identity in age of the conglomerates, of which he exhibited specimens ; all were basement-beds and similar in partaking of the mineral character of the rocks on which they rested.

Prof. Bonney said he had scarcely anything to say in reply, except to thank the speakers for the way they had received his papers. He had unfortunately not been able to examine the rock noticed by Prof. Reusch in Norway. He was trying to work out the whole question of change of structure, approaching it from different sides. He had seen it noticed by Dr. Barrois that some Cambrians occurred near Morlaix. He mentioned instances of patches of sedimentary rocks infolded in old strata, as at Obermittweida, and said that he also was surprised at not finding the matrix of the Obermittweida rock more affected by pressure.

6. *Note on a new* Wealden Iguanodont *and other* Dinosaurs.

By R. Lydekker, Esq., B.A., F.G.S. (Read November 23, 1887.)

[Plate III.]

Introductory.—The primary object of this communication is to bring to the notice of the Society numerous remains of an apparently new Iguanodont Reptile obtained by Mr. C. Dawson, F.G.S., of St. Leonards, from the Wadhurst Clay (one of the beds of the Hastings Sand, or lower division of the Wealden), and recently acquired by the British Museum; and also a maxilla from the Wealden of the Isle of Wight, apparently referable to *Ornithopsis.* Having, however, recently examined the whole of the collection of Dinosaurian remains preserved in the Museum, in the course of the preparation of the first part of the forthcoming 'Catalogue of Fossil Reptilia' of the collection, I have also made certain observations regarding other members of the order, which may be conveniently recorded at the same time.

Iguanodonts.—Commencing with the Iguanodonts, I may first of all observe that I fully concur in the view which M. Dollo informs me he now takes as to the specific identity of *Iguanodon bernissartensis* and *I. Seelyi*; and, although the original description is very meagre and unaccompanied by a figure, I think we ought to adopt the former and earlier name for the species which has been so well described by the Belgian naturalist. The British Museum possesses a considerable series of the remains of this species, many of which were referred by Sir R. Owen to *Cetiosaurus* and *Pelorosaurus*, while others have been described under the name of *Iguanodon Mantelli.*

In addition to the two Wealden species of *Iguanodon* (*I. Mantelli* and *I. bernissartensis*) and the perfectly distinct genus *Hypsilophodon*, Prof. Seeley has described other Iguanodont vertebræ from the same formation in the Isle of Wight, under the name of *Sphenospondylus* *; while at the recent meeting of the British Association he has proposed to refer *I. Prestwichi*, Hulke †, of the Kimeridge Clay, to a fourth genus under the name of *Cumnoria.*

With regard to *Sphenospondylus*, I find from specimens in the Museum that several of the anterior dorsal vertebræ were opisthocœlous, while those later in the series retain a trace of the same feature; and from this circumstance I am disposed to regard this form as not improbably entitled to generic distinction from *Iguanodon*, and showing some resemblance to the genus usually known as *Hadrosaurus* (but of which the correct name is *Trachodon*), characterized by all the dorsals being opisthocœlous. The later

* Quart. Journ. Geol. Soc. vol. xxxix. p. 55 (1883).
† *Ibid.* vol. xxxvi. p. 433 (1880).

dorsals approximate, however, to those of an unnamed *Iguanodon* in the Museum from near Hastings; and the absence of teeth like those of *Trachodon* in the Isle of Wight tends, as far as it goes, to indicate that *Sphenospondylus* agreed in dental character with *Iguanodon*. That we should find in England a form more or less intermediate between *Trachodon* and *Iguanodon* is, however, to be expected from the occurrence in this country of a Dinosaur which I provisionally refer to the former. This determination is based on a tooth from the Cambridge Greensand (B. M. No. R. 496), figured by Sir R. Owen in his 'Cretaceous Reptilia' (Mon. Pal. Soc.), suppl. ii. pl. 7. figs. 15, 16, under the name of *Iguanodon Mantelli*; but which, as Prof. Seeley has pointed out on page 591 of vol. xxxv. of the Society's Journal, agrees so closely with the teeth of Leidy's *Trachodon Foulki*, from the Upper Cretaceous of New Jersey, that, in the absence of any evidence to the contrary, I propose to refer it provisionally to that genus, with the name of *T. cantabrigiensis* *. This tooth exhibits the peculiar groove on the inferior side of the root made by the point of the tooth immediately below, which is so characteristic of the genus. Finally, since Prof. Seeley has not applied a specific name to the type of *Sphenospondylus*, I propose that it should be known as *S. gracilis*.

Turning to *Iguanodon Prestwichi*—the type of *Cumnoria*—which in the structure of its sacrum differs very widely from the typical forms, there is much to be said for the view expressed by Prof. Seeley as to its right to generic distinction; but, after having been for some time inclined to adopt this view, I think on the whole that it is better to retain it in the original genus, of which it will form the type of a very distinct group. The pelvis is unfortunately very imperfectly known, all that can be definitely predicated being that the preacetabular process of the ilium is considerably elongated. In the structure of the sacrum this form agrees very closely with the North-American Upper Jurassic genus *Camptosaurus*, Marsh †, in which the ilium is remarkable for the great reduction of the preacetabular process, the pubis is of equal length with the ischium, and the latter is stouter and shorter than in *Iguanodon*, the two latter features being also found in *Hypsilophodon*.

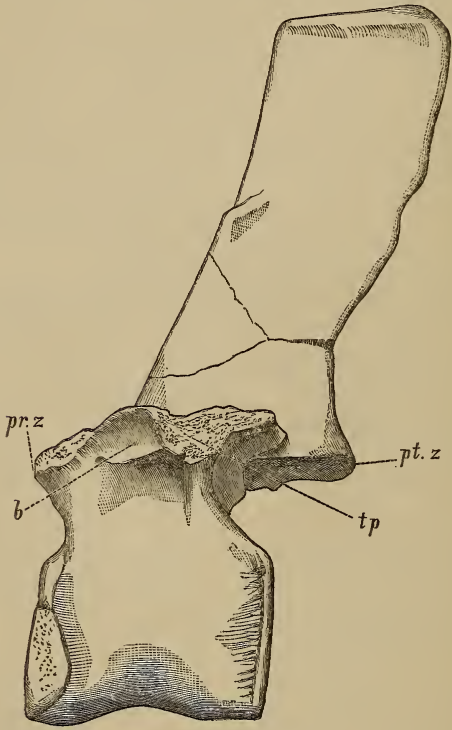
The first of the Iguanodont specimens from the Wadhurst Clay that I propose to notice comprises a part of an associated skeleton including the left ilium, the acetabular region of the pubis of the same side, a number of more or less imperfect dorsal, lumbar, and caudal vertebræ, the proximal half of a tibia, and two metatarsals; besides some imperfect bones which it is difficult or impossible to determine. Of the vertebræ, one of the most perfect from that portion of the dorsal region where there is a rib-facet distinct from the transverse process, is represented in fig. 1. The Iguan-

* The vertebræ from the same formation described on p. 613 of the above cited paper under the name of *Eucercosaurus*, being unlike those of *Trachodon*, are not likely to belong to this form.

† Amer. Journ. Sci. ser. 3, vol. xviii. p. 501, pl. iii. (1879). Here named *Camptonotus*, but subsequently amended.

odont character of this vertebra is self-apparent, and from the comparatively slight degree of compression of the centrum compared with that of some dorsals to be noticed below, and the circumstance that all the other parts of the skeleton belong to the hinder region, I think it probable that it should be regarded as coming from the middle of the dorsal series. In its comparatively low arch, and the high position of the rib-facet, it differs from all the anterior and

Fig. 1.—*Left lateral aspect of a middle Dorsal Vertebra of* Iguanodon Dawsoni, *from the Wadhurst Clay.* (About $\frac{1}{5}$ nat. size.)

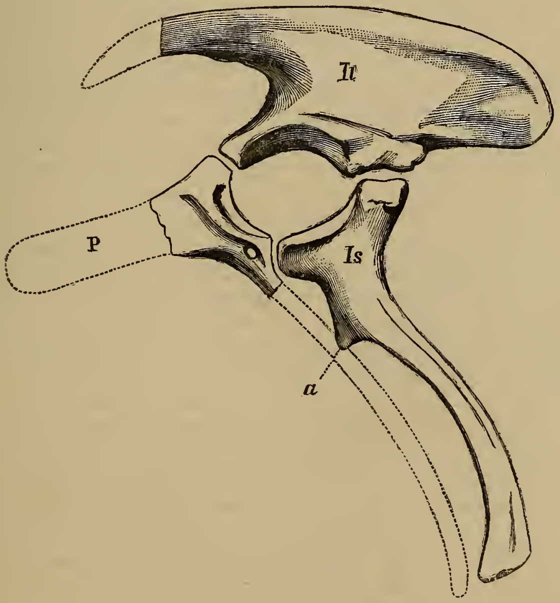


b. Facet for rib.
pr.z. Præzygapophysis.
tp. Base of transverse process.
pt.z. Postzygapophysis.

middle dorsals of *I. bernissartensis* with which I have been able to compare it, while its centrum is also less compressed, lower, and more wedge-shaped. In its low arch and the position of the rib-facet it resembles the vertebræ of *Sphenospondylus*, but the centrum is relatively shorter, and other specimens probably belonging to the same form show that the anterior dorsals had higher arches than in *Sphenospondylus*. The dorsals of *I. Prestwichi* described by Mr. Hulke differ from those of *I. bernissartensis* and *I. Mantelli* by the smaller compression of their centra, which are consequently more wedge-shaped in section. Unfortunately only an anterior dorsal is figured by Mr. Hulke, and in this the neural arch is relatively high; but since there must be a gradual lowering of the height of the arches from the anterior dorsal to the lumbar region, where (as in other species) the arches are very low, there seems to be no reason why the middle dorsals of the Kimeridge form should not have closely resembled the specimen under consideration. The posterior dorsal or lumbar vertebræ associated with this specimen cannot be distinguished from those of the Kimeridge species described and figured in Mr. Hulke's paper. The length of the centrum of the figured specimen is 0·120, the vertical diameter of its anterior face 0·110, the transverse diameter of the same 0·118, and the total height 0·447.

Of the associated bones, the left ilium (No. R. 802) is represented in fig. 2 (*Il.*), in association with an ischium to be immediately mentioned. The length of this ilium, which wants the extremity

Fig. 2.—*The left side of the Pelvis of* Iguanodon Dawsoni, *from the Wadhurst Clay of Hastings.* (About $\frac{1}{16}$ nat. size.)



Il. Ilium. *Is.* Ischium. *P.* Pubis. *a.* Obturator process.

of the preacetabular process, is 0·830, and its greatest depth posteriorly 0·260; the preacetabular process, when entire, was long, the superior border is convex, and the postacetabular portion is long, deep, and has its termination blunt, rounded superiorly, and angulated inferiorly. The difference in the form of the hinder half of this bone from the pointed extremity of the same part in both *I. Mantelli* and *I. bernissartensis* is very marked and, coupled with the greater vertical depth of the bone, would, apart from other evidence, indicate the specific distinctness of its owner. The ilium indicates a species intermediate in point of size between the two above-mentioned forms, and in contour comes nearer to that of *Hypsilophodon*, but is very widely different from the corresponding element in *Camptosaurus*. The pubis associated with the ilium is too imperfect to afford much information, but the portion immediately in advance of the acetabulum is deeper than in *I. bernissartensis*. The apparently associated metatarsals are of the short and massive type of typical species of *Iguanodon*; a second left metatarsal (No. R. 999) being undistinguishable from the corresponding bone in small examples of *I. bernissartensis*.

I have now to mention a sacrum and the associated ischia (No. R. 811) also obtained from the Wadhurst Clay, although belonging to a different individual from the preceding specimens, which I regard as the types. Other specimens (No. R. 604) from the same locality and bed, comprising part of a left pubis and a considerable number of imperfect vertebræ, may be regarded, according to Mr. Dawson's information, as well as from their mineral condition, as almost certainly belonging to the same individual. An anterior dorsal agrees very closely with the figured anterior dorsal of *I. Prestwichi*, although its arch is slightly lower, and thereby differs widely from *Sphenospondylus*. Turning to the sacrum and ischia, and seeing that the latter, although clearly Iguanodont, differ from the corresponding bones of both *I. Mantelli* and *I. bernissartensis*, and agree approximately in relative size with the ilium of the present form (as is shown in fig. 2, where the left ischium is figured), the presumption is so great as to amount almost to a certainty that they belong to the same species as the latter, and they will accordingly be so regarded. These ischia measure 0·870 (36·5 inches) in length, and closely resemble in general contour the corresponding elements of *Camptosaurus*, and less closely those of *Hypsilophodon*. They differ from the ischia of typical species of *Iguanodon* by being relatively shorter and stouter, by the absence of twisting in the axis of the shaft, by the more hammer-like head, and the longer interval between the pubic process of the latter and the obturator process. Their resemblance to the ischia of *Camptosaurus* and *Hypsilophodon* suggests that in the present form the pubis may have been equal in length to the ischium. The sacrum included five anchylosed vertebræ, which are of the inferiorly flattened type of those of *Camptosaurus* and *I. Prestwichi*.

The foregoing notes indicate that we have here to do with a Wealden Iguanodont which is certainly distinct from both *I. Mantelli* and *I. bernissartensis*, and which I cannot identify with *Sphenospondylus gracilis*. It was probably more nearly allied to the Kimeridgian *I. Prestwichi*, although, in the absence of any definite knowledge of the pelvis of the latter, the closeness of its relationship cannot be determined. Its higher geological horizon renders it, however, pretty certain that it cannot be specifically the same as the latter. In the structure of the pelvis this Iguanodont approximates to *Camptosaurus* and *Hypsilophodon*, and it also agrees with the former in its sacral characters; its hind foot was, however, essentially that of *Iguanodon*, and the presumption therefore is that the manus was also of similar structure. In the opinion of many authorities I have little doubt that these differences would be regarded as of generic value, and the question would then arise whether this form should constitute a new genus, or whether it should be classed with *I. Prestwichi* as a species of *Cumnoria*, or possibly with *S. gracilis* as a *Sphenospondylus*. I am, however, inclined to the opinion that it is preferable, at least for the present, to employ the generic term *Iguanodon* in a sense which will embrace all the variations between the typical and the present form, and I accordingly propose to include the latter in that genus, under the name of *Iguanodon Dawsoni*.

In this sense the genus *Iguanodon* may be divided into a Euiguanodont group comprising *I. Mantelli* and *I. bernissartensis*, and characterized by the pointed posterior extremity of the ilium, the short pubis, the twisted ischium, and the compressed sacrals, as well as by certain features of the anterior dorsal vertebræ; and into a Proiguanodont group, including *I. Prestwichi* and *I. Dawsoni*, and characterized by the blunt extremity of the ilium, the probably long pubis, the absence of twist in the ischium, and the hæmally flattened sacrum. The Proiguanodont group will be the one connecting the typical forms of the genus with *Hypsilophodon* and *Camptosaurus*.

I may here call attention to certain specimens some of which may probably belong to the Wadhurst-Clay *Iguanodon*. The first is a fine left scapula (No. R. 966) obtained by Mr. Dawson from the Wadhurst Clay, which agrees in relative size with the type ilium. This bone is remarkable for having a conical puncture on the posterior side on the middle of the dorsal surface, which appears to have been not improbably caused by a wound from the strong spike terminating the pollex of another, and probably male, individual. It may also be observed that on the anterior border of the proximal expansion there occurs a facet, which I at first thought might indicate the articulation of a clavicle; but Prof. Seeley, to whom I pointed it out, suggests that it may merely indicate a cartilaginous epiphysis *.

Among the Fox Collection from the Isle of Wight, I find the centrum of a posterior dorsal or lumbar vertebra (No. R. 136) from the Upper Wealden, which, from its precise resemblance to the hinder trunk vertebræ of *I. Dawsoni*, I refer provisionally to that species. If this should prove the existence of that form in the

* It may be observed that in the 'Geol. Mag.' 1887, p. 85, Prof. Seeley states that the absence of such a facet is one of his reasons for rejecting Mr. Hulke's interpretation of the sternal ossifications.

Upper Wealden, I would suggest, without venturing to enter on the vexed questiom of their homology, that the bones of the sternal region of an Iguanodont figured by Mr. Hulke in vol. xli. pl. xiv. fig. 1, of the Society's 'Journal,' may belong to the same form, since the difference in their contour from the corresponding bones of both *I. Mantelli* and *I. bernissartensis* appears to me to support the view expressed by M. Dollo, that they are not referable to either of those species.

Before leaving the Iguanodonts, I may draw attention to two scapulæ and a coracoid from the Upper Wealden which differ somewhat from the corresponding bones of the skeleton of *I. bernissartensis* figured by M. Dollo, although I do not know to what other form to refer them. The coracoid is in the Cambridge Museum, and is figured by Prof. Seeley in the 'Quart. Journ. Geol. Soc.' vol. xxxviii. pp. 367, 371, where it is provisionally referred to *Ornithopsis.* It is, however, essentially Iguanodont, but differs from M. Dollo's coracoid of *I. bernissartensis* by its greater breadth, and the presence of a complete foramen in place of a notch. The scapulæ are likewise from the Isle of Wight, and belong to the Mantell Collection of the British Museum (Nos. R. 1012 and 32913). The less imperfect of these bones differs from that in M. Dollo's figure by its greater curvature, and also by diminishing gradually in width above the proximal expansion, instead of expanding towards the summit. It is totally unlike any Sauropodous scapula, and is decidedly Iguanodont; while it is not improbable that it may have belonged to the same individual as some of the vertebræ of *I. bernissartensis* in the same collection. I do not think that these bones can indicate the distinctness of *I. Seelyi* from *I. bernissartensis,* especially since the Museum has a coracoid like M. Dollo's specimen, associated with an ilium which cannot be distinguished from Mr. Hulke's type of the former. These scapulæ, besides being of too large dimensions for *I. Dawsoni,* differ widely from the specimen of that bone which I provisionally refer to that species.

Scelidosauridæ.—The specimen to which I desire to particularly direct attention under this heading is a right ilium (No. 2150), from the Wealden of Cuckfield, which has long been labelled *Iguanodon Mantelli,* but which has nothing whatever to do with that genus. This specimen is figured (reversed) in the accompanying woodcut; it is clearly of an Ornithopodous type, and has long pre- and postacetabular processes, of which the former is laterally compressed, and the latter, by the giving off of an inner horizontal plate, has a triangular cross-section. In general contour this ilium comes nearer to that of *Scelidosaurus* than any other with which I am acquainted, and I am therefore inclined provisionally to refer it to the Wealden genus *Hylæosaurus,* of which the pelvis has been hitherto unknown, and with the other bones of which the present specimen would agree well in relative size. This ilium presents, however, a considerable resemblance to the one from the Wealden, figured by Mr. Hulke in vol. xxxv. pl. xxi. of the Society's 'Journal,' under the name of *Vectisaurus*; and this induces me to regard the latter as probably referable to the Scelidosauridæ rather than to the Iguanodontidæ, in which its founder was inclined to place it. If this be so, the question will arise whether *Vectisaurus* may not be identical with *Regnosaurus*, Mantell (Phil. Trans. 1848, p. 198), founded upon a Scelidosaurian lower jaw from the Wealden of Cuckfield, which Sir R. Owen subsequently referred to *Hylæosaurus*.

Fig. 3.—*Outer aspect of a right Ilium (reversed) provisionally referred to* Hylæosaurus.

A section of the postacetabular process is shown.

That *Regnosaurus* is not, however, identical with *Hylæosaurus* is almost certain if the detached teeth referred to the latter by Sir R. Owen are correctly determined—and I do not know to what other form they can belong—and the dimensions of the type mandible of the former are such as to accord well with the vertebræ and ilium of *Vectisaurus*.

Before leaving *Hylæosaurus*, I may mention that the imperfect metatarsals provisionally referred by Sir R. Owen to that genus, but which Mr. Hulke pointed out could not well belong to it, are referable to *Megalosaurus*; since I find that a similar specimen from Hastings, acquired by the Museum from Mr. Dawson, not only agrees in contour with the corresponding bone of the Stonesfield *Megalosaurus*, figured by Phillips, but was found in association with a dorsal vertebra and a tibia undoubtedly belonging to that genus.

Sauropoda.—Turning to the Sauropoda, I may observe that although I agree with Prof. Seeley in regarding this suborder as closely allied to the Theropoda, yet I am not prepared to accept the proposal made by him at the recent meeting of the British Association to unite these two groups. Apart from the difference in the pelvis, the wide divergence in the type of cranial structure exhibited by *Ceratosaurus* and *Diplodocus* appears to me to be decidedly of subordinal value, even if we should eventually find forms connecting the two. While, indeed, the former agrees in the position of the anterior nares with the Ornithopoda, the latter approximates in this respect as closely to the Parasuchian Crocodilia; and there seems to me to be almost as much ground for uniting the latter suborder of the Crocodilia with the Sauropoda as for taking the course proposed by Prof. Seeley.

What, however, I have especially to say in regard to the Sauropoda, is to endeavour to point out the relationships of the two best-known English genera, to notice a maxilla which I refer to one of them, and also to show how extremely unsatisfactory is our knowledge in respect of other specimens to which generic names have been applied. First, in regard to *Ornithopsis*, it appears to me to be incumbent to take as the type of the genus, and therefore also of the type species *O. Hulkei*, the vertebra from the Isle of Wight (B.M. No. 28632), which probably belongs to the anterior dorsal region; although I am aware that Mr. Hulke has proposed to take in this sense the smaller Sussex specimen, described by Prof. Seeley as generically identical with the former, but which appears to me as probably belonging to a different genus.

The dorsal and cervical vertebræ of this genus, thus regarded, closely resemble those of the American *Brontosaurus*, while the resemblance between the ischium and pubis, figured by Mr. Hulke in vol. xxxviii. pl. xiv., and the corresponding bones of the last-named genus is (as Mr. Hulke has already indicated) so close as to leave no doubt as to the near alliance of the English and American forms. This being so, and seeing that *Brontosaurus* has amphicœlous caudal vertebræ with closed chevrons, it becomes necessary that I should retract the opinion expressed in a paper published in the last volume of the Society's 'Journal'* that the caudal vertebræ on which *Titanosaurus* was founded might perhaps be referable to *Ornithopsis*; to the former genus I shall have to allude again, later on, but its apparent distinctness from the latter removes all grounds for referring that genus to a family distinct from the Atlantosauridæ of Prof. Marsh.

Here I may notice a very interesting specimen which may, I think, be probably referred to *O. Hulkei*. Some years ago the late Dr. Wright figured in the 'Annals and Magazine of Natural History'† a reptilian tooth from Brixton Bay, in the Isle of Wight, of which he was unable to determine the affinity, the figure being subsequently reproduced by Sir R. Owen in his 'British Fossil Reptiles'‡ and provisionally referred to *Cetiosaurus* or *Pelorosaurus*. This specimen has now come into the possession of the British Museum (No. R. 964), and from its close resemblance to the tooth of the American *Morosaurus*, figured by Prof. Marsh, there can be no doubt that it belongs to the Sauropoda, while from its large size I am inclined to refer it to *Ornithopsis* rather than to *Cetiosaurus*. A figure of its inner surface is given in Plate III. fig. 4. So far as

* Vol. xlii. pp. 156–160. I take the opportunity of correcting two misstatements on p. 159 of that paper. First, it appears that the beds regarded by Prof. Marsh as Upper Jurassic are classed by Prof. Cope as Lower Cretaceous, so that *Amphicœlias* and *Camarasaurus* are of the same age as *Brontosaurus*, and may be identical with that or some of the allied forms. Secondly, misled by Sir R. Owen's reference of Iguanodont vertebræ to *Cetiosaurus brevis*, I have stated that the vertebral centra of that genus are solid.

† Ser. 2, vol. x. p. 90 (1852). ‡ Ser. 2, vol. iii. p. 422.

I know, no similar detached tooth has yet been found; but some months ago Mr. William Davies, F.G.S., called my attention to the portion of the right maxilla of a large reptile, represented in Plate III. figs. 1, 2, 3, which he regarded as Dinosaurian. This specimen was one of those collected by the late Mr. Fox in the Isle of Wight, and is likewise in the National Collection. When it came into my hands it merely showed the nine empty dental alveoli seen on the outer border; closer examination showed, however, on the inner side of the first alveolus, what appeared to be the section of the summit of a tooth (figs. 1, 3 *a*) with a spatulate, crescentoid crown, and on chipping away a portion of the matrix and bone there was revealed the summit of a tooth precisely like Dr. Wright's specimen. Further development gave indications of a more imperfect tooth (fig. 1 *b*) in a similar relative position to the later alveoli. These teeth are only partially protruded, and were evidently destined to replace those which originally occupied the empty alveoli; the latter, in their oval form and small size, agreeing with the constricted roots of Dr. Wright's specimen. The maxilla is remarkably depressed, and thereby closely resembles that of a Crocodile; it exhibits three, apparently vascular, foramina situated in a horizontal line on the outer surface. Compared with a very minute figure of the skull of *Brontosaurus* given by Prof. Marsh, the specimen appears to accord perfectly with the maxilla; and as it also agrees with the latter skull, in being of relatively small size in proportion to the vertebræ of *Ornithopsis*, I am confirmed in my conclusion that both Dr. Wright's specimen and the maxilla under discussion are referable to *Ornithopsis*.

I may next mention two other bones, one of which I refer certainly, and the other provisionally, to *Ornithopsis*, both being among the Fox Collection. The first (No. R. 212) is the distal half of a scapula agreeing so closely with the same portion of the corresponding bone of *Brontosaurus* figured by Prof. Marsh as to leave no doubt of its belonging to the present form, and thereby confirming the affinity of the latter with the American genus. A fragmentary bone in the collection of Mr. Hulke I believe to be the distal half of a coracoid, also agreeing very closely with the corresponding bone of *Brontosaurus*.

The second specimen (No. R. 156) is a bone which has long puzzled me, but which, thanks to a suggestion of Mr. Hulke, I now believe to be a left posterior sacral rib. This bone corresponds fairly well with the rib of the fourth vertebra of the sacrum of *Brontosaurus*, figured by Prof. Marsh in the 'American Journal of Science,' vol. xxi. pl. xvi (1881), and is very nearly of the same dimensions. I cannot regard it as belonging to *Iguanodon*, in which genus the flattened plate of the bone is placed vertically instead of horizontally.

Now comes the consideration of the humerus (No. 28266) from the Wealden of Cuckfield, in Sussex, on which the late Dr. Mantell founded his genus *Pelorosaurus*. This huge bone, which is clearly Sauropodous, is peculiar in having a distinct median cavity; but since all other described limb-bones are solid, I am inclined to think that this hollow may be due to *post-mortem* decay. This bone is distinguished from the humerus of *Cetiosaurus oxoniensis*, by its more slender form and the greater prominence of the deltoid crest; and in the latter respect, so far as I can see from the small-sized figures published by Prof. Marsh, accords more nearly with the homologous bone of *Brontosaurus*. The question then arises whether this form may not be generically identical with *Ornithopsis*, in which case, in strict right of priority, that name should yield place to the older *Pelorosaurus*. It should be observed that Mantell identified with *Pelorosaurus* the caudal vertebræ which we may regard as the types of *Cetiosaurus brevis* of Sir R. Owen; and I observe, in a recent note, that Prof. Seeley * now not only accepts this identification, but regards both forms as belonging to *Ornithopsis*. The occurrence of the remains of both *Pelorosaurus* and *Cetiosaurus brevis* in the Sussex area is, so far as it goes, in favour of their belonging to one and the same form; but since anterior caudal vertebræ of the latter occur (as I shall mention immediately) in the Isle of Wight, I do not think much stress can be laid upon this point, one way or the other. On Professor Seeley's view all the remains of large Wealden Sauropoda (excepting *Thecospondylus* and *Titanosaurus*) will be referable to *Ornithopsis*; but the British Museum possesses cervical vertebræ †, from the Isle of Wight, which are greatly longer than those of *Ornithopsis Hulkei*, and in this respect are much more like those of the American *Morosaurus*; and as I shall show that the latter appears to be the Transatlantic representative of *Cetiosaurus*, there is a considerable probability that these specimens may be referable to *C. brevis*. The anterior caudal vertebræ of the latter differ, moreover, from those of *Brontosaurus* (the ally of *Ornithopsis*) by the absence of distinct postzygapophyses, by the broad angulated faces of their centra, and their articulation by two facets with the open chevrons. A series of associated specimens in the British Museum, from Brook (Nos. 36559, 28640), belonging to *C. brevis*, and comprising the last lumbar vertebra, the sacrum, and an anterior caudal vertebra, also affords evidence tending in the same direction. Thus the last lumbar vertebra has small lateral pits, but is otherwise solid, while the sacrum consists of four hæmally flattened vertebræ, solid throughout, as in the sacrum of *Morosaurus* ‡; that of *Brontosaurus* being, on the other hand, completely hollowed. These specimens are, moreover, much too small to have belonged to *Ornithopsis*; while in the Fox Collection there is the imperfect right half of a vertebral centrum (No. R. 209) of the latter, which I regard as belonging to the last of the lumbar series, and which is much larger than the last lumbar of the preceding specimen, and differs by the more extensive lateral pits, and the complete honeycombing of the body of the centrum. Again, I find part of the centrum of a trunk-vertebra from the Wealden of Sussex differing considerably from the dorsals of *O. Hulkei*. So

* Geol. Mag. 1887, p. 479.

† Nos. R. 96 and 46780.

‡ See Marsh, "Classification of Dinosauria," in Rep. Brit. Assoc. for 1884.

far, therefore, as the vertebral evidence goes, it tends to show that *Cetiosaurus brevis* is much more nearly allied to *C. oxoniensis* than to *Brontosaurus*; and I cannot consider it by any means proved that it even belongs to the same family as *Ornithopsis*, while I shall have to mention a specimen which may indicate its distinctness from *Cetiosaurus*. The somewhat remarkable fact still, however, remains, that I can find in the Wealden no anterior caudal vertebræ of the type of those of *Brontosaurus* which I can refer to *Ornithopsis*; but this is counterbalanced by anterior caudals, shown me by Mr. Hulke, of which drawings have been found in association with his *Ornithopsis Leedsi* (of which more anon), which are of the characteristic *Brontosaurus* type.

With regard, then, to *Pelorosaurus*, all that can be safely stated is that the type humerus approximates to the *Brontosaurus*- rather than to the *Cetiosaurus*-type, and that such approximation is in favour of its reference to *Ornithopsis*. I do not, however, think it would be safe to say, at present, that these two genera are certainly the same; and even if it be eventually shown that they are so, I am inclined to think that this would be an occasion where strict adherence to priority would be a disadvantage rather than otherwise, and that it would be advisable in any case to retain the name *Ornithopsis*.

A humerus closely resembling, in general contour, the type specimen of *Pelorosaurus*, but with a perfectly solid shaft, is the one from the Kimeridge Clay of Dorsetshire figured by Mr. Hulke in vol. xxx. pl. ii. of the Society's 'Journal,' under the name of *Cetiosaurus humerocristatus*, and now preserved in the British Museum (No. 44635). I find, however, on comparing this bone with the smaller humerus (No. 41626) from this formation, figured by the same writer in vol. xxv. pl. xvi. of the 'Journal,' and subsequently made the type of the genus *Ischyrosaurus*, Hulke, that the latter, which has lost the side bearing the deltoid ridge *, evidently belongs to a closely allied form, and can only be distinguished from the former by its inferior dimensions.

Under these circumstances the obvious course would be to refer *Cetiosaurus humerocristatus* to *Ischyrosaurus*, were it not for other considerations. In the first place, the name *Ischyrosaurus* is preoccupied by Prof. Cope, and accordingly cannot stand. Secondly, Prof. Seeley has described some Sauropodous remains from the Kimeridge of Ely, which there is a strong presumption for thinking are specifically the same as *C. humerocristatus*, under the name of *Gigantosaurus megalonyx*. If this be so, there would be grounds for adopting the name *Gigantosaurus* for the form in question; but as the types of the former have never been figured, the name can only be regarded as a manuscript one. I do not, however, think that it will be necessary to make a new generic name for these huge Kimeridge Dinosaurs, because it appears to me that there is every reason for believing that the larger Dorsetshire humerus, at least, is generically, and very probably also specifically, identical with the

* Mr. Hulke did not apparently notice this imperfection, and was thus led to refer the two specimens to different genera.

Dinosaur from the Kimeridge of Peterborough, of which one side of the pelvis * is figured by Mr. Hulke on p. 697 of the preceding volume of the Journal under the name of *Ornithopsis Leedsi*. The latter is evidently a member of the Atlantosauridæ, and I agree with Mr. Hulke in regarding the characters of the pelvis as not generically different from those of the Wealden form. Under these circumstances we may, I think, pretty safely refer the so-called *Cetiosaurus humerocristatus* to *Ornithopsis*, and I would venture to suggest that there are no grounds for separating *O. Leedsi* from that species. The type of Mr. Hulke's *Ischyrosaurus* may also be provisionally placed in the same genus, and, if adult, will indicate a second and smaller species, which we may call *O. Manseli*, from a MS. name of Mr. Hulke's.

With regard to *Cetiosaurus*, in which I take *C. oxoniensis*, Phillips, of the Great Oolite as the type, the caudal vertebræ agree with those of the North-American *Morosaurus* in their open chevrons, articulating by double facets; while the humerus is of the same broad and massive type, and the scapula has also its distal extremity similarly expanded. I find, moreover, that by reversing the relative position of the pubis and ischium in Phillips's diagram (in which the incorrect position has been pointed out by Mr. Hulke) these bones closely accord in contour with those of the American genus, the ischium being directed backwards, with the middle of the acetabular portion placed far above the axis of the shaft, and the latter slender and devoid of distal expansion †. There appears, therefore, to be but little doubt as to the close alliance between *Cetiosaurus* and *Morosaurus*, and further evidence is required as to the right of the latter to distinction. I have already mentioned *Cetiosaurus brevis* under the head of *Pelorosaurus*, but I may here bring to notice an associated humerus, radius, and ulna, from the Wealden of the Isle of Wight, in the collection of Mr. S. H. Beckles, of which the British Museum possesses casts (No. 28701). The length of the humerus is 0·620 (24·5 inches); its shaft is much shorter than that of the corresponding bone of *C. oxoniensis*; but it approximates to that type in its widely expanded head, and there appears a probability that these bones may belong to *C. brevis*, in which case that form would differ widely from the type species, and would likewise be certainly distinct from *Pelorosaurus*. On the other hand, these limb-bones may perhaps be referable to *Titanosaurus*, or possibly even to a new genus. *Titanosaurus* itself is, I find, represented, not only in the Wealden, but also by a postmedian caudal vertebra (No. 32390) of a larger form from the Upper Greensand of the Isle of Wight; and this leads me to think that the imperfect limb and pelvic bones from the Lower Greensand of Hythe, figured by Sir Richard Owen in his 'Cretaceous Reptilia' (Mon. Pal. Soc. pt. 1, pls. xii., xiii.) under the name of *Polyptychodon*, but subsequently regarded by the

* I am indebted to Mr. Hulke for the inspection of a larger photograph of this specimen.

† In *Brontosaurus* and *Ornithopsis* the middle of the acetabular portion is placed on the axis of the shaft, and the distal end is much expanded.

same authority as Dinosaurian, and named *Dinodocus Makesoni* *, may possibly belong to this genus.

The limb-bones of the Indian species of *Titanosaurus* are of the solid Sauropodous type, and since the caudal vertebræ of the type species agree with those of *Cetiosaurus* in the absence of distinct postzygapophyses, and in having open chevrons articulating by double facets, I am disposed to revert to my original view of regarding *Titanosaurus* as nearly allied to *Cetiosaurus*.

With respect to the above-mentioned dorsal vertebra from Cuckfield (B.M. No. 2239), figured by Sir R. Owen as the quadrate of an *Iguanodon*, then made one of the types of *Ornithopsis* by the founder of that genus, and subsequently figured by the former writer under the name of *Bothriospondylus magnus*, I am very undecided as to its affinities. It is certainly specifically distinct from the Isle-of-Wight *Ornithopsis*, and the relatively narrower centrum induces me to regard it as in all probability likewise generically different. Although of rather smaller dimensions, it appears to approximate to the imperfect dorsal vertebra from Sussex, which I have mentioned under the head of *Cetiosaurus brevis*, and it may perhaps have belonged to a smaller individual of that species, although there is no reason against its being referable either to *Titanosaurus* or to the same form as that to which the above-mentioned casts of limb-bones pertained, if such form be distinct from both *C. brevis* and *Titanosaurus*. Finally, there appears to be no possibility of arriving at any conclusion as to the identity with, or distinctness from, any of the above-mentioned forms of the genus *Thecospondylus* † founded upon the natural cast of part of a sacrum, which is regarded by its describer as not improbably belonging to the present group.

Theropoda.—In respect of this suborder, the remarks that I have to make are very brief. First, I find that the vertebræ from the Kimeridge Clay, on which Sir R. Owen founded the genus *Bothriospondylus*, appear to indicate a Dinosaur, closely allied to the genus *Creosaurus*, described by Prof. Marsh from the Upper Jurassic of North America, which is included by its founder in the Megalosauridæ; and it may therefore be a question whether some of the teeth hitherto referred to *Megalosaurus* may not belong to the former genus. In regard to *Megalosaurus* itself, some of the teeth from the Wealden agree with the tooth from the corresponding formation of Germany, recently figured by Dr. Koken ‡ under the name of *M. Dunkeri*, in showing no trace of serrations on the anterior border of the crown. A large series of specimens shows, however, that this feature is due to abrasion, and a complete transition is observable from teeth with well-marked, though small, serrations to those in which they have completely disappeared. The small size of the serrations and their tendency to early disappearance seems, however, to be a good specific character distinctive of

* History of British Fossil Reptilia. List of woodcuts.

† Quart. Journ. Geol. Soc. vol. xxxviii. p. 457 (1882).

‡ Palæontologische Abhandlungen, vol. iii. p. 316, pl. xxxi. fig. 2 (1887).

the Wealden form from *M. Bucklandi,* and still more from the Kimeridgian *M. insignis* of Deslongchamps, and I am accordingly disposed to adopt Dr. Koken's name for the former.

Conclusion.—In conclusion I may observe that the foregoing brief survey of the English generic forms referable to the Sauropoda shows how extremely unsatisfactory is our knowledge of these reptiles, and how little hope there is of arriving at any certain conclusion as to the number of genera that should really be maintained. This unsatisfactory state of things teaches us, I venture to think, a lesson as to the extreme caution which should be observed in founding new genera in this and other groups, upon the evidence of one or two bones, or even fragments of a single bone, and still more upon yet more unsatisfactory specimens. It is the easiest thing in the world to apply a new name to any specimen that turns up; but when we find one genus founded upon a humerus, another on a cervical vertebra, a third on a caudal vertebra, and a fourth on a cast of a sacrum, the evil results of such a system are self-apparent. In the old days of Palæontology it was natural and right that every specimen of importance should be definitely named; but I venture to suggest that in the present state of our knowledge the time is past for applying new generic terms, except in those cases where it can be shown with almost complete certainty that the forms to which such terms are applied are distinct from all that have been previously named. It would, indeed, be advantageous if we were beginning *de novo* to take one particular part of the skeleton, and say that on the evidence of that part, and that part alone, generic terms should be made; but now, even if we could get such a rule assented to and enforced, its application would not be of much value, owing to the heterogeneous materials on which our genera have been founded. Still, even now, something may be done in this direction, if Palæontologists will but refrain from applying new generic names to specimens belonging to parts of the skeleton totally different from those upon which allied genera have been founded. A specimen, to my mind, is quite as interesting and quite as important if left without a generic name, as it is when made the type of a so-called new genus to which we are unable to assign its proper position in the system, and which, for all we know, may be not separable from a form which has already received one or more names.

EXPLANATION OF PLATE III.

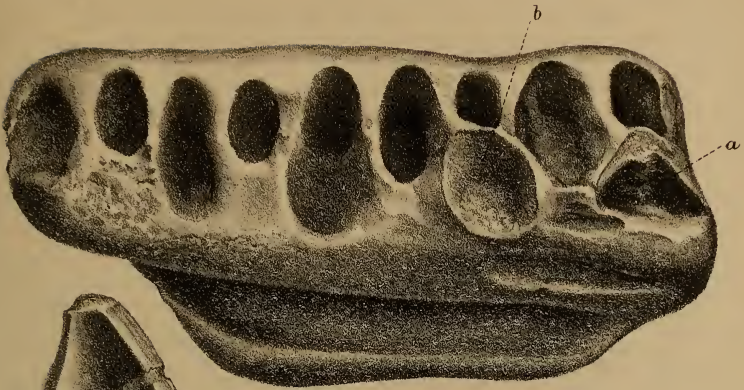
Figs. 1 & 2. Palatal (1) and outer (2) aspect of the greater portion of a right maxilla, probably referable to *Ornithopsis Hulkei,* from the Wealden of the Isle of Wight (Brit. Mus. No. R. 751). ½ nat. size.

3. Anterior extremity of the same specimen. Nat. size.

4. Inner aspect of a tooth referable to the same species as the preceding, from the Wealden of Brixton, Isle of Wight (Brit. Mus. No. R. 964). Nat. size.

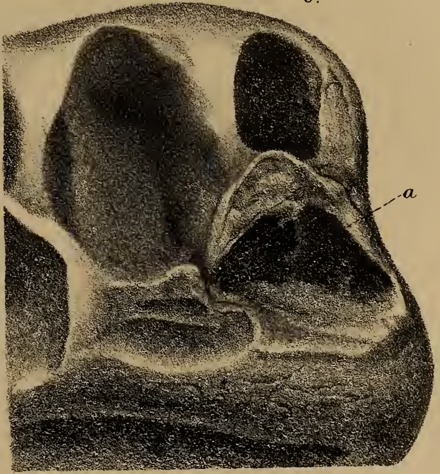
In figs. 1, 3, *a* indicates the tooth; while in fig. 1, *b* shows the shell of a tooth.

1.

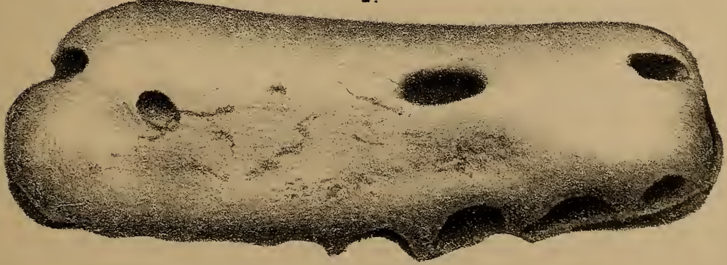


4.

3.



2.



W. H. Crowther del. et lith.

Mintern Bros. imp.

ORNITHOPSIS HULKEI.

Discussion.

The President agreed with the Author that judgment ought to be used in applying names to isolated fragments of organisms, though such a course was often unavoidable.

Prof. Seeley congratulated Mr. Lydekker on the additions he had made to our knowledge of Dinosauria. With many of the conclusions arrived at he was disposed to agree. The attempted correlation of evidence from American fossils was an important addition to the fragmentary evidence available in this country, as in the instance of the teeth and food of *Ornithopsis*. The whole group of Iguanodonts being extinct, their structure could only be made out in detail; evidence from existing orders as to their classification was worthless. The paper was one of wide grasp.

Dr. H. Woodward said Mr. Dawson, the discoverer of some of the fossils described, deserved great praise for his energy in collecting, and for the valuable specimens contributed by his assistance to the Museum.

Mr. Lydekker, in reply, thanked the speakers for their criticisms.

7. *On the* Age *of the* Altered Limestone *of* Strath, Skye. By Archibald Geikie, Esq., F.R.S., F.G.S. (Read December 7, 1887.)

The alteration of the Lias limestone of Skye into white marble by the intrusion of masses of eruptive rock has been long regarded as one of the most interesting features of that attractive island. The first announcement of this metamorphism was made by Macculloch, in a paper read by him before this Society in the beginning of the year 1815. He there described the transition from ordinary unaltered shelly Secondary limestone into an irregular shapeless "marble limestone" in which all semblance of stratification had been lost, and of which the general structure resembled that of the Assynt limestone of Sutherland. He was at first inclined to regard this massive rock as a "primary" limestone, which it had naturally been supposed to be; for he found it exactly to resemble the limestones associated with schists and granites in various parts of the Highlands. But he discovered what he considered to be a regular alternation of the marble limestone and shell-limestone, which removed "the last shadow of a doubt" from his mind as to the real identity of the rocks. The obliteration of the stratification and the assumption of a more crystalline texture he believed to be not improbably due to the invasion of the limestone by eruptive masses of "syenite" *.

Four years after the appearance of this memoir, Macculloch gathered together his numerous observations on the geology of the West of Scotland, and published them in his classic work on the Western Islands. Among the sections of that book which arrested the attention and evoked the admiration of geologists, none has probably been more widely read and more frequently quoted than that which describes the igneous rocks of Skye and their effects on the adjacent strata. It contains a fuller description of the metamorphism of the Secondary limestone, but the statements of the original paper remain essentially unchanged. The writer points out that on both sides of the narrow part of Skye, Secondary limestones and shales, crowded with well-preserved organic remains, can be traced in regular succession for miles along the coast-line. In lithological character and general sequence these strata were recognized by him to be unquestionably parts of that great series of Secondary formations which he was the first to trace out along the western sea-board of Scotland. But though the coast-sections were perfectly clear and intelligible, he stated, more emphatically than in his earlier memoir, that this regularity and continuity entirely disappeared in the interior of the island. Instead of well-bedded and gently inclined strata, he found limestones in which he said he could detect no stratification, but which on the other hand had acquired a crystalline structure more suggestive of some of the

* Trans. Geol. Soc. vol. iii. pp. 1–3 (1816).

ancient or so-called "primary" masses than of the Lias or any other member of the Secondary series. "The interior," he remarked, "presents a scene of confusion that no ingenuity can develop; in which stratified and unstratified limestone, calcareous conglomerate, quartz, sandstone and syenite occur in apparent defiance of all regularity" *. As the final result of his examination, he arrived at the conclusion that notwithstanding the tumultuous disorder described by him, the whole of the limestone must be referred to one group which formed a part of the Secondary formations of the West of Scotland. He reaffirmed the existence of a gradation from the unstratified into the stratified limestone and of an alternation of the one with the other, "which," to use his own words, "is highly satisfactory, as tending to establish their perfectly consecutive nature, and consequently to determine the place of the former limestone without the shadow of a doubt" †. He accounted for the striking contrast between different portions of the limestone by the action of the eruptive igneous rocks. He had noticed several masses of what was then termed "syenite" traversing the limestone in the interior, and inferred that there might be others concealed beneath superficial accumulations or existing below the surface, though not actually reaching it. "It will be easily conjectured," he says, "that I am inclined to attribute the whole of this confusion of character or change of structure in the limestone deposit to the influence of the syenite" ‡.

The conclusions thus announced were, of course, received with incredulity by the Wernerian geologists of the day. Ami Boué, who occupied a curious intermediate position between the extreme Plutonists and Neptunists, expressed himself hesitatingly on the subject. Bad weather had hindered him from visiting the sections in question during his rambles in the Inner Hebrides; but the possibility alluded to by Macculloch had occurred to his mind also, that the so-called "unstratified" limestone of Strath might quite well belong to the transition period or at least to his series of "chloritic and quartzose rocks" which he had found to cover so large an area of the Highlands, and he saw how easily an error might be made if limestone of so high an antiquity should here and there rise up in the midst of similar younger stratified deposits. He could not understand how such younger earthy and sandy limestones, even by the intensest heat and pressure, could be changed into crystalline masses containing silica, alumina, magnesia, and even transparent serpentine. Macculloch's views were, he contended, opposed to known analogies elsewhere and, on the other hand, were supported only by that geologist's direct observations, which might possibly be erroneous, but which nobody was then in a position to controvert. Hence, after balancing the contrary opinions, Boué impartially left the question in doubt, but with the remark that the verdict might ultimately be in Macculloch's favour §.

* 'Western Islands,' vol. i. p. 322. † *Op. cit.* p. 328.
‡ *Op. cit.* p. 332. § 'Essai géologique sur l'Ecosse,' pp. 207–211.

Ten years after the appearance of Macculloch's work, the Western Islands were visited by two able observers, Von Oeynhausen and Von Dechen, the latter of whom still survives as the universally esteemed Nestor of German geology. In the careful description which they gave of the portions of Skye visited by them we find no trace of a suspicion that the limestone in the interior of Strath ought not to be classed with the Lias. To quote their words: "the connexion between the crystalline-granular limestone and the ordinary Lias presents itself clearly before the eyes in so many places that the former cannot be mistaken for a primary limestone, which otherwise it most closely resembles" *. "The Lias is altered to a granular limestone in the neighbourhood of the syenite" †. A statement resting on the authority of the pioneer of Hebridean geology and confirmed by such competent foreign geologists was accepted as one of the established facts of the science. The alteration of the Lias limestone of Skye into a white saccharoid marble by the intrusion of syenite was thenceforth quoted in text-books as one of the recognized examples of contact-metamorphism.

Such was the state of opinion when, as a boy, I began my geological career in the island of Skye. In exploring the geology of Strath, I found it impossible to discover some of the sections described by Macculloch, and I believed that he had mistaken the meaning of others, but I accepted undoubtingly his view of the age of the altered limestone ‡. A few years later, when again in Skye, tracing the boundaries of the schists and older Palæozoic rocks, I began to suspect that some part of the Strath limestone could not possibly be Lias, but must form an extension of the Lower Silurian belt which runs from the north of Sutherland into the south-eastern part of Skye. This suspicion was mentioned by me in a footnote to the paper by Sir R. I. Murchison and myself "On the Altered Rocks of the Western Islands of Scotland" §; but I was unable at that time to investigate the subject further. Many busy years have since passed away. It was not until two years ago that I found an opportunity of returning to the examination of this interesting question. Last summer I completed the mapping of the district, and as I am now able to correct my original observations, I offer the present communication to the Society, that the correction may appear in the same Journal where these observations were published.

I now propose to show that in Strath two totally distinct groups of limestone have been confounded, one of them belonging to the Lower Silurian system and a prolongation of the fossiliferous limestones of Sutherland and Ross, the other forming part of the Lias of the Inner Hebrides, and to establish this distinction by the clearest evidence, lithological, stratigraphical, and palæontological.

At the outset I would remark that the error into which geologists have fallen in this matter was one which the structure of the

* "Die Insel Skye," Karsten, Archiv. i. (1829), p. 41.
† *Ibid.* p. 44.
‡ Quart. Journ. Geol. Soc. xiv. (1857), p. 1.
§ *Ibid.* xviii. (1861), p. 199.

ground made very natural. Without pleading for the existence of any such confusion in the interior as Maculloch's exaggerated language would lead one to expect, I think the occurrence of a group of limestones on both the east and the west coast of the island would predispose any observer to take the limestone of the intervening inland district for part of the same series. This obvious inference is strengthened by the first examination of the coast-sections. At Broadford, for instance, the limestones, which elsewhere dip seaward at gentle angles, are found between the harbour and the bridge to be thrown into highly inclined positions and to strike straight for the interior, where after a short concealed space, the massive or so-called "unstratified" limestone makes its appearance. Then, on the opposite side, the shore of Loch Slapin, south-west of Kilbride, displays an admirable section, where the two limestones are actually in contact. I shall describe this section in a later part of the present paper, and will only remark here that unless one's suspicions were aroused to look out for a break between these limestones, no such break would probably be noticed even by a tolerably alert observer. All that would be likely at first to engage his attention would be the transition from an overlying well-bedded group of limestones full of *Gryphæa* and with thin shaly partings, into a lower group of more massive limestones with no *Gryphæa* and no layers of shale. If he were told that the seeming gradation conceals so vast a hiatus as that between Lower Silurian and Lias, he would probably express an emphatic dissent from such a statement. It was this coast-section which chiefly deceived me in my early rambles over the ground, and blinded me to the meaning of other evidence which I could otherwise hardly have failed to recognize. And from the importance assigned to it by Macculloch, I imagine that it had the same unfortunate influence upon him.

§ 1. Lithological Characters of the Limestone.

The thin-bedded, dark blue, more or less earthy Lias limestones of the coast-sections, alternating as they do with courses of dark sandy shales and sandstones, present such well-marked lithological characters that even in the midst of much confusion, produced by faults or eruptive rocks, they ought to be easily distinguishable from any other group of strata in the geological structure of Skye. That they stretch across the island from sea to sea, as stated by Macculloch, is indisputable. They can be followed continuously from the eastern shore at Lussa south-westwards, along the escarpments which they form, to the shore of Loch Eishort near Borereaig. But instead of spreading northwards from these escarpments over all the low ground of Strath, as hitherto believed, they form merely a narrow strip averaging about a mile and a half broad, of which the western and northern margin is bounded by a line drawn from a point on Loch Slapin near Camas Malag eastwards to the glen above Borereaig, and thence northwards to near Broadford Mill. The belt of Lias, which at Broadford is not more than half a mile broad, turns westward, keeping close to the shore until it widens out south of the church, ascending inland as far as Sithein and disappearing towards the mouth of the Sound of Scalpa. The Liassic band which crosses Strath may be described as a long, flat, synclinal trough with the basement-beds coming to the surface on both the north-west and south-east sides, but with such a general predominant westward inclination that at the south-western end of the tract higher beds appear than are to be found to the north-east.

To the north and north-west of this belt of Liassic limestone, shale and sandstone, the older or so-called "unstratified" limestone covers most of the ground up to the flanks of the chain of Red Hills, which stretches across the island from the head of Loch Slapin to the Sound of Scalpa. The tracts not occupied by the limestone are covered with eruptive bosses of granophyre (Macculloch's "syenite") except the district of Loch Lonachan and Beinn Suardal, where red sandstone (Cambrian or Torridon sandstone) makes its appearance. Even from a distance the areas occupied by the limestone are easily recognizable by the brightness of their verdure and by the innumerable knobs and pinnacles of bare white or grey stone that project from the ground. On closer examination, the rock is seen to have a general lead-grey colour, more or less veined with white. Some portions are darker, almost black in tint, while others are nearly pure white. This range of colour, so unlike anything to be seen among the Liassic beds, exactly resembles that of the Durness limestone and of its prolongation southwards through the counties of Sutherland and Ross.

Though on the whole more crystalline than any portions of the Lias, the limestone throughout most of its extent is not more altered than most Palæozoic limestones are. Certainly it does not deserve the name of "marble," except locally around the eruptive bosses that have broken through it. It is for the most part firm, close-grained, and compact, breaking with a splintery, semiconchoidal fracture. Many of the more sandy beds are crowded with dark wavy plant-like stripes, most of which are probably worm-casts. Much of the limestone is tolerably pure; some parts are dolomitic. It weathers with a clean smooth surface. Many of the dark beds are crowded with nodules and nodular layers of black or blackish-grey chert. These concretions protrude in enormous quantities from the weathered surface of the rock, to which they give a singularly rough aspect. As they break up under the influence of subaerial disintegration, they gather on the slopes into curious cinder-like heaps. Now, I have not succeeded in finding a single concretion of chert in any of the Lias limestones so well exposed for several miles along the shores of Broadford Bay and Loch Eishort *. But every geologist who has seen the rocks of Durness will remember how full are some of the limestones there of similar dark irregular chert-concretions.

* The occurrence of pieces of chert derived from the older limestone, as at Boreraig, obviously does not invalidate this statement.

Another character by which the older is strongly contrasted with the younger group of limestones is its much less distinctly marked bedding. Along the shore-sections nothing can be more decided than the division of the Liassic strata into layers varying from less than an inch to two or three feet in thickness. Limestones of varying texture and composition there alternate with each other, and are sometimes separated by bands of dark micaceous shale. In the limestone tract of the interior, however, no such alternations are to be found. Thick solid masses of limestone occur there with only faint marks of stratification and with no trace of any associated micaceous shales. It is impossible to believe that such a contrast can be explained by any process of welding or other alteration due to the action of eruptive rocks. The limestones have been lithologically distinct from the beginning. But though the bedding is far less conspicuous than it is among the gently inclined Liassic strata of the shores, it may almost anywhere be detected in the older limestone. It is traceable by bands of different colour and texture, and conspicuously by the lines of dark cherts which run parallel to each other like flints in the Chalk. Hence it is a mistake to speak of this limestone as "unstratified." Its component beds are for the most part placed at high angles of inclination, sometimes even on end, and the direction and amount of dip vary continually within a short space. In these respects they offer a striking contrast to the undisturbed Liassic strata that surround them; while, on the other hand, they present the closest resemblance to the Lower Silurian limestone of Sutherland and Ross.

§ 2. Stratigraphical Characters of the Limestone.

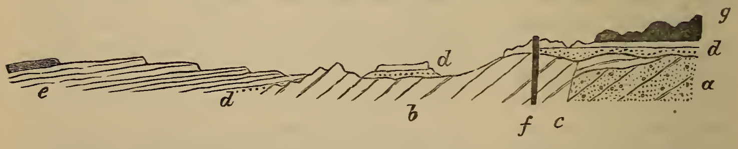
Every observer who has rambled through the inland parts of the district of Strath has noticed the remarkably disturbed condition of the limestone just referred to. The beds rapidly change their angle and direction of dip as one tries to follow them along the hill-sides, until it may seem altogether hopeless to make out any recognizable order of succession among them. Nevertheless I am convinced that when they are attacked in full detail and traced upon maps of a large scale, they will ultimately be reducible to order. The frequent and sudden alterations in their inclination are precisely like those that mark the outcrop of the Sutherland limestone where it comes within the influence of the great thrust-planes of that region. In Assynt, for example, the same group of rocks has been heaped up and pushed forward to such an extent that a few hundred feet of strata are repeated again and again in highly inclined or even vertical positions and made to cover a breadth of several miles of ground. So too in Strath, the great breadth of limestone and the high dip of the beds do not probably indicate a considerable thickness of rock, the same beds being constantly brought in again by thrusts, faults, and folds.

Until a detailed survey of the ground is made, any attempt to fix the order of sequence among the various portions of the limestone would obviously be premature. It is quite certain, however, that several well-marked groups occur in the deposit. What seemed to me to be the lower members of the series consist chiefly of lead-grey and dark mottled limestones, some of them full of the dark worm-casts above referred to, others crowded with nodules and nodular layers of chert. These lower beds cover by far the larger part of the district. They are succeeded by massive white limestones of greater purity and without the abundant dark cherts. These beds are best exposed at Torrin, where they form a group of conspicuous hills between the base of Ben Dearg and the head of Loch Slapin.

Comparing the Strath limestones with the similar rocks of Sutherland and Ross, in which the order of succession has been so well established, it is impossible not to be struck with their general resemblance to the lower members of the Durness and Assynt series. The dark limestones of Strath, with their abundant worm-casts and cherts, recall the basal or "Grudie group" of Sutherland, while the white limestones remind one of the "Eilean Dubh group." I do not, of course, at present insist on these identifications with particular zones in the northern Lower Silurian formations. It is enough for my purpose to point out the close resemblance in lithological and stratigraphical characters between the limestones of Strath and Sutherland.

Another fact which links the Skye rocks with those of the north-west Highlands is the association of white quartzite with the limestone. Unfortunately the way in which the latter has been jumbled prevents the relations of the two rocks from being satisfactorily determined in Strath. But that the quartzite underlies the limestone, and is a continuation of the same quartzite which can be traced from Skye continuously northwards to the far headlands of Sutherland, can hardly be doubted. An interesting section at Torr Mor, on the north shore of Loch Eishort, proves the relation of this quartzite to the red (Cambrian or Torridon) sandstone (fig. 1).

Fig. 1.—*Section at Torr Mor, Boreraig, Loch Eishort.*



a. Cambrian (Torridon Sandstone). *b.* Quartzite. *c.* Fault. *d.* Lias Limestones with pebbles of quartzite, chert, &c. *e.* Limestones and shales with abundant *Gryphæa*, &c. *f.* Dyke of felsite. *g.* Overlying sheet of granophyre.

On the shore a marked fault separates the two rocks, but on the hill-side above the quartzite with its usual conglomeratic base is seen to lie upon the edges of the red sandstone beds. On the opposite side of the Loch the quartzite expands into the broad mass which forms the range of the Sgiath-bheinn hills around Ord, and encloses the well-known limestone basin of that locality. I lately revisited these Ord limestones and at once recognized their identity with the limestones of the interior of Strath. On the western flank of Sgiath-bheinn an Uird I likewise found the yellow dolomitic "fucoid beds" which form so distinct and persistent a member of the Lower Silurian series of Sutherland and Ross, lying between the top of the quartzite and the base of the limestone. I have not yet succeeded in detecting these easily recognizable beds in Strath, but they will most probably be found there. In the meantime I submit that the stratigraphy of the Strath limestone removes it from the surrounding Lias with which it has been confounded, and places it in the Lower Silurian series of the north-west of Scotland.

§ 3. Palæontological Relations of the Limestone.

Though the true position of the massive limestone of Strath was now, in my opinion, established beyond doubt, I was desirous, if possible, to obtain the convincing testimony of organic remains. Recent experience of the Sutherland limestone led me to hope that among the less crystalline portions of the Skye rock fossils would be found. I accordingly searched the flanks of Beinn Suardal, where the largest area of limestone occurs free from intrusions of "syenite." In a preliminary visit I was accompanied by Mr. H. M. Cadell, of the Geological Survey of Scotland, who was fortunate enough to find the first recognizable fossil. Subsequently I spent some time in a more careful examination, and obtained a sufficiently large number of species for purposes of adequate comparison.

The fossils can hardly be said to be abundant. They occur only in certain dark leaden-grey beds, from the weathered surface of which they project in relief. On a fresh fracture no organic structure is recognizable, but the substance of the fossils is seen to consist of a whiter and more distinctly crystalline calcite. In these respects the Skye rock is precisely the counterpart of some of the beds of the Durness limestone. The subjoined list of species obtained from both sides of Beinn Suardal is sufficient to demonstrate the identity of the horizon of the limestones in these two distant localities, and thus to prove that the altered limestone of Strath is not Lias but Lower Silurian.

List of Fossils from the Limestone of Beinn Suardal, Strath *.

Cyclonema, sp.
Murchisonia, sp.
Maclurea Peachii (?), *Salt.*
—— or Ophileta, sp.
Gasteropod, undeterminable.
Orthoceras mendax, *Salt.* (O. vertebrata, *Salt.*).
—— baculoides (?), *Blake.*
—— sp.
Piloceras invaginatum, *Salt.*
Sponge-like bodies (? Piloceras).
Annelide-burrows.

* Compared with the collection of Durness fossils in the Geological-Survey collection, Jermyn Street, and determined by Mr. George Sharman.

§ 4. Relations of the Limestone to the other Rocks of the District.

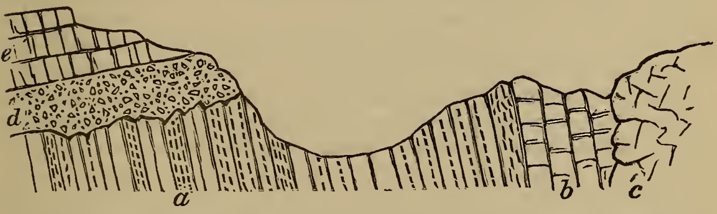
Having now established the Silurian age of the older more massive limestones of Strath, I may be permitted to add some observations as to the structural relations of these rocks in the general geology of the district, inasmuch as these relations reveal some interesting facts in the geological history of the north-west of Scotland.

(1) *The Cambrian or Torridon Sandstone.*—Though the limestone can be traced for more than five miles along the margin of the red sandstone belt which rises in the heart of Strath, it is nowhere seen resting directly on that rock. In the glen below Loch Lonachan it forms the western side of the valley, while the sandstone occupies the eastern side, the hollow itself coinciding generally with the line of a fault which here separates the two formations. Between this glen and Strath Suardal, as the main valley of Strath is called, the boundary can be easily traced in a singularly tortuous line over the northern portion of the ridge of Beinn Suardal. Although, on the whole, the limestone forms an anticlinal arch upon that ridge, yet its truncated and steeply inclined strata, where they abut upon the red sandstone, show that it does not lie in its normal position. I can only compare the structure visible there with what is seen where portions of the Silurian strata have been heaped up on the larger thrust-planes in Sutherland. The non-occurrence of the "fucoid-beds" and the quartzite here between the limestone and red sandstone lead to the inference that the lower portion of the Silurian series has been cut out; and the way in which the beds of the limestone have been jumbled together inclines me to believe that the whole of the limestone of Beinn Suardal is not in its original position, but has been pushed westwards upon a floor of red sandstone. If this inference is well founded, it leads to the further conclusion that probably the whole of the Lower Silurian limestone of Skye has been similarly displaced. Along the flanks of the Red Hills we find this rock broken up and intermingled with portions of the quartzite. In some places these two rocks have been sheared together so as to produce a calcareous quartz-schist. A good example of this structure may be observed in Corry Uaigneich at the foot of Blath Bheinn (Blaven). On the Sound of Scalpa also, to the west of Strollamus, the red sandstone, quartzite, and limestone have undergone enormous crushing. In Sleat the quartzite and limestone have been extensively dislocated, while the red sandstone along its south-eastern margin has been so sheared as to pass into micaceous schist. Connecting these evidences of enormous terrestrial disturbance with the lines of gigantic thrust which the Geological Survey has now traced from the north of Sutherland to the shores of Lochs Keeshorn and Carron, opposite to Skye, I should not be surprised to find that no portion of the older rocks in that

island is in its original or undisplaced position, but that the whole of them have been dislocated and driven bodily westward.

(2) *The Lias.*—That the Silurian Limestone must be separated from the Lias by a complete discordance is obvious from the structure above described, even if no visible unconformability were traceable. But there is the most complete proof of a great physical break between the two rocks. The base of the Lias along the western margin of the belt which crosses Strath is formed of a conspicuous breccia, consisting mainly of fragments of limestone, with pieces of chert, quartzite, and red sandstone. In my early survey of Strath, when the whole of the limestone was regarded as of Liassic age, I naturally considered this limestone breccia to mark a local break in the Secondary series of rocks. Its true meaning is now apparent. The limestone fragments of which it mainly consists are not derived from any part of the Lias, but from the Silurian series, and prove the extensive denudation of that series in Liassic time. From Sithein, in Strath Suardal, where it contains a large percentage of quartzite fragments and lies between the areas of Cambrian sandstone and Silurian limestone, it can be traced all round the margin of the red sandstone area, dipping gently under the overlying Lias limestone and shales. Only at one place have I found it visibly touching the older limestone; this is in the glen of the Allt Leth Slighe, or halfway burn, between Kilbride and Suishnish Point, where the breccia attains its maximum thickness—some 50 or 60 feet—and lies with a striking unconformability upon the edges of the steeply inclined Silurian limestone. The section, which is represented in fig. 2, completes the demonstra-

Fig. 2.—*Section in Allt Leth Slighe, Strath.*



e. Blue, somewhat fetid limestones, full of broken shells (Lias). *d.* Limestone breccia (50–60 feet) consisting mainly of fragments of the underlying limestones, with abundant pieces of chert and quartzite. *c.* Granophyre ("Syenite") of Beinn an Dubhaich. *b.* White limestone. *a.* Dark-grey limestone full of worm-casts and pieces of chert.

tion of the entire separation of the Liassic strata from the more massive or so-called "unstratified" limestone of Strath.

Immediately to the west of this instructive section the breccia is rapidly overlapped by higher Liassic beds, which rest directly on the Silurian series. The boundary between the two groups of rock runs down the glen, and in half a mile reaches the little ravine by which the stream discharges itself into the sea. Thence the line of separation turns north-westward, and can be traced for some 200 yards along the steep declivity and the rocky shore until, owing to the trend of the coast, it strikes into Loch Slapin. This is the locality to which I have already referred as so deceptive in regard to the real relations of the two series of limestones. The fossiliferous Lias beds, dipping south-westwards at an angle of about 20°, consist of well-bedded limestone and calcareous shale, some of the layers being charged with *Gryphæa.* Immediately underneath them, and without the intervention of any conglomerate, come the Silurian limestones, the dip of which, though not very distinct, seems to be parallel with that of the younger strata. The two groups are here, as it were, welded together at the juncture. Yet all along the slope above, the older limestone with its abundant cherts stands on end, with a north-west strike, which is maintained as it runs out to sea on the one hand, and away inland on the other.

Another outcrop of the basement-beds of the Lias may be traced between Heast and Boreraig on Loch Eishort. At Heast a thick group of conglomerates and pebbly sandstones underlies the lowest of the Lias limestones. These detrital beds, with a band of limestone-conglomerate in the middle of them, rest on the red sandstone along the base of the escarpment on the east side of Beinn à Chàirn. But as they are followed south-westwards they disappear, and the limestone, in some places full of fragments of quartzite and black chert, lies directly upon the red sandstone and quartzite (fig. 1).

(3) *The Granophyre bosses.*—Though it is no part of my purpose to describe the contact-metamorphism which has given to the limestone of Strath its place in geological literature, I may refer to the relation of the limestone to the Tertiary eruptive rocks of the district, and to the alteration which these have superinduced. In my early paper on the geology of Strath, I pointed out that the "syenites" of this district were easily divisible into two groups, one of which embraces disruptive bosses that ascend with steep sides through the surrounding rocks; while the other includes overlying sheets which spread over the strata without violently disturbing them. The separation of the Silurian from the Lias limestone now enables us further to perceive that the bosses are confined to the Silurian area, and the overlying masses to the territory of the Lias. The latter have produced only a trifling alteration of the rocks. Except therefore along the flanks of the Red Hills, where, in some places, portions of the Secondary strata have been thrust up and invaded by the large eruptive masses, the Liassic beds are not seriously altered. The metamorphism for which Strath has so long been known turns out to be confined to the Silurian limestone. On the whole, it is restricted to the near neighbourhood of the bosses of granophyre, and consists in the usual marmarosis or assumption of a saccharoid crystalline texture. The white limestones become granular statuary marbles, and their bedding partially or wholly disappears. The darker beds retain their dull leaden-grey hues, but become coarsely crystalline and still expose, on weathered surfaces, their abundant rugged prominences of black chert.

Besides the protrusions of granophyre, innumerable basalt-dykes, likewise of Tertiary age, traverse the Silurian limestone, as well as all the other rocks of the district. The amount of alteration they have effected is trifling, notwithstanding their number and the prolonged period during which they continued to be injected into fissures in the rocks. They began to be formed before the appearance of the granophyres which cut them off and send veins into them; but their extravasation was afterwards resumed, for some of them are found running across the bosses of granophyre. It is not to the intrusion of the basic dykes, but to the uprise of the bosses of eruptive acid rocks that the Lower Silurian Limestone of Strath owes the metamorphism which has made it famous.

Discussion.

The President expressed his satisfaction at the lucid explanation of the old problem offered by Dr. Geikie. He had himself fallen into the same error as others with regard to the passage of Lias limestone into white marble in Skye.

Mr. Etheridge pointed out the close resemblance of the species exhibited from Durness and Skye. He also specially called attention to some of the fossils exhibited.

Dr. Hicks agreed that the similarity between the Durness and Skye limestones was unmistakable; the latter appeared to be the same as the lower beds of Durness. There was very little change in the general sequence throughout the west coast of N. Scotland.

Mr. Marr observed that the Durness Limestone is precisely similar to the widely spread *Orthoceras*-limestone of Sweden and the Stinchar limestone of Girvan, so the occurrence of the same formation in Skye is natural. It was to be hoped that as rich a fauna would be found in Scotland as in Scandinavia.

Dr. Hinde pointed out the similarity of the fossils from Durness and Skye to those described by Billings from the Calciferous Limestones of the Mingan Islands, on the north shore of the St. Lawrence. Amongst others, the doubtful genus *Archæocyathus* is present at Mingan, at Newfoundland, and at Durness, and in all these localities it is associated with similar forms of *Maclurea*, *Murchisonia*, &c.

Mr. Bauerman had seen limestones in Matto Grosso, in Brazil, containing peculiar aggregations of quartz somewhat resembling fossils, and similar rocks were found in the province of S. Paulo, about 700 miles distant from the first locality. The latter were considered to be of Huronian age.

The President expressed a hope that full details of the Durness Limestone and its fossils would be published before long.

Dr. Geikie thanked the Fellows for the reception they had given to his paper. A preliminary sketch of the results of the recent work of the Geological Survey in the north-west of Scotland would, he hoped, be presented to the Society early next year.

8. *On the* Discovery *of* Trilobites *in the* Upper Green (Cambrian) Slates *of the* Penrhyn Quarries, Bethesda, *near* Bangor, North Wales. By Henry Woodward, LL.D., F.R.S., V.P.G.S. (Read December 7, 1887.)

[Plate IV.]

The Cambrian rocks of Wales, once so barren of all evidence of organic remains, have now, thanks to the late Mr. J. W. Salter and Mr. T. Belt, to Mr. Homfray of Portmadoc, but most of all to the researches of Dr. Henry Hicks, F.R.S., at St. Davids and elsewhere, become peopled with an extensive series of organisms, amongst which the Trilobites make up a large proportion of the fauna *.

It is true that the Longmynd Group elsewhere had only yielded Annelide-burrows and a portion of a Trilobite (*Palæopyge Ramsayi*); but the investigations of Dr. Hicks at St. Davids have contributed a Sponge (*Protospongia major*), two Ostracods (*Leperditia cambrensis* and *L. Hicksii*), eight Trilobites (*Agnostus cambrensis, Plutonia Sedgwickii, Paradoxides Harknessi, P. aurora, P. Hicksii, Conocoryphe Lyelli, C. bufo, Microdiscus sculptus*); in addition to which two *Lingulellæ* and two *Thecæ* must be added.

The following table shows the fauna of each formation, from the Longmynd up to the Tremadoc:—

Cambrian.	Spongida.	Graptolites.	Echinodermata.	Crustacea.			Polyzoa.	Annelida.	Brachiopoda.	Lamellibranchiata.	Pteropoda.	Cephalopoda.	Total.
				Ostracoda.	Phyllopoda.	Trilobita.							
5. Tremadoc Slates .	...	2	3	...	2	36	1	...	12	12	15	2	85
4. U. Lingula Flags	...	...	...	...	...	25	1	3	6	...	...	...	35
3. L. Lingula Flags	...	...	...	1	1	8	...	4	2	...	3	...	19
2. Menevian	3	...	1	...	...	25	...	...	3	...	5	...	37
1. Longmynd Group	1	...	...	2	...	7	...	3	2	...	2	...	17

Dr. Hicks writes:—"The Longmynd series, so well exposed in coast-sections at St. David's, is evidently identical with that of North Wales and Shropshire, the lithological characters and the order of

* No fewer than 25 genera and 85 species of Trilobites are recorded from the Longmynds to the Tremadoc Slates.

succession being strangely alike. In Shropshire, North Wales, and Ireland they have yielded a few indications of life, but these districts *need further exploration*" *. How true was this last remark will be seen in the sequel.

On the 5th August last I received a letter and box of specimens from Professor James J. Dobbie, of the University College of North Wales, Bangor, accompanied by the following statement:—

"The specimens of Trilobite, Nos. 1 & 2, were found by Robert Edward Jones and Robert Lloyd, two quarrymen employed in the Penrhyn Quarry, Bethesda, near Bangor.

"As no fossils had ever been found in this quarry before, the discovery excited considerable interest in the locality, and the quarrymen brought the specimens to the University College, and left them in my hands for examination. Some doubt having been thrown, by residents, upon the authenticity of the specimens, I visited the quarry along with the men on the 18th June, and examined them minutely as to the circumstances of the discovery.

"The place where they allege they found the fossil is in an old working of what is known as the 'Upper Green Bed' of the quarry. This bed, which is about 150 feet in thickness, is the highest in the quarry. It immediately underlies the Grits forming the brow of Bronllwyd, and is itself underlain by a bed of purple slate. The fossils were found close to the *junction* of the 'Green and Purple Slates.'

"The men showed me the block from which the fossil was taken, and I could detect no difference between the slate of which the block is composed, and the slate in which the fossil lies imbedded."

"Whilst searching amongst the débris close by," writes Prof. Dobbie, "I found specimen No. 3" (which has since been determined to be the obliquely squeezed head of a second example of the same Trilobite, see Pl. IV. fig. 2).

Prof. Dobbie adds:—"The men who found the specimen are very intelligent quarrymen, and have made some little study of geology. They were in the unused working for the purpose of examining its geology, when they discovered the Trilobite."

I think, if any doubt at all existed about the genuineness of the "find," that is now entirely removed by the fact that Prof. Dobbie was so fortunate as to knock out a second specimen with his own hammer.

The specimens have been seen and examined by Dr. Hinde and Mr. A. S. Foord, both of whom know the American Lower Palæozoics very well, and they do not recognize these specimens as at all resembling, lithologically, any North-American rock †.

Dr. Hinde has also pointed out that the freshness and sharpness of the specimens is opposed to their having been carried about by workmen, in which case the angles would have become abraded, and the surface of the matrix greasy from handling. Prof. Bonney was

* See Proc. Geol. Assoc. 1872, vol. iii. pp. 101–103.

† It had been suggested that one of the men, who had worked in slate-quarries in America, might have brought the specimens over with him.

also so good as to look at the specimens, and considered their lithological character superficially to agree with the other rock-specimens of the slate sent up by Prof. Dobbie from the same bed. Lastly, Dr. Hicks, F.R.S., has seen and examined the specimens, and is quite satisfied with their genuineness, and also with my determination of the genus.

The surface of the fossil is covered with minute chlorite grains, all slightly drawn out, in the direction of the squeeze, along the friction-plane.

Description of the Specimens.—The specimen from Bethesda *, found by Messrs. Jones and Lloyd on 9th April 1887, exhibits on two slabs the impression and counterpart of a Trilobite, which, when perfect, measured about 3 inches in length, and about $1\frac{3}{4}$ inch in breadth (see Pl. IV. fig. 1).

The relievo side is only $2\frac{1}{2}$ inches long, the hinder inch having been lost in breaking the slate; but the intaglio, although injured along the side, gives us, as nearly as possible, the entire length of the whole body.

The head, which is the widest part of the animal, is $1\frac{3}{4}$ inch in breadth by $1\frac{1}{2}$ inch in length; the length has, perhaps, been slightly increased by squeezing along the long axis of the specimen.

The glabella is elevated and rounded in front; it is seven lines broad, and above the neck-furrow it is marked by three lateral furrows, the first or basal furrow actually crossing the glabella, and the middle and frontal furrows being each rather deeply marked and inclined somewhat backwards. The sides of the glabella are nearly parallel; it is $1\frac{1}{4}$ inch long, and in front of the central axial portion, upon its fixed margin, is a small circular raised prominence. The margin of the head-shield is rounded, and was marked by a distinct rim, and circumscribed by a furrow within the border. The cheeks are rounded and rather inflated. The posterior angles may have been produced into a short spine, but it is not preserved in the fossil before us. The facial suture appears to have run obliquely across the cheeks and united with the glabella near the anterior border, the eye (or rudimentary eye-spot) being near the centre of the cheek; the suture emerged on the frontal border nearly in a line with the axial furrows. There are 14 free thoracic rings seen in the counterpart.

The axis is $\frac{1}{2}$ inch broad at its widest part next the head, and scarcely diminishes in breadth till near the pygidium, where it is 5 lines broad. Each segment of the axis appears to have been notched on its posterior border. The thoracic rings measure $1\frac{1}{2}$ inch across; the pleuræ are straight, the extremities rounded and facetted for rolling up.

The pygidium consists of about 3 coalesced segments; but the termination is somewhat indistinct; breadth 11 lines, length $\frac{1}{2}$ inch.

Of 25 genera of Trilobites met with from the Longmynds to the

* Although the working is in the face of Bronllwyd, I do not think the name is ever used except for the mass of grit above the quarry (J. Dobbie).

Tremadoc Slates, the two most abundant forms, *Conocoryphe** (with 19 species) and *Olenus* (with 15 species), possess many characters by which they approach one another and also the Penrhyn Trilobite. The forms of *Agnostus*, of which 12 have been described from these Cambrian rocks, may be dismissed here as outside the present inquiry.

In *Paradoxides* the glabella is too much produced and globular in front, and the body-segments and the axis taper gradually to the pygidium; there are not fewer than about 20 segments to the body.

In *Asaphus*, *Ogygia*, and *Niobe* there are only 8 thoracic rings; but the caudal shield is very large, and the entire form is very broadly oval.

Angelina agrees with our Penrhyn fossil very well in size, and in the number of its free thoracic segments, but its glabella is quite smooth, and the pleuræ are broader, and its cheek-spines are very long.

Olenus has 14 free body-rings, the glabella is furrowed, but the head-shield is shorter and broader, and the ends of the pleuræ and margin of the caudal shield are usually more produced into spines than is the case in our fossil, and the *Oleni* are generally of much smaller size.

Conocoryphe, Corda, 1847 (= *Conocephalites*, Barr., 1852), has 14 free segments, the axis (as in the Bangor specimen) is parallel-sided, and does not diminish from the head backwards to the pygidium; each ring of the axis is notched on its posterior border; the ends of the pleuræ are rounded; the glabella is furrowed obliquely on each side; the eyes are sometimes wanting, but when present are small, and are commonly placed in the axial furrow, near the latero-anterior border of the glabella. Cheek-spines are sometimes absent, and when present are never very long.

From these considerations I conclude to place the Penrhyn Trilobite in the genus *Conocoryphe*, and I have ventured to dedicate the species to Mrs. Dobbie, under the name of *Conocoryphe Viola*.

It is certainly distinct from any of the 19 species already described from the Cambrian rocks of Wales or from other localities.

Those who desire to consult the memoirs which have appeared on the Trilobites of this area are referred to the following papers:—

J. W. Salter, 1863. Quart. Journ. Geol. Soc. vol. xix. p. 274.

J. W. Salter, 1864. Mem. Geol. Surv. dec. xi. (Trilobites) chiefly Silurian.

J. W. Salter, 1864. Quart. Journ. Geol. Soc. vol. xx. p. 233, pl. 13.

* *Conocephalus* was the name originally proposed by Zenker for certain Trilobites, but it was found to have been already used by Latreille for a genus of Insects. In 1847, Corda proposed to substitute the name *Conocoryphe* for the first-described form of *Conocephalus* of Zenker, and the other species he placed under the genera *Ptychoparia* and *Ctenocephalus*. Barrande later (1852) proposed to retain *Conocephalus* by simply *altering the termination* to *Conocephalites*; but this course is not consistent with the prevalent rules of nomenclature, and Corda's name *Conocoryphe* should be adopted, even if the other two genera proposed by him are not maintained.

J. W. Salter and H. Hicks, 1869. Quart. Journ. Geol. Soc. vol. xxv. p. 51, pls. ii. & iii.

Henry Hicks, 1871. Quart. Journ. Geol. Soc. vol. xxvii. p. 399, pls. xv. & xvi.

Henry Hicks, 1872. Quart. Journ. Geol. Soc. vol. xxviii. p. 173, pls. v.–viii.

J. W. Salter and R. Etheridge. Mem. Geol. Survey. "The Geology of North Wales," by A. C. Ramsay. *Appendix on Fossils.* 2nd edition, 1881. (26 plates.) London, 8vo.

EXPLANATION OF PLATE IV.

Fig. 1. *Conocoryphe Viola,* H. Woodw. Nat. size.
Longmynd Group, Penrhyn Quarries, Bethesda, near Bangor.

2. Detached head of same species, squeezed obliquely by slaty cleavage (nat. size), from same locality and formation.

3. Restoration of fig. 1, by the author.

(The originals of figs. 1 and 2 are in the possession of Prof. James J. Dobbie, University College of North Wales, Bangor.)

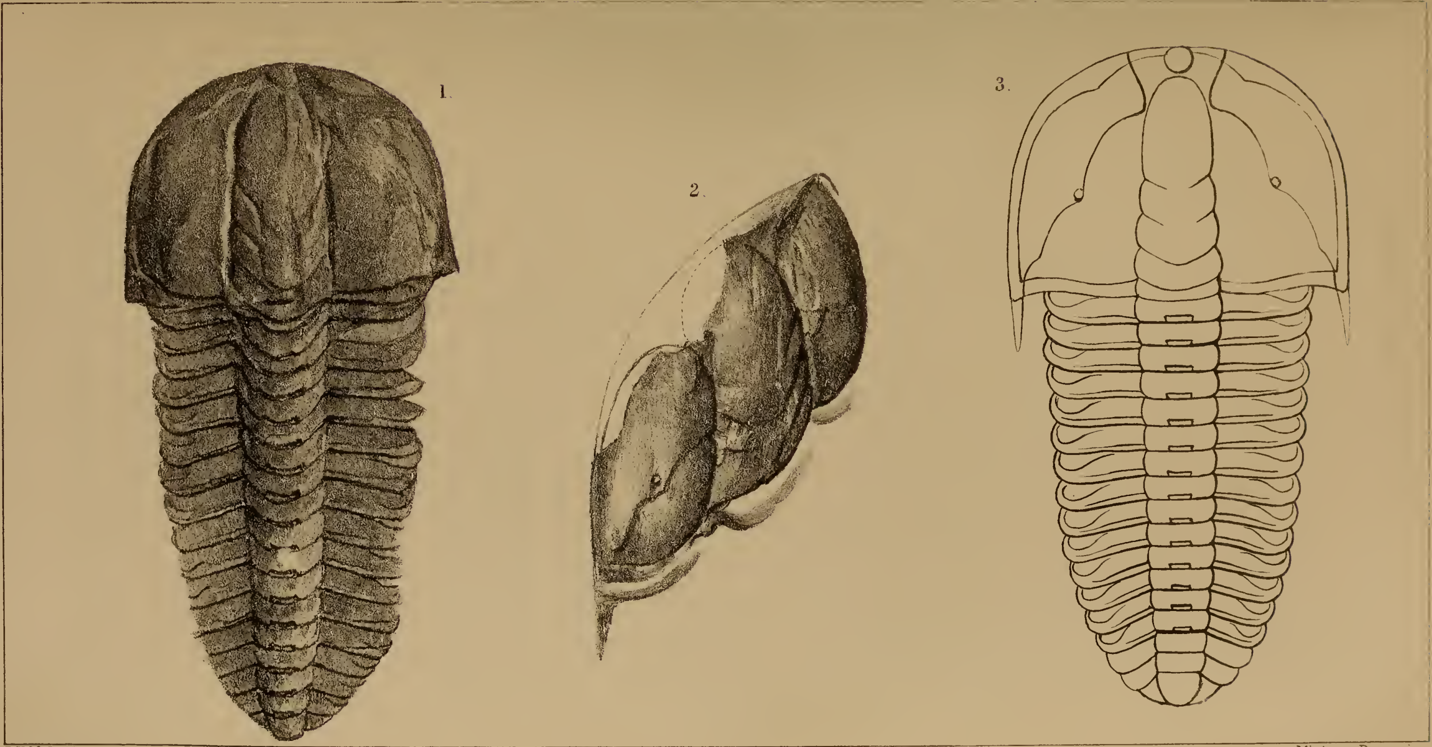
Discussion.

The President rejoiced that the charge of barrenness had been so effectually removed from these rocks.

Mr. Etheridge commented on the good work done by Dr. Hicks and others amongst the Cambrian rocks of Wales. Nothing had hitherto been found in the Bangor and Llanberis rocks. There was some question at first whether the Trilobite was more allied to the Olenidæ or to the Conocephalidæ.

Dr. Hicks said the fossils, according to the section, occurred in Lower Cambrian rocks, but the lowest fossiliferous horizon at St. David's was yet older. The position seemed to be above the Llanberis Slates, but at the base of the Harlech-grit series. There could be no reasonable doubt of the authenticity of the fossils.

Dr. Woodward called attention to a diagram showing a restoration of the fossil.



F. H. Michael del. et lith.

Mintern Bros. imp.

CONOCORYPHE VIOLA, *H. Woodw.*
Longmynd Group. — Bangor.

9. *On* THECOSPONDYLUS DAVIESI (*Seeley*), *with some* REMARKS *on the* CLASSIFICATION *of the* DINOSAURIA. By H. G. SEELEY, F.R.S., F.G.S., Professor of Geography in King's College, London. (Read December 7, 1887.)

IN the Fox Collection in the British Museum is the anterior third of a vertebra, with the number $\frac{R}{181}$, from the Wealden Beds of Brook, in the Isle of Wight, which indicates an animal of a type which hitherto has had but one other representative in Europe. With his usual acumen Mr. William Davies, F.G.S., recognized it as being the cervical vertebra of an animal closely allied to the genus *Cœlurus* of Marsh. No one would have been more competent than that veteran palæontologist to have written its history; and if I gladly undertake the task, it is because it enables me to suggest this honour to the work of a distinguished pioneer, whose labours on the Fossil Vertebrata have smoothed the way and facilitated the studies of every student of the National Collections for the last quarter of a century.

Imperfect as the specimen is, it may serve as a nucleus round which knowledge will accumulate, until the genus becomes as well known as the larger Wealden reptiles.

The centrum is elongated, compressed from side to side, with a flattened base, and flattened subquadrate anterior articular face, with the sides of the face prolonged backwards as subparallel sides, and as a ventral surface which is subparallel to the neural canal. The cervical ribs are co-ossified with the centrum and neural arch. The bony tissue, not unlike that of Ornithosaurs for its relative thickness, forms a dense external film, which defines the form of the bone, and is connected with some delicate internal supports in the chambered neural arch; so that there is no solid tissue in neural arch or centrum, and the densest layer is the film around the large neural canal. The neural arch forms a long pent-house ridge, which is penetrated in front above the neural canal by a large subtriangular cavity.

The only European genus hitherto described in which the vertebræ are similarly elongated, compressed from side to side, and enveloped in a dense external film of bone, is that indicated by the sacrum named *Thecospondylus Horneri*. The internal mould of that specimen, and the fragmentary vertebra of this, are confessedly scanty materials for comparison; but as they agree in characters which define them from all other animals, I believe it will be legitimate to refer both to the same genus, though there is the possibility of their belonging to distinct genera which are nearly allied. In the type of *Thecospondylus Horneri* the sacral vertebræ are about 11 centimetres long, and I estimate the vertebra about to be described as having been 9 centims. long, so there is no great difference in size. But since *Thecospondylus Horneri* has the sacral vertebræ convex transversely on the ventral aspect, while the ventral aspect of this vertebra is transversely subquadrate, I regard the remains as indicating distinct species, because I have often noticed among Ornithosaurs that the flattened or rounded ventral condition, as the case may be, in the cervical region also obtains in the sacrum.

Fig. 1.—*Anterior aspect of the vertebra, which has lost the pre-zygapophyses and cervical ribs.*

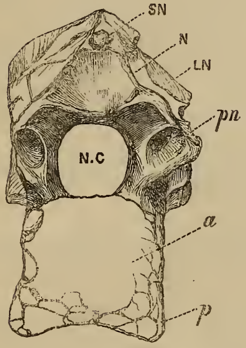


Fig. 2.—*Right lateral aspect of the same specimen.*

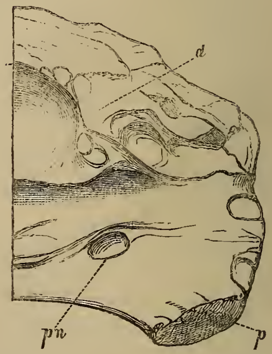


Fig. 3.—*Ventral aspect showing the base of the centrum.*

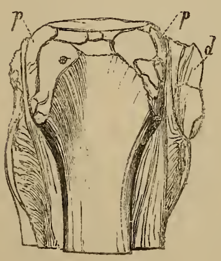
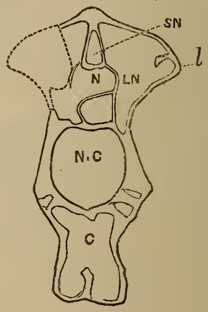


Fig. 4.—*Polished vertical section of the vertebra, showing the chambers in the neural arch and centrum.*



a, articular face of centrum, showing coarse cellular tissue on its slightly worn margin; *p*, attachment for the cervical ribs on the centrum; *d*, attachment for the cervical ribs on the neural arch; N.C, neural canal; *pn*, pneumatic foramen; N, cavity in neural arch, and corresponding air-chamber in fig. 4; SN, supra-neural air-chamber; LN, lateral air-chamber in the neural arch; C, centrum.

The anterior end of the vertebra (fig. 1) is imperfectly preserved, having lost the cervical ribs and adjacent tissue of the neural arch to which they were attached, as well as the adjacent prezygapophyses. If these parts were restored they probably would approximate in shape to those of *Cœlurus fragilis*, Marsh, except that the lateral extension of the ribs was less, and their supra-neural development was much less, for the lateral expansion of the neural arch has a relatively higher position than in that genus. As preserved, the anterior aspect of the bone is remarkable for narrowness relatively to its height. The articular face of the centrum (fig. 1, *a*) is flat or slightly concave, inclined slightly forward, subquadrate, being horizontal on the neural surface above, vertical laterally, and on the base it is concave from side to side, owing to the anterior corners having a downward development to form the basal attachments for the cervical ribs (fig. 1, *p*). The transverse width of the articular face of the centrum is 19 millim., and its vertical depth in the middle is about as much. The margins are somewhat worn, and show large cells defined by delicate tissue. The subtriangular facets of the cervical ribs at the inferior anterior corners of the centrum are probably but little worn, and in a line with the original sutures. They are oblique, and look downward, forward, and outward, and measure 13 millim. long by 9 millim. wide in front, where they are separated by an interspace of half a centimetre, which is convex as it descends from the articular surface on to the base of the centrum. The surface of the rib-facets is divided into two or three cells.

Above the articular face of the centrum is the transversely expanded subhexagonal entrance to the neural canal, 2·5 centim. wide and half as high in the middle, where the thin transverse bony plate which forms the upper limit of the arch extends from side to side with a downward curve. The neural canal itself (fig. 1, N. C) is higher than wide. The lateral angular expansions or antrum in front of the canal contain on each side an oval transversely oblique foramen (*pn*), which was probably pneumatic. It is situate in the lateral angle of the arch in such a way that the bone above it appears as though excavated, and that below it descends to form the stout pedicle of the neural tunnel, which has a transverse measurement of half a centimetre. The plate which limits the neural canal above is 8 millim. behind the articular face of the centrum. Upon this plate is a large aperture of a cavity in the neural arch, apparently penetrating conically, which is only inferior in size to the neural canal. It is 12 millim. wide at the base, and about 8 millim. high, with the sides converging upward to a transverse width of half a centimetre, while the upper border is 2 centim. behind the articular face of the centrum. The cavity penetrates far into the bone, and I regard it as having given attachments to ligaments which were attached to the extremity of the neural spine. The whole supra-neural region retreats backward as it ascends. Above this neural cavity is a circular foramen about 4 millim. in diameter, which assists in completing the triangular contour of the area above the neural canal (fig. 1, N, SN). The lateral margins of this triangular area are approximately parallel to the external surfaces of the neural arch; only much of the external bone is broken away with the cervical rib which it supported. The interval was occupied by lateral air-cavities, one on each side, which included some delicate supporting bony films. The four supraneural chambers thus indicated appear to extend longitudinally throughout the neural arch.

The superior external surface of the neural arch is very imperfect. In the median line it forms a longitudinal blunt ridge from which the smooth flat lateral halves of the neural arch diverge outward at a wide angle (fig. 4), becoming convex as they descend, and terminating outward in a blunt ridge, which ascends from the hinder border of the diapophysial attachment of the rib, and defines the upper border of a large lateral concavity on the side of the arch, like an impression of the finger (fig. 2). Its lower half rests against the upper half of the neural arch, and its upper part, which has a thin wall, is bounded by the lateral air-chamber of the neural arch. There is a small foramen in the upper anterior part of the concavity. This concavity is bordered below by a strong longitudinal ridge, which is placed below the middle of the side of the neural canal (fig. 4). As this ridge extends forward it expands to form the anterior border of the concavity, which is 2·5 centim. behind the articular face of the centrum. It is prolonged further forward, decreasing in height (fig. 2). Its inferior surface is horizontal and sinuous; as preserved, it is 2 centim. long. The greatest transverse measurement on it, through the centrum, is 2·5 centim. It is apparently upon the line of junction of the neural arch with the centrum, $1\frac{1}{2}$ centim. from the base of the centrum, and $2\frac{1}{2}$ centim. from the median ridge of the neural arch. The remainder of the neural arch is badly preserved, and does not admit of description.

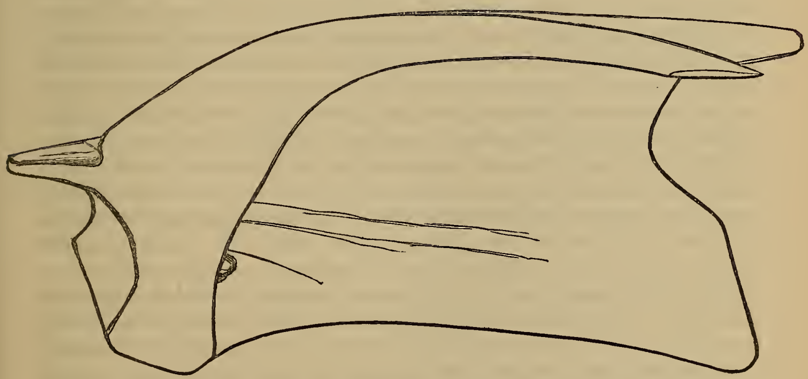
The region below the neuro-central ridge is the side of the centrum. Anteriorly it rises into the bases of the pedicels of the neural arch, which curve obliquely outward and upward towards the rib (fig. 2). So much of the side of the centrum as is preserved is approximately vertical, concave from the neuro-central ridge to the angle at the base of the centrum, and more gently concave from front to back. At more than $1\frac{1}{2}$ centim. behind the articular face, and half a centim. from the base, is a transversely oblique foramen, over half a centim. long, margined superiorly by a slight arched border (fig. 2, *pn*), which extends beyond it. This was probably covered by the cervical rib, and appears to have been pneumatic. The least transverse measurement in the middle of the centrum is 8 millim. at the posterior fracture (fig. 4). There is a slight constriction anteriorly at the base of the neuro-central angle, so that the centrum bulges a little below it.

The base of the centrum is elongated, flattened, with concave sides. It is concave transversely, and widened anteriorly (fig. 3) by the development of the parapophysial tubercles for the rib, which extend the base till it is as wide as the centrum. At the posterior fracture the transverse measurement is one centimetre, so that it has become narrowed to about one half of the anterior width. A long foramen runs in the anterior part of the left lateral angle of the base.

The posterior vertical fracture of the specimen has been polished (fig. 4); it shows the vertical height of the vertebra to be 4 centim. The transverse width of the neural arch at its superior expansion was 2·3 centim.; the transverse width at the neuro-central suture is 1·7 centim., and at the base 1 centim. The height of the centrum to the neural canal is 13 millim.: so its form is vertically oblong in section, concave above and at the sides, and margined all round by a thin wall of dense bony tissue, forming a perfect box, as in the vertebra of an Ornithosaur. The neural canal is slightly higher than wide, and measures 1 centim. transversely. The lateral walls of the neural canal are thick, 3 millim. on the left side, and 4 millim. on the right side, which includes two small foramina. The section of the neural arch is subpentagonal. It is divided into four chambers. First, a vertically oblong cavity with the angles rounded (N) is placed above the neural canal; secondly, a small and narrow isosceles triangle extends from above that cavity to the neural ridge (SN). Externally on each side are the large lateral subtriangular chambers (LN). These cavities are defined by the thinnest films of bone (fig. 4).

From this fragment it is only possible to attempt a restoration of the vertebra on the basis of general principles and the structure of allied animals; and such an outline, of the natural size, is here given (fig. 5).

Fig. 5.—*Outline of the Vertebra of* Thecospondylus Daviesi, *restored.* Nat. size.



The restoration, no less than the specimen described, indicates a close resemblance and affinity with the cervical vertebra of *Cœlurus fragilis*, Marsh *, which I suppose to indicate an animal not more than two thirds as large as this, or smaller. Both have a similar plan of vertebral construction, as shown in the elongated form, and

* Am. Journ. Sci. vol. xxi. pl. 10. fig. 1 (1881).

the correspondence extends to the lateral compression of the centrum and neural arch, inclined articular face of the centrum, mode of attachment of the ribs, the convex external surface of the neural arch, almost total suppression of the neural spine, thin texture of the bone, and internal chambers in the neural arch and centrum. Yet this strong evidence of affinity does not, I think, amount to generic identity. The following points seem to me important differences :—First, in this specimen the anterior part of the neural arch is much higher, ascends as it extends backwards, shows a large cavity above the neural canal, has no trace of a neural spine, and much more extensive diapophysial attachment for the ribs. Secondly, the chambers in the neural arch of *Cœlurus* are divided by a vertical median septum ; while in this specimen there are two important median chambers in addition to the lateral chambers. I attach less importance to the differences in the lateral walls of the neural canal, in the character of the forward extension of the postzygapophysial ridge, and in the form and condition of the articular face of the centrum, or to the other minor differences which are evident on comparison of the figures. But the sum of the differences seems to define a genus, but so close to *Cœlurus* that other parts of the animal may be expected to conform to the general construction of that type.

The sacrum of *Thecospondylus* being only known from a cast (Quart. Journ. Geol. Soc. vol. xxxviii. pl. xix.), from which the external film of bone has almost disappeared, is compared with some disadvantage ; and the resemblances which can be detected are limited to the thinness of the investing layer of bone, the smoothness of its internal surface, the elongation and lateral compression of the vertebræ, and a certain approximation in their general form. The difference which is most remarkable is the absence from the cast of *Thecospondylus Horneri* of indications of films of bone such as might have been expected to divide the neural arch from the centrum, or the sacral ribs from both, or other evidence of internal plates, such as are seen in the present specimen. But since such structures must have existed, their absence may be attributed to fossilization, and is no evidence of organic difference. It is because these animals are both British Wealden fossils that I attach importance to resemblances which show an approximation which is consistent with generic identity, especially as there is no known character, direct or inferential, which would justify their location in distinct genera. If I am warranted in referring this vertebra to the genus *Thecospondylus*, it follows that the identification makes the type of sacrum known, which might be expected in such a genus as *Cœlurus*, and completes a knowledge of the vertebral column in the family which that genus evidences.

I should infer that *Thecospondylus Daviesi* had the head elongated, with long slender jaws ; that the neck was over half a metre long, that the back and sacrum together were less than a metre and a third long ; so that the measurement from the tip of the snout to the extremity of the tail may have been under three metres. The narrowness of the sacrum in *Thecospondylus Horneri*, which measures 20 centimetres between the iliac bones, no less than the elongation of the ilium over six or seven vertebræ, and the general build of the animal, lead to the conclusion that its habits were active, its limbs long, and its extremities specialized.

In endeavouring to form an opinion on the systematic position of *Thecospondylus*, there is little evidence available beyond these British specimens. For although Professor Marsh * states that he possesses portions of ten or twelve individuals of *Cœlurus fragilis* from the middle Secondary rocks of Wyoming, which yielded the Atlantosaurs, little is known of their structure beyond what his figures demonstrate. He places the animal in a new subordinal group, and observes (p. 340):—"its remains preserved suggest resemblance to Dinosaurs, to Pterodactyles, and more remotely to Birds, and it is apparently a generalized Sauropsid which, when fully investigated, may serve to bridge over some of the present breaks in the lines of descent. The sum of its known characters indicates that it is a reptile and not a bird. Its structure, so far as known, presents more similarity to Dinosaurs than to Pterodactyles; but for its nearer affinities we must await the discovery of further remains." I concur in the general spirit of these conclusions, but they admit of some elaboration.

When the first notices of *Ornithopsis* were published, Dinosaurs with a pneumatic skeleton were unknown; and it was remarked of the type specimens (Annals and Mag. Nat. Hist., April 1870):—"both vertebræ agree in being constructed after the lightest and airiest plan, such as is only seen in Pterodactyles and Birds; and they agree in possessing pneumatic foramina, which are an Avian and Ornithosaurian peculiarity. The foramina are of enormous size, and approximate to those of the Pterodactyles rather than to those of birds." On its affinities it was observed "it does not conform closely in the shape of vertebræ to either Pterodactyles or birds. And from the bones preserved, and many indications of allied animals which I have seen from the Wealden and Potton Sands, I anticipate that it will form the type of a new Order of animals, which will bridge over something of the interval between birds and Pterodactyles, and probably manifest some affinity with the Dinosaurs."

At that time, *Hypsilophodon*, *Iguanodon*, *Hadrosaurus*, and *Scelidosaurus* gave the best conception of the Dinosauria. It has been the fortune of others to elaborate the group thus indicated. Mr. Hulke has admirably described *Ornithopsis*, and Professors Cope, Huxley, and Marsh have investigated the structure of its allies, and their classification. But it has seemed to me that the classificational value of the pneumatic skeleton has been underestimated in the results which have been formulated. Professor Marsh has been led to form an order of animals for the type to which *Ornithopsis* belongs. This order was named Sauropoda †, and has for its European types *Cetiosaurus* and *Ornithopsis*.

* Amer. Journ. Sci. vol. xxi. (April 1881).

† *Ibid.* vol. xvi. p. 412 (Nov. 1878), vol. xxiii. p. 83 (Jan. 1882).

As early as December 1874 * I suggested the name Cetiosauria as an ordinal division of the Dinosauria, and therefore am in harmony with Professor Marsh in separating these types from the remainder of the Dinosauria, though the separation may be based upon different data from those adopted by Professor Marsh. These animals are characterized by pneumatic vertebræ. And therefore when an additional order is instituted for animals with cavernous or pneumatic vertebræ, the Theropoda of Marsh †, under which *Cœlurus* is grouped, it becomes necessary, in order to determine the systematic position of *Thecospondylus*, to briefly review its relations to allied animals. I have no doubt that the two ordinal groups Sauropoda and Theropoda should be united into one order, the Saurischia, while the Stegosauria and Ornithopoda should be united into an order, the Ornithischia.

If Prof. Marsh is correct in attributing to *Cœlurus* the pelvic bones which have been figured (Amer. Journ. Science, vol. xxvii. pl. xi., April 1884), then there can be no doubt that the genus correctly finds its place in the Saurischia, in some such position as its discoverer suggests; for its pubis does not show a generic difference of form from *Allosaurus*. But in his account of the vertebral column (Amer. Journ. Science, vol. xxi., April 1881) it is said that the ribs preserved have undivided heads, and in the figure of a dorsal vertebra (*l. c.* pl. xi. fig. 2 *a*) there is no sign of a capitular facet on the neural arch, while the fractured, compressed, transverse process is subcrocodilian. This is a remarkable divergence from the divided rib-articulation hitherto found in the Ornithischia; but is an intelligible modification of the Saurischian type. Its chief interest lies in the rib being attached to the transverse process as in the Ornithosaurian genus *Pachyrhamphus*, with a vertical compression of the process, which is Crocodilian or Avian. But while the Saurischia may thus be exceptionally modified in vertebral characters, the pneumatic skeleton is an approximation towards Ornithosaurs and Birds, which may be a stronger evidence of organic affinity. And it serves to demonstrate the way in which the pneumatic skeleton was developed, in animals which not only did not fly, but show no sign of degeneration from flying types. It cannot therefore be classed as an adaptive modification of structure consequent on flight. Hence it may be regarded as indicative of a community of plan of vital organs so far as the respiratory system is concerned. It is curious that while the Saurischia thus make an approximation to Ornithosaurs, and the pelvic structures and hind limb to some extent support the comparison,—the pelvic structures and the hind limb, in the Ornithischia, on the other hand, rather approximate towards Birds in plan of the skeleton, although the pneumatic condition of the vertebræ is not a character in common between them.

* Quart. Journ. Geol. Soc. vol. xxx. p. 690.

† Amer. Journ. Sci. vol. xxi. p. 423 (May 1881), vol. xxiii. p. 84 (Jan. 1882), vol. xxvii. p. 337 (April 1884).

Discussion.

The President congratulated the Author on the opportunity afforded him for paying a tribute to that excellent palæontologist Mr. William Davies, which he cordially endorsed.

Mr. Hulke would not enter into the question of classification. He had great hesitation in accepting the Author's identification with *Thecospondylus*. It was difficult to institute a comparison between a structure such as the fossil under description and one which has no structure. Then there was the great difference in size. On the whole the resemblance of the fossil to *Cœlurus* was so close that he was inclined to refer it to that genus.

10. *Further* Observations *on the* Correlation *of the* Eocene Strata *in* England, Belgium, *and the* North *of* France. By Prof. Joseph Prestwich, M.A., F.R.S., F.G.S., &c. (Read December 21, 1887.)

[Plate V.]

It is not my intention to reopen the whole question of the position and correlation of the Eocene strata of England and France, but merely to bring again before the Society such portions of them as involve some yet unsettled points of classification and some necessary rectifications of my own work.

The synchronism of the Thanet Sands with the Lower Landenian, of the London Clay with the Lower Ypresian, of the Bracklesham Beds with the Calcaire Grossier, and of the Barton Beds with the Grès de Beauchamp is now perfectly well established. But with respect to the exact relation of the Sands of Bracheux and of the Soissonnais to the English Series, of the Oldhaven Beds to the Woolwich Series, and of the Lower and Upper Bagshots to equivalent strata in the Paris Basin, there are still differences of opinion and some open questions.

Since the publication of my early papers on the Eocene strata, the important monographs on the Eocene Mollusca of Edwards * and Searles Wood † in this country, and the last great work of Deshayes‡ in France, have made large additions to the Eocene faunas of the English and French Tertiaries. At the same time, the work of the Geological Survey and others in the London and Hampshire Basins §; of MM. Hébert ‖, Dolfuss ‖, De Mercey ‖, and others in the Paris Basin; of MM. Gosselet ¶, Ortlieb, and Chelloneix ** in the North of France; and of MM. Briart and Cornet, M. Dewalque, MM. Rutot, Van der Broeck, and others in the Belgian Basin ††, have done much to settle many doubtful points of stratigraphy and palæontology in the Eocene Series. Especially did the second comprehensive work of M. Deshayes serve to correct the synonomy of species, and their right location.

The classification of the Eocene Series, now that the fluvio-marine strata of the Isle of Wight, and a portion of those of the Paris Basin have been relegated to the Oligocene, is generally ‡‡ tabulated as follows:—

* 'The Eocene Cephalopoda and Univalves.' Pal. Soc. Monogr.

† 'The Eocene Bivalves.' Pal. Soc. Monogr.

‡ 'Histoire des Animaux sans Vertèbres découverts dans le Bassin de Paris,' 2nd series.

§ 'On the Geology of the Isle of Wight,' by H. W. Bristowe, 1862; 'On the Geology of the London Basin,' by W. Whitaker; and sundry papers by Professor Rupert Jones, the Rev. A. Irving, and Mr. Starkie Gardner.

‖ Various papers in the Bull. Soc. Géol. de France.

¶ Papers in Bull. Soc. Géol. de France, and Ann. Soc. Géol. du Nord.

** 'Études géologiques des Collines Tertiaires du Dépt. du Nord,' 1871; and other papers.

†† Various papers in Mém. Acad. Roy. Bruxelles, and Ann. Soc. Géol. du Nord.

‡‡ Lyell's 'Student's Elements,' 4th edit. pp. 103 and 236; Archibald Geikie's 'Text-Book of Geology,' pp. 844, 850; De Lapparent's 'Traité de Géologie 2nd edit. p. 1163.

Table of the accepted Classification of the Eocene Series.

	England.	Belgium.	France (Paris Basin).
Upper Eocene ...	Barton Beds and Upper Bagshots.	Wemmelian System.	Marine Gypseous beds, Sables Moyens, or Grès de Beauchamp.
Middle Eocene .	Bracklesham Sands, Middle and Lower Bagshots, Leaf-beds of Bournemouth and Alum Bay.	Laekenian and Bruxellian Systems.	Calcaire Grossier.
Lower Eocene ...	(Part of the Lower Bagshots in the Isle of Wight ?)	Paniselian and	Sands of Cuise-la-Motte.
	London Clay and Basement-bed.	Ypresian Systems.	*Wanting.*
	Oldhaven Beds.	*Wanting.*	*Wanting.*
	Woolwich and Reading Beds.	Upper Landenian.	Lignites of the Soissonnais; Argile plastique.
	Thanet Sands.	Lower Landenian.	Sands of Bracheux and part of the Soissonnais.
	Wanting.	Sands and Marls of Heers.	Sands and Marls of Rilly.
	Wanting.	Calcaire de Mons.	*Wanting.*

Calcaire de Mons.

With this formation there is no difficulty. It is not represented either in England or in France, unless, as suggested by some of the French geologists, the Strontianiferous Marls of Meudon, with which it has two species in common, or the Calcaire Pisolitique of Mont Aimé, be related to it (see list). It is almost equally distinct from the overlying Tertiary strata as it is from the Maestricht Chalk. It seems to be a passage-series, though connected with the Tertiary by all the genera, and a few species, of its Mollusca.

Notwithstanding its local importance, it has a very limited range, being confined to a small district near Mons, where it underlies the Lower Landenian, and attains in one place a thickness of above 300 feet. It contains a rich Molluscan fauna of above 100 species of Lamellibranchs *, and nearly 300 species of Gasteropods, which latter have been described by MM. Briart and Cornet †. The general facies of the fauna resembles that of both the Lower and Upper Eocene, though only 22 species of the Gasteropods are common to the two series. The others are new species peculiar to this deposit, but all the genera are Tertiary forms.

The species described by MM. Briart and Cornet as being common to the Calcaire de Mons and to strata of Eocene age elsewhere are given with their range, according to Deshayes and the above authors, in the following list:—

Actæon (Tornatella) parisiensis, *Desh.*, c. c.	Lower Landenian; Sables Inférieurs, Sands of Chalons-sur-Vesles.
Adeorbis similis, *Desh.*, r.	Sables Inférieurs, Hérouval.
Buccinum stromboides, *Herm.*	Lower and Upper Eocene of the Paris Basin; Bruxellian and Bracklesham.
Calyptræa trochiformis, *Lamk.*, r.	(same as above)
—— suessoniensis, *D'Orb.*	Lower Landenian; Sables Inférieurs ‡.
Cerithium inopinatum, *Desh.*	Conglomerate (Lignites) of Meudon.
—— striatum, *Brug.*	Upper Eocene of the Paris Basin.
—— unisulcatum, *Lamk.*, var. A	All the Eocene strata of the Paris Basin.
Cornetia modunensis, *Mun.-Chal.*, c.	Strontianiferous Marls of Meudon §.
Cylindrellina Briarti, *Mun.-Chal.*, r.	Sands of Jonchery? (Sables Inférieurs).
Melanopsis buccinoidea, *Férussac*	Lignites; Sables Inférieurs.
Natica infundibulum, *Watelet*	Sables Inférieurs.
—— parisiensis, *Desh.*	Upper Eocene of the Paris Basin.
—— Wateleti, *Desh.*	Sables Inférieurs.
Oliva mitreola, *Lamk.*, r.	Sables Inférieurs; Calcaire Grossier.
Pyramidella eburnea, *Desh.*	Calcaire Grossier.
Turbonilla acicula, *Lamk.*	All the Eocene Strata of the Paris Basin.

* These have not yet been described.

† Mém. de l'Acad. Roy. de Belgique, 1871–1877.

‡ The term "Sables Inférieurs" embraces all the strata in the Soissonnais and Laonnais between the Chalk and the Calcaire Grossier, including the sands of Chalons-sur-Vesles, Brimont, Laon, Hérouval, Aizy, Jonchery, Sainceny, Cuise-la-Motte, &c.

§ I should be disposed to refer all the Lower Tertiaries at Meudon to the same zone as the Woolwich and Reading series, but on this point I speak with hesitation.

Turbonilla Deshayesi, *B. et C.*	Sands of Cuise-la-Motte and Calcaire Grossier.
—— (Odostomia) hordeola, *Lamk*.......	Upper Eocene, Paris Basin.
Turritella multisulcata, *Lamk*...........	Calcaire Grossier.
Voluta elevata, *Lamk.*	Sables Inférieurs.
—— spinosa, *Linn.*	Calcaire Grossier.

The Heersian

Are beds of very local occurrence, with a very small fauna, but an abundant flora. I am not, however, satisfied with the reasons assigned for placing them by themselves as a separate division. The few Mollusca are those of the Lower Landenian and Thanet Sands; and the presence of the remarkable group of plant-remains arises apparently from purely local conditions, due to the proximity of land (chalk), to which also is to be attributed the exceptional petrological character of the beds, which consist in great part of a white chalk-like marl, with subordinate sands.

The two Gasteropods are Lower Landenian species; and of the 16 Lamellibranchs, 10 are found in the Lower Landenian beds, 6 in the Thanet Sands, 2 in the Woolwich and Reading Beds, and 1 in the Sands of Bracheux, while 2 only are new species (named but not described). Of the 12 Fishes, 5 belong to Landenian genera and species, 1 is a Chalk and Upper-Eocene genus, 1 Eocene and Recent, 1 belongs to a family which ranges from the chalk to recent times, 2 are Upper Tertiary, while the other 2 species are referred to new genera.

The 62 plants are, with one exception, all new and peculiar to the locality. They are mostly dicotyledonous plants of existing genera, and have been described by De Saporta and Merian.

There is certainly nothing in these fossils to indicate a higher antiquity than the Landenian. It seems to me, therefore, that these Heersian beds should be grouped with the Lower Landenian,—possibly, as originally proposed by Dumont, as a lower subdivision. In their general aspect the Gelinden plants seem to resemble the plants of the Reading Beds.

The Thanet Sands or Lower Landenian.

There can be no doubt of the synchronism of these English and Belgian deposits, but I would limit their range in France to the northern edge of the Paris Basin, and exclude the Sands of Bracheux, with which they have hitherto been considered synchronous *. For this synchronism various reasons have been assigned, the chief one being the immediate superposition of both on the Chalk, and their position at the base of all the Tertiary strata of the Oise and adjacent district. There has also been some confusion in the fossils referred to these Sands, arising from the circumstance that, owing to the slight thickness of so many of the divisions of the Lower Ter-

* In 1855 (Quart. Journ. Geol. Soc. vol. xi. p. 206) I stated my opinion that the Sands of Bracheux were synchronous with the Woolwich Beds, but I had not then the means, subsequently afforded by Deshayes's later investigations, of obtaining the necessary palæontological information respecting the foreign localities.

tiaries both in England and France, it constantly happens that more than one group or zone is exposed in the same section, so that there is frequently a risk of the specimens getting mixed, or being referred to a wrong zone. It is further to be observed that the Anglo-Belgian Basin is separated from the Paris Basin by a wide plateau of Chalk, and, although there are connecting links left here and there upon the Chalk hills, these masses are generally isolated, and this, together with changes of conditions and distance, frequently renders it difficult to follow the sequence of the zones, so that, in this case, beds belonging to different levels may have been referred to the same geological horizon, and their fossils have passed current under the name of one dominant zone. Thus the Sands of St. Omer and La Fère, which belong rightly to the Thanet Sands and Lower Landenian, are held to be synchronous with those of Bracheux, and it has been customary to speak of the fossils of those beds indifferently as Bracheux-Sands species. Somewhat similar circumstances have occasionally arisen with respect to the fossils of the Oldhaven and Basement-beds, and of the Woolwich Beds and Thanet Sands in East Kent.

To avoid any confusion from these sources of error, I have in the following lists confined myself, as far as possible, to the one locality where one zone only is exposed, and which may be regarded as affording a true type of the zone in question. Thus Pegwell Bay offers such a section for the Thanet Sands, and the Butte de la Justice near Beauvais offers such another for the Bracheux Sands. In the same way, I take as a type of the Oldhaven Beds the bed immediately beneath the London Clay at Oldhaven Gap, which I originally designated the Basement-bed of the London Clay, and I have eliminated the Sundridge and Charlton fossils, which my friend Mr. Whitaker places with the Oldhaven.

To resume with the Thanet Sands and Lower Landenian, the described Mollusca of the former amount at Pegwell Bay only to 27 species, whereas, taking the Tufeau de Lincent as the type of the latter, the number of known shells there recorded by Dumont, Nyst, and Dewalque amounted to 33, and to these M. Vincent has now added 31, most of them new and peculiar species, and 34 others which he has only named, but not described. It is not, however, necessary to say more about these beds than that they are in both countries characterized by such common species as *Cyprina Morrisii*, *Cucullæa crassatina*, *Pholadomya Koninckii*, *P. cuneata*, *Scalaria Bowerbankii*, &c. The following list of the Pegwell-Bay fossils will show that a considerable proportion of the species are peculiar to that zone *; and while a certain number of characteristic species are common to the Thanet Sands and Lower Landenian, each group possesses a certain proportion of peculiar species.

* The relative proportion of the Lower Landenian fossils to those of the Bracheux is made larger by M. Vincent; but this arises from embracing under the designation of Bracheux Sands, not only those of the Beauvais district, but of various other localities in the Departments of the Aisne, Marne, and Somme, which are habitually referred to the Bracheux Sands. Eliminating these, there are 66 peculiar species out of M. Vincent's total of 97.

A.

Mollusca of the Thanet Sands, Pegwell Bay †, with their range in other Lower Tertiary Deposits.

(The asterisk marks the more characteristic species.)

	Lower Landenian.	Bracheux Sands.	Woolwich and Reading Beds.	London Clay and Basement-Beds.
LAMELLIBRANCHIATA.				
R Astarte tenera, *Morr.*				
Cardium.				
Corbula Arnouldi, *Nyst* ?	...	...	*	
*—— regulbiensis, *Morr.*	*	*	*	*
Crassatella, sp.				
*Cucullæa crassatina, *Lamk.*	*	*	*	
*Cyprina Morrisii, *Sby.*	*	...	*	
—— scutellaria, *Desh.*?	*	*	*	
*Cytherea orbicularis, *Edw.*	?	...	*	
*Glycimeris rutupiensis, *Morr.*	...	...	*	
Leda substriata, *Morr.*				
Lucina, sp.				
Modiola, sp.				
*Nucula Bowerbankii, *Sby.*	*	...	...	*
—— cardioides, *Edw.*				
—— fragilis, *Desh.*	*	*	*	
—— margaritacea, *Lamk.* ?	...	...	...	*
—— sextans, *Edw.*				
—— thanetiana, *Edw.*				
Ostrea cymbuloides, *Wood.*				
*Panopæa granulata, *Morr.*				
R*Pecten Prestwichii, *Morr.*				
*Pholadomya cuneata, *Sby.*	*			
*—— Koninckii, *Nyst*	*			
Pinna, sp.				
*Sanguinolaria Edwardsi, *Morr.*	*	*	*	
Saxicava compressa, *Edw.*				
Thracia oblata, *Sby.*	...	...	*	*
GASTEROPODA.				
Calyptræa trochiformis, *Lamk.* ?	...	...	*	*
Dentalium nitens, *Sby.* ?	...	...	...	*
Eulima, sp.				
Fusus, sp.				
Natica subdepressa, *Morr.*	...	...	*	
Rostellaria, sp. ?				
R*Scalaria Bowerbankii, *Morr.*	*			
R*Trophon subnodosum, *Morr.*				
	10	5	12	6

† To these are added four (marked R) from my original collection from the Reculvers.

It would appear, therefore, that out of the 28 Pegwell-Bay species, there are 10 common to the Lower Landenian, 12 pass up into the Woolwich Beds, and 6 extend to the London Clay, while only 5 are common to the Bracheux Sands.

The Sables de Bracheux.

The exact determination of the horizon to which these sands belong is of importance, not only with respect to the synchronism of the Lower Eocene groups in the London and Paris Basins, but also for fixing the age of the very interesting Mammalian and Avian faunas discovered by M. Lemoine in the neighbourhood of Rheims, of the curious freshwater deposit of Rilly, and of the rich flora of Sézanne. I only regret that in putting forward my views on this subject I have to differ on many points from some of my friends abroad and at home. These differences are, however, as they know, not of recent date, and have often been discussed by us, and I should not have ventured upon expressing so wide a divergence of opinion unless I had had a long acquaintance with most of the localities concerned.

It was fortunate for Tertiary geology that Beauvais possessed an excellent local geologist (M. Graves), whose work on the Department of the Oise, though without map or sections, is full of most complete and accurate details of every part of the Department, with the names of all the localities at which every fossil is found *. He divided the Lower Tertiaries of the Oise into three groups, which I give, with the names by which they have been subsequently known:—

Glauconie Supérieure	=	Glauconie Grossière forming the base of the Calcaire Grossier.
Glauconie Moyenne	=	Sands of Cuise-la-Motte, and possibly other zones.
Glauconie Inférieure and Lignites	=	Sands of Bracheux; Lower zone of the Sables Inférieurs.

M. Graves makes the Lignites subordinate to the Sands, and it is the lower bed of these sands, which is about 30 feet thick, that forms the knoll at Bracheux. The Lignites and mottled clays cap this bed in other places, and they are in turn surmounted by another bed of from 10 to 20 feet of sand, with many of the same shells, such as *Ostrea bellovacina*, *Pectunculus terebratularis*, *Nucula fragilis*, *Turritella edita*, *Cytherea obliqua*, *Natica glaucinoides*, &c. The characteristic fossils of the Lignites are *Cyrena cuneiformis*, *Paludina lenta*, *Cerithium variabile*, *Melania cuneiformis*, *Ostrea bellovacina* and *O. sparnacensis*.

* 'Essai sur la Topographie Géognostique du Département de l'Oise.' Par L. Graves. Beauvais: 1847.

The Glauconie Inférieure presents a marked analogy with the Woolwich Series, where we also have two beds of fossiliferous marine sands divided by fluviatile carbonaceous clays and thin lignites. The deposits are also alike in lithological character, that of Beauvais consisting of white and light-green sands, often very pebbly, while the carbonaceous clays form large lenticular masses in the middle of the sands. There is also the like passage, on the same level, of massive mottled clays into sands, and of sands into pebble-beds. The fossils, which abound in some places and are absent in others, are subject to similar variations, dependent upon variability of conditions. Further this Glauconie Inférieure is replaced in the neighbourhood of Paris, as the Woolwich Beds are in the neighbourhood of Reading, by red and mottled clays with a few beds of sand. There is, however, this difference, that while the bulk of the fossils in the Woolwich Series are in the sands above the fluviatile clays, those in the Paris Basin at Beauvais are in the lower division of the sands; but, as at Woolwich, while there are a few species peculiar to either bed, the greater part are common to the two.

M. Graves enumerates 82 species* of Mollusca from the different localities of these sands in the Oise; but his list was made before the publication of Deshayes's last work on the shells of the Paris Basin, in which many rectifications were made, both in the names of species and in their range. Consequently the list requires considerable revision. Deshayes, in that work, gives the names of all the localities from which his specimens came. It is by taking all his Bracheux specimens in combination with Graves's specifications that the following list (p. 96) has been drawn up. It will serve as a truer term of comparison than Graves's original lists.

Here, out of 45 species, only 6 seem to be common to the Thanet Sands, and 5 to the Lower Landenian, whereas there are 10 common to the Woolwich Series. The numbers are not large†, but the balance in favour of the higher horizon is clear; and if the Lignite species are to be included with them, as by M. Graves, the case in favour of their synchronism becomes stronger. The absence in the Thanet Sands and Lower Landenian of such characteristic forms as the *Cardita pectuncularis* and others, is an additional piece of evidence that the two zones are distinct. In fact out of the 8 Bracheux species selected by M. Graves as characteristic of the Bracheux Sands, only 2 occur in the Thanet Sands and Lower Landenian.

* This includes a number of freshwater species, some of which are given in the second list.

† If we had taken the beds of Abbecourt and Noailles, which belong to the same zone as the Bracheux Sands, it would have increased the number of species, but would not materially have altered the proportional distribution.

B. *Mollusca of the Sands of Bracheux, near Beauvais, with their range in time.*

(The asterisk marks the more characteristic species according to M. Graves.)

	Thanet Sands.	Lower Landenian of Lincent.	Woolwich Beds.	Chalons-sur-Vesles, Jonchery, &c.	Sands of Cuise.	Elsewhere.
LAMELLIBRANCHIATA.						
*Cardita multicostata, *Lamk.*	...	...	...	...	...	Nice.
*—— pectuncularis, *Lamk.*						
Cardium hybridum, *Desh.*	...	...	...	*	*	
—— Edwardsii, *Desh.* .... (C. semigranulatum, *Sby.*?)	...	*	*	*		
Corbula regulbiensis, *Morr.*	*	...	*	*		
—— obliquata, *Desh.*	...	...	...	*		
*Crassitella bellovacina, *Lamk.*	...	...	...	*		
*Cucullæa crassatina, *Lamk.*	*	*	*	*		
—— incerta, *Desh.* ?						
*Cyprina scutellaria, *Desh.*	*	*	*	*		
Cytherea bellovacina, *Desh.*						
—— obliqua, *Desh.*	...	...	*	...	Bognor.	
—— proxima, *Desh.*	...	...	...	*	*	
—— fallax, *Desh.*						
Fimbria (Corbis) Davidsoni, *Desh.*						
Lucina contorta, *Defr.*	...	...	...	...	...	Nice.
*—— grata, *Defr.*	...	Upper Landenian.				
—— scalaris, *Defr.*	...	...	...	*		
—— uncinata, *Defr.*	...	...	...	*		
Nucula fragilis, *Desh.*	*	...	*	*	*	
*Ostrea bellovacina, *Lamk.*	...	Upper Landenian.	*			
Panopæa remensis, *Desh.*	...	...	...	*		
*Pectunculus terebratularis, *Lamk.*....	...	Upper Landenian.	*	*		
Psammobia (Sanguinolaria) Edwardsii, *Morr.*......................	*	...	*			
Tellina Edwardsii, *Desh.*...............	...	...	...	*	*	
GASTEROPODA.						
Buccinum latum, *Desh.*						
Bulla angystoma, *Desh.*						
Calyptræa suessoniensis, *D'Orb.*	...	...	...	*	*	
Cerithium bellovacinum, *Desh.*						
—— gibbosum, *Defr.*						
—— obesum, *Desh.*						
Dentalium striatum, *Sby.*?	...	...	...	...	...	C.Gr.
Pyrula (Ficula) Smithii, *Sby*..........	...	* ?	Bognor.	*		
Carried forward......................	5	4	9	16	5	

B. *List of Mollusca* (continued).

	Thanet Sands.	Lower Landenian of Lincent.	Woolwich Beds.	Chalons-sur-Vesles, Jonchery, &c.	Sands of Cuise.	Elsewhere.
Brought forward	5	4	9	16	5	
GASTEROPODA (*continued*).						
Melania plicatula, *Desh.*						
Natica abducta, *Desh.*	...	...	...	*		
—— Deshayesiana, *Nyst*...............	*	...	...	*		
—— infundibulum, *Wat.*	...	...	...	*		
—— semiplicata, *Desh.*	...	...	...	*		
Rostellaria callosa, *Desh.*						
Tornatella parisiensis, *Desh.*	...	*	...	*		
Turritella bellovacina, *Desh.*	...	...	...	*		
—— hybrida, *Desh*.....................	...	...	...	*	*	
Voluta depressa, *Lamk.*	...	...	...	*		
—— Baudoni, *Desh.*	...	...	...	...		
Pseudoliva fissurata, *Desh*............	...	...	*	*		
	6	5	10	25	6	

The fossils of the fluviatile and estuarine clays and lignites, which seem to bear the same relation to the Bracheux Sands that the fluviatile beds of Woolwich do to the sand- and pebble-beds below and above them, present a still closer analogy with the fossils of the Woolwich series, as the following list of some of the most characteristic of the Beauvais (Lignite) species will show:—

	Woolwich.	Upper Landenian.
Cerithium funatum, *Mant.* (C. variabile, *Desh.*) ...	*	
Melania inquinata, *Defr*..............................	*	*
Melanopsis buccinoidea, *Fér*.........................	*	*
Paludina lenta, *Sby.*	*	
Neritina consobrina, *Fér.*	*	
—— globulus, *Defr.*	*	
Planorbis.		
Cyrena cuneiformis, *Fér.*	*	*
—— antiqua, *Fér.*	...	*
Modiola.		
Ostrea bellovacina, *Lamk.*	*	*
—— sparnacensis, *Defr.*		
	8	5

Woolwich and Reading Beds.

I have shown in former papers * that the non-fossiliferous clays and sands of Reading pass, as they approach London, into pebbly sands; and, as the mottled-clay element gradually disappears, these sand- and pebble-beds become fossiliferous. At the same time an intercalated zone of fluviatile clays and thin lignites sets in in the middle of the series, attaining considerable importance immediately east of London, and extending nearly to Faversham. There these fluviatile beds, which at Woolwich divide the pebbly marine and estuarine sands into two groups, thin out, and the upper and lower sands inosculate, so that at Herne Bay all traces of the freshwater element are lost, unless it be represented by the few fragments of drifted wood, and none but marine fossils remain.

These fuller marine conditions bring in at the same time other fossils wanting in the London district, which serve to connect this zone with the Bracheux Beds, such as *Cyprina scutellaria* and *Cucullæa crassatina*. But these would hardly be sufficient to establish the contemporaneity of the two deposits were it not for other general conditions and the help of certain negative evidence.

The characteristic shells of the Thanet Sands—*Pholadomya Koninckii*, *P. cuneata*, *Panopæa granulata*, and *Scalaria Bowerbankii*—are wanting in the glauconiferous sands representing the Woolwich Beds in East Kent; while such characteristic Woolwich shells as *Ostrea bellovacina*, *Pectunculus terebratularis*, *Pseudoliva fissurata*, and *Cardium semigranulatum* are wanting in the underlying Thanet Sands.

A shell which, though not found at Bracheux, is common in the equivalent beds at Gannes a few miles distant, was also found a short time since in the Woolwich Beds in the fine section exposed near Croydon in making the railway-cutting on the Oxted line. This is a *Perna* which seems to be *Perna Bazini*, a shell of very definite form and of limited range.

Another character of secondary importance, but which, from its bearing on the origin of the strata, becomes of consequence, is the mineral composition of this series. In the Paris Basin the strata consist essentially of light-coloured quartzose and glauconiferous sands, mixed, when in the proximity of the fluviatile beds, with large quantities of flint pebbles, and elsewhere passing into red and mottled unfossiliferous plastic clays. Further, while a peculiar condition of the sands is presented by the Sarsens and Puddingstones of the London Basin, blocks of hard sandstones (passing into quartzites), together with extensive pebble-beds (associated in places with fluviatile beds and lignites), extend in France irregularly over the plains of Picardy, passing southward into mottled clays and northward into the Upper Landenian, in which organic remains are, as a rule, extremely scarce. M. Gosselet, however, records the occurrence of *Pectunculus terebratularis* in these beds (to the south of Lille), which he terms the Sands of Ostricourt. He also notices the common

* Quart. Journ. Geol. Soc. vol. x. pp. 75–170.

occurrence in the sandstones of imperfect vegetable impressions. In Belgium the fluviatile conditions are more marked, *Cyrena cuneiformis* and *Melania inquinata* having been found in wells at Ghent and Ostend. Another connecting link is the abundance of silicified wood and of silicified shells in these beds in East Kent and in some parts of the north of the Paris Basin.

These general features point to a common origin,—the mottled and plastic clays in both areas having been, in all probability, derived from the decomposition of plutonic and metamorphic rocks to the southward, and the flint pebbles from neighbouring Chalk areas; while the quartzites, pudding-stones, and silicified shells result from the cementation and fossilization effected by the soluble silica set free simultaneously with the liberation of the kaolin which went to form the mottled clays.

This variability is characteristic of the whole of this series in the Paris as well as in the Anglo-Belgian Basin, certain very distinct mineral characters prevailing in adjacent areas, although on the same horizon; and while in some of these areas fossils abound, in others they are rare or altogether absent. The fluviatile beds are merely local lenticular intercalations. There is nothing, therefore, out of line in the character of the Bracheux fauna, which, while having many connecting links with the Woolwich fauna, yet has a local type of its own. As the other beds to which this group belongs range further eastward, they become more fully developed and undergo considerable changes. They then constitute more especially the series there better known as the "Sables Inférieurs," which, in the Soissonnais and Champagne, is divided into several zones, the lower one being the Sands of Chalons-sur-Vesles, and the upper ones forming the zones of Aizy and Sainceny; but it is not my object to describe these beds, which become in this eastern area very fossiliferous, the total of the Mollusca amounting, according to the late M. Watelet, to above 400 species.

I would merely note that the French geologists consider the Sands of Chalons-sur-Vesles to be the equivalent of the Sands of Bracheux. The former, I have reason to believe, pass, in the neighbourhood of Rheims, under the freshwater concretionary marl of Rilly *, with its peculiar species of *Helix*, *Cyclostoma*, *Physa*, &c. Mr. Whitaker has identified one species of *Paludina* (*P. aspera*) with a form occurring in the Woolwich Beds at Dulwich. I therefore place, as I did originally †, the Rilly Beds at the base of the "Lignites" which immediately overlie them; and it is probable that the beds which directly underlie the Mottled Clays at Meudon belong to the same zone.

In the following list of the Woolwich shells, I have included those of the Sundridge and Blackheath Beds, which Mr. Whitaker places within the Oldhaven zone:—

* This is not the opinion of my friend M. Hébert, who places the Rilly Beds at the base of the Tertiary series.

† Bull. Soc. Géol. de France, 2e sér. vol. x. p. 300.

C. *Mollusca of the Woolwich and Reading Series.*

	Thanet Sands.	Bracheux Sands.	Chalons-sur-Vesles, &c.	Lignites and overlying beds.	London Clay.
LAMELLIBRANCHIATA.					
Arca depressa, *Sby.*	...	...	...	...	*
—— dulwichiensis, *Edw.*					
Cardium Laytoni, *Morr.*					
—— plumsteadiense, *Morr.*	...	...	...	...	*
—— semigranulosum, *Sby.*	...	*?			
Corbula Arnouldi, *Nyst*	*	...	...	*	
—— regulbiensis, *Morr.*	*	*	...	...	*
Cucullæa decussata, *Park.* (C. crassatina, *Lamk.*)	*	*	*		
Cyprina Morrisii, *Sby.*	*				
—— planata, *Sby.*? (C. scutellaria, *Desh.*)	*	*			
Cyrena cordata, *Morr.*					
—— cuneiformis, *Fér.*	...	...	...	*	
—— dulwichiensis, *Nich.*					
—— Forbesii, *Desh.*	...	...	...	*	
—— intermedia, *Mell.*? (C. Deshayesii, *Héb.*)	...	...	*		
—— tellinella, *Fér.*	...	...	...	*	
—— trigona, *Desh.*	...	...	...	*	
—— strigosa, *Wood.*					
Cytherea obliqua, *Desh.*	...	*	...	...	*
—— ovalis, *Sby.*					
—— orbicularis, *Desh.*	*	...	*		
Dreissena serrata, *Mell.*					
Glycimeris retupiensis, *Morr.*	*				
Modiola Mitchelli, *Morr.*					
—— dorsata, *Morr.*					
—— subcarinata?, *Sby.*	...	...	...	...	*
Mytilus?					
Nucula fragilis, *Desh.*	*	*	...	Cuise.	
—— gracilenta, *Wood.*					
Ostrea bellovacina, *Desh.*	...	*	...	*	
—— pulchra, *Sby.*	...	...	...	...	*
—— tenera, *Sby.*					
Pectunculus terebratularis, *Sby.*	...	*	*		
—— plumsteadiensis, *Sby.*					
—— brevirostris, *Sby.*	...	...	...	...	*
Perna Bazini, *Desh.*	...	...	*		
Scrobicularia (Psammobia) Condamini, *Morr.*					
Sanguinolaria Edwardsii, *Morr.* (Psammobia, *Desh.*)	*	*			
Tellina, sp.					
Teredina personata, *Desh.*	...	...	...	*	*
Teredo attenuata, *Sby.*	...	...	...	...	*
Thracia oblata, *Sby.*	*	...	...	...	*
Unio subparallela, *Edw.*					
—— Edwardsii, *Wood.*					
Carried forward	10	9	5	7	10

C. *Mollusca of the Woolwich and Reading Series* (continued).

	Thanet Sands.	Bracheux Sands.	Chalons-sur-Vesles, &c.	Lignites and over-lying beds.	London Clay.
Brought forward	10	9	5	7	10
GASTEROPODA.					
Aporrhais Sowerbyi, *Mont.*	...	...	...	...	*
Auricula (Conovulus) pygmæa, *Morr.*					
Buccinum ?					
Calyptræa trochiformis, *Lamk.*	*	...	...	...	*
Cerithium funatum, *Mant.* (C. variabile, *Desh.*)	...	...	...	*	
—— gracile, *Morr.*					
—— Lunnii, *Morr.*					
—— Bowerbankii, *Morr.*					
Dentalium nitens, *Sby.*	*	...	...	...	*
Fusus latus, *Sby.*	...	...	*?	*	
—— gradatus, *Sby.*					
—— planicostatus, *Mell.*	...	...	*		
—— subnodosus, *Morr.*	*				
Hydrobia Parkinsoni, *Morr.*	...	...	...	*	
—— Websteri, *Morr.*	...	...	...	*	
Melania inquinata, *Defr.*	...	...	...	*	
Melanopsis ancillaroides, *Desh.* ?	...	...	*	*	
—— brevis, *Sby.*					
—— buccinoides, *Fér.*	...	...	*	*	
Murex foliaceus, *Mell.* ?	...	...	*		
Natica subdepressa, *Morr.*	*				
—— labellata, *Lamk.*	...	...	*	...	*
Neritina consobrina, *Defr.*	...	...	...	*	
—— globulus, *Defr.*	...	...	...	*	
—— pisiformis, *Fér.*	...	...	...	*	
—— vicina, *Mell.*					
Paludina aspera, *Mich.* (P. Desnoyersi, *Desh.*).	...	...	...	Rilly.	
—— lenta, *Desh.*	...	...	...	*	
Pitharella Rickmani, *Edw.*					
Planorbis hemistoma, *Sby.*	...	...	...	*	
—— lævigatus, *Desh.*	...	...	...	*	
Pseudoliva (Buccinum) fissurata, *Desh.*	...	*			
—— semicostata, *Desh.*	...	...	...	*	
Ringicula turgida, *Sby.*	...	...	...	...	*
Rostellaria, sp.					
Turritella.					
	14	10	11	21	15

Of the 75 shells here named, 14 pass up from the Thanet Sands, and 10 range to Bracheux; but if to these latter we add 9 other species occurring in the Sands of Chalons-sur-Vesles, which the French geologists place on the same horizon, the number common to this zone in France and to the Woolwich Beds becomes increased to 19, which is close to the number common to the "Lignite" zone of the same district and the more estuarine portion of the Woolwich series.

The Basement-bed of the London Clay.—The Oldhaven Beds.

Next in succession is the Basement-bed of the London Clay. This bed, which is thin but very fossiliferous in the western area of the London Basin, acquires greater importance in East Kent, swelling out to a thickness of about 25 feet in the cliffs east of Herne Bay. The fossils of this bed are mostly those of the London Clay, though a few of the Woolwich and Thanet-Sands shells pass up into it.

Mr. Whitaker takes the same view as myself with respect to the vertical limits to be assigned to the Basement-bed in East Kent and in the districts west of London; but in the central area he considers that this bed expands, and forms the mass of fossiliferous pebble-beds and conglomerates so conspicuous at Sundridge, Blackheath, Bromley, and in some adjacent districts. Taking the Basement-bed at Oldhaven Gap, in the cliffs between Herne Bay and the Reculvers, as his type, he applies the term of Oldhaven Beds to the whole of these extensive pebble-beds. We both agree in the relation of the Basement-bed and Woolwich-and-Reading Series to the west of London and east of Upnor; but in the intermediate area, while I placed the Sundridge and Bromley pebble-beds on the level of the upper marine beds of Woolwich, Mr. Whitaker places them above the Woolwich Beds proper. There has evidently been in those districts considerable erosion of the Woolwich fluviatile and underlying estuarine beds; and in the depression thus formed* the Sundridge, Bromley, Bexley, and other such pebble-beds were deposited, and they are therefore often found to abut against the fluviatile and lower Woolwich Beds. But while I attributed this erosion and the false-bedding of the strata to shifting currents during the upper part of the Woolwich period, Mr. Whitaker considered that it was connected with the next zone above, or that of the Basement-bed of Oldhaven. My reasons for coming to the above conclusion are that the mottled clays of Reading, in the western area, extend from the Chalk to the very base of the London Clay and its Basement-bed; but as they range eastward and pass under London they gradually become mixed with pebbles and finally pass into pebbly sands, which shortly become loaded with the ordinary Woolwich shells, *Ostrea bellovacina* occurring throughout. In the midst of this series the fluviatile beds gradually set in, with mottled

* My section in Quart. Journ. Geol. Soc. vol. x. pl. i. might be supposed to favour this view; but it does not exactly express my meaning. I intended it to have been less definite in connecting the depression in the Woolwich area with the Basement-bed.

clays and pebble-beds above and below. With the appearance of the pebble-beds, false-bedding, indicative of the existence of strong currents such as would be needed for the transport of these pebbles, begins. It is this action which has in places removed so much of the lower beds of the Woolwich series; but this involves no real unconformity, and I look upon these fossiliferous pebble-beds as part of the Woolwich series.

I felt originally some difficulty about this part of the series; and my view of it may still admit of discussion on stratigraphical grounds. It is, however, supported by the palæontological evidence, although, as so many species are common throughout all the divisions of these Lower Tertiary beds, from the Thanet Sands upwards, that evidence is not strongly marked.

In the following list I have taken the fossils of the Basement-bed of Hedgerley, Reading, and other places about which there is no question, together with the similar group of fossils from the bed in the Herne-Bay cliffs, marked in my section as the Basement-bed, and named by Mr. Whitaker the "Oldhaven Bed," from the name of the Gap, near Herne Bay, where it is best seen. The total number of species amounts to 48, of which 23 are common to the Woolwich beds and 30 to the London Clay. The Sundridge and associated beds show, on the contrary, a much greater affinity with the fossils of admitted Woolwich localities; thus, the list of the Sundridge shells in the Survey 'Memoirs' amounts to 51 species, of which only 16 are London-Clay species; while the *Ditrupa plana*, *Buccinum junceum*, *Cancellaria læviuscula*, *Cassidaria striata*, *Pyrula Smithii*, and other common London-Clay and Basement fossils are absent, and we have, on the contrary, a profusion of *Ostrea bellovacina*, *Pectunculus terebratularis*, *Cerithium Bowerbankii*, *Fusus latus*, *Melanopsis buccinoides*, *Cyrena cuneiformis*, *C. tellinella*, *Modiola Mitchelli*, and other such common Woolwich fossils.

D. *Shells of the Basement-bed of the London Clay or Oldhaven Beds* (exclusive of the Sundridge species) *and their range.*

	Thanet Sands.	Woolwich Beds.	London Clay.
Astarte, sp.			
Cardium Laytoni, *Morr.*	......	*	
—— nitens, *Sby.*	......	......	*
—— plumsteadiense, *Sby.*	......	*	*
—— semigranulatum, *Sby.*	......	*	*
Corbula regulbiensis, *Morr.*	*	*	*
—— Arnouldi, *Nyst* ?	*	*	
Cyprina Morrisii, *Sby.*	*	*	
Cyrena cuneiformis, *Fér.*	......	*	
—— intermedia, *Mell.*	......	*	
—— tellinella ?, *Desh.*	......	*	
Cytherea obliqua, *Desh.*	......	*	*
Carried forward	3	10	5

D. *Shells of the Basement-bed &c.* (continued).

	Thanet Sands.	Woolwich Beds.	London Clay.
Brought forward	3	10	5
Cytherea orbicularis, *Edw.*	*	*	
—— ovalis, *Sby.* (? orbicularis).			
Lithodomus, sp. ?			
Modiola depressa, *Sby.*	......	......	*
—— elegans, *Sby.*	......	......	*
—— Mitchelli, *Morr.*	......	*	
Nucula Bowerbankii, *Sby.* ?	*	......	*
—— margaritacea, var., *Desh.* ?...	*?		
Ostrea bellovacina, *Lamk.*	......	*	
—— pulchra, *Sby.*	......	*	*
Panopæa intermedia, *Sby.*	......	......	*
Pecten, sp.			
Pectunculus brevirostris, *Sby.* ...	......	*	*
—— decussatus, *Sby.*	......	......	*
—— plumsteadiensis, *Sby.*	......	*	
—— terebratularis, *Lamk.*	......	*	
Solen, sp.			
Teredo antenautæ, *Sby.*	......	......	*
Actæon, sp.			
Aporrhais Sowerbyi, *Mant.*	......	......	*
Buccinum junceum, *Sby.*	......	......	*
Calyptræa trochiformis, *Lamk.* ...	*?	*	*
Cancellaria læviuscula, *Sby.*	......	......	*
Cassidaria nodosa, *Brand.*	......	......	*
—— striata, *Sby.*	......	......	*
Cerithium variabile, *Desh.* (C. funatum, *Mant.*)	......	*	
Fusus complanatus, *Sby.*	......	......	*
—— subnodosus, *Morr.*	*	*	
—— tuberosus, *Sby.*	......	......	*
Melania inquinata, *Defr.*	......	*	
Natica hantoniensis, *Sby.*	......	......	*
—— labellata, *Lam.* (N. glaucinoides, *Sby.*)	......	*	*
—— subdepressa	*	*	
Pleurotoma comma, *Sby.* ?	......	......	*
—— acuminata, *Edw.*	......	......	*
Pyrula Smithii, *Sby.*	. ....	......	*
—— tricostata, *Desh.*	......	......	*
—— nodulifera, *G. B. Sby.*			
Scalaria, sp.			
Turritella, sp.			
Voluta denudata, *Sby.*	......	......	*
Ditrupa plana, *Sby.*	......	......	*
Lingula tenuis, *Sby.*	......	......	*
	9	23	30

The proportion of London-Clay species is therefore much larger than in the Woolwich Beds, in the ratio of 30 to 14, and, if we exclude the fluviatile shells, this is very nearly the proportion that holds good in the Sundridge Beds.

For these reasons, which might be extended, I do not see how the quadruple divisions of Thanet Sands, Woolwich Beds, Oldhaven Beds, and Basement-bed can be maintained. Either the Oldhaven Beds should go with the Woolwich or with the Basement-bed. In adopting an alternative name, I feel there is now an objection to the use of the term Basement-bed. So long as it was confined to a few feet at the base of the large formation of which it seems to form part, the term was suitable; but if, as in this case it promises to do, it becomes more important and individualized, it is better to use a more distinctive term. At present the Basement and Oldhaven Beds have not been recognized on the continent; but from the greater dimensions this zone attains in the Herne-Bay and Reculvers cliffs, and the increase in its fauna, I consider it probable that it may be found to correspond, when the fossils are more carefully compared, with some of the upper beds of the Sables Inférieurs; and I would especially direct attention to the beds of Aizy and Sainceny, in the Soissonnais and Oise, or to some of those between the Upper Landenian and the Ypresian in the neighbourhood of Lille *. Therefore I think Mr. Whitaker's term, "Oldhaven Beds," is a better one than that of the "Basement-bed of the London Clay," and wish that it may be substituted for it, with, be it understood, the limitation I have proposed, if such limitation be found correct.

The London Clay.

This needs no question. Its identity with the Lower Ypresian is well established, and it is clear that, with the exception of the small outlier near Dieppe, it is wanting in the Paris Basin, although it is probably in part represented, together with the overlying sands, by the beds of Cuise-la-Motte, the argillaceous strata passing as they range south into the fossiliferous calcareous sands of the Aisne and Oise.

The Lower Bagshot Sands.

In the absence of fossils in the Lower and Upper divisions, and in face of the similarity of composition, I grouped the three divisions of the Bagshot in one series, of which the Middle division alone, which has a definite relation to the Calcaire Grossier, formed the centre round which the others were grouped; and the whole were made synchronous with the Bracklesham Sands. At the same time I placed the Lower Bagshots on the level of the Upper Ypresian, but, in the absence of organic remains, left it as a member of the Upper Eocene†. This

* I think it probable that the Upper or Sundridge division of the Woolwich Series may be found to correspond with the Sainceny beds, and the Basement or Oldhaven Beds with those of Aizy; but a closer comparison of the fossils is needed.

† Quart. Journ. Geol. Soc. vol. xi. p. 240, pl. viii.

grouping has been generally accepted, with the exception that a portion of the Lower Bagshots in the Isle of Wight has by some been referred to the Lower Eocene.

Since that period (1855), however, a group of fossils has been discovered in the Ypresian Sands of Belgium which leaves no doubt of their being of Lower Eocene age, and consequently the Lower Bagshots must be placed on the same horizon. At Watten, between Calais and St. Omer, there is a small capping of these sands, with *Nummulites planulatus*, overlying the London Clay (Lower Ypresian). At Mons-en-Pévèle, where the Sands are about 100 feet thick, *N. planulatus* occurs in profusion. More recently, again, MM. Rutot and Vincent have discovered in the same Sands in the neighbourhood of Renaix and Brussels as many as 65 species of shells, of which about 20 occur in the London Clay and 44 in the sands of Mont-Panisel and Cuise-la-Motte. Amongst the former are such common London-Clay species as *Nautilus centralis, Voluta elevata, Vermetus bognoriensis, Pinna margaritacea, Pectunculus decussatus, Panopæa intermedia*, and *Pholadomya virgula*.

The Lower Ypresian (London Clay) itself, in Belgium, is singularly barren of fossils, Foraminifera and a few rare Crustacea (*Zanthopsis bispinosus*, &c.) excepted. It thins out both eastward and southward. The Paniselian Beds, which overlie the Ypresian Sands, and which have been grouped with them by M. Hébert, contain a fauna related to the underlying series by means of *Nummulites planulatus, Pinna margaritacea, Nucula fragilis*, and other fossils; while at the same time a large proportion of Calcaire-Grossier species make their appearance. It is a local deposit, apparently forming, with the Ypresian, the equivalent of the Sands of Cuise-la-Motte (the Lits Coquilliers of d'Archiac), and thinning out westward: there is no representative of it in the London Basin.

In the Hampshire Basin the Lower Bagshots form, at Whitecliff Bay, a well-defined mass of unfossiliferous yellow sands, about 100 feet thick, between the London Clay and the Bracklesham Sands; but at Alum Bay the division is obscure, and it is not possible to draw any definite line there in the thick series of variegated sands and clays lying between the London Clay and the Barton Beds. The Bracklesham is probably represented by the Middle and Upper portions of this series, and the Lower Bagshots possibly by strata Nos. 7 to 19 (?) of my original section. It was in one of these beds (No. 17), a seam of fine foliated clay, that I discovered the plant-remains afterwards described by De la Harpe and by Heer. These plants, which are admirably preserved, differ materially from those of Bournemouth. The leaves of one of them, *Apeibopsis Laharpei*, are supposed by Heer to belong to the tree which furnished the fruit named *Cucumites variabilis*, so common at Sheppey. Altogether 48 species have been determined, which, on the whole, show a greater affinity to the Lower than to the Upper Eocene. Thirty of the genera are common to Alum Bay and Sheppey. A similar fauna exists in the Lower Tertiary Beds of Wareham and Studland, with which these beds are probably synchronous.

The Rev. A. Irving* also contends that the Lower Bagshots exhibit great irregularity in thickness, as though the Middle Bagshots rested upon their eroded and denuded surface. He considers that the thickness of the Lower Bagshots varies as much as from 20 feet or less to 120 feet within the distance of a few miles. There is evidently some variation of thickness, but I do not think its extent is yet sufficiently proved.

For the reasons named above, I consider that the Lower Bagshot Sands should now be separated definitively from the Bracklesham and grouped with the London-Clay series; and it may be advisable to alter the name from "Lower Bagshot" to "London Sands," in consequence of their relation to the London Clay. There is no separating line of erosion between these divisions: the upper part of the London Clay is sandy, and the lower part of the Bagshot Sands is frequently argillaceous, showing a gradual change of conditions but no marked unconformity, though Mr. Hudleston† has detected slight irregularities of surface due to local causes.

It is the same with the Ypresian in Belgium. No definite line can be drawn between the lower and upper divisions, and they pass into one another; whereas they are separated from the overlying series by a well-marked line of erosion, indicative of a considerable physiographical change. In confirmation of this I may mention that M. Hébert has pointed out that at Chaumont (Oise) a bed of sandstone forming the top of the lower series is drilled with lithodomous borings, whilst its surface is covered with oysters belonging to the Calcaire-Grossier series. This shows, therefore, an elevation at the close of the first period, and a depression at the commencement of the second period, which led to the transgressive covering of the Lower Sands (Sables Inférieurs) by the Calcaire Grossier.

The Bracklesham Sands.

The base of the Calcaire Grossier in France is formed by the Glauconie Grossière—a bed of pebbly green sand resting on an eroded surface of the sands of Cuise-la-Motte. In Belgium it forms also a fine conglomerate, with rolled fossils derived from the underlying beds. In both these districts therefore the Upper Eocene rests upon an eroded and worn surface of the Lower Eocene. At Whitecliff Bay the Bracklesham Sands are separated from the sands beneath by a bed of pebbles; and in the Bagshot district the base of the Middle Bagshot division presents a marked analogy with the Glauconie Grossière. The Upper Bagshot is the equivalent probably of the upper part of the Calcaire Grossier; but a more exact knowledge of the few scarce fossils that have been found‡, and those only in the state of casts, has to be arrived at before this point can be definitely settled.

With regard to the general classification of these strata, the close

* "Physical History of the Bagshot Beds of the London Basin," Quart. Journ. Geol. Soc. vol. xliii. p. 374; also vol. xli. p. 492.

† Section through Walton Common in Quart. Journ. Geol. Soc. vol. xlii. p. 147, and vol. xliii. p. 443.

‡ See the papers by Messrs. H. W. Monckton and R. S. Herries in Quart. Journ. Geol. Soc. vol. xxix. p. 348, and vol. xlii. p. 492.

Proposed Classification of the Eocene.

	Engla	Belgium.	France (Paris Basin).
Upper Eocene ...	*a.* Barton Beds.	*a.* Wemmelian.	*a.* Sables Moyens or Grès de Beauchamp.
	b. Bracklesham Beds. =Upper and *b**. Middle Bagshots.	Laekenian and Bruxellian.	*b.* Upper Calcaire Grossier. *b**. Glauconie Grossière.
Lower Eocene...	*Wanting.*	Paniselian.	Sands of Cuise-la-Motte.
	London Sands=Lower Bagshot.	Upper Ypresian.	
	London Clay.	Lower Ypresian.	*Wanting?*
	Oldhaven or Basement-beds.	?	Sables Inférieurs of the Soissonnais, including the Marls of Rilly, the Argile Plastique and 'Lignites,' and the Sands of Bracheux, Chalons-sur-Vesles and Rilly.
	Woolwich and Reading Beds.	Upper Landenian.	
	Thanet Sands.	Lower Landenian and Heersian.	Sands of St. Omer, Douai, and the lower sands of La Fère.
	Wanting.	Calcaire de Mons.	*Wanting.*

relation between all the strata below the Bracklesham Sands is so clear that by general agreement they are assigned to the Lower Eocene. It is otherwise with the strata above. By some geologists the Bracklesham Sands are retained as a middle division, and the Barton Beds as an upper division of the Eocene; but whereas Etheridge has shown that out of the 543 Mollusca of the Bracklesham Beds only 81 are common to the London Clay, he finds that of the 310 Barton Mollusca 93 are Bracklesham species—the percentage of common species in one case being 11, and in the other 30. The general facies of the faunas is also much alike. It seems, therefore, better to link together these two formations as an upper division of the Eocene series, as was done by Alcide d'Orbigny, and to make two main divisions of the Eocene, corresponding with his Suessonian and Parisian series of the Paris Basin.

In conclusion, the classification I would now propose for the Eocene is shown on p. 108.

EXPLANATION OF PLATE V.

In section No. 1 certain well-established sections between London and Brussels are given. That of Bagshot is based on the railway section at Goldsworthy Hill and on the well at Chobham Place; London, on the mean of the deep-well sections; Sundridge, on the several sections on the railway at and near Chiselhurst and in Sundridge Park; Rochester, on the Upnor pit-sections; Herne Bay, on the cliff-section between Herne Bay and the Reculvers; Cassel, near Dunkirk, and west of Brussels, on sections given by the Belgian geologists.

Section No. 2. Hampstead, on the Heath and well-sections; Woolwich, ballast-pit near Charlton and well-section on Shooter's Hill; Richborough, pit adjoining the Castle ruins; Watten, pits on the slope and summit of the hill; Mons-en-Pévèle, various pits and well-sections; Bracheux, pit at the Butte de la Justice; Cuise-la-Motte, various pits and sections near Compiègne.

For fuller details of these and several other sections between Orchies and Beauvais see my first correlation paper in Quart. Journ. Geol. Soc. vol. xi. explanation of plate, pp. 241–246.

The dotted lines represent the probable original prolongation of the strata. The continuous line gives the level of the surface at the several localities; but owing to the great disproportion between the vertical and horizontal scales, the connecting lines are only ideal.

Discussion.

The President referred to the value of the Author's early papers, wherein he had succeeded in bringing order out of confusion, and in establishing correlations between the British Eocene strata and those of Belgium and the North of France. He now submitted a revision of some parts of that early classification, whilst supporting that classification on other points.

Mr. Whitaker's chief cause of complaint against the Author was that his work had been so thorough that there was but little left for one who followed him to criticize. He referred to the character of the earlier writings with respect to Lower London Tertiaries in the neighbourhood of London, and how, in the year 1846, there appeared the first of a series of papers which swept away errors, and out of chaos evolved order. Whilst some of us knew a limited district or certain beds, the knowledge of Prof. Prestwich was not only detailed, but also general. He himself would confine his remarks to the beds between the Chalk and the London Clay. There had been a difference in their views about certain pebble-beds in a limited district. His business, as a Surveyor, had been to map beds that could be mapped, and when he found miles of pebble-beds without a break, some without fossils, others with calcareous matter and fossils, he had thought that the fossiliferous character might be a matter of accident, and that elsewhere the fossils might have been dissolved out where not protected. The Author would admit that a certain degree of community in the fossils rendered the palæontological test somewhat uncertain. He thought that eastward of Faversham only the lower part of the Woolwich Beds was represented. The term Basement-bed might seem to show that these beds formed part of the London-Clay series, which in great part they did not; hence a local name such as Oldhaven Beds was suitable, though for the neighbourhood of London the name of "Blackheath Beds" was better.

Dr. Evans had some acquaintance with the Eocenes of the neighbouring continental areas, and the correlation of our English beds with these was one of great interest. He thought that the transfer of the Sands of Bracheux from the horizon of the Thanet Sands to that of the Woolwich and Reading series would be universally accepted. These questions must be decided mainly on palæontological evidence. There were three main points in the paper: the transfer of the Upper Bagshots to the Brackleshams, the closer union of the Lower Bagshots with the London Clay, and the transfer, to which he had already alluded, of the *Sables inférieurs* of the Soissonnais, &c. to the horizon of the Woolwich and Reading series. He thought that the Author's conclusions would, in the main, be generally received.

Dr. Geikie said that he had no practical acquaintance with the ground himself, but he was glad of the opportunity of acknowledging the obligations the Geological Survey had had to Prof. Prestwich, of the value of whose work he had himself the highest appreciation.

Mr. Irving was afraid lest he might anticipate the contents of a paper shortly to be read before the Society. There might be a closer connexion between the Lower Bagshots and London Clay than had been hitherto recognized, in spite of attenuation and local erosion and unconformities on the north side of the basin. He fully recognized the subordination of local details to data covering a wider range in such a question as this.

Mr. G. F. Harris thought that some allusion might have been made to the "Tufeau de Ciply." He questioned whether the table represented the present classification. He thought the Lower Landenian should be placed higher than the Thanet Sands. As to the greater part of the Upper Landenian in Belgium, it was very doubtful what they represent, and the same thing might be said of the almost unfossiliferous division of the Ypresian.

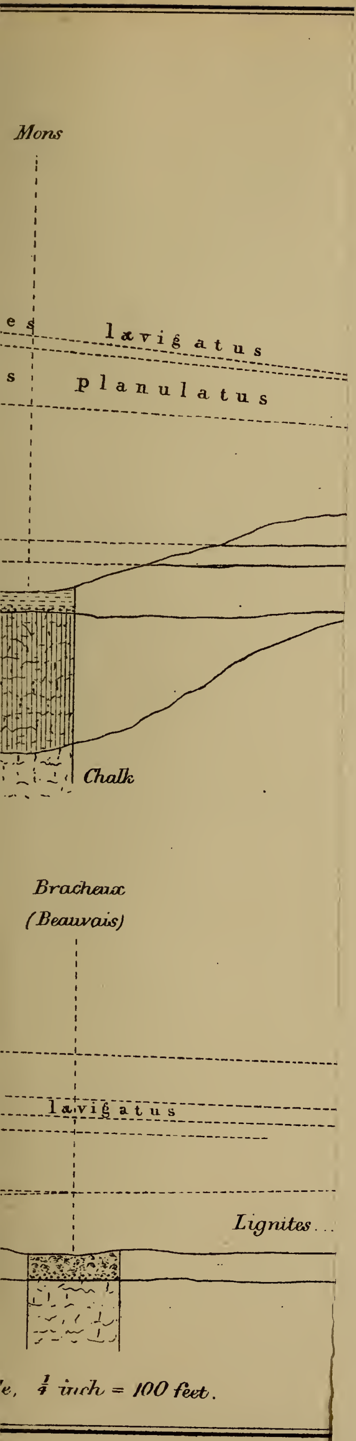

Mons
es
lævigatus
s
planulatus
Chalk
Bracheux
(Beauvais)
lævigatus
Lignites...
e, ¼ inch = 100 feet.

FIG. I. TYPICAL SECTIONS FROM THE NEIGHBOURHOOD OF LONDON TO THAT OF BRUSSELS.

FIG. 2. TYPICAL SECTIONS TO SHOW THE CONNECTION OF THE LONDON & THE PARIS BASINS.

Dangerfield Lith. 22, Bedford St. Covent Garden. 1.88.15600.

Mr. Gardner contended that the Reading Beds should be allowed to come in as a separate formation. They were now shown to be quite distinct both in matrix and fossils from the Woolwich Beds, being characterized by a separate flora. For the sands above the London Clay in the near neighbourhood of London the proposed name was good; but these were not very extensive, as fluviatile conditions were soon reached. In classification we should separate the marine sands from the entirely freshwater series. He quite agreed that the Lower Bagshots of Alum Bay should be placed in the Lower Eocene. He was not prepared to see the Middle Eocene effaced. In the Upper Bagshots of the London Basin, Barton forms decidedly preponderate. This has been further confirmed recently by the discoveries of Mr. Herries.

The Author, after alluding to the friendly reception accorded to his paper, observed that with Mr. Whitaker his differences were slight, and while restricting the vertical dimensions of the Oldhaven Beds in the neighbourhood of London, he admitted their greater importance in East Kent, and considered the term there a better one than "the Basement-bed of the London Clay." Fossils might easily have been dissolved out in some of the sandy pebble-beds. He did not consider the evidence doubtful, but thought it not strong. He indicated how the mottled clays of Reading became replaced by sands and pebble-beds as they ranged past London. With regard to the Tufeau de Ciply, that was classed by the Belgian geologists at the top of the Cretaceous series. The tables exhibited were confined to the Eocene series.

11. *On the* Cae Gwyn Cave. By T. McKenny Hughes, M.A., F.G.S., Woodwardian Professor of Geology, Cambridge. (Read November 23, 1887.)

In a communication which I made to the Society "On the Drifts of the Vale of Clwyd and their Relation to the Caves and Cave-deposits" *, I considered the subject under the following heads:—

(1) The Age of the Drift.
(2) The Relation of the Deposits in the Caves to that Drift.

In discussing the age of the drift, I was of course obliged to offer a tentative classification of the Pleistocene deposits of the district, in order to show the relative position and age of the St. Asaph beds, to which I referred the drift on the flanks of the hill in which the Ffynnon Beuno Caves occur.

The classification I suggested has been called in question, and I have relegated the discussion of this part of the subject in its wider bearing to a separate paper.

It will be desirable, however, to restate briefly the conclusions at which I then arrived. They were:—

That the interpretation of the glacial phenomena of North Wales is much more simple than that suggested by most recent observers in East England.

That we have evidence of the following sequence of events:—

That glacier-ice came down from the Snowdon and Arenig group of mountains, riding across pre-existing north and south valleys as far at any rate as the Cheshire plain on the east, and as far as the Irish Channel, which was the corresponding north and south valley on the west.

That glacier-ice came also from the north and held back the Welsh ice along the whole of the north coast; that it once sent a tongue further down the Irish Sea and, perhaps, another down the east side of Wales towards the "Severn Straits"; that this north-country ice was melted back when the Welsh ice was receding, so that it never left any moraine matter far south of the coast-line.

That there may have been interruptions in the movements, but that there is no evidence of any interglacial age.

That there was a submergence of the mountain lands, southern Mollusca coming in as the sea advanced and the glaciers were melted into the recesses of the Welsh mountains, and the more northern forms following the ice as it receded to the north.

That there was a great denudation of the old glacial deposits and a using up of the morainic deposits of both northern and western ice along their ancient line of contact.

That there was never again any ice action in the Vale of Clwyd different from what may be seen at the present time in the estuary of the Dee.

* Quart. Journ. Geol. Soc. 1886, vol. xliii. p. 73.

In this paper I shall only bring forward the additional evidence which has been obtained bearing upon the age and origin of the marine drift near Ffynnon Beuno without going far into the question of the place of those beds among the Pleistocene deposits of North Wales.

From an examination of its lithological character and mode of occurrence, I referred the main mass of drift outside the Cae Gwyn Cave to the second stage; that is, I considered it to be post-glacial, and of approximately the same age as the St. Asaph drift. This view, however, was disputed. It was asserted that "the high-level drift at Cae Gwyn is a true undisturbed glacial deposit," while it was allowed that the St. Asaph drift "must certainly be considered the newest, as it is mainly *remanié*." But no satisfactory explanation was offered of the mixture of granite and flint with the western fragments, on which I chiefly relied for the identification of the Cae Gwyn deposit with the St. Asaph Drift.

The views I then put forward have been fully sustained by the observations made during the last summer.

We have again to record our thanks to Mr. Morgan, of Cae Gwyn, for allowing us to carry on the work, and for much kindness during its progress.

There are many caves in the Ffynnon Beuno gorge. There is the large cave (to which it has been proposed to confine the name Ffynnon Beuno), which was occupied by cattle when first I knew it. There is the upper cave, now spoken of as the Cae Gwyn Cave, along the lower or southern opening into which a small quarry has been opened. There is a cavernous mass behind the cottage on the opposite side of the gorge, two of the caves in which I have referred to and figured in illustration of the mode of formation of the Cae Gwyn Cave; and in the potato-garden behind Ffynnon Beuno Inn there is a cave, probably one of a system running down in a westerly direction with the fall of the rocks towards the Vale of Clwyd. These last are probably flushed by water in every flood, and connected with the drainage-system which feeds St. Beuno's well. The latest excavations in Cae Gwyn Cave have shown that that cave extends in a northerly direction, dropping in all probability by swallow-holes to the level of the lower and larger cave mentioned above.

The literature of the subject is beginning to assume considerable dimensions, not only because different observers approaching the phenomena from different points of view have arrived at different conclusions, but also because the progress of discovery has brought to light new evidence from time to time, and inquiries into analogous cases and into the sequence of events elsewhere in Pliocene and Pleistocene times have furnished arguments in support of the various interpretations put upon the facts brought to light during the excavations.

The first notice is, I believe, the Report of the Excursion of the Chester Society of Natural Science, published in the 'Chester Chronicle' of July 28, 1883, when, in the course of my observations on the district, I made a few remarks on the Ffynnon Beuno Caves, which appear thus in the report:—

"They found another kind of deposit in a cave nearer to Tremeirchion. There were recent deposits in it, and recent animals . . . (to wit a black sheep), but at the end there was a deposit of that brownish earth commonly known as cave-earth, in which they found the remains of the sheep of earlier days. In ancient times the remains of stags would be found there, and in still more ancient times those of hyæna, and of other animals of that time which the hyænas found in the woods below and dragged in there . . . . If permission could be obtained, he proposed to visit that cave some day with the members . . . . perhaps they would find the remains of primæval man, and certainly some of the extinct animals." The bone-earth had been disturbed by mining trials along the fissures which had determined the position of the caves, and thus fragments of bone from the lower cave-deposits were lying on the surface. The only recognizable remains found on that occasion belonged to Bos and Hyæna.

In the following month Dr. Hicks partially explored these caves, and made a further examination of them in the autumn of the next year. He gave the results of his investigations in an interesting paper read before the Geologists' Association in Nov. 1884 *. He notices the dissimilarity in the character of much of the material which had apparently filled these caverns before they were explored and that with which he was conversant in those of South Wales, pointing out that it is identical in appearance with the upper Boulder-clay in this area, especially that about St. Asaph, and that it contains the same derived boulders. The bones, he adds, are in disturbed positions, and filled by material unlike that in which they now lie. In this earth, associated with bones of reindeer, a flint flake was found, respecting which he quotes the opinion of Dr. Evans that it is of the La Madelaine or newest palæolithic type. Dr. Hicks explains that the flake, like the bones, was "evidently not in its original position, but had been disturbed by water-action and had been carried there from some other point in the cavern"—a fact of considerable importance undoubtedly, as it showed that the disturbance of the cave-deposits which he observed there was later than the reindeer age.

At the meeting of the British Association at Aberdeen †, Dr. Hicks read a paper on these caves, in which he gave some further details as to the character and mode of occurrence of the deposits. In the first sentence of the first paragraph in his description of the Cae Gwyn Cave, where he says that "all the deposits were entirely undisturbed, except by burrowing animals, when we first discovered it," he means, of course, that the deposits had not been disturbed by man, because a few lines lower down he offers reasons for believing "that the water-action which disturbed the original materials in the

* Proc. Geol. Assoc. vol. ix. 1885, p. 1.

† Rep. Brit. Assoc. Aberdeen, 1885, Trans. Sect. C, p. 1021; Geol. Mag. 1885, dec. 3, vol. iii. p. 510.

cave must have been of a violent nature," and infers "that during a period of great submergence either during, or subsequent to, the glacial epoch, the material was introduced by marine action." He quotes Dr. Evans's opinion that the flint flakes found in the lower caves were "of the type of the wrought flakes found in Kent's Cavern." A list of the animals whose bones were discovered is given on the authority of Mr. Davies.

These views were more fully set forth in a paper read before the Geological Society, in November 1885 *, in the discussion on which Dr. Evans and Professor Boyd Dawkins expressed their doubt as to the author's conclusions respecting the evidence of marine action in the caves.

Dr. Hicks communicated the results of some further excavations in a short note which appeared in 'Nature,' July 1886 †, in anticipation of the full report which he drew up for the British Association meeting at Birmingham ‡ in the September following. In these papers he describes what he considered to be the "abrupt termination" of the cave "in a plateau of glacial deposits" at what must have been the main entrance into the cavern when it was occupied by the Pleistocene animals, and states his belief that "the glacial beds in and upon it must have been deposited subsequent to the occupation by the animals," and "that the contents of the cavern must have been washed out by marine action in midglacial time, and that they were afterwards covered by marine sands and by an upper Boulder-clay." He further notices that "within the entrance there was a greater thickness of sand, less of laminated clay, and more bone-earth than in other parts of the cavern," and that the bone-earth seemed "to diminish in thickness rather rapidly outwards under the glacial deposits." He also brought the matter under discussion in Section H §.

At the same meeting ‖ I pointed out the distinction between the land-ice drift of the Western Mountains and the Marine Drift, which I considered to be of much later date and due to the destruction of the older glacial beds; and then offered reasons for believing that none of the bone-deposits yet found could be referred to as early an age as even the marine drift.

I communicated the substance of this paper to the 'Geological

* "Results of recent Researches in some Bone-caves in North Wales (Ffynnon Beuno and Cae Gwyn)," by Henry Hicks, M.D., F.R.S., F.G.S., with a Note on the Animal Remains, by W. Davies, F.G.S., Quart. Journ. Geol. Soc. Feb. 1886, vol. xlii. p. 3; Reported in abstract, Geol. Mag. Jan. 1886, dec. 3, vol. iii. p. 39.

† "Evidence of Man and Pleistocene Animals in North Wales prior to Glacial Deposits," 'Nature,' vol. xxxiv. 1886, p. 216.

‡ "Report of the Committee appointed for the purpose of exploring the Caves of N. Wales," drawn up by Dr. Hicks, Secretary. Brit. Assoc. Rep. Birmingham, Sept. 1886, p. 219.

§ "Evidence of Preglacial Man in North Wales," Brit. Assoc. Rep. Birmingham, 1886, Trans. Sect. H, p. 839.

‖ "On the Pleistocene Deposits of the Vale of Clwyd," Brit. Assoc. Rep. 1886, Trans. Sect. C, p. 632; Notices of ditto, Geol. Mag. Nov. 1886, dec. 3, vol. iii. p. 509.

Magazine' in November *, especially noticing that the blocking of the upper opening seemed to have taken place gradually, and that while it was going on drift-material was washed into the cave, and various objects got into the crevices of the broken limestone—my point always being that the upper opening was not stopped by undisturbed drift, but by moved and slipped portions of the drift and of the overlying head or rainwash; and that even if it had been blocked by undisturbed drift, such as lay on the hill-side near by, that would not prove the contents to be preglacial, because that marine drift was not laid down till after glacial conditions had entirely ceased to prevail in that district.

I explained my views on the subject in a lecture delivered at Chester in October 1886 †, in which I pointed out that the character of the drift was not such as to allow us to refer it to an ordinary beach-deposit, but it must have crept down the hill-side either subaerially or into deep water, where there would not be the same sorting of the material as is usual on such a coast; that the drift which finally closed the cave was in its upper part superficial talus, and below that moved marine drift, but that there was a communication with the cave from the surface by swallow-holes down to quite late times.

In November of the same year I read a paper ‡ before this Society, in which I discussed more fully the characters of the various drifts in the district, giving my reasons for assigning to the deposits outside the Cae Gwyn Cave a place among newer series which I considered not to have been laid down until after glacial conditions had passed away from that area. I gave full lists of shells from the marine drifts of that and adjoining areas, but at that time the shell-bearing bed at Cae Gwyn had not been touched. I again stated my reasons for believing that the drift-deposits outside Cae Gwyn Cave were not a true beach, but the result of the working down the slope of débris from the drift, first into deep water, and subsequently subaerially; and that "the drift which finally closed the mouth of the cave" (p. 110) was not even as old as the marine drift, but that some of the material was a mere superficial talus, that some of it was the moved drift (p. 104) which had sunk into an irregular swallow-hole, and that all the drift which overlapped the bones had settled down on them in consequence of this swallow-hole action long subsequent to the deposition of that drift (p. 109).

In the 'Geological Magazine' of December 1886, Dr. Hicks § reprinted the Report which he had drawn up for the Meeting of the British Association at Birmingham, with a long footnote commenting upon the observations I had made on the subject.

He states that the accumulation against the upper side of the old

* "On the Ffynnon Beuno Caves," Geol. Mag. Nov. 1886, dec. 3, vol. iii. p. 489.

† "Caves and Cave Deposits," 'Chester Chronicle,' Nov. 6, 1886.

‡ "On the Drifts of the Vale of Clwyd and their Relations to the Caves and Cave Deposits," Quart. Journ. Geol. Soc. vol. xliii. 1887, p. 73.

§ "On the Ffynnon Beuno and Cae Gwyn Caves," Geol. Mag. Dec. 1886, dec. 3, vol. iii. p. 566.

fence to which I had referred "is merely material conveyed there during the explorations." He objects to the same name being applied to "the true glacial deposits" "at the entrance to Cae Gwyn Cave" and to the drift about St. Asaph, which "is in the main *remanié*." "The Cefn and Plas Heaton Caves" are, he goes on to say, "so near to the rivers that" he does "not think the evidence furnished by them can be quoted as of much value either way." He combats the palæontological evidence which I had adduced from what I considered the late Pleistocene facies of the mammalian remains, on the ground that "a large proportion of the animals occur in the Norfolk Forest-bed."

In December 1886, Dr. Hicks * also read a paper before the Geologists' Association in which he questions the possibility of distinguishing the various drifts of the Vale of Clwyd, and quotes Mr. Strahan in support of his view. He restates the case for the preglacial age of the deposits in the Cae Gwyn Cave.

In February 1887, I read before the Victoria Institute a paper in which I described the mode of formation of caves and cave-deposits, and referred to the Cae Gwyn Cave and the analogous case of the Victoria Cave in Yorkshire, in both of which I believe that beds which are the result of ordinary subaerial and subterranean agencies have been attributed to direct glacial action.

Mr. E. T. Newton † published a note on the Cae Gwyn mammals in the 'Geological Magazine' of February 1887, in which he pointed out that all the Ffynnon Beuno mammals were found in undoubted Pleistocene. The Lion, Reindeer, and Woolly Rhinoceros occurred in the Ffynnon Beuno caves, but were not found in the Forest-bed, while *R. etruscus, Trogontherium Cuvieri, Myogale moschata, Elephas meridionalis, Cervus Sedgwickii, C. verticornis, C. polignacus, C. Savinii*, characteristic Forest-bed mammals, were none of them found in the Ffynnon Beuno caves ‡.

In the following number Dr. Hicks § replied, endeavouring to explain the discrepancy by reference to the general absence of cave animals in ordinary sedimentary deposits and *vice versâ*. He urged that "if the Forest-bed is proved to be of preglacial age, because it is covered by glacial deposits, then certainly we can claim the remains found in the Ffynnon Beuno cave to be of preglacial age, since they also were completely covered over by undoubted glacial deposits."

At the Meeting of the British Association at Manchester ‖, September 1887, Dr. Hicks presented the "Second Report on the Cae Gwyn Cave," in which he described the progress of the further excavation the results of which are now being laid before the Society

* Proc. Geol. Assoc. Feb. 1887, vol. x. p. 14.

† "The Ffynnon Beuno Cave," Geol. Mag. Feb. 1887, dec. 3, vol. iv. p. 94. A review of the subject at this stage is given by Koken, Neues Jahrbuch, 1887, Band xi. pp. 487–489.

‡ See also Quart. Journ. Geol. Soc. vol. xliii. p. 110.

§ Geol. Mag. March 1887, dec. 3, vol. iv. p. 105.

‖ Brit. Assoc. Rep. Manchester, 1887; 'Nature,' vol. xxxvi. Sept. 29, 1887, p. 516.

for discussion. He gave also a list of the shells found in the drift outside the cave.

In October 1887, the President of the Liverpool Geological Society, Mr. G. H. Morton, in his presidential address*, referred to the work which had been carried on in the Ffynnon Beuno Cave, during the greater part of which he had been present, and gave it as his opinion that "the bone-earth represents the preglacial period, and the bed of stalagmite the cold period, when North Wales was glaciated and uninhabited.... when the land subsided.... the force of the waves .... broke up the stalagmite floor.... disturbed the bone-earth, and drove the bones and teeth before it, so that these were not only found in the bone-earth, but forced into hollows and cavities at the sides, and even outside the mouth of the cave."

Mr. Worthington Smith †, in a short note published in 'Nature' in November last, expressed his doubt as to the glacial age of the deposits outside the Cae Gwyn Cave, and said that from an examination of the flake itself he would be inclined to refer it to the very latest of palæolithic times, and thought it might even pass for neolithic.

Mr. Morton ‡, in the following number, questioned the value of Mr. Worthington Smith's observations.

I have received many letters on the subject, some of my friends agreeing with me upon points which I consider most essential to my interpretation, while they do not accept my conclusion as to the age of the cave-deposits.

Dr. John Evans and Gen. Pitt-Rivers saw the section in September, when there was still a considerable part of the festooned margin of the swallow-hole visible. None but the first excavators saw the central plug.

Mr. Tiddeman is "at one with me in considering the Cae Gwyn drift as being late in time," but believes it to be "marine glacial."

Dr. Stolterforth and Mr. Shone cannot get over the impossibility of accounting for the presence of material derived from the drift throughout the bone-earth, except on the hypothesis that the drift is older than the cave-deposits.

Dr. Geikie says "the bone-earth projects beyond the present limits of the cave, but it probably never did so originally; hence I have no doubt that the roof or wall of the cavern has given way;" but he believes that "this fall of the roof or wall of the cave took place before the deposition of the glacial deposits." This view is obviously inconsistent with the facts to which attention is called by Dr. Stolterforth and Mr. Shone, namely, that the bone-earth and other cave-deposits are full of material derived from the marine drift.

The old excavation at the upper mouth of the Cae Gwyn Cave has been reopened, and a clear section cut through the "Head" into the undisturbed drift, in which, at a distance of some 8 feet from the

* 'The Liverpool Courier,' Thursd. Oct. 13, 1887.

† "The Ffynnon Beuno and Cae Gwyn Caves," 'Nature,' Nov. 3, 1887, vol. xxxvii. p. 7.

‡ "The Ffynnon Beuno and Cae Gwyn Caves," 'Nature,' Nov. 10, 1887, vol. xxxvii. p. 32.

rock above the cave and about 7 feet below the surface of the ground, in a bed of sandy clay (see fig. 1), 17 species of shells were found, of

Fig. 1.—*Portion of the north-west face of the Cutting outside the upper opening to the Cae Gwyn Cave.* (From a photograph by Mr. Helsby, of Denbigh.)

b

a

Showing the most northerly point to which the shell-bed (*a*) has yet been traced near the cave, and the manner in which the upper beds (*b*) were looped down towards the swallow-hole. The long flat stone indicates the slope of the beds where the end of the shell-bed (*a*) is cut off by *b*.

which a list* is recorded in column I. of the following table, in which a full list of the shells found in the drift of St. Asaph and Colwyn is given in column II., and in columns III., IV., and V. an indication of which of these occur at Rhyl, or on any part of the British coast, or in the Bridlington Drift.

* Determined by Mrs. M'Kenny Hughes. See Report Brit. Assoc. Manchester, 1887, "Second Report on the Cae Gwyn Cave, North Wales," by Dr. Hicks.

	I. Cae Gwyn.	II. St. Asaph and Colwyn.	III. Rhyl.	IV. British Coast.	V. Bridlington.
Ostrea edulis, *Linn.*	*	*	*	*	
Mytilus edulis, *Linn.*	*	*	*	*	*
—— (Modiola) modiolus, *Linn.*	...	*	*	*	*
Nucula nucleus, *Linn.*	...	*	*	*	*
Pectunculus glycymeris, *Linn.*	*	*	...	*	*
Cardium echinatum, *Linn.*	*	*	*	*	
—— edule, *Linn.*	*	*	*	*	*
Cyprina islandica, *Linn.*	*	*	*	*	*
Astarte borealis, *Chemn.*	*	*	...	...	*
—— sulcata, *Da Costa*	*	*	...	*	*
—— sulcata, var. elliptica	...	*	...	*	*
Artemis exoleta, *Linn.*	...	*	*	*	
—— lincta, *Pult.*	*	...	*	*	
Venus gallina, *Linn.*	?	?	*	*	
Tapes, sp.	?	?	*	*	
Tellina balthica = solidula	*	*	*	*	*
Psammobia ferröensis, *Chemn.*	*	*	*	*	
Donax anatinus, *Lamk.*	*	?	*	*	*
Mactra solida, *Linn.*	...	*	*	*	
—— solida, var. elliptica = ovalis	...	*	*	*	*
Corbula gibba, *Olivi.*	...	*	*	*	*
Mya truncata, *Linn.*	*	*	*	*	*
Dentalium, sp.	...	*	...	*	*
Fissurella græca, *Linn.*	*	...	...	*	
Littorina littorea, *Linn.*	...	*	*	*	*
—— obtusata, *Linn.*	*	...	*	*	
Turritella terebra, *Linn.*	*	*	*	*	*
Purpura lapillus, *Linn.*	...	*	*	*	*
Buccinum undatum, *Linn.*	*	*	*	*	*
Murex erinaceus, *Linn.*	...	*	*	*	
Trophon clathratus, *Linn.*	...	*	...	...	*
—— truncatus, *Ström*	...	*	...	*	*
Fusus antiquus, *Linn.*	...	*	*	*	
Nassa reticulata, *Linn.*	...	*	*	*	
Pleurotoma rufa, *Mont.*	...	*	...	*	
—— turricula, *Mont.*	...	*	*	*	*
Balanus, sp.	...	*	*	*	*
Cliona	...	*	*	*	*

All these are recorded by Gwyn Jeffreys as now occurring on the coast of the British Isles, except *Astarte borealis*, of which only dead and, possibly, derived shells have been found. All except *Pecten varius* and *Fissurella græca* have been found in the marine drift of St. Asaph and Colwyn; and the two exceptions go for nothing, as these shells are common on our coast at the present day.

There is only the *Astarte borealis* which is locally extinct, and it occurs in the high and low marine terraces, from Moel Tryfan to

Macclesfield. It has gone north, while all the other shells still live on our coast.

Somewhat analogous is the occurrence of two locally extinct shells in our postglacial river-gravels. *Corbicula fluminalis* and *Unio littoralis* have gone to the Nile and Loire, while the Mammoth and Tichorhine Rhinoceros, whose remains are found in the same gravels, seem to indicate colder conditions, and the rest of the freshwater Mollusca are still found in the Cam and other rivers of the south-east of England.

In deposits of such antiquity we might expect to find some locally extinct forms; but no one who compares the shells found in the drift outside Cae Gwyn Cave with those of any of the undoubted glacial deposits, such as that at Bridlington, could allow that the Cae Gwyn shells indicate glacial conditions.

Some have seen on the shells in the St. Asaph Drift, outside the Cae Gwyn Cave, and elsewhere, small striæ, which they refer to glacial action. I exhibit* fragments of shell, picked up on the coast of North Wales this year, which are similarly scored by the accidents of a gravel beach. Some are from Deganwy, some from the Menai Straits, all too far from any shell-bearing drift to have been derived from it.

It has been remarked that the shells in these marine drifts, though nearly all of existing species, are thicker than those now living on our coasts. It is natural that the thicker shells and the thicker parts of shells should have the best chance of being preserved among the stones and sand of a sea-beach; but I have failed to see any difference in this respect between the shells in the marine drift of the Vale of Clwyd, or the equivalent beds elsewhere, and those found in modern deposits of the same character on our coast at the present day. In confirmation of which I exhibit* recent specimens from the coast of North Wales or further south, quite as thick as, or rather, I should say, much thicker than any of those in the marine drift.

In many cases the southern varieties are characterized by their thickness and the northern by their thinness, as, for example, in the case of *Tellina balthica*, of which Gwyn Jeffreys † says: "Our usual form (which may be termed *solidula*) abounds in all the Tertiary deposits, including the boulder-clay or 'till' and the Mammalian Crag. It may, therefore, be regarded in the main as a northern species; but it is likewise common in many parts of the south of Europe." The variety *attenuata*, in which the shell is smaller, more compressed, and of a *thinner* consistency, is the *Baltic* form.

In the var. *truncata* of *Mactra solida* the shell is *thicker* and the teeth *stronger*. This form occurs "South of Devon and Cornwall, Tenby, Irish coasts, Firth of Forth, Clyde district, Orkneys, and Lerwick." *Mactra solida* and the variety *truncata* have been chiefly noticed as littoral and in *southern* latitudes, their furthest limit being Sicily, where the former is also fossil; the only northern locality that appears

* *I. e.* at the meeting of the Geological Society.
† British Conchology, vol. ii. pp. 376, 377.

to be recorded is the Scandinavian coast, on the authority of O. F. Müller. The variety *elliptica* ("shell invariably smaller than the typical form, broader in proportion to its length, in consequence of the sides being more produced, and of a *thinner* texture") has essentially a northern range, from Iceland to Kulla in the south of Sweden *.

In the table given above (p. 120) I have indicated which of the shells found in the drift outside Cae Gwyn Cave occur also in the marine drift at St. Asaph and Colwyn; which are common to the glacial beds of Bridlington collectively; and which are found on our coasts at the present day.

These shells prove conclusively that the high-level drift at Cae Gwyn is not "a true undisturbed glacial deposit," but that it belongs to the St. Asaph Drift, which "is mainly remanié" †.

The deposit itself consists of fine sand, clay, and gravel, with boulders of various size and origin scattered through it. It is not such as would occur along a shore lashed by the wind waves. The whole of the rocky ledges and most of the fissures and caves would have been swept clean by such a sea. But it might easily have resulted from the working-down of débris from cliffs of older drift after the land had been submerged far enough to sink these crags below the action of the waves. When it was rising from the sea, in the emergence which followed, there was such a mass of drift hanging on the hill-sides that it has not yet all been washed away, and the remaining patches protect the material first thrown down. But that a cave or terraced crag not so covered can ever have been at sea-level without being swept clean is difficult to believe. The preservation of cave-deposits under land-ice drift from Snowdon and Arenig is credible; but an examination of the deposits shows that no part of those exposed can be referred to the land-ice drift; moreover, the discovery of the shells in the drift outside this cave conclusively proves that it was not the land-ice drift, but a marine deposit derived from it, some having worked down the steep slope into deep water, while part was subaerially derived from it at a much later time.

The mixture of north-country boulders and flint in the same deposit with those from the west is very marked and difficult of explanation; but this locality cannot have been far from the line along which the terminal deposits of the northern and western ice met, as a little way to the west we find the glacial drift exclusively of western origin, and a short distance to the north-east we find the drift wholly made up of material from the north and east. If that be so, we may expect that some glaciated stones of northern origin may have got washed into the marine deposits of the lower part of the Vale of Clwyd without obliterating the striæ; but, for some reason or another, they have not yet been found in the drift near St. Asaph; possibly they may occur on the higher ground to the east.

The deposit inside the Cae Gwyn Cave cannot be synchronous

* Gwyn Jeffrey's 'British Conchology,' vol. ii. pp. 417, 418.

† Hicks, Quart. Journ. Geol. Soc. vol. xliii. 1887, p. 117.

with the shell-bed outside it—one is terrestrial, the other is marine; there is no ground for the hypothesis that the sea re-sorted the terrestrial deposits. We have to inquire, therefore, whether the cave-deposits are earlier or later than the marine deposits. If earlier, then we must carry back the cave-animals through the time when glacial conditions prevailed over all this area, and refer them to the preglacial age.

But I must say I cannot get over the stratigraphical difficulty that material which was not transported into that area till after the recession of the Snowdon and Arenig ice is found in the cave-earth, nor the palæontological difficulty that the group of mammals found in the cave is of the newer postglacial type, and identical with that found in other caves known to be postglacial and in postglacial river-gravels, while there is an entire absence of distinctly preglacial forms *. This argument was combated by Dr. Hicks † and Professor Boyd Dawkins ‡, but their objections have recently been effectually disposed of by Mr. E. T. Newton §.

Another hypothesis is that the occupation of the cave should be referred to an interglacial age; but I know of no geological evidence in North Wales of a mild interglacial age; and if we can get over the difficulties connected with this cave, without calling in theories founded on a very forced correlation of geology with astronomy, it will be better to do so.

A third hypothesis, that these cave-animals lived between the glaciers and the sea in the early age of the submergence, before the sea had reached the Cae Gwyn Cave, may be true. But that would not make them preglacial, glacial, or interglacial. It is probable that the glacier-ice came down in tongues to the sea, leaving extensive areas along the coast fit for man and the lower animals. It is probable that man and the large mammals followed the receding ice on one hand, and the sea-shore on the other. It is possible that they may in some places have pushed on between the ice and the sea on an area afterwards submerged; but there is no proof of it, and with so much evidence in the surrounding district that man and the early associated group of animals came in after the flints and granite and other material introduced during the submergence, it does seem desirable to get much clearer evidence than any yet obtained from the Cae Gwyn Cave, that being the only case, before we admit that man was there before the submergence. A northern mountain region which rose the highest and sank the lowest, where the ice gathered soonest and lingered longest, is not the place where we are likely to find the earliest traces of man.

These two points, then, I consider perfectly well established:—

1. That the drift on the flank of the hill near Cae Gwyn must be referred to the same division of the St. Asaph beds; and

2. That it was deposited not only after the climax of the glacial

* Quart. Journ. Geol. Soc. vol. xliii. p. 110.
† *Ibid.* p. 117.
‡ *Ibid.* p. 118.
§ Geol. Mag. 1887, dec. 3, vol. iv. p. 94.

age, but after glacial conditions had entirely passed away in the Vale of Clwyd—that, in fact, the deposit is postglacial.

It was obvious that if the deposits in and outside the cave were of direct glacial origin, the rock-face which had been so rapidly and quietly covered that the fine earth and bones had not been swept away might be expected to show marks of glaciation; and the wish being father to the thought, it was stated that the rock was rounded and smoothed by ice from the north. On the contrary, however, veins and less soluble sparry portions of the rock stood out in lines and bands all over the rock in a manner never seen on any ice-worn rock. On the occasion of reading my former paper I exhibited specimens of the rock illustrating this point.

Fig. 2.—*View of upper opening into Cae Gwyn Cave, looking north-east.* (From a water-colour sketch by Mrs. M'Kenny Hughes.)

The point of view is indicated by the arrow *j* on the ground-plan, fig. 8. (p. 135). The left-hand figure is represented looking into the cave towards the entrance. Behind him, in the direction of the handle of the pick, is the continuation of the cave not yet explored.

There was sufficient evidence also that the rock did not owe its present surface to the sea. Ledges and points that a man could stand on projected straight out from the rock-face just where the waves and pebbles would have hammered them all away. The character of the rock is well shown in the sketches and photograph (see figs. 2, 3, and 4). Funnel-shaped cavities (as seen in fig. 2

Fig. 3.—*View of the upper opening into Cae Gwyn Cave, looking north.* (From a water-colour sketch by Mrs. M'Kenny Hughes.)

above the left elbow of the man in the centre), tapering down or opening out both ways like an hour-glass, told of swallow-holes under a land-surface, rather than blowholes from a sea-cave. The fretted surface of the rock, the unctuous clay lining the holes and fissures, the travertine plastering the walls of the cave and filling the cracks, the lines of sand in the crevices, all pointed to chemical decomposition and subterranean denudation only.

As the result of such operations, it necessarily happened that some of the drift had moved downwards without much change, except the destruction by percolating water of any shells or fragments of limestone that might happen to have been in it. No distinction had been drawn between this marine drift (itself remanié from older glacial deposits) and the modified or even re-sorted upper part of this marine drift.

Fig. 4.—*Lower left-hand corner of Section seen in* fig. 3, *looking north-north-west.* (From a photograph by Mr. Helsby.)

a. Bedded sand belonging to marine drift which has sunk in towards the swallow-hole.
b. Angular and weathered fragments of limestone from the broken-down wall and roof of the cave.
c. Loam, in places standing vertical from the settlement of the mass.
d. Large block of limestone (shown also in figs. 2 and 3), which barred further progress into the northerly extension of the cave.

With the strong suspicion that I had in my mind of the unsatisfactory character of the evidence that the cave-deposits were earlier than even the submergence, this was, I thought, a point of some importance, seeing that, in the first place, it bore upon the question as to whether the beds had been correctly identified; secondly, because the removal of many feet of superficial deposit would leave the rock nearer the surface; and thirdly, because the character and distribution of the surface-deposits might help us to form a judgment as to the position of any swallow-holes or lines of soakage into the cave. In this I was not mistaken, and the importance of the question was at once recognized by those who differed from me in the interpretation of the section.

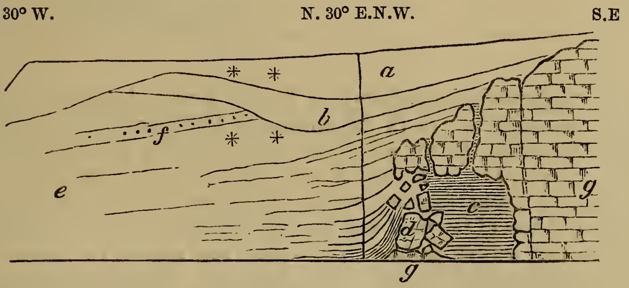
To fix a point where I considered that the re-sorted surface of the marine drift (itself remanié) attained an appreciable thickness, I pointed out an old hedge against which the *head* or *run of the hill* had been caught. Of the existence of this old fence I might adduce other evidence, if the photographs I exhibited were not sufficient, as it was removed and a portion of the bank levelled by the present owner less than 10 years ago.

It is within 16 feet of the upper opening into the cave, and runs much nearer to the rock in which the cave occurs. The last excavations cut across this bank, and have shown a depth of 6 feet of surface-soil here. This deposit rises to the N.E. and thickens out again at the north-east end of the pit, as indicated in fig. 5, which

Fig. 5.

The left-hand portion represents the section seen along the north-west face of the cutting in September 1887, and shows the festooning of the upper part of the superficial deposits at the margin of the swallow-hole. The portion included within the asterisks is that shown in the photograph, fig. 1. The right-hand portion is the section along the north-east face as exposed by the excavations carried on in October following.

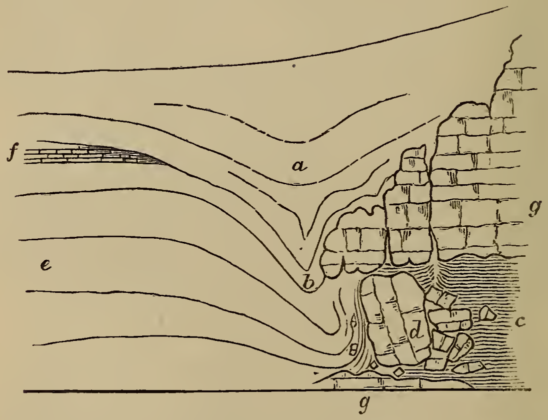
(Scale 20 ft. to 1 inch.)



a. Head, Rainwash, Run-of-the-Hill.
b. Moved drift; marginal portion of that which slipped into swallow-hole, and finally closed the upper opening.
c. Cave-deposits.
d. Angular limestone; broken-down wall and roof of cave.
e. Marine drift.
f. Shell-bed in drift.
g. Limestone.

shows the section as seen by General Pitt-Rivers and Dr. John Evans in September. This face was afterwards cut back a little, but still, in October, the section given from a photograph (fig. 1) shows the margin of the looped drift cutting off the shell-bed and the surface-soil falling with it in towards the swallow-hole. The section facing the observer, looking a little east of north along the length of the pit, showed this surface-soil about 4 feet deep, moved drift 4 feet deep, red clay a few inches; this red clay was very irregular and consisted chiefly of the earthy residuum of the decomposed limestone, corresponding to some of the clay with flints of the Chalk districts. The surface-soil and moved drift thinned off against the rock a little further east, as shown in the diagram, fig. 6. The

Fig. 6.—*Diagram-section, showing the looping-down of the deposits into the swallow-hole before the Section was cut back as far as represented in* fig. 5. Index as in fig. 5. (Scale about 11 ft. to 1 inch.)



core of the principal swallow-hole has, of course, long gone; it was where the earth fell in in the winter of 1886 (see fig. 6), just over where, according to my view, the water soaked first through the jointed, fissured, and funnelled rock into the cave, and afterwards through the great angular masses of limestone derived from the breaking down of the wall and roof of the cave. Some of the superficial deposit was of so late a date that the marks of plough and harrow were found on the included stones. I produced specimens so scored, and the evidence seemed satisfactory, as I thought, to the Fellows of the Society; but these specimens were claimed by Dr. Hicks as stones marked by the picks of the excavators. I now exhibit, as further evidence upon this point, an artificially perforated stone found in the surface-soil from the part of the section above referred to, which is scored all over by similar accidental marks of agricultural implements.

The cave had been filled in the usual way with material from superficial deposits washed in through openings, or from the decay of the rock, or carried in by beasts. The sand that occurred all along it was such as would be derived from the running sand of the drift outside, which was still being carried in in wet weather even during the recent excavations. Under these circumstances there was no wonder that the cave-deposits so nearly resembled the drift as to be considered by some a continuation of the marine beds.

There was no difficulty in accounting for the character of the contents of the cave on the hypothesis that the drift already covered a great part of the surface of the rock while the cave was being filled. But on the supposition that the drift sealed the mouth of a filled-up cave, how can we explain the occurrence in the cave of material which must have been derived from that drift, such as the flints which occurred in the lowest bone-earth?

Some account for this by supposing that the sea broke up stalagmitic floors and mixed up preexisting cave-deposits with drifted sand and Boulder-clay; but there was no trace of such action in the cave. The principal masses of travertine were in the line of the most recent drainage to the north, where the water disappears now. This continuation of the cave is indicated by the dark shades in the lower right hand of fig. 4, and the lower left hand of figs. 2 and 3.

There were no sea-shells in the cave. Curiously, we did not happen to find even one carried in through the swallow-holes. It may be that all the shells perished in that process. But had they been deposited fresh by the sea in the bone-earth, they would have been preserved. The material was not arranged as it usually is in sea-caves, tossed up into sloping banks of shingle; it was an ordinary cave-deposit, and all the phenomena could be simply explained by reference to what are known to be the common processes of subterranean denudation.

It has been frequently stated that the sands of the drift outside the cave passed uninterruptedly into the cave. I saw the material that closed the opening before anything was known as to the nature of the drift immediately beyond. I saw in it no such sand, except the recently scraped sand on the very top of the cave-deposits along the rabbit-burrows. I prodded vertically upwards into clay, opposite to where sand occurred in the section outside. It is quite clear that sand would not have stood in such a position. The next thing that happened was that a plug of clayey sludge descended into the cave and cut off all further observations for some time. Yet, on the occasion of my last visit to the cave, the continuity of the sand with the upper beds in the cave was again asserted. I asked how that opinion could be reconciled with the admitted fact of the settlement of the plug of clay before we had got through the cave into the drift outside, but could get no satisfactory answer. The fact is that the material inside the cave did much resemble the drift outside, but that was simply because it was derived from it by swallow-hole action, and is an argument in favour of the view that the drift must have been outside during the whole of the time of the accumulation of the deposits in the caves, and not that the marine-drift sealed up the mouth of a previously filled cave.

The section in the Brit. Assoc. Rep. 1886, p. 219, is not a section seen at the opening of the cave, but of what was seen after the actual mouth had been cleared. It is a section of the drift which abutted against the rock south of the opening, but was never seen running continuously into the cave as there drawn.

No direct continuity between the deposits in the cave and the several beds of drift outside can have been observed. The bone-earth and other cave-deposits and the overlying great angular fragments of limestone were, of course, traced for some feet in front of what was supposed to be the upper entrance of the cave, but these were afterwards found to extend only as far as the cave itself was proved to have originally extended. The upper beds were cut off by the mass of clayey drift (see fig. 6) which was looped down over the upper opening, and fell in soon after the backing of cave-deposits had been removed during the excavations.

The rock rose to the surface within a short distance above the cave, and the chief percolation of water was through the re-sorted surface material down to the rock, and then along the face of the rock and through fissures in connexion with the cave. The principal line of drainage was, in later times, at any rate, outward to the north from the upper opening of the cave. As stated above, the water now disappears into a large hole in the lower left-hand corner of the cave, as shown in the sketches (figs. 2, 3, and 4). This hole was proved, by thrusting in a stick to a distance of nearly 6 feet, still in limestone; but even in June of this droughty year, the cave just within the upper opening was so wet that visitors were advised not to attempt to walk through it. And there is a fall of about two feet to the other and original entrance. Thus it appears that the cave sloped both ways from this swallow-hole.

The occurrence in the cave-deposits of material which must have been derived from the marine drift, such as the flints and granites, proves that the drift is older than the cave-deposits, except on the untenable hypothesis that the cave-deposits were marine, or re-sorted by the sea that broke up stalagmitic floors, dashed great boulders about, but did not sweep away beds of cave-earth full of bones.

So we must turn elsewhere, and either find along the coast conditions in which the sea washes terraced crags without removing the subaerial débris from them, or find some operations of nature tending to modify caves and their contents in such a manner as will explain the difficulties in Cae Gwyn.

The estuary of the Conway offers the most nearly similar conditions to those which must have prevailed in the estuary of the Clwyd during the submergence: if we could imagine the whole of the vale of Clwyd submerged to a depth of some 400 feet; cliffs of ancient drift being wasted in one place, and the solid rock touched in another; here banks thrown up which divert the currents, and clay and sand and gravel alternating. Fragmentary shells in exactly the same condition, the same part preserved, and most of them of the very same species as those in the Vale of Clwyd, occur in the shore-deposits of Deganwy. But wander on to where the sea rises and falls across the terraced rock, and stand there while the waves are moved by even such a breeze as would just let you sail a boat, and judge whether any loose subaerial deposit could remain. Angular talus in submerged corners, especially where covered by clay drift, has often long withstood the wind and waves, as for instance on the coast west of Llandulas Station, but that such a thing as the few feet or inches of broken rock and interstitial débris outside Cae Gwyn Cave could survive the passage of those waves is inconceivable.

A good deal of the force of the arguments here put forward depends upon the establishment of the existence of swallow-holes above the cave. This is proved by the opened fissures and vertical cylindrical holes in the limestone. They communicated with the porous re-sorted drift above, and were now open, now choked with drift, or plugged by a boulder. They were filled, according to their size and position in the rock-drainage system, with coarser or finer material. The red clayey residuum of the decomposed limestone formed an important part until the opening was enlarged to allow of a free current of water carrying in material from the drift. Down in the cave the action of streams was seen in the curious manner in which bones and teeth were jammed into nearly horizontal fissures where they stuck, as coarse material gets caught in a sieve. Near the bottom of the last explored part of the cave, a little to the right of the pick shown in fig. 3, about 20 feet from the surface, where the drainage was outward to the north, a land-shell, *Hyalina* (*Zonites*), was found in the clayey earth close to the wall of the cave, just as we find them in fissured limestone everywhere.

In other caves in this district we see clearly how the drift is carried down through swallow-holes, and arranged in the wider spaces in the cavernous rock below. On the opposite side of the valley, in the little quarry behind the cottage, there are very good examples of this. Here it will be seen that sometimes washings from the drift (fig. 7, from a photograph by Mr. Helsby), and sometimes apparently masses of drift, as seen on the extreme left of the same figure, have worked down into the openings as they were from time to time enlarged by the chemical action of the acidulated water upon the limestone. That, from the nature of the case, this sort of thing must happen is obvious, but here we can see evidence that it has taken place in the dragging down of the infilling deposit along the walls of rock. So that the clay is pulled out, slickensided, and has, when dry, almost a cleaved look, and the flat and elongated stones are arranged with their longer axes parallel to the direction of movement (fig. 7). The surface of the limestone shows the usual fretted appearance quite different from the surface of a sea-worn limestone. When large masses get detached by this chemical weathering along the joints, and one cave breaks into another, or the mouth of a cave breaks down, or when the drainage leads into broken rock, the same process goes on among and around the great angular fragments, so that there is a kind of extension of the cave and cave-deposits into the talus.

This is precisely what has taken place in the Cae Gwyn Cave, where the cave-earth penetrates also the mass of angular blocks which occur in the cave where the roof has fallen, and outside where the wall or mouth of the cave has broken down.

Fig. 7.—*Section in quarry behind cottage by road on hill-side south of, and opposite to Ffynnon Beuno Cave.* (From a photograph by Mr. Helsby.)

Here masses of drift washed down into the fissured and decomposing rock were exposed in cavities in the progress of quarrying; some of this drift was relaid horizontally, as shown behind the standing figure, while some was dragged down by its own weight, and, in places, stood vertical, as shown in the cavity on the right of the picture.

Recent excavations have conclusively proved that the upper opening now seen did not exist as an entrance to the cave during the period of its occupation, although many fissures and cylindrical holes, sometimes open sometimes choked, lead from the surface of the rock and the water-carrying strata of the overlying drift into this part of the cave.

When the bone-earth was followed out from the upper opening it was found to be overlain by a mass of broken limestone, which the floor of solid rock rose to meet, at a distance of some 6 feet more or less from the inner wall of the cave (see fig. 6). This mass of angular rock sloped in over the cave-deposits, as shown in fig. 4; and when followed to the north end of the excavation in front of the opening, it was seen to extend from the floor of the cave to meet the rock above, which again projected forward (as seen in figs. 2 and 3) to form a roof to the cave. Broken rock extended in a similar manner in front of the opening up to the exterior wall of the cave at the south end of the excavation, and immediately in front of the cave great masses of rock were found in the soil and drift that blocks the opening (as seen in figs. 2, 3, 4, and 6). It was perfectly clear that these masses of rock represented the roof and walls of a portion of the cave which had yielded to subterranean denudation and gradually crumbled down or collapsed more rapidly. Dr. Geikie, who visited the cave in October, quite concurred in this view (see p. 118).

So the bone-earth which was said to occur 4 feet beyond the entrance to the cave was really all within the original cave before this portion of it had fallen in.

It was impossible that this could be an ancient mouth of a cave round which talus from the rock above had accumulated, and that the sea had afterwards crept over it and deposited the marine drift upon it, because the great angular blocks occurred at various levels in the clayey and sandy débris, and the drift was crushed in upon some of the fallen masses so as to stand vertically, with the included fragments arranged as described above in the case of the drift in the quarry on the other side of the gallery, where also it has sunk into fissures and caves of the limestone.

The same thing has happened here also in the case of the Cae Gwyn Cave (as shown in figs. 2 and 4). The pebbles stood with their longer axes vertical, and the bed of grey clay was even a little reversed in places. The inclination of the beds decreased through about 4 feet of angular limestone and overlying sand and loam till the drift by degrees resumed its almost horizontal position.

In the lower right-hand corner of the sketch, fig. 2, close to the right foot of the right-hand man, the flake was found; it was under some overhanging rock, which had to be removed in the progress of the work, and was overlain by great masses of limestone. The deposit in which it occurred was a slightly sandy, red, sticky clay, like the earthy residuum of the limestone, with a little more sandy material washed in from the drift, and resembling rather the material that filled the fissures than the stratified cave-deposits.

This satisfactorily explains some difficulties connected with the flake; for instance, the curious fact that, although many flints were found in the bone-earth, their surface was in a very different state from that of the flake. It also explains the position of the flake, which was tucked into a corner far inside the recesses of the cave, instead of, as is mostly the case, somewhere near the entrance; for it has been shown that this upper opening was not an entrance during the period of occupation of the cave.

The flake is considered by Dr. John Evans * and Mr. Worthington Smith † to be of a late palæolithic type, if not newer still, and if it did occur in the true bone-earth it would go far to prove that the bone-earth is postglacial, whereas if it did not occur in the true cave-deposits (as distinguished from the swallow-hole importations) all evidence of the existence of man in this cave falls to the ground. It is more probable that the flake was carried in much later times into the position in which it was found. The *Zonites* had reached a still lower level, where it lay, not far off, in clay identical with that

* Quart. Journ. Geol. Soc. vol. xlii. p. 11.
† 'Nature,' vol. xxxvii. Nov. 3, 1887, p. 7.

in which the flake was found. The bones and teeth caught in the fissure were only about 6 feet from where the flake lay.

The overlying drifts and surface-wash were festooned over the broken opening to the cave. The core of the swallow-hole was, of course, the portion that sunk in in the winter of 1886. The looping of the beds decreased as the face of the drift was from time to time cut back; but it extended for a considerable distance, and the outside portion of the festooned beds (as shown in fig. 5) was seen by General Pitt-Rivers and Dr. John Evans in the first week in September of this year (1887). The margin of it was still to be seen in October, when the photographs exhibited were taken. See especially fig. 1, in which *a* indicates the shell-bed, cut off, it will be noticed, by the brown clay which slopes down towards the opening to the cave in the direction of the flat stone seen opposite the *b*.

When, on digging through the cave from the lower entrance, this broken place in the side of the cave was reached, it appeared as if the bone-earth extended several feet beyond what seemed to be another entrance to the cave. It was not at first an objection to this view that many cartloads of large angular masses of limestone had to be removed before the bone-earth was touched, as such angular débris, owing to the falling of masses from the roof, often occurs in such caves in and on the bone-earth, and it was to be expected that a larger quantity would be found around the mouth. But when it became clear that the cave went on, and that this mass outside the opening lay in the line of and represented the wall and roof of a portion of the cave that had fallen in, then it was evident that the bone-earth extended no further than the original cave; and we soon ascertained that the bones were entirely confined to the beds within and under the angular blocks that represented the original outer wall of the cave.

No marine deposits were found inside of it, and no cave-deposits outside of it.

The broken limestone over the bone-earth contained a few foreign fragments, but they were only such as would naturally work in from the drift. If the overhanging rock were to fall in now, it would contain some such boulders, one of which is seen plugging the cylindrical hole which descends through the limestone immediately over the opening. (See fig. 2, above the elbow of the man in the centre of the sketch.)

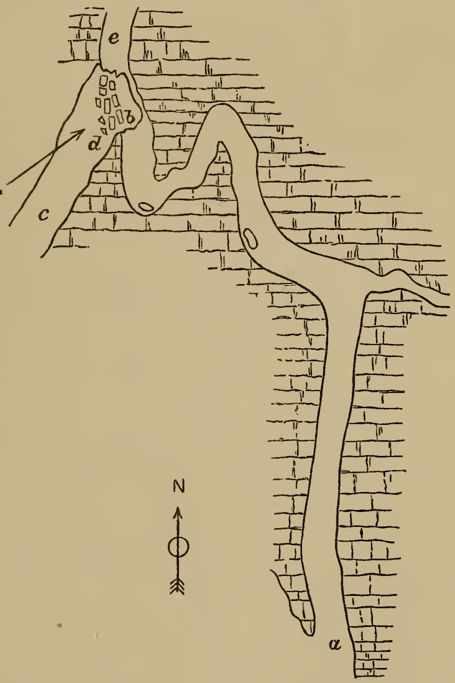
The drift lay upon this angular débris. *A priori* it seemed improbable that the sea could have been there and spared the soft cave-deposits and incoherent débris outside. This, however, was all cleared up by our finding loam standing vertically against the blocks which had fallen in, and showing that the drift, which was there before the breakdown of the roof and wall of the cave, had sunk in upon the crumbling and decomposing limestone. That the effect of this falling-in was not more marked was probably due to the fact that the cave was by that time nearly filled, and the displacement therefore was not so great as it would have been had the cave been empty. Still, the drag along the margin showed evidence of a very considerable settlement, probably not less than 4 feet, in the section shown in the lower left-hand corner of figs. 2 and 3.

Instead, therefore, of the less satisfactory task of proving that there were in the district many well-known processes connected with subterranean denudation which might explain the superposition of the marine drift upon the bone-earth, each of which had played a part in producing the results observed, we have now the clearest evidence as to the exact manner in which it has all been brought about, namely:—

That the marine drift was deposited before the occupation of the cave by the animals whose remains have been found in it;

That at the time of the occupation of the cave the upper opening

Fig. 8.—*Plan of Cae Gwyn Cave.* (Scale 34 feet to 1 inch.)



a. Entrance to cave.
b. Break in the side of cave known as "Upper Opening," where the bones &c., were found outside the then existing cave.
c. Cutting made after discovery of the upper opening *b.*
d. Débris of roof and wall of cave overlying bone-earth.
e. Extension of cave to the north along which water now drains away under the drift.
f indicates the point of view in fig. 2.

(*b*, fig. 8) now seen did not exist, but the animals got in by the other entrance (*a*, fig. 8);

That against the wall of the cave, where it approached nearest to the face of the cliff, the drift lay thick, as we now see it close by.

That by swallow-hole action the cave was first partially filled, and then the thinnest portion of its wall gave way gradually, burying the bone-earth below it, and letting down some of the drift and newer superficial deposits above it, so that some of it now looks as if it might have been laid down by the sea upon pre-existing cave-deposits.

Discussion.

The President regretted the absence of several who were well qualified to speak on this question.

Dr. Hicks said the Author had acknowledged that he was thoroughly biassed against the views of the other members of the Committee when he began to criticize them. Prof. Hughes had not been present during the most important stages of the explorations. Dr. Hicks protested strongly against the arguments of the Author, and complained that the subject was treated by him quite differently from last year, when he insisted that the whole of the drift in front of the entrance was *remanié*, that it contained no shells, that it was quite unlike the drifts in the valley, showed no evidence of sea-sorting, and resembled only rain-wash. Now that bands of marine shells had been found, Prof. Hughes was obliged to admit that it is a true marine drift, and correlate it with the St. Asaph drifts. Dr. Hicks exhibited photographs and diagrams in explanation of the points at issue, and said it was quite impossible for the enormous amount of deposit which they had removed from the cavern to have been carried in through a swallow-hole which had left no evidence whatever of its existence. Mr. Luxmoore had also shown to Prof. Hughes, in the cavern near the entrance, and before it was known that they were approaching the entrance, sands and gravels similar to those in the section in a stratified condition overlying the laminated clay and bone-earth. There was also a most distinct and undisturbed section to be seen all round the pit when it was first dug out, and when it was only five feet across at the bottom, as could be testified by several witnesses. He stated that he had explained to Prof. Hughes that the land-shell was found at a spot which had been disturbed last year, and where fallen material had been thrown in. He distinctly denied that the looping down of the surface-deposits was to be seen when the section was first exposed, and regretted he had been absent when this appearance, an entirely recent change, was indicated to Dr. Evans and General Pitt-Rivers. It would not do to rely upon a drift section after a heavy shower. The bone-earth had been proved to pass under the drift section at all the points examined. Dr. Geikie, who had been asked to give his opinion on the section, found himself obliged to dissent from the Author's views, and Dr. Hicks believed that Dr. Geikie's views, as stated in his report to Prof. Hughes and himself, were the correct ones. The disturbance near the large block of limestone, which is imbedded in the sandy clay with bones, proved to be of no consequence, and it does not affect any of the beds immediately above. The bone-earth had been disturbed by marine action, and therefore contained irregular bands of gravel and sand and some foreign materials. Mr. De Rance had made a further exploration, in conjunction with Mr. Morgan, the owner, and one of the members of the Committee, with the result that bones of hyæna had been found overlying the block, under layers of sand which passed from the vertical drift-section well beyond the point where any pothole could possibly have occurred, and under the shelving rock to the inner wall of the cavern. His diagrams were exhibited. The whole evidence, therefore, is most distinctly opposed to Prof. Hughes's views, and confirmatory of the statements made by those members of the Committee who have superintended the explorations.

Mr. E. T. Newton spoke in explanation of a diagram which he exhibited in illustration of the subject. On comparing the list of Mammalia found in the cave with (1) those of the forest-bed taken as a type of a preglacial fauna, and (2) those of the presumably postglacial or interglacial fauna of the river-gravels, he concluded that the Mammalia of the cave are of the same age as those of the river-gravels.

Mr. Lydekker criticised the lists and inferences of the last speaker.

The Author emphasized the points which had been made by Mr. Newton. The age of the cave-deposits could only be decided by that of the deposit which finally closed it. It was certainly singular that Dr. Hicks had put everything there for him to find—the scratched stone, the land-shell, and even the old fence itself. When the cave was filled up, the swallow-hole action to which he referred was no longer in operation. Of course, there was no difficulty about the sand and gravel in the cave; that had been derived from the material outside. A plumb-line might have been let fall where the bones were found, but the original roof of the cave extended beyond them. The looped surface-deposits spoken of were part of the great slip, and he claimed that this was due to swallow-hole action. The barrier of limestone was not paralleled in any portion of the drift; the chief mass of travertine is not floor-travertine, but wall-travertine, such as may now be seen in the cave. Dr. Geikie had allowed that the bone-earth projected beyond the present limit of the cave, but thought it probably never did so originally. Hence he had no doubt that the roof or wall of the cavern has given way, but believed that this fall took place before the deposition of the glacial deposits. To these remarks the Author would reply, that in the bone-earth, below the angular limestone, were flints and other material which only came into the district with the marine drift. Therefore the marine drift cannot have been deposited after the break-down of the wall and roof of the cave.

12. *On two New* Lepidotoid Ganoids *from the* Early Mesozoic Deposits *of* Orange Free State, South Africa. By A. Smith Woodward, Esq., F.G.S., F.Z.S., of the British Museum (Natural History). (Read January 25, 1888.)

[Plate VI.]

The fine series of South-African fossils brought to the British Museum in 1883 by Dr. Hugh Exton, F.G.S., Curator of the Bloemfontein Museum, Orange Free State, has already furnished two important novel types of Vertebrata, made known at the meetings of this Society by Professor Sir Richard Owen *. There still remain, however, other interesting forms, adding to our knowledge of the palæontology of the early Mesozoic strata whence they were derived, and among these are some beautifully preserved examples of a Lepidotoid Ganoid fish. Two specimens of another new Ganoid have also been lately received from the same source, and the affinities of these types have so important a bearing upon the question of the age of the Stormberg Beds of South Africa, that it seems advisable to place on record their discovery and to offer a detailed description of their characters.

I. Semionotus capensis, sp. nov.† (Pl. VI. figs. 1–5.)

The first series of the fossil fishes in question comprises portions of four individuals displayed upon the surface of a slab of sandstone, mainly in counterpart. Each of these shows more or less of the scaly trunk; and, in addition, one example exhibits the head, pectoral fin, and dorsal fin; another, the dorsal and caudal fins; a third, a nearly complete tail and the anal fin; while the fourth is almost perfect behind a point a little in advance of the pelvic fins. There are thus materials for determining all the more salient features of the fish, as illustrated in the accompanying figures.

In general outline the body is elongated and fusiform, the greatest depth being contained about three and a half times in the total length, and the head occupies about one fourth of the whole. Both the paired and median fins are well developed, the pelvic pair being situated a little in advance of the opposing dorsal; and all are characterized by the enormous proportions of the anterior fulcra. The trunk is covered with rhomboidal scales of moderate size, and these exhibit neither ornament nor marginal serrations.

Head and Opercular Fold.—The only specimen retaining the head and opercular bones (fig. 2) is much crushed, but the outlines of some of the elements are distinguishable, and, fortunately, these can be studied in counterpart. Viewed from the side, the roof of the skull is seen to slope rapidly downwards from a position somewhat in advance of the parieto-frontal suture, and the snout was evidently acutely pointed. The parietals (*par*) and frontals (*fr*) have been so displaced as to exhibit their shape and proportions,

* *Tritylodon longævus*, Owen, Quart. Journ. Geol. Soc. vol. xl. (1884), p. 146, pl. vi., and *Rhytidosteus capensis*, Owen, *ibid.* p. 333, pls. xvi., xvii.

† This fish has already been quoted under the MS. name of *Extonichthys*, Owen (J. Prestwich, 'Stratigr. Geol.' 1888, p. 18).

and the former have about half the length of the latter; the parietals are united by an undulating median suture, and vary little in width, but the frontals appear to taper considerably in front, and their middle sutural line is almost straight. Behind these elements one of the supratemporal bones (*st*) is apparently recognizable; but in advance of the frontals nothing beyond crushed bone-fragments can be seen, with the remains of a terminal conical tooth. Of the palato-pterygoid arcade there is an undeterminable fragment; and pertaining either to this or to the maxilla is a broken series of powerful, hollow, conical teeth. A portion of the mandible (*d*) is also observed, bearing traces of a similar dentition.

The operculum (*op*) is of the form of a parallelogram, about once and a half as deep as broad; and the suboperculum (*s.op*), which must have been scarcely half as large as the operculum, shows the upwardly directed process of its antero-superior angle, so characteristic of the genus *Lepidotus*. In front of these bones there are obscure remains of the preoperculum (*p.op*), and immediately anterior to this is a large superficial plate (*x*), situated between it and the remains of the circumorbital ring. No traces of ornamentation are visible, either on these elements or on the skull, unless a tubercle upon one of the frontal bones is an indication of this character.

Vertebral Column.—Nothing can be seen of the internal skeleton of the trunk, with the exception of four of the hindermost hæmapophyses of the vertebral column, which are widened distally for the support of the caudal fin. There are no certain traces of ossified ribs, though the fossils can hardly be regarded as sufficient to demonstrate the absence of these structures.

Appendicular Skeleton.—In the *pectoral arch* the clavicle (fig. 2, *cl*) is well shown, of the ordinary Lepidotoid type; and situated posteriorly to the lower extremity of this is a small element (*co.*), which may probably be interpreted as coracoid. The *pectoral fin* consists of about 11 or 12 robust rays, which—as in all the other fins except the caudal—are unarticulated for a considerable distance proximally, though closely jointed nearer their extremities. The anterior fulcra are destroyed, but they would probably be of enormous size, like those of the other fins, this great development of the fulcral scales being one of the most characteristic features of the fish. The *pelvic fins* appear to have each comprised not more than six rays, and these, as already stated, are placed slightly in advance of the commencement of the opposing dorsal.

In the *dorsal fin* the series of very large fulcra is succeeded by at least 11 widely spaced rays, of which the anterior two are more closely approximated than the remainder. The *anal fin* shows a very strong interspinous bone supporting the fulcra, and there are eight rays rapidly shortening behind. The atrophied upper lobe of the tail is fringed above with fulcral scales, which diminish as they extend upon the *caudal fin*; and there are also well-developed fulcra upon the inferior margin of the latter. This fin is symmetrical and not forked, and the rays, in number about 14, are strong and closely articulated from near the base, dichotomously branching distally.

Scales.—The scales are strong and enamelled, varying in form in different parts of the body in the usual manner; those of the middle of the flank (fig. 4) are deeper than broad, gradually becoming relatively less deep dorsally and ventrally (fig. 5), and passing behind into the smaller rhomboidal lozenge-shaped scales of the caudal pedicle. The posterior border is not in any case denticulated. There is a slight median rib on the inner side of each scale, and on the more anterior portion of the flank the ordinary peg-and-socket articulation is observable. The "lateral line" is well marked, and is very slightly arched upwards.

Systematic Determination.—On consideration of the foregoing anatomical details, it at once becomes evident that the South-African fish is an ally of the widely distributed Mesozoic genera *Lepidotus* and *Semionotus*, if, indeed, it does not belong to one of the two. The structure of the skull is essentially similar, and likewise the form and proportions of the trunk and fins. The size of the fin-fulcra is no greater than that of the fulcra met with in certain species of *Lepidotus* (e. g. *L. minor*, Ag.); but the head in the present fossil is sufficiently well preserved to show that the dentition was quite distinct from that of the last-named genus, and the scales also evidently differ in the form of the overlapped margin. From *Semionotus*, however, no point of divergence of generic value is apparently discoverable; and the American species referred by Egerton to *Ischypterus* * (in allusion to the dimensions of their fin-fulcra) seem to connect precisely the earlier recognized forms of the genus with the new type here made known. The South-African fossil has still larger fulcra even than the latter, and this character especially serves to distinguish it from all the species hitherto defined. It may therefore be appropriately termed *Semionotus capensis*, as being the first recorded example of this European and American early Mesozoic genus occurring in the region of the Cape.

Formation and Locality.—Stormberg Beds (Upper Karoo Series); the Drakensberg Range, Orange Free State, South Africa †.

* Sir Philip Egerton, quoted by Sir Charles Lyell, Quart. Journ. Geol. Soc. vol. iii. (1847), p. 277. As shown by Dr. Traquair's description (Quart. Journ. Geol. Soc. vol. xxxiii. 1877, p. 559), *Ischypterus* presents no certain points of difference from the typical species of *Semionotus* which can be regarded as of generic value. The fin-fulcra are certainly larger than those of most forms referred to the last-named genus; but there are gradations between the extremes, and there appears to be an equal variation in the development of the fulcra in the different species of the closely allied genus *Lepidotus*.

† These particulars have been kindly furnished by Prof. T. Rupert Jones, F.R.S., F.G.S., to whom I am indebted for the following information from the 'Bloemfontein Gazette' of July 5th, 1883, relating to the precise locality from which the specimens of this fish were obtained. The fossiliferous bed occurs in a precipice upon the farm of M. H. K. van der Merwe, about three-and-a-half hours' march from Senekal, in the direction of Ficksburg. The precipice is hollowed at the base by caves and rock-shelters, and the natives, who at present use these as store-houses for their corn-baskets, first observed the fossil impressions, pointing them out to the neighbouring farmers. "The late Mr. Stow chiselled and split the portions of rock into fragments, and it seems probable all available specimens have been removed till another slip of rock takes place." In his 'Report of the Geol. Survey of the Orange Free State,' 1879, p. 48, Mr. Stow remarks that "the fish are evidently new to science, but of an old-world type, the scales being arranged in regular diagonal lines." The rocks at the base of the precipice at Weltevredren are described by the same geologist

II. Cleithrolepis Extoni, sp. nov. (Pl. VI. figs. 6 & 7.)

The latest specimens received from Dr. Exton are two imperfect examples of a deep-bodied Ganoid fish from Rouxville, Orange Free State. The larger specimen (fig. 6) is destitute of most of the head and caudal fin, while the smaller exhibits only a portion of the trunk, with the operculum and postorbital bones, and the pectoral fin.

The general proportions of the fish are well shown in the figure just quoted. The head is relatively small; pelvic fins are present; the anal and dorsal fins are similar and opposite; and the upper lobe of the caudal pedicle is atrophied.

Head and Opercular Fold.—An undeterminable fragment of the roof-bones is the only portion of the cranium exposed to view, and the more superficial circumorbital elements are in such a state of preservation that the sutures can only be indistinctly recognized (fig. 7). There is also some appearance of a chain of three small membrane bones extending backwards from the postero-superior angle of the circumorbitals, above the operculum, and between it and the cranial roof, and these, as in *Polypterus* and some other Ganoids, are perforated by the "lateral line" as it passes upon the head. The fossil (fig. 7) shows the sensory canals very clearly; from the second of the three ossicles, one branch is directed upwards across the occiput, while further forwards the line divaricates, one division passing over the orbit and the other downwards. There are also other portions of the "lateral line" system beyond the occipital region, the precise connexions of which are not shown.

No preoperculum or interoperculum is recognizable, but the operculum and suboperculum are shown in both the specimens. The operculum (*op*) is almost square, with the postero-superior angle rounded off, and it is considerably smaller than the suboperculum (*s.op*), having only about two thirds the vertical extent of the latter. In the large fossil (fig. 6) there are likewise faint impressions of two or three short and broad branchiostegal rays beneath the suboperculum; and all these bones, as well as those of the head, exhibit a superficial ornament of sparsely scattered ganoine tubercles.

Appendicular Skeleton.—Of the paired fins the *pectorals* are placed laterally, being situated in a position almost on the level of the lower border of the suboperculum. So far as can be ascertained from the smaller fossil (fig. 7), each fin seems to have consisted of about 10 delicate rays, ornamented externally with tubercles, but the state of preservation is too imperfect to allow of determining any more precise structural features. The *pelvic* fins are even more indistinctly shown, though the large specimen (fig. 6) indicates that these were very small, and placed almost midway between the head and the commencement of the anal.

Of the median fins, both the *dorsal* and anal are nearly complete. The former consists of about 18 stout rays, each articulated, at moderate distances, beyond a point near the base, and dividing distally; and in front of the fin there are some indistinct small fulcra.

(*loc. cit.*) as consisting of "a belt of ribbon sandstone, some parts of which, when worked down, show a beautiful ribbon-pattern of varying colours—red, white, yellow, and light buff."

The first eight rays are placed close together, while those succeeding are more widely spaced, and the height of the fin rapidly diminishes posteriorly. The *anal* is somewhat shorter than the dorsal, its hinder end being opposite to that of the latter, but its commencement is slightly further back than the front rays of the same. There are about 15 rays, preceded by very distinct small fulcra and the remains of larger basal fulcra, and the first eight are closely approximated, while the remainder are more widely spaced and much the shortest. All the rays, both of this fin and the preserved fragment of the caudal, are comparatively robust, and articulated similarly to those of the dorsal, and the branching is seen to commence at a point quite near to the base.

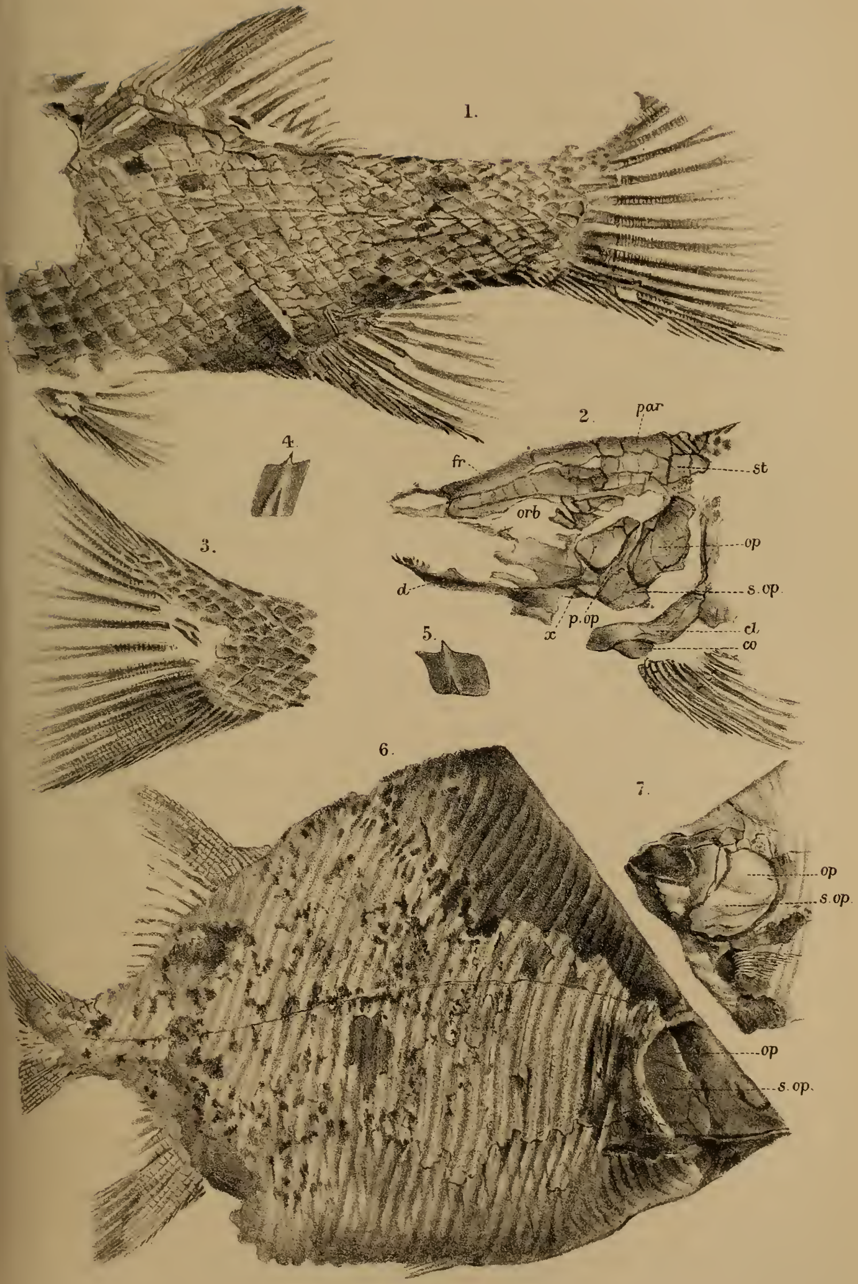
Scales.—The scales exhibit the vertical elongation on the flank usually met with in deep-bodied Ganoids, and are strikingly similar to those of certain Platysomidæ (e. g. *Cheirodus* or *Amphicentrum*) and Pycnodonts (e. g. *Gyrodus*). They are ornamented externally with prominent granulations, which tend to merge and form striæ parallel to the margins, and the anterior border of each is thickened in the ordinary "pleuro-lepidal manner"—an arrangement so well known from Sir Philip Egerton's graphic description * as to require no further explanation. The "lateral line" upon the trunk is distinct, and extends in a gentle curve from the summit of the operculum to the middle of the caudal pedicle.

Systematic Determination.—A hasty glance at this interesting fish impresses one at once with its remarkable superficial resemblance to some of the Platysomidæ; and the relative dimensions of the operculum and suboperculum might also be regarded as indicating some affinity with that ancient tribe. One characteristic feature, however, is happily preserved, by which it is possible to definitely decide the question of relationship, namely, the semi-heterocercal tail. This (as well as the nature of the circumorbital bones) is sufficient to lead to the institution of comparisons with other deep-bodied Ganoids of a more modern type, all the Platysomidæ and their allies being markedly heterocercal, and we accordingly proceed to the Dapediidæ and the Pycnodonts. The latter are immediately excluded from consideration by the incompleteness of their opercular apparatus, which seems to consist merely of a single plate†, and by the absence of fulcra on their fins. The Dapediidæ, however, show an agreement in almost every respect. The form of the body and the relations of the fins, the characters of the opercular bones, and the small fulcra fringing the anterior margin of the fins, are all similar; and the new South-African fossil may thus be placed in this family with but little hesitation.

Having decided upon the family position, it remains to determine the genus. *Dapedius*, *Heterostrophus*, and *Tetragonolepis* are the only hitherto recognized Dapedioids with which it seems necessary to compare the fossil, and the first two of these are quite distinct

* Sir P. Egerton, "On the Affinities of the Genus *Platysomus*," Quart. Journ. Geol. Soc. vol. v. (1849), p. 331.

† R. H. Traquair, "On the Structure and Affinities of the Platysomidæ," Trans. Roy. Soc. Edinb. vol. xxix. (1879), p. 383.



W H Crowther del. et lith. Mintern Bros. imp.

SEMIONOTUS AND CLEITHROLEPIS.

in the mode of articulation of the scales. *Tetragonolepis* (Bronn, *non* Agassiz*), on the other hand, has a truly "pleurolepidal" squamation, the inner articulating ribs of the scales being anterior and marginal. But the typical species of this genus are much less symmetrically shaped than the South-African form, owing to the great development of the ventral part of the abdominal region; though, it must be admitted, at least one of the fragmentary Indian fossils referred by Egerton † to *Tetragonolepis* exhibits an almost corresponding general outline, so far as it is known. Whether the latter is a correct determination or not remains to be decided by the discovery of more satisfactory materials; but, under any circumstances, it is obvious that the fish now under discussion is quite distinct from the type defined by Bronn ‡, and must therefore be looked upon as representing a different genus. At first sight I was inclined to regard it as new, but Dr. Traquair has kindly reminded me of a fish from the Hawkesbury Beds (supposed Trias) of New South Wales, described many years ago by Sir Philip Egerton § under the name of *Cleithrolepis granulatus*, and I am convinced that the South-African fossil is generically identical with this. *Cleithrolepis*, up to the present time, has been doubtfully placed either with the Platysomidæ or the Pycnodontidæ, but Sir Philip Egerton's figures and description clearly show that its true affinities are with the family Dapediidæ; and the new discoveries here recorded amply confirm this determination. The South-African fish, however, is distinctly a new specific type, as will be seen on comparing the figures, and I therefore venture to name it *Cleithrolepis Extoni*, in reference to Dr. Exton's important explorations in the early Mesozoic deposits of the Cape.

Formation and Locality.—Stormberg Beds (Upper Karoo Series); Rouxville, Orange Free State, South Africa.

EXPLANATION OF PLATE VI.

Fig. 1. *Semionotus capensis*, A. S. Woodw., hinder portion of trunk.
2. Ditto, head and pectoral fin. *cl*, clavicle; *co*, coracoid; *d*, dentary; *fr*, frontal; *op*, operculum; *orb*, orbit; *par*, parietal; *p.op*, preoperculum; *s.op*, suboperculum; *st*, supratemporal; *x*, cheek-plate.
3. Ditto, caudal pedicle and fin.
4. Ditto, scale of flank, inner aspect, twice nat. size.
5. Ditto, ventral scale, inner aspect, twice nat. size.
6. *Cleithrolepis Extoni*, A. S. Woodw.
7. Ditto, fragment of head and trunk, with pectoral fin.

All the figures, except Nos. 4 and 5, are of the natural size, and the original specimens are preserved in the British Museum.

(For the Discussion on this paper, see p. 269.)

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* See Sir Philip Egerton, "On the Affinities of the Genera *Tetragonolepis* and *Dapedius*," Quart. Journ. Geol. Soc. vol. ix. (1853), pp. 274–277. In this paper *Tetragonolepis* was assigned to the Pycnodontidæ, but the error has subsequently been pointed out by both Heckel (Denkschr. k. Akad. Wiss. Wien, vol. xvii. 1855, p. 200) and Traquair (*loc. cit.* p. 380).

† Sir P. Egerton "On some Remains of Ganoid Fishes from the Deccan," Palæont. Ind. [4] vol. i. pt. 2 (1878), p. 5, pl. iii. fig. 1.—*Tetragonolepis analis*, Eg.

‡ H. G. Bronn, "Ueber zwei fossile Fischarten aus dem Gryphitenkalke bei Donau-Eschingen," Neues Jahrb. 1830, p. 22, pl. i. fig. 2.

§ Sir P. Egerton, "On some Ichthyolites from New South Wales, forwarded by the Rev. W. B. Clarke," Quart. Journ. Geol. Soc. vol. xx. (1864), p. 3, pl. i. figs. 2, 3.

13. *On some* Remains *of* Squatina Cranei, sp. nov., *and the* Mandible *of* Belonostomus cinctus, *from the* Chalk *of* Sussex, *preserved in the Collection of* Henry Willett, Esq., F.G.S., Brighton Museum. By A. Smith Woodward, Esq., F.G.S., F.Z.S., of the British Museum (Natural History). (Read February 8, 1888.)

[Plate VII.]

Last year, when attempting to elucidate the dentition of the Cretaceous Selachian genus *Ptychodus*, I had the honour of bringing before the notice of the Society an important specimen from the cabinet of Henry Willett, Esq., F.G.S., of Brighton; and in subsequent studies both of this and of contemporaneous ichthyic types I have been favoured by the same gentleman's kind permission to make use of the whole of his valuable collection. Among the fossils there are two, bearing upon the subject of recent inquiries, which seem to reveal points of considerable interest and significance; and of these I propose to offer a brief notice in the present communication. The one specimen adds the "Angel-fish" (*Squatina*) to the list of English Chalk Fishes, and apparently indicates a new species; the other makes known some hitherto unrecognized features in one of the most singular of Cretaceous Ganoids, *Belonostomus cinctus*.

I. Squatina Cranei, sp. nov. (Pl. VII. figs. 1–6.)

The remains referable to the Selachian genus *Squatina* consist of a crushed skull, with the mandibular and hyoid arches, and an associated fragment of the pectoral fin, with dermal tubercles. The fossil indicates a small animal, probably not more than thirty inches in length, and the most important of the features it presents are illustrated in figs. 1–6 of the accompanying Plate.

The skull has been crushed somewhat obliquely from above downwards, the jaws of the right side being displaced to a position beneath the middle of the cranium, and the right hyomandibular cartilage, thrown outwards, is completely severed from these. The difficulties of interpretation are, moreover, increased by the unfortunate chance-fracture of the specimen on its discovery. One half of the block of chalk (fig. 1) retains the left hyomandibular (*hm*) and pterygo-quadrate (*ptq*) cartilages, with a portion of the left mandibular (*md*) and ceratohyal (*ch*) viewed from the inner side; in addition to numerous scattered teeth, and the impression of the left half of the cranial roof, to which some of the cartilage adheres. The counterpart block shows the remainder of the left mandibular and ceratohyal cartilages, the complete right hyomandibular, and a fragment of the right mandibular; while there are also undeterminable portions of the cranium itself, besides the associated dermal shagreen already referred to.

The form and relative proportions of the cranium and its appended arches are very similar to those of the living representative of the genus, so far as they are recognizable. The antorbital process of the skull (*ao*) presents its usual aspect, and there is the same excavation of the middle of the anterior extremity (*ex*) of the cranial " box." The postorbital process seems to be buried in the matrix, but the contour of the postero-lateral angle of the skull (*pla*) is quite normal, and the depression in the roof in advance of the occiput is apparently of its accustomed proportions. The pterygo-quadrate cartilage (*ptq*) is stout and narrow, with the large pterygo-trabecular process ; the precise outlines of the mandibular element are not seen. The left hyomandibular (*hm*) is perfect, in position, of the ordinary shape and size ; and the large ceratohyal (*ch*) is shown in pieces upon both halves of the fossil, about two thirds the length of the mandible. There are also apparently some obscure remains of the well-developed labial cartilages.

The dentition is not completely preserved, but the anterior teeth of both the upper and lower jaw are exposed to view. Those near the symphysis of the mandible are relatively high and slender (fig. 3), while the opposing teeth attain but small dimensions (fig. 2) ; more posteriorly, both above and below, the teeth begin to exhibit the usual lateral elongation (fig. 4) characteristic of the sides of the mouth.

The minute dermal tubercles (fig. 5) are mostly of an oval form, having the outer enamelled surface ornamented with longitudinal or radiating ridges. They were probably scattered over almost the entire trunk. The larger tubercles, like those occurring upon the margins of the paired fins of the existing *Squatina*, are also oval in shape, with a slightly crenulated margin (fig. 6). From the middle of each there rises a large backwardly-directed spine, laterally compressed, and well enamelled.

On comparing the fish, thus fragmentarily indicated, with the species of *Squatina* already satisfactorily known, it is readily distinguished by the great relative size of the spinous dermal tubercles. No defences of this character have hitherto been observed in the extinct forms, and those of the living species are considerably smaller in proportion to the size of the fish. The anterior lower teeth are also more slender than in the existing *Squatina angelus*. I would therefore venture to designate the new English fossil *Squatina Cranei*, associating with it the name of my friend Edward Crane, Esq., F.G.S., Chairman of the Brighton Museum Committee, as a slight acknowledgment of the services he has rendered to the cause of Palæontology and the Institution over which he now presides.

II. Belonostomus cinctus, Agass. (Pl. VII. figs. 7–13.)

The lower jaw of *Belonostomus* has already been, to some extent, elucidated by the researches of Otto Reis*; but no specimen hitherto described has revealed the precise characters of the dentition, or the relations of the hindermost bones. Mr. Willett's fine

* O. Reis, "Ueber *Belonostomus*, *Aspidorhynchus* und ihre Beziehungen zum lebenden *Lepidosteus*," Sitzb. math.-phys. Cl. königl.-bay. Akad. Wiss. München, 1887, pp. 169-172, pl. i. fig. 4.

examples of *Belonostomus cinctus* supply this deficiency in our knowledge of the genus to a considerable extent, and explain the peculiarities of the fragmentary fossils described by Agassiz, besides making known more completely than before the largest presymphysial bone recorded in the annals of vertebrate anatomy.

The principal specimen is shown two thirds of the natural size in fig. 7, and exhibits the mandible and dentition tolerably well preserved, except at the anterior and posterior extremities. The two rami occupy only one half the entire length of the jaw, the anterior half being formed by the enormously elongated presymphysial bone. Each ramus is narrow and deep, gradually tapering in front, and the upper border rises behind, immediately beyond the posterior termination of the tooth-bearing portion. The two rami meet in front at a very acute angle, but imperfections in the fossil do not permit of a determination of the precise characters of the union: the symphysis is elongate, gradually diminishing to a thin edge below, and the enormous presymphysial bone is articulated to the sloping triangular surface thus formed (fig. 8). The last-mentioned bone is a median unpaired element, very gradually tapering to a point anteriorly; it is hollow, compressed below (fig. 9 *a*), keeled inferiorly in the anterior portion, and marked by a shallow longitudinal channel above.

As shown both by this specimen and by another less perfect fossil (fig. 9), originally figured by Dixon, the presymphysial bone is provided with a powerful prehensile dentition. There is a median row of large conical teeth, widely and irregularly spaced, but smaller and more closely approximated in front than behind. These teeth are nearly thirty in number, and each has the form of a hollow cone, enamelled to within a very short distance of the base (fig. 10). The greater length of the enamelled portion is delicately striated, but near the tip the tooth suddenly tapers more rapidly and is smooth. A great number of similar teeth of small size—the largest being little more than one sixth the height of the largest of the median series—are placed irregularly upon the lateral margins of the bone; they are closely clustered together in more than one row, and perhaps somewhat more pointed than the median teeth. Like the latter, they are not placed in sockets, but merely anchylosed to the bone.

The large median teeth end abruptly at the posterior extremity of the presymphysial element; but the small lateral teeth are continued backwards upon the rami of the jaw, increasing in size and at the same time becoming relatively shorter and adapted for crushing. Anteriorly, for a very short space, the dentigerous margin is evidently formed by the true dentary (*d*); but this bone is soon excluded from the upper border, and the large splenial element (*spl*) takes its place. The suture between the two bones is well shown in the side view (fig. 8 *s*). Minute teeth extend far downwards upon the inner side of the splenial, and as the dentition becomes still more adapted for crushing behind, the upper margin of the element is considerably widened, until the anterior width of 2·5 millim. has passed into a horizontal extent measuring 8 millim. across. The teeth upon this surface are quite mamilliform—somewhat suggestive of the tubercles upon the test of certain Echinoids, like *Cidaris*; and some of the stages by which this extreme form is reached are illustrated in figs. 11–13.

It thus becomes evident that the original specimens described by Agassiz as portions of the mandibular rami of *Belonostomus cinctus* are really fragments of the presymphysial bone of this species.

In the closely allied genus, *Aspidorhynchus*, a relatively small, dentigerous, presymphysial bone has been known for some years, and its homologies have already been discussed, in conjunction with the corresponding element in certain Dinosaurs, by Messrs. Dollo * and Hulke †. It is only lately, however, that the same bone has been discovered in *Belonostomus*. A specimen of *B. speciosus*, Wagn., from the Lithographic Stone of Bavaria, described last year by Otto Reis (*loc. cit.*), reveals a presymphysial bone of considerable size, articulating with the mandible by a < - shaped suture; and a detached example of the same bone of the Liassic *B. Anningiæ* ‡, in the British Museum (no. P. 513), exhibits the same peculiarities (fig. 14). In *B. cinctus*, as described above—and as is especially well shown in the original of fig. 9—the surface of sutural union with the symphysis is one plane without angulation; and the presymphysial element itself may perhaps be relatively larger than in the earlier species. It may also be added that the mandibular rami of *Aspidorhynchus* present a very close approximation to those of *Belonostomus*, although the splenial, in the last-named genus, assumes greater importance as a dentigerous element, and the teeth it supports appear to be more adapted for crushing.

Some interesting general considerations are suggested by the foregoing brief study of the detached mandible, when taken together with certain other known points in the skeletal anatomy of *Belonostomus*; but these questions have been so recently discussed in the memoir by Otto Reis already quoted, that it will suffice in conclusion merely to note that he has treated the subject in detail.

EXPLANATION OF PLATE VII.

Fig. 1. Crushed head of *Squatina Cranei*, A. S. Woodw., natural size. Lower Chalk, Clayton, near Brighton: *ao*, antorbital process of cranium; *ch*, portion of ceratohyal; *ex*, excavated anterior extremity of cranium; *hm*, hyomandibular; *md*, portion of mandibular ramus; *pla*, postero-lateral angle of skull; *ptq*, pterygo-quadrate.

2. Anterior upper tooth of ditto, side view, twice natural size.
   2 *a*. Base of another, under view.

3. Anterior lower tooth of ditto, inner aspect, twice natural size.
   3 *a*. Base of another, under view.

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* L. Dollo, "Quatrième Note sur les Dinosauriens de Bernissart," Bull. Mus. Roy. d'Hist. Nat. Belg. vol. ii. (1883), pp. 226–229.

† J. W. Hulke, Presidential Address, Proc. Geol. Soc. 1884, pp. 47–51.

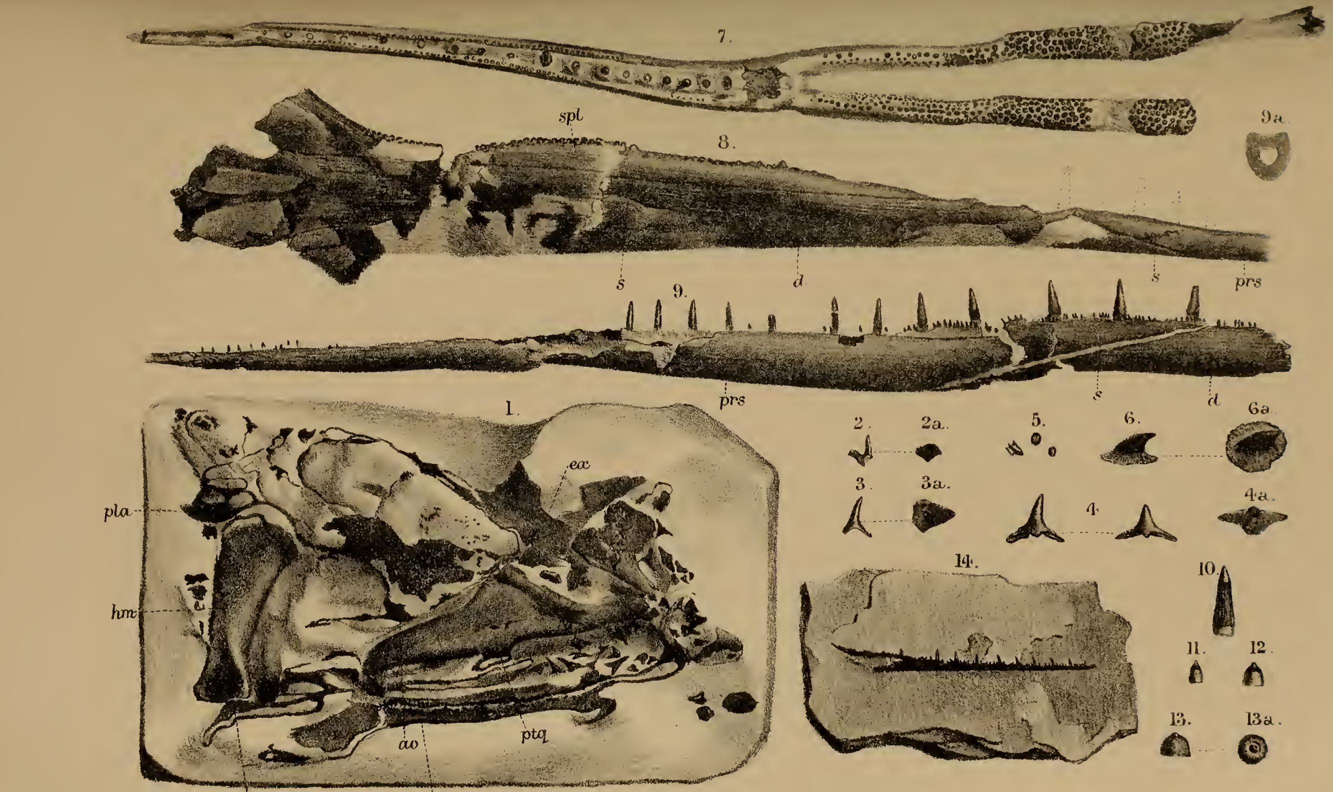
‡ Since the reading of this paper I have discovered that this species is truly referable to *Belonorhynchus*, Bronn, and is not improbably identical with *B. acutus*, Agass. sp.

Fig. 4. Posterior side teeth of ditto, twice natural size.
4 *a*. Base of another, under view.
5. Minute dermal tubercles of ditto, four times natural size.
6. Large spinous dermal tubercle of ditto, twice natural size.
7. Mandible of *Belonostomus cinctus*, Agass., viewed from above, two thirds natural size. Upper Chalk, Brighton.
8. Side view of portion of ditto, natural size: *d*, dentary; *prs*, presymphysial bone; *s*, sutures; *spl*, splenial.
9. Another presymphysial bone of ditto, showing suture, natural size. Upper Chalk, Brighton.
9 *a*. Transverse section of presymphysial bone.
10. Median presymphysial tooth of ditto, twice natural size.
11. Lateral presymphysial tooth of ditto, thrice natural size.
12, 13. Teeth of splenial bone of ditto, side view, thrice natural size.
13 *a*. The second, viewed from above.
14. Presymphysial bone of *Belonorhynchus Anningiæ*, Ag. sp., natural size. Lower Lias, Lyme Regis. [Brit. Mus. no. P. 513.]

The originals of all the figures, except the last, are in the collection of Henry Willett, Esq., F.G.S., Brighton Museum.

Discussion.

The President spoke of the clear manner in which the Author had laid before the Society the salient points of his paper, with the conclusions of which there appeared to be general agreement.



W. H. Crowther del. et lith.

Mintern Bros. imp.

CRETACEOUS SQUATINA AND BELONOSTOMUS.

14. *The* Red-Rock Series *of the* Devon Coast-section. By the Rev. A. Irving, B.Sc., B.A., F.G.S. (Read January 11, 1888.)

A stay at Sidmouth during the past summer (supplemented by a second visit to the county in the Christmas holidays) has afforded me the long-wished-for opportunity of forming a personal acquaintance with the Red-Rock series of the Devon region, rocks which were described many years ago by Mr. Godwin-Austen * under the name of New Red Sandstone, and have been more fully described since by Mr. Ussher †. The paper by the latter author is of great value, as it is a very mine of facts and observations. In working along the coast-sections, however, I saw reasons for doubting the correctness of including the whole series in the Trias, and as I went on and compared what I observed with the results of the work of former years ‡ in the Dyas and Trias of Germany and of the northern and midland counties of England, I was forced to the conclusion that in the Devon region we have those two systems represented.

I propose to lay before the Society in this paper an account of the observations which I have made, and to state the conclusions which (on comparative grounds) I have drawn from them.

Sidmouth (East).

(1) The escarpment of the Sid, for some 300 yards from its mouth, consists of about 50 feet of thick-bedded coarse sandstones, of a prevalent peppery-grey colour, in fresh sections, the general red colour of their weathered surfaces being due to rain-wash from above and subsequent infiltration. They exhibit magnificent current-bedding, such as we commonly meet with in the Bunter. They are slightly brecciated. Intercalated with these and quite subordinated to them stratigraphically are current-bedded breccias in a marly matrix, the contained fragments being mostly of indurated red marl. This series is seen dipping east in the coast-section and passing under

(2) A series of massive beds of sandstone of finer texture, of a pale French-grey (except on their weathered exterior §), containing occasional fragments of red marl from which the calcareous matter has gone, and from the surfaces of which the iron has been leached out, so that they have acquired a superficial tint like that of the mass of the sandstone in which they are found. Only the very feeblest current-bedding is seen in these sandstones. Subordinated

* "The Geology of the South-east of Devon," Trans. Geol. Soc. vol. vi.

† "The Triassic Rocks of Somerset and Devon," Quart. Journ. Geol. Soc. November 1876.

‡ *Vide* Geol. Mag. dec. ii. vol. ix. (1882), dec. iii. vol. i. (July 1884); Quart. Journ. Geol. Soc. November 1876, *ibid.* August 1884; Proc. Geol. Assoc. vol. iv. "Notes on the Geology of the Nottingham District."

§ The irony colouring-matter has penetrated in some cases to a depth of 3 or 4 inches.

to them, and increasing in importance as we ascend the series, proper Keuper marls occur, mostly brown-red, but variegated with pale-grey layers and irregular patches. The first important marl-bed is from 10 to 12 feet thick. The sandstone bed next above this is 10 feet thick. In some of these marls there are included well-rolled blocks of an older marl, the parent rock of which we shall perhaps be able to identify as we proceed.

(3) Next, in ascending order, comes on, by a gradual transition, a series in which marls predominate, the sandstones (although pretty persistent) being much more fully developed and quite subordinated to the marl-beds. These marls occur in very massive, well differentiated beds, with little or no lamination, very hard and tough, splitting on the face of the cliff in a rude prismatic and subcuboidal fashion, the fallen masses weathering subspherically. In the more fine-grained and compact varieties, where masses have been split off by frost action, the rock shows what one must be allowed to call "conchoidal" combined with "splintery fracture" on a large scale. This character of the beds is maintained through a vertical range of about 150 feet. Throughout this range the marls are characterized by the presence of numerous calcareous concretions *, many of these being geodes lined with crystals of calcite. I saw one rock mass on the shore, partly buried in shingle, of a decided tufaceous character; but this I regard as the result of deposition from the calcareous springs which escape from these beds on the cliff-face. Regular layers of the concretions described (like the layers of flints in the Upper Chalk) run through the more compact marls in parallel lines of bedding.

Passing from east to west (*i. e.* towards Sidmouth), the concretionary masses first crop out on the cliff-face about $\frac{1}{3}$ mile west of Salcombe Dingle, in a bed of rather sandy marl about 2 feet thick. From the pale-grey colour of this bed, it marks a very definite horizon, which can be followed with the eye all along the face of the cliff as it rises to the west, until it is cut off on the hill-flank. This gives us a very good upward limit for the concretionary calcareous series. So far as I could see, all the beds above this are more uniformly marly and devoid of these concretions.

(4) East of Salcombe Dingle the marls become gypsiferous for about 150 feet; and as they are continued upwards subordinate beds of pale green marls begin to appear. These become more pronounced higher up the cliff, until at last they supersede the deep red marls altogether. These pale-green marls were examined in numerous fallen blocks at the foot of the cliff, weathering subcuboidal (occasionally shaly). Traces of pseudomorphs after sodium-chloride crystals were noted, but time did not permit a thorough search for these. They are probably soon obliterated by the attrition of sand and shingle driven by the waves at high tides. The gypsum is only

* An analysis of the more compact portion of one of these nodules in my laboratory failed to detect any trace of magnesia. A further quantitative analysis gave 11·01 per cent. of carbonate of lime, and 1·01 per cent. of Fe_2O_3. The residue was for the most part a fine earthy powder, very little sand.

seen in veins, none apparently more than from 1" to 2" thick. There seems to be an entire absence of massive beds of anhydrite, such as occur at Newark and elsewhere in the Midlands; but the relation of the gypsiferous beds to the green marls is the same.

In this cliff-section to the east of Sidmouth we have the most complete development of the normal Keuper formation of the Midlands. I saw no trace of the Rhætic formation (properly so called) as represented in this country by the *Avicula-contorta* shales *. The pale-green marls here as elsewhere † cannot be separated on physical or stratigraphical grounds from the Keuper, of which they form the uppermost portion, though for purposes of mapping it may be convenient to include them in the "Penarth Series."

Beneath the Upper Greensand beds which cap the hills between Salcombe and Weston Dingles, the pale green marls are developed in such force as to mark the *uppermost horizon of the Keuper*. Owing to their inaccessibility on the face of the cliff, I could not determine their actual thickness above the highest red-marl bed, nor could I ascertain to what extent they may have been disguised by the down-wash of material from the Upper Greensand beds above. Estimating the thickness of the Keuper exposed in this portion of the cliff at 300 feet, and adding to this another 100 feet for the beds which crop out in the cliff below them to the west and above the calcareous series, we get about 400 feet of marls in which marked beds of sandstone seem to be of rare occurrence ‡. This, for some reasons, we might take as the approximate thickness of the Upper Keuper here; or, if we include in this division the 150 feet of beds marked by the prevalence of calcareous concretions, we get 550 feet. Then the Lower Keuper series of massive sandstones and red and variegated marls gives us another 60 feet. We thus get an estimate of 610 feet for the Keuper as against the 1350 feet estimated by Mr. Ussher §; or, if we allow, say, 50 feet for removal by denudation of pale-green marls at the top, an outside estimate of 660 feet. There is very little faulting in this part of the cliff; two small faults with an aggregate downthrow to the east of about 15 feet are cancelled by an apparent fault with a downthrow to the west of from 15 to 20 feet at Salcombe Dingle. The red marls at Seaton, which I examined about four years ago, I take to be a repetition of the beds in the middle part of the cliff between Salcombe Dingle and Branscombe Mouth, by the faulting which has let down the Chalk at Beer Head, just as in the beds east of the Sid those in the Peak and High Peak hills are repeated by the faulting at Sidmouth.

* By this is intended the series of paper-shales and thin-bedded sandstones, marked by the occurrence of the "bone-bed," of *Cardium rhæticum*, *Pecten valoniensis*, *Avicula contorta*, and *Pullastra arenicola*.

† *E. g.* at Newark and Edwalton (Notts), and in the Garden Cliff at Westbury-on-Severn.

‡ I saw on the beach a solitary block of ripple-marked sandstone, to the great abundance of which in the Upper Keuper of Notts I have previously drawn attention (Quart. Journ. Geol. Soc. November 1876, p. 515).

§ *Loc. cit.* p. 392.

Sidmouth (West).

The Chit Rock at the western end of the Esplanade is a portion of the same coarse, strongly current-bedded series which is exposed in part in the escarpment of the Sid, near the eastern end. The projection of this rock towards the sea is obviously explained by a great fault on its western face, by which it is brought against the calcareous concretionary series in its upper portion. Its "throw" cannot be less than 200 feet. The beds dip *west* from this fault for about 200 yards, when another fault of about 50 feet downthrow to the *west* occurs. From this point they gradually rise westwards, so as to form a gentle faulted synclinal. In consequence of this the dip of the Keuper beds in Peak and High Peak Hills is to the east, concordantly with the dip of those in Salcombe Hill to the east of the Sid. The highest beds accessible from the beach are marked by the same concretionary calcareous nodules as in the eastern cliff; there appears to be a similar upward limitation of them; and as the beds below crop out in succession along the shore, these conditions are maintained until their downward limit is reached on the outcrop of a massive marly bed, with many included lumps of grey and red marl (such as those described in the marls about the same horizon to the east); and to these a somewhat concentric laminated structure has been imparted, as if they had been rolled about in water while in a pasty state. This well-marked bed (on both sides of Sidmouth) makes a convenient horizon for separating the Upper Keuper marls from the Lower Keuper Sandstone series. The latter, with their interstratified red and variegated marls, attain here about the same dimensions (60 feet) as in the cliffs to the east; but the marls are more feebly developed. Such massive sandstone beds are (as is well known) a common feature of the Lower Keuper in other districts, as, for example, near Nottingham (Quart. Journ. Geol. Soc. Nov. 1876, p. 515), at Grinshill, Salop, and in the Severn country. The Grinshill stone, one of the most durable of sandstones, is quarried in them.

Beneath the beds just described as forming the Lower Keuper, the massive, strongly current-bedded (Bunter) sandstones, with intercalated marly breccias, crop out; and these are continued to the mouth of the Otter and Budleigh Salterton. As they are followed to the west they continue to rise steadily until Ladram Bay is reached, where a considerable (nearly vertical) fault occurs. The downthrow to the west cannot be less than 100 feet, since it has let down the Lower Keuper sandstone series of beds and a portion of the marls above them to a level with beds of rather a low horizon in the Bunter series. These Lower Keuper sandstones form the Lade Rock, the promontory on which the coastguard station is placed; and it is the boring of the sea through the weaker, current-bedded Bunter beds at the base which has formed the "natural arch," an object of curiosity to tourists and others. The beds then rise again westwards; but in the higher part of the cliff above the smaller bay to the west (separated from Ladram Bay by Bad-field's Point) the Lower Keuper series is recognized again. This is their last appearance in the coast-section as we work west. The very unequal weathering of these Bunter beds, owing in part to their being slightly but very unequally calcareous in places, has given to the cliffs and the outstanding "stacks" a very weird and grotesque appearance all along to Otterton Point *.

The Otter Mouth and Budleigh Salterton.

On the east side of the mouth of the Otter the deeply eroded Bunter cliffs are well worthy of study. Here we seem to come across the first traces of reconstructed materials from the great breccia series which occupies such a large extent of country further to the west and south. An irregular band of breccia † occurs intercalated with the sandstones, just above high-water mark. I searched the exposed portion of this minutely, but failed to find more than one or two fragments sufficiently rounded to be called pebbles; nearly all the fragments appeared to be slightly subangular. Among them I noted fragments of slate slightly cleaved (such as occurs around the granite on Dartmoor), vein-quartz, trap (various), reddish granite (the felspar slightly kaolinized), an older grit containing felspathic fragments, quartzite (dark grey, red, and yellow). The few pebbles which formed the exceptions to the rule were composed of either trap, quartz, or quartzite. A second breccia occurs hereabouts, in which all the contained fragments are of hard red marl. The matrix of both these breccias is fairly hard, owing to calcareous cementation.

On following the river escarpment inland for about a mile, this breccia-bed is met with frequently; and in some places I saw overlying it a fairly indurated sandstone, with pebbles and subangular fragments scattered rather freely through it, as so often happens in beds of the Middle Bunter. These beds are to be identified on the other side of the mouth of the Otter at the eastern end of the Esplanade, where 12 feet (vertical) of them are exposed, with the same breccia at their base, lying on an eroded surface of more homogeneous sandstone, a capital instance of "contemporaneous erosion." The same beds appear again (evidently on the same horizon by the dip) about 100 feet above the principal pebble-bed, west of the Rolle Hotel (see *infrà*).

A striking feature on both sides of the Otter is the occurrence of hard, liver-coloured, calcareous sandstone, in regular layers several inches thick, while the same material occurs as (apparently) infillings of curious irregular tubes in the sand rock, in such a manner as to suggest the ramifications of roots of trees in a soil, and the possible traces here of a Triassic "submerged forest."

In all the sections in which I have identified these coarse current-

* It is possible that these rocks on the cliff-face have undergone some 'hyperphoric' change, from the long-continued action of the spray of the sea.

† These I take to be the "Conglomeratic beds" of Mr. Ussher, *loc. cit.* p. 380.

bedded sandstones inland, they have a prevailing colour of yellowish white with streaks of red, becoming, of course, more reddened by exposure in road- and railway-cuttings, especially where (as it often happens) the surface-soil contains much red marl; and even in the cliff-section their variegated (bunt) coloration is in places observable.

The magnificent pebble-bed cut through in the coast-section at Budleigh Salterton has had so much attention bestowed upon it that it would be superfluous to attempt to describe it here minutely. While the "pebbles" are for the most part of quartzite, it should be noted that I observed in it occasional fragments of Dartmoor granite in an advanced stage of disintegration; but the important point is the index as to their origin (in many cases) furnished by their contained fossils of Silurian age. The bed thus appears to consist of a mixture of detrital material derived partly from the rocks of the ancient Devon highlands, and partly (mostly) from strata lying at a greater distance (perhaps in Cornwall or Brittany, or the intermediate region*). Whether the latter came *directly* from such sources or were brought into their present *locale* indirectly by the waste of older pebble-beds of Old Red age, we have, perhaps, no means of determining. It leads to the necessary inference that considerable changes in the physiography of the region must have taken place in order to bring into the basin materials from more distant sources than those from which the materials of the older breccias and conglomerates were derived.

It seems pretty clear that the two series were deposited in different hydrographic basins which were far from being conterminous with one another, the later (the Triassic) having been very much the more extensive. I have inspected the collection of Silurian fossils from the Salterton pebble-bed in the Exeter Museum, and have had the privilege of seeing the private collection of Mr. Vicary. The presence of these fossils in the pebbles, added to the extremely smooth and worn condition (the pebbly roundness) of some 90 per cent. of the Salterton pebble-bed (the materials which can be traced to the breccia series further to the west not exceeding, I should say, 10 per cent), together with the recognition in the fossils of a strong French type by Salter, argue strongly for the view which is here put forward.

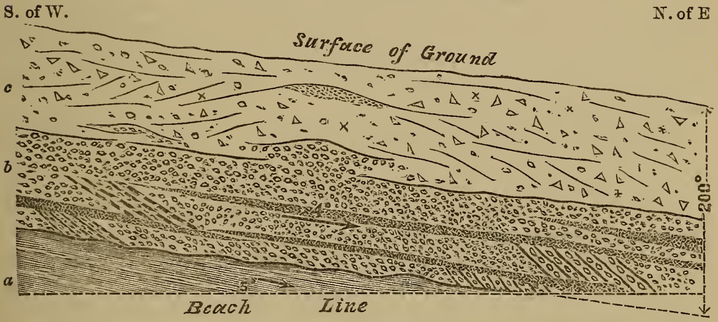
Whatever their source, there is to my mind very little difficulty in recognizing in the beds which contain them representatives of the great Middle Bunter pebble-beds, as these are splendidly developed at Sutton Coldfield and elsewhere in the Midlands; even the pitting of the pebbles by the crunching effect of mutual pressure is as common in the one case as in the other; but they are not the sole representative of that division of the Bunter. In the strata which occur for about 100 feet above the main pebble-bed, and are in part parallel and interdigitate with it, I recognized the *pebbly sandstone* of the Middle Bunter, as this is exhibited in the Castle

* Compare Bonney, Quart. Journ. Geol. Soc. vol. xl. p. 25.

Rock at Nottingham, on the Nottingham Forest, at Sneinton *, and in many other places in that district. We thus get about 200 feet of beds in the Devon coast-section, with a distinctly *Middle Bunter* facies, just in the position, with reference to the Keuper, in which we should be prepared to find them, if we recognized in the current-bedded sandstone series between them and the Keuper basement-beds the equivalents of Prof. Hull's *Upper Bunter*.

The Deep Red Marls which crop out beneath the pebble-bed in the cliff at Budleigh Salterton differ, so far as I have observed them, in some respects from the undoubted Keuper Marls to the east. There appears to be just that difference which those who are familiar with them could hardly fail to recognize between the Keuper and "Permian" marls of Nottinghamshire. Of these latter I consider the red marls at Budleigh Salterton the representatives. In colour, in their fine argillaceous composition †, in their way of weathering, in the frequent occurrence of small grey-green specks of more calcareous material, in the apparent absence of any very distinct stratification, there is, to say the least, a strong similarity between these and the Permian Marls which are associated with the Magnesian Limestone in Nottinghamshire. I have but little doubt that the weathering

Diagram-section showing junction of the Budleigh-Salterton Pebble-bed and Permian Marls.



a. Marls of deep purple-red, referred to the Post-Carboniferous (Permian).

b. The Budleigh-Salterton Pebble-bed, strongly current-bedded in parts, with strong bands of coarse irony current-bedded sands intercalated.

c. Coarse current-bedded irony sandstone, with pebbles of quartz and quartzite and angular and subangular fragments of (in some cases) younger rocks scattered through it (fragments of the marls *a* very common). A type of pebbly sandstone very frequent in the Middle Bunter of the Midland Counties.

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* There is at present (Sept. 1887) a very fine exposure of these beds in the railway extension works in progress at this place. Above them lie about 8 feet of thin-bedded sandstones which, I think, Prof. Hull would call Upper Bunter.

† This comes out in the superior qualities (compactness, hardness, density) of the bricks made from them. This is well known in the Nottingham district; and at the Society's meeting I exhibited a portion of a very fine-grained paving-brick made from these (Permian) marls at brick-works situated just below the boundary of the pebble-bed, on the Exmouth road.

and disintegration of these marls has furnished the numerous indurated fragments of precisely similar marl which are found (as described above) throughout the series of beds which I have ventured to identify as the Bunter; and it would be difficult to deny that it is to these marls that we may look for the finer marly detritus which constitutes the material of the intercalated (often lenticular) marly bands of that formation in Devon as in the Midlands.

At the base of the Salterton pebble-bed we have, I believe, direct evidence of a physical break in the series. It may be summarized thus:—

(a) *Stratigraphical.*—Not very direct or conclusive. Taking the sandstone-beds as indicating the dip of the pebble-bed as a whole, a careful measurement gave a dip 4° N.N.E. An equally careful measurement of the dip of the underlying marls along the line of one of the even pale-grey bands, where the marls first appear from beneath the pebble-bed on the shore, gave a dip 5° N.N.E. Half a mile west of Budleigh Salterton is a fine gorge in which the horizontal strike of the pebble-bed is seen running due N. and S.; the dip noted above must be therefore very nearly the true dip of the pebble-bed. There is a considerable discordancy of dip among the marl-beds themselves, so that it is not easy to say what the general dip of that formation may be. Beyond the gorge just mentioned both they and the pebble-bed are nearly horizontal in the upper part of the cliff; and west of the coastguard station I measured the dip of the marls and found it *nil* on both the converging sides of a cove about 300 feet above the shore.

(b) *Physical.*—This I consider to be strong. (i.) The pebble-bed at Budleigh Salterton lies on an eroded surface of the marls. This is not always seen on the cliff-face, owing to the lodgment of fallen débris from the pebble-bed above on the projecting ledge formed by the more coherent marls; but at and near the easternmost portion, where the loose débris is swept away by the waves, it is very clear (see diagram, p. 155). At the eastern end I found a surface of several square yards, showing erosion into a wave-like form, exactly as in the Reading Clays (*e. g.*) beneath the quaternary gravels. *This surface was coated over with a limonitic paste, which followed the inequalities of the surface, and filled up the interstices between the pebbles above*, sometimes for as much as a foot or more. It is undoubtedly a deposit by infiltration through the pebble-bed. At one place a layer of reconstructed marl was seen about two yards up in the pebble-bed—evidence, as I take it, of contemporaneous denudation of these marls. The erosion of the marls at the base of the pebble-bed may be seen by the side of the footpath up the gorge. (ii.) There is no trace whatever of a passage. The Red Marls (an indurated silt of the finest powder) give place suddenly and abruptly (without any sign whatever of approaching change in the marls) to a deposit of the coarsest rolled detritus, as strongly current-bedded as any I ever saw. The change is in fact such as can only be explained by previous induration and planing-off of the marls, contemporaneously with such changes in the physiography of the region as must imply a considerable lapse of time.

Taking the evidence altogether, there appears to be about as great a break as that insisted on by Mr. Aveline in the Nottingham and Yorkshire area; not quite so great perhaps as that described by me at the same horizon in Central Germany (Thüringen, Meerane), but certainly as great as has been recognized by our sub-committee (Permian and Trias) at this stage of the British geological series.

Here, then, we seem to have recorded a certain *definite break in time*, and to have reached the *lowest limit of the Trias*, as it is exhibited in the coast-section; and if we recognize in the 200 feet of the sandy series next above (including the chief pebble-bed) the equivalent of the Middle Bunter of the Midland and Cheshire Area, it will be seen that the absence here of the whole of the Lower Bunter marks *a stratigraphical as well as a physical break in the series.* One thing I assert with some degree of confidence, namely, that the rocks of the Devon coast-section, from the base of the Budleigh-Salterton pebble-bed to the base of the Keuper (as it is defined in this paper), are the Devon equivalents (taken as a whole) of the Bunter series, as worked out and demonstrated many years ago by Prof. Hull * in numerous sections.

The Breccia-Series.

In this are included the "Lower Sandstone" group of Mr. Ussher; for in these true breccias seem to form a very large proportion of the rocks, and even the interbedded sandstones are often markedly brecciated, as may be seen in the railway-sections between Star Cross and Dawlish. They form apparently the upward extension (with a more sandy facies) of the more uniformly brecciated series which is so splendidly developed in the bold cliff-sections between Dawlish and Teignmouth.

The following points seem to me specially worthy of note, by way of contrast between these breccias and the strata which I have recognized above as constituting the Trias of Devon:—

(1) They are distinctly brecciated (more or less) throughout, with a very crude stratification, and appear to be a series of terrestrial and littoral deposits on the flanks and near the shore-line, probably in land-locked bays, of the Palæozoic and Archæan mountain-region, of which Devon, Cornwall, Brittany, Wales, the Isle of Man, Cumberland, the Scottish Highlands, the Outer Hebrides, the Shetlands and the Orkneys are but the "worn-down stumps," as I have previously suggested elsewhere †.

(2) Their high inclination (the dip being, I believe, never less than 10°, though often 20° or more) is a fact to be perhaps explained by their being mainly composed of the detritus of a mountain-system (somewhat as the Rigi Conglomerates are related to the

* *Vide* 'Permian and Triassic Rocks of the Midland Counties,' figs. 28, 41, 45, 47, *et passim.*

† Quart. Journ. Geol. Soc. Feb. 1883, p. 79; also August 1884, p. 400.

higher and older Alps) undergoing subaërial waste, and not of necessity resulting altogether from subsequent upheaval. For the most part the (false) dip is probably only current-bedding on a large scale. Vast accumulations of such detrital matter are not unfrequently met with in the wider parts of modern Alpine valleys as the work of great downpours in the mountains *.

(3) These breccias, as compared with the softer rocks of the Trias (even though the matrix is much less calcareous), are much more indurated. This may not appear so manifestly on the weathered surface of the rocks as where the rock is quarried and used for building-stone.

(4) As pointed out long ago by Mr. Godwin-Austen †, and more recently by Mr. Ussher ‡, the materials of the breccia-series appear to have been derived wholly from the adjacent primæval land, exactly as those of the Rothliegendes are traceable to the older porphyritic and other rocks of Thüringen, where they flank that ancient mountain-island, and to the syenitic rocks of the Dresden region further to the east §. On the other hand, the materials of the Triassic series (as that term is limited in the present paper) do not admit of such a distinct derivation; they are rather admixtures of reconstructed materials from the breccia-series with materials brought from other and probably more distant sources. The distinction holds good in the Devonian region as in that of the Thüringerwald and other parts of Central Germany.

(5) The larger fragments (boulders, in fact) included in these breccias seemed, so far as I observed them, to be just about as much rounded off by the rolling action of water as we commonly observe in the diluvial detritus which is frequently met with where great mountain-gorges terminate in lakes. The valleys, moreover, which intersect the Northern Alps often exhibit just such accumulations of detritus for miles, in the clean sections cut by the erosive action of the present (and, in some cases, of older) rivers.

On the other hand, I failed to observe a single "pebble" of the Salterton type in any of the sections of these breccias or in the blocks of fallen débris on the shore, though constantly on the look-out for them; and inquiries made of intelligent residents at Teignmouth led to the same negative result ||.

* A few summers ago I observed such a widespread sloping mass of material brought down from the mountains by a single storm, and spreading (with a general slope of about 10°) right across the wide valley below Davos-am-Platz; fields and gardens were all obliterated, and the high road had to be re-excavated, a good example of a *Schlammstrom*. Similar work was done in the Puster Thal in the autumn of 1885. *Cf.* also Lyell, 'Student's Elements,' 3rd ed. pp. 19, 20, and fig. 7.

† Trans. Geol. Soc. vol. vi. pp. 453–7.

‡ *Loc. cit.* p. 388.

§ See Quart. Journ. Geol. Soc. August 1884. Compare also the derivation of the "Brockram" of the Vale of Eden from the Carboniferous Limestone (Geikie, 'Textbook,' p. 758).

|| I made a special, though fruitless, search for them in the enormous quantities of fallen material of the more conglomeratic strata between the Ness and the inn known as Labrador.

(6) The deep rich red colour of the rocks of the breccia-series and the marls, as compared with the comparative absence of colour in the Bunter (except on weathered surfaces), is another (though minor) point of distinction. This difference extends even to the colour of the soils, the deep crimson-red of the fresh-ploughed fields over the area occupied by these rocks being (as in the Thüringen country) at once distinguished by the eye from the reddish-brown colour of the soils of the Triassic region *.

(7) The admixture (as pointed out above) of materials derived in all probability from these breccias with materials from more distant sources in the Budleigh-Salterton pebble-bed.

(8) What is perhaps the most significant fact of all after (7) is the difference between the general direction (if there is one) of the dip (and consequently of the strike) of the breccia-series as compared with that of the true Triassic series.

In the study of the diagram (fig. 1) which accompanies Mr. Ussher's paper (Quart. Journ. Geol. Soc. *loc. cit.*) it is obviously necessary to bear in mind the fact that the coast-line at the mouth of the Exe takes a turn to the south, and the general dip for that portion of the section is nearly in the direction north.

In the upper part of the Crediton Valley about a mile above Yeoford Station, some fine railway-sections show a dip of 10° W. (20° S.). It is well seen in the cutting on the Plymouth line, which is in the plane of dip, as proved by the horizontal strike of the beds (1) in the vertical weathered face of an older section at right angles to this line, (2) in the cutting near by on the Barnstaple line, which by the compass is at right angles to the Plymouth line. The direction of the dip and the nature of the detritus both point to the great felspathic outburst of the Posbury Hills to the east as the source of the materials. Mr. Ussher records a similar local dip of 10° S. on the north side of the valley (p. 391).

There is a very fine fresh section just south of Dawlish, the cliff having been recently shorn down to a smooth surface, where the fall of the cliff happened some two years ago. A comparison of the beds, here laid bare in the most perfect fashion, with the beds which rise to the south on the other side of the gorge reveals the presence of a fault with a downthrow of about 150 feet to the south, the several beds being easily identified on either side of it †.

Conclusions.

I. The rocks which have been described as a sort of reduplicated Trias (recognizing six divisions) seem to fall into *two separate and*

* *Cf.* Jukes, 'Manual of Geology,' p. 608; Geikie, 'Textbook,' p. 751.

† With reference to the importance here attached to the very brecciated character of this lower series, as compared with the "pebble-beds" of the Bunter, attention may be drawn to the value assigned by Sir Charles Lyell to such evidence. See 'Student's Elements,' p. 381, 3rd ed.

independent systems *—the Post-Carboniferous and the Trias—between which a certain break seems to be indicated at the base of the Budleigh-Salterton pebble-bed.

II. The Post-carboniferous (Permian) of Devon seems to maintain, in broad outlines, the Dyassic order of the German series. The great breccio-conglomeratic series (including the Lower Sandstones of Mr. Ussher) is recognized as the equivalent of the Unter-Rothliegendes of Germany, even to the extent of assuming a more sandy facies in the higher beds, as that formation does, *e. g.* near Gera, where it visibly underlies the Zechstein and overlies the contorted Culm-Measures with seams of anthracite; and again at the base of the Wartburg Hills, where it is seen underlying the Zechstein series in the splendid sections at Eppigsnellen on the one side, and on the other side in the sand-pits by the Frankfort road beneath the Wartburg (as well as in Wilhemsthal below the Hohe Sönne), subjacent to the granitoid breccio-conglomeratic series of the Ober-Rothliegendes.

The "Lower Marls" of Mr. Ussher appear to be the southern equivalents of the Magnesian Limestone series of Durham, and the representatives of the "Permian" Marls of Warwickshire and Staffordshire, an intermediate facies of the upper division of the Dyas appearing in the interstratified series of Magnesian Limestones and Red Marls of Nottinghamshire.

The Lower Sands of Mr. Ussher must be regarded as merely the transitional assortment of materials between the breccias and the marls; they are thus all three closely linked together in one and the same *geological system*.

III. From the base of the Budleigh-Salterton pebble-bed upwards we have the English Trias (properly so called) of the Midlands repeated in outline. While there may be room for difference of opinion as to the correlation of the several divisions of the Bunter of Devon with those of the Bunter of the Midlands and of Salop and Cheshire †, the Keuper of Devon (as the term is limited in this paper) presents quite the normal facies of the Keuper of those regions.

IV. The much lower estimates given in this paper for the groups of strata here recognized as Keuper and Bunter respectively than those given by Mr. Ussher, owing to repetition of the beds by faults, compare very well with those of Prof. Hull for the same formations (Keuper 500 or 600 feet) as they are developed in Nottinghamshire and Gloucestershire ‡.

V. I need hardly say that Mr. Ussher's suggestion that the Salterton pebble-bed may be the homotaxic equivalent of the Muschelkalk must appear to me altogether inadmissible. It is far

* No objection could perhaps be urged to the comprehension of the whole Devon series under the older term 'New Red Sandstone,' as was done by De la Beche and Godwin-Austen; and this, if admitted, is a condemnation of their inclusion under the name *Trias*, a term of much more restricted range.

† See Jukes, 'Manual of Geology,' p. 608, fig. 160.

‡ 'Permian and Triassic Rocks of the Midland Counties,' p. 103.

more likely that this is to be found in the lower part of the sandstone-marl series of the Keuper (as here defined); and those who are familiar with the succession in continuous sections of the Bunter, Muschelkalk, and Keuper of the German area (*e. g.* in the hills about Jena, in the Ramsberg and Hörselberg on the north side of Thüringen, and in the valley of the Upper Neckar) will not, I think, be prepared to deny that such a partial equivalency may exist. But when all this is admitted, it is of high importance not to forget the great attenuation of the Muschelkalk and its gradual assumption of a more arenaceous character in the direction of the British area *.

It would not be right to overlook the fact that there is much less clearness of definition (stratigraphically) between the Bunter and Keuper of the Devon area than there is between the same two formations in those parts of the Midlands (*e. g.* about Nottingham) where the Upper Bunter is wholly, or for the most part, wanting. When this is taken into account along with the fact of the unusually calcareous nature of the 150 feet or so of strata above the Lower Keuper sandstones, and with the further fact that many of the limestones of the Muschelkalk contain more or less clay (Credner, Elem. der Geol. p. 497), it does not seem unreasonable to recognize a possible homotaxial equivalency between this group of beds and the Muschelkalk. The suggestion of Mr. J. H. Blake, with reference to another portion of this region which Mr. Ussher has quoted †, is therefore probably deserving of more consideration than he seems willing to allow.

VI. I stated four years ago (Quart. Journ. Geol. Soc., August 1884), after my work in Central Germany, with reference to the Dyas and Trias of Central Europe, that "not only is there a stratigraphical break, but a marked petrological contrast between the two groups" (p. 396); and, again, "The direct relation of the Rothliegendes to the character of the adjacent (older) land, which is so marked throughout that formation, and is generally wanting in the formations of the Trias, serves to establish a general broad physical distinction between the two groups of strata, as they are developed in Central Europe" (pp. 397, 398).

These statements (*mutatis mutandis*) I consider applicable to the Devon Red Rock Series. The great breccia-marl series consists of the roughly assorted direct products of atmospheric waste and degradation of the Devon palæozoic land, the true Trias of the region being derived partly from these older sediments, and partly composed of materials brought into the basin from other areas, owing to some of those changes in physiography of which the Post-Carboniferous rocks contain such plain records over great parts of the European area.

Some remarks of Mr. Ussher himself (Quart. Journ. Geol. Soc. vol. xxxii. pp. 393, 394) show that the difficulties of grouping the

* *Vide* Geol. Mag. dec. ii. vol. ix. p. 276; also Quart. Journ. Geol. Soc. August 1884, p. 401.

† *Loc. cit.* p. 380.

whole Red Rock series of Devon in the Triassic System were not altogether unperceived by him; and I have little doubt that on further consideration he will be led to suspect, as Sir A. Ramsay was inclined to do (*loc. cit.* p. 394), that the Lower Breccia-series may be of Permian age. We certainly are "at a loss to account for them," *quâ* members of the Trias, as Mr. Ussher saw, from their absence in the Somerset area, and, as he has shown in a subsequent paper (Quart. Journn. Geol. Soc. vol. xxxv. pp. 245 *et seq.*), in Normandy, where the marginal conditions of the Triassic basin proper of the south-west seem to be recorded.

As the Thüringen conglomerates are the land- and shore-deposits accumulated from the degradation-products of the adjacent palæozoic land; as the great Permian breccias of the west of England are related to the older land further to the west; as (to my mind at least) the so-called basement-beds of the Carboniferous series of Northumberland are but the still older local degradation-products of the old Cheviot mountain-island; and as, lastly, the great conglomeratic Nagelfluh of the northern Alps (*e. g.* of the Rigi) shows the clearest evidence of direct derivation, by subaërial waste and the transporting-agency of mountain streams, from the highlands exposed by the great elevation which followed the period of the Nummulitic Limestone, the *terrestrial* conditions under which they were accumulated being shown (in some cases) by the inclusion in them of seams of coal; so, it appears, in the Devon area a record of similar physical conditions may be recognized as marking the Post-Carboniferous period, with which the palæozoic history of the globe terminated.

Then as to the deep-red marls, which in this paper are assigned to the Permian, these bear a relation to the breccia-series remarkably similar in some respects to that which the Löss bears to the older and coarser detritus of the valleys of the Danube, the Rhine, and other rivers of Central Europe. Recent investigations by Dr. Jentsch and other observers quoted by von Hauer, in his masterly work 'Die Geologie' (pp. 706–707), have led to the rejection of Richthofen's theory as to the æolian origin of the European Löss, without denying its application to that of Central Asia. The marls, with which we are here concerned, are not supposed to be a Permian normal Löss. They agree with it petrographically in the extreme fineness of their material (a grain of $\frac{1}{2}$ millim. in diameter having never been found in the true Löss), in their homogeneity, and in the general want of definite stratification; but they differ from it in the large proportion of argillaceous material they contain, the Löss being essentially an extremely fine sand. But on the lower slopes of the Carpathians, contiguous to the trachytic regions of these mountains, there is a lower member of the Löss, known to the Austrian geologists under the vernacular name of "Nyirok," a "for the most part reddish, tough, plastic clay, which contains no trace of organic remains, and is always found at higher elevations on the mountain-slopes than the true Löss." This is considered by Szabo, who has most fully investigated it, to be "the final product of the weathering of different trachytic rocks, and to be essentially related to *laterite*." Wolf distinguishes in Northern Hungary the diluvial marginal deposits of the mountains from the contemporaneous deposits formed in aqueous basins. The former he describes in ascending order as breccias (Schötter), Nyirok, and Löss—the latter as drift-clay, drift-sand, and Löss-sand. Stur, again, draws a distinction between the "mountain-löss" and the "valley-löss," the latter containing freshwater molluscan remains *. By comparative reasoning it is not difficult to assign a similar terrestrial origin to the Permian Marls; and this is a sufficient explanation of their entirely unfossiliferous character. The siliceous rocks of the ancient mountain-system, of which the palæozoic land of Devon, Cornwall, and Brittany are the remains, would furnish by their subaërial destruction the materials for both the breccias and the marls, the intrusion of the Dartmoor granite *massif* being in all probability connected with the great upheaval, which would give us both the supply of materials and the conditions for rapid disintegration and degradation of the mountain-land of the south-west which our hypothesis requires.

The intensely ferruginous character also of the breccias, sands, and marls alike (the state of the irony investment indicating contemporaneous precipitation by oxidation) points indirectly to immediate Post-Carboniferous times, for the extensive waste of vegetation which would be required to furnish the natural solvents which produced the solutions from which precipitation was effected.

Discussion.

The President pointed out the interest attaching to the question. The absence of Prof. Hull and Mr. Ussher was to be regretted.

Mr. Smith Woodward called attention to a supposed spine figured by Mr. Metcalfe in the last contribution to the present subject, published in the Society's Journal (vol. xl. p. 260). Prof. Huxley's recent researches upon Triassic Rhynchocephalians enabled this fossil to be determined as a portion of the premaxilla of *Hyperodapedon*.

* See also Senft's description of the formation (Bildungsmassen) of the Rothliegendes of North-western Thüringen, 'Gaea, Flora und Fauna der Umgegend Eisenachs,' pp. 29, 30.

15. Supplementary Notes *on the* Stratigraphy *of the* Bagshot Beds *of the* London Basin. By the Rev. A. Irving, B.Sc. (Lond.), B.A., F.G.S., Senior Science Master in Wellington College. (Read January 11, 1888.)

In this paper it is intended to lay before the Society the results of additional work in this Formation done during the year 1887. It deals with the succession of the beds all along the northern margin of the district, from Farley Hill near Reading to Englefield Green, and with the development of the formation in the more westerly portion of the area (basin of the Kennet).

Part I.

In this part of the paper I shall attempt to show from the description of numerous sections that the inference as to marginal conditions in my last paper is found to hold all along the northern flank of the district.

In the recent discussion of this subject some ambiguity has crept into the use of the term "Middle Bagshot." For my part I have, as I believe, consistently used the term throughout with the exact connotation which I gave to it in the year 1883 *, and in the Quarterly Journal of the year 1885 (vol. xli. p. 494). In the Wellington-College section it is seen to include beds of the horizons Nos. 3–10; and whenever I have found a complexus of beds answering in general physical character to these, I have assigned them to the Middle Stage without taking the empirical consideration of mere thickness into account; since in none of the deep-well sections of the interior of the district have we anything approaching to a recurrence of such a series in either the Upper or Lower stages.

North Flank of Easthampstead Plain and Chobham Ridges.

Referring now to fig. 1 and section E of my last paper †, I proceed to consider a series of sections in which we can recognize (wholly

* Proc. Geol. Assoc. vol. viii. pp. 144, 146. On this point I am, I believe, quite in harmony with the Survey, and with Prof. Prestwich (see Quart. Journ. Geol. Soc. vol. xliv. "On the Correlation of the Eocene Strata").

† During this winter the basement-line of the beds Nos. 9 and 10, with fine whitish quartz sands (No. 11), current-bedded below, has been exposed to open day in a sand-pit 470 yards east of the new Wokingham road, and 120 yards north of Nine-mile Ride, at 230′ O.D. This is found, when scaled, to be in perfect stratigraphical alignment with the altitudes given for that horizon in the table on p. 384 (Quart. Journ. Geol. Soc. vol. xliii.). In the clay-pit further to the east the dark grey sandy shales (of which about 6 ft. are exposed in the sand-pit just mentioned) are reached beneath 7 ft. of the "mild clay" (with ferruginous concretions), a very good brick-material, over which there lies 6 ft. of drift, consisting of contorted sands and pebbly gravel. Taking into account the altitude of the base of No. 10 (230′ O.D.), the depth of several wells, and the fall of the ground until the London Clay crops out, the 40 ft. obtained by scaling appears to be an outside limit of the thickness of the quartz-sand series (Nos. 11 and 12) as compared with the 92 ft. of them in the well-section at Wellington College.

or in part) the beds of the Middle Group. These sections will be found to lie almost in a straight line (nearly parallel to the general strike) with the outcrop of these beds three-quarters of a mile north of Wellington College (section E). Their outcrop on the northern flank of Cæsar's Camp is half a mile north of this line, and will be noticed in its proper place.

Section K *. *South side of Bull-Brook, near Red Lodge.*

a. Pebble-bed *in situ*, seen in the ditch near the corner of South Hill Park (300′ O.D.)	No. 3.
b. Loam and stiff clay, passing down into green earthy sand	Nos. 4 and 5.
c. Pebble-bed	No. 6.
d. Green earthy sands and loams	Nos. 7 and 8.
e. Clay and loamy ferruginous sand (250′ O.D.)	Nos. 9 and 10.
f. Fine quartz sand	No. 11.

Bed *d* apparently thins out entirely in the hill, on the north flank of which (N.E. of South Hill Park) only the clays appear to crop out. The altitudes give us a total thickness of about 50 feet for the group of beds which, on comparative lithological grounds, we can assign with a pretty high degree of certainty to the Middle Group, though the section is not sufficiently open to give us the several thicknesses of the individual beds.

The hill near the Deer Park, with a plentiful scattering of flint pebbles on its summit, owes its fine timber-bearing capacity to the clays of horizons Nos. 4 and 5, which are powerfully developed here and in the section last and next to be described. There is a good exposure of the Lower Sands, with thin seams of pipe-clay, in a sand-pit at the northern foot of the Deer Park hill; and on the south side of this pit the base of the Middle Group is seen, overlain by from 1 to 2 feet of the drift of the hill-slope (mixture of pebbles and reconstructed clay).

Section L. *Mr. T. Lawrence's Brick-field, Swinley.*

a. Upper Sands of Tower Hill (about 60′) with a good fresh exposure of 20′ in a new sand-pit (base 300′ O.D.).	
b. Loamy clay (a much-prized brick-material), passing down into a strong laminated clay (12′ to 14′)	Nos. 4 and 5.
c. Dark-green earthy sand full of flint pebbles at the top; proved beneath *b* in trial-holes, and cropping out at the north end of the brickfield.........	Nos. 6 to 8.
d. Mixed clay and sand bed, exposed in a pit close to the tramway (base about 260′ O.D.)	Nos. 9 and 10.
e. Fine quartz sand in the valley	Nos. 11 and 12.

* It is convenient to make the sections of this paper form a continuous series with those of my last paper (Quart. Journ. Geol. Soc. vol. xliii. August 1887). All the numerical references to the sectional order of the beds are (as in the last paper) to the section on p. 494 of vol. xli. of the Quart. Journ. Geol. Soc.

Section M. *Brick-pit in Hagthorn Hill, Ascot* *.

	feet.
a. Clayey drift-material of the hill-slope	2
b. Laminated clay-and-sand bed with irony concretions (No. 5)	7
c. Laminated purplish clay with subordinated layers of greensand (No. 7)	1½
[On the east side of the pit *c* thickens to 4 feet and becomes a normal green earthy sand.]	
d_1. Laminated layers of purplish clay with very little sand	1
d_2. Grey and green sand with subordinated layers of purplish clay	1
[d_1 and d_2 apparently=No. 8.]	
e. Hard chocolate-coloured shale, strongly laminated with glauconitic greensand in patches and small layers (=No. 9)	4 seen
(*f.* Portion not exposed, representing No. 10)	6
g. Fine quartz sand (No. 11) exposed to	4
Total of section	26½

[Bottom of this section about 250′ O.D.]

A slight dip to the south-east is observed in the beds in sections at right angles in this pit; a similar dip is observed in the railway-cutting † nearly half a mile to the south-east of the pit; and the lower levels of the beds of the Middle Group at Windlesham point to its continuation as far as that place. The dip is also perceptible in the railway-cuttings at Sunninghill. It gives us the pebble-bed (No. 3), 2 feet thick, on the northern nose of the hill, about 290′ O.D.

Section N. *Cutting on the South-western Railway, halfway between Ascot and Sunningdale Stations.*

	feet.
a. Clay (=No. 5)	5
b. Glauconitic green earths (Nos. 7 and 8)	14
c. Strongly laminated light purplish and grey clay (=No. 9)	6
(No. 10 apparently wanting.)	
d. White and yellow fine quartz sand (No. 11), exposed to the level of the line	4
Total exposure	29

[The level of the line here is about 200′ O.D.]

Comparing the altitudes given in the foregoing sections for the top and base of the Middle Group, there seems to arise a necessity for inferring the existence of a slight anticlinal (seen to be very slight indeed when drawn to true scale), with an axis running nearly through Bracknell, Swinley Park, and Windlesham, and inclining to the S.E. or thereabouts. This agrees with the general rise of the base of the Middle Group as it recurs passing eastwards

* *Cf.* Mem. Geol. Survey, vol. iv. p. 332.
† Quart. Journn. Geol. Soc. vol. xxxix. p. 349.

along Nine-mile Ride, and a similar slight rise of beds of the same horizon from Wokingham to Bracknell *. It also accounts for the slight dip to the west of the clay-and-sand beds at Bracknell noted below. As a stratigraphical fact its effect must be allowed for in correlating altitudes.

Sunningdale †.—The succession here is clearly marked. Close to the Station the Middle Group forms almost an escarpment. The hill is capped over a considerable area with a pebble-bed a little below 240′ O.D. This must be on the horizon of No. 3, as it passes with a gentle dip to the south under hills of the Upper Sands. On the eastern flank of this hill, below Titlark Farm, we find the section noted in the Quart. Journ. Geol. Soc. vol. xlii. p. 404, including about 10 feet of quite normal green earthy sands, with the underlying clays of the Middle Group.

The lower clay-beds (Nos. 9 & 10) crop out at the foot of the hill about the level of the Station, and were worked for bricks a little further north only a few years ago‡. The fine quartz sand (No. 11) is seen beneath the laminated clay-and-sand bed, in an old pit there at about 200′ O.D. At a rather lower level the London Clay is exposed along the banks of the brook south of Broomhall Farm§, and from this it would appear that about 30 feet is the most we can assign to the thickness of the Lower Sands at Sunningdale, beneath the Middle Group. The outlier (mapped i. 5) on Shrub's Hill is more extensive, probably, than is there represented. Its assignment to the Middle Group is verified by the occurrence of a strong dark-green sand (which did not appear, when I dug into it, to be reconstructed) all across the floor of an extensive gravel-pit in Potnall Wood ‖. A little way further north the London Clay is exposed on the south side of Virginia Water, according to the Survey-map, which I have verified. Due south of this outlier is Chobham Place, where 100 feet (? more) is recorded ¶ for the thickness of the Lower Sands in the well-section.

There is apparently considerable attenuation of the quartz-sand series (Nos. 11 & 12) in this hill.

The beds of the Middle Group are well developed in the Long-

* See fig. 2 of my last paper, vol. xliii. of the Quart. Journ. Geol. Soc.

† To my friend Lieut. H. G. Lyons, R.E., F.G.S., I am indebted for many stratigraphical details about this neighbourhood, to which he has drawn my attention.

‡ On the opposite side of the valley (*i. e.* the west side) a similar bed overlies the fine quartz sands in a road-cutting at a corresponding altitude: it is also exposed in Brick-kiln Lane, at Sunningdale village, with quartz sand in the valley below.

§ The Survey mapping here needs to be reconsidered.

‖ That part of the horizontal section of the Survey which cuts through this hill would be in perfect accord with the results of my observations, if the base of the Middle Group were drawn *in the same line as it is in the section further south.*

¶ Mem. Geol. Surv. vol. iv. p. 543. It is difficult to account for the record of 100 ft. of Upper Sands in this section. Prof. Prestwich tells me an old workman gave him the account from memory. The sections in the immediate vicinity give abundant evidence (clays and green earths) of horizons to justify the Survey-mapping, which represents Chobham Place on the Middle Beds (i. 5).

Cross Hills. There are traces of the pebble-bed all over the cap of the hill; the upper clays are exposed in a disused brick-field, a little way to the south-west, and there are some exposures both of this clay and of the underlying green earthy sands in several road-cuttings; a pond at the bottom of the hill (western side) is most likely on the lower clays of this Group. At quite a high horizon (certainly above the green sands) there is an exposure in a sand-pit of some of the most strongly 'false-bedded' sands * to be found anywhere. A similar instance was observed lately in a sand-hole behind the Wellington Hotel near Wellington College Station.

The section of the Lower Sands at Stroud Green (Quart. Journ. Geol. Soc. vol. xlii. p. 404), at about 50′ O.D., the section in the cutting north of Virginia-Water Station (with a line of pebbles and some slightly carbonaceous shales), and the 110 feet of sands pierced in the well at the Holloway Sanatorium †, show that they thicken out in the direction of St. Anne's Hill, where they probably attain their full normal development.

It will be observed that the foregoing sections of the Middle Group, showing the outcrop along the northern flank of the main mass of the formation, are all on the same line of outcrop as section E of my last paper. The direct correlation of them with the same group of beds in the Wellington-College Well is therefore a comparatively easy matter.

The Northern Line of Hills. (See Fig. 2 of my former paper.)

In considering the progressive, though not uniform, subsidence which admitted of the formation of the estuarine series hitherto known as the Bagshot Beds of the London Basin, I think that the evidence now before us, furnished by recently and formerly published deep-well sections, justifies us in considering the river-sands of the Lower Group as deposits formed in the silting-up of the more central parts of the London-Clay estuary; and that while the process was going on, the London Clay was in part exposed to that amount of denudation and erosion which we should expect on the margin of an estuary, evidence of such displacement as we should require for this being furnished in the Warfield Brick-yard. (See Section F of my last paper, Quart. Journ. Geol. Soc. vol. xliii.

* Another very fine example of false-bedding (oblique lamination) is seen in a section high up in the Upper Sands near the Rifle-butts, N.E. of Ash Vale Station. There is also much pipe-clay in thin laminæ. Such facts will be seen at once to discount largely the importance of these structural phenomena, on which so much stress has been laid, as evidence of horizons.

† Whitaker, 'Surrey Wells and their Teaching,' p. 66. I doubt the correctness of assigning the whole 110 ft. to the Lower Sands, as at Holm Lea, the residence of my friend Dr. Ginsburg, I have lately seen a capping of flint pebbles, and below these a strong clay-and-sand bed (proved to 12′) laid bare in excavations. The layer of pebbles (at a lower horizon), which is seen in the railway-cutting, is seen also in the fine white sand in a lane on the north flank of the hill. The clay-and-sand bed (which I regard as = Nos. 9 & 10) runs, I believe, through Callow Hill, its base being seen at the top of a sand-pit in Hunter's Dale, where 18′ of the quartz-sand series (Nos. 11 & 12) are exposed.

p. 386). To the evidence there adduced I now add the following facts:—(1) A new clay-pit at Warfield shows (so far as any bedding can be traced in the London Clay) a dip in accordance with that previously recorded. (2) The laminated clay- and-sand bed (referred to horizons Nos. 9 & 10), which rests horizontally on the London Clay in the brick-field, is found to do so also in two recent well-sections on the *western* side of the Bracknell Hills, and is exposed in the cutting to the west of the Station. (3) Along the *east* flank of the same hills the fine quartz-sand exposed at the Bracknell cutting is proved (by wells and other sections) to be intercalated between the clayey bed (which cannot, therefore, be a "passage-bed") and the London Clay, from Borough Green * to Holly Spring. (4) Strong lithological evidence of lower horizons of the London Clay (abounding in Septaria) in the brick-fields to the west †. Post-Eocene movements of the ground have probably given a slight tilt to the west of the Bagshot Beds in these hills. This may account for the higher level of the pebble-bed recorded in the eastern part of the Bracknell cutting, and so does away with any necessity for referring that to the Upper Bagshot. All this requires a slight alteration of the Bracknell portion of fig. 2, p. 388 of the Quart. Journ. Geol. Soc. vol. xliii.

The beds of the Middle Group (the two clays ‡ with the intermediate green earthy sands and traces of a pebble-bed above) crop out below the 300-foot contour north of Cæsar's Camp, with at least 100′ of Upper Bagshot above them. London Clay is found in the valley just south of Easthampstead Church, and has been proved lately in a well 12 ft. deep at the village school, indicating a considerable attenuation of the Lower Sands exposed in a sand-pit at the foot of the Church Hill on the east side. A line drawn due south from Cæsar's Camp passes halfway between Wellington College and Bagshot Orphan Asylum, at both of which places we know the thickness of the green earthy sands (41′ and 58′ respectively). Taking the mean of these (50′), and the intermediate distances, we find by ordinary rules of stratigraphy that the green earthy sands should have thinned away to 0 by the time Easthampstead Church is reached §. There seems therefore no longer any difficulty in understanding how the Upper Sands of Bill Hill with their subjacent pebble-bed come at once upon the beds of horizons Nos. 9 & 10 at Old Bracknell. (Compare sections F to I of my paper.)

* A fine section in a sand-pit near the inn.

† The fine yellow sands, "false-bedded," mentioned as occurring in this brick-field (Quart. Journ. Geol. Soc. vol. xlii. p. 405) I have never been able to find; but I have seen rather extensive masses of sands answering to that description included in an older (pre-glacial) gravelly drift, which rests on an eroded surface of London Clay.

‡ The lower clayey beds (Nos. 9 & 10) are very well exposed (5′ or 6′ vertical) at the back of the pond by the Bracknell road $\frac{1}{2}$ mile further west along the same line of valley. A good deal of the fine oak and beech timber of Easthampstead Park grows in the strong loamy soil furnished by these beds.

§ Compare note on Section K of this paper.

Ascot Hills.—As further evidence of the stratigraphical structure of the hills between Bracknell and Ascot, represented in the right-hand part of fig. 2 (former paper), I now submit the following:—(1) On the south flank of Long Hill we find the two clayey beds (No. 5, and Nos. 9 & 10) cropping out with the intermediate green earths (5 to 6 feet). The latter, not being found on the north slope, appear to thin away in the hill *. The Lower (fluviatile) Sands occupy the valley on both sides of Bull Brook, and there is a good exposure of them (about 25′ vertical) in a sand-pit on the north side of Long Hill. The beds of this hill admit of direct correlation with beds which crop out in Swinley Park and South-Hill Park. (2) A mile and a half further east, along the same line of hills, we find a similar succession of beds. Here, again, occur the two clayey beds, with green earthy sands between them, cropping out on the same flank of the hills, *vis-à-vis* of the Middle Group of beds which crops out from beneath the Upper Sands of Tower Hill in the Swinley brickfield †. The Lower Sands are exposed in the railway-cuttings, and in many smaller sections of the valley below, and have lately been proved to the water-bearing line, at a depth of 28 feet in a new well near Englemere.

These Ascot Hills, therefore, have a capping of Upper Sands, the base of which (about 300′ O.D.) corresponds in altitude with the base of the same sands along the southern side of the valley. It presents a very simple case of valley-erosion. The thinness of the Lower Sands in the floor of this valley, towards the west, accounts for the presence of Whitmoor Bog, which has somehow been mapped as London Clay. From what has been now stated it is pretty clear that the mapping by the Survey Officers all along this piece of country needs some revision.

If we could restore the beds removed by denudation across the valley of Sunningdale and Virginia Water, we should doubtless find the beds of the Middle Group continued along the southern portion of Windsor Park ‡, since at Englefield Green we have a succession very similar to that which we have described at Bracknell. The recent excavations in connexion with the new Beaumont College have proved (after clearing the run of the hill) that the London Clay reaches an altitude of 250′ O.D. on the northern flank of the hill. Upon this rests from 10 to 15 ft. of fine quartz-sand, which is found, at New Egham and Stroud §, to thicken southwards; and the whole hill is capped by a strong clayey bed, which there is no difficulty in assigning to horizons Nos. 9 & 10, with a pure pebble-bed in places at or near the surface ‖.

* Compare Section M at Hagthorn Hill.

† See Section L.

‡ The low hills around Virginia Water owe, I believe (from the small exposures examined), their magnificent timber to the outcrop of the strong loams of Nos. 9 & 10.

§ Quart. Journ. Geol. Soc. vol. xlii. p. 404.

‖ The altitude of the London Clay here is accounted for by a dip of the Tertiary beds, see Mem. Geol. Survey, vol. iv. fig. 50, p. 191: it is also shown by a comparison of the altitudes of the Chalk in well-sections at Windsor and Old Windsor (*ibid.* App.).

Towards the West.—Finchampstead, Bearwood, and Farley Hills.

Finchampstead Ridges.—All doubt as to the capping of these hills by Upper Bagshot Sands (see Mem. Geol. Surv. vol. iv. p. 335) is now removed. The highest points of the hill are respectively 333′ and 336′ O.D. There is, as usual, a heavy capping of plateau-gravel for which we may allow from 12 to 16 feet.

The sands are, or have been quite recently, exposed—(1) In a new road-cutting at North Court (glauconitic sand filling old root-stock holes in the uppermost bed)*; (2) in excavations for building at Sunnyside (300′ O.D.); (3) beneath the gravels in the pits; (4) in the churchyard at Finchampstead, and in a sand-hole and road-cutting close by; (5) in excavations on Pie Hill; (6) in the lane below Ridge Farm. The sands are quite 30 feet thick in the Church Hill, the highest point of which is 330′ O.D., with little or no gravel. In the eastern part of The Ridges they probably reach a thickness of 50 or 60 feet. There is a slight dip (about 1 in 340) in these hills towards the College Well, as found by a comparison of the levels of the base of the Upper Sands under Finchampstead Church, and of the pebble-bed, of which there are strong signs at the top of the clay in the ditches by the side of the road which runs from the Station to the top of the hill at the eastern end.

The outcrop of the beds of the Middle Group (pebble-beds, clays, and green earths) is to be observed in many places around their flanks. Following Barkham Ride, which runs N.W. along the flank of the hill from the Wellington Hotel, we find, as we should expect from the section in the railway-cutting and the well behind the hotel (see my former paper), the green earths of Nos. 7 and 8 cut into by the first line of erosion. The rise of the road takes us over the base of the upper sands, when we come to—

Section O. *Middle Bagshot Strata at Heath Pool.*

	feet.
a. Stiff clay (more sandy in places) (No. 5)	6 (250′ O.D.)
b. Pebble-bed (No. 6)	½
c. Green earthy sands and clays (Nos. 7 and 8), exposed in the side of the lake last summer, also in ditch- and road-sections below	20
Total exposure	26½

The mixed sands and clays (Nos. 9 and 10) crop out from under *c* a little further on, are continued along the road, then pass

* Probably for a long time the bottom of a post-Eocene marsh or shallow lake.

under the green-earth series again, only to crop out in the California brickyard. This settles the horizon of the clays at that place. (See below, Sect. Q.)

Section P. *Clay-pit at Wick Hill, Finchampstead.* 265′ O.D.

	feet.
a. Pebbly run of the hill	2
b. Loamy sand with green grains in rough layers	4
c. Dark green earthy sands with very distinct seams of purplish clay	3
[Layer of bog-iron-ore here.]	
d. Stiff clay, strongly laminated deep purple and chocolate-coloured, black and more shaly below	7
e. Stiff clay, drab-coloured, laminated, with patches of green glauconitic sand	4
f. Brown irony loam with much green glauconitic sand in subordinated layers, and irony nodules	6
g. Sand (proved to)	2
Total of section	28

Two small pits dug this winter at rather different levels on the other side of the hill have exposed the drab-coloured clay *e* of this section at the same altitude (at a distance of 250 yards) with 5 or 6 feet of normal green sand above (= bed *d*). Taking this into account, with the occurrence of patches of the same green sand in the beds of *e* and *f*, we may regard the beds *c* to *g* of this section as a local phase of the green-earth series (Nos. 7 and 8), the clays being developed at the expense of the green earths *.

Section Q. *Clay-pit in California Brickyard* (330 *yards north-east of P*).

	feet.
a. Sandy drift	2
b. Coarse sands with seams of strong grey clay, marked by very pronounced current-bedding with a *northerly* false dip of nearly 3°†	6
c. Mild clay (brick material), more sandy below, strongly laminated, with no appreciable dip in good sections at right angles (215′–235′, O.D.)	20
d. Grey-green dirty quartz-sand (proved in 2 wells)	6
Total exposure in pits and well-sections	34

The plentiful supply of water in the wells here points to the probable presence of London Clay at no great depth. The carbonaceous character of the under strata (*d*) is confirmed by the character of the water, its action on iron ‡, and analysis in my laboratory. In a sand-pit a little way to the north, in the wood,

* Compare Section M, where a similar lateral transition is noted.

† I doubt this being an Eocene deposit without excavating further into the hill.

‡ *Cf.* Geol. Mag. for September 1883 and January 1885; papers by the author on "Water Supply."

these sands are seen as clean fine quartz-sand, finely current-bedded, and overlain by the irony loam which often occurs at the base of No. 10, from the admixture of clay material with the sands next below. No. 10 can be traced in ditch-sections a good way to the west towards Longmoor, an extensive lake-basin dug partly in London Clay, just below the 200-foot contour. Near this a well at a higher level gave the following:—

Section R. *Well at Longmoor, Finchampstead.*

	feet.	
a. Gravelly drift	1	
b. Soft loamy particoloured clay (laminated), "like that dug at California, but not quite so strong"	3	(= No. 10).
c. Soft loose sand	12	(= No. 11).
	16	

Bed No. 10 is seen in a road-cutting on Nine-mile Ride, above the 200-foot contour, three-quarters of a mile west of California; and at another three-quarters of a mile west we come to the end of Nine-mile Ride, where London Clay is dug at 185′ O.D.

Western Spur of The Ridges. (*The Church Hill.*)—As this hill presents some rather puzzling points of structure, I may be excused for going more into details here.

1. By the levels of the new six-inch Map of the Ordnance Survey *, the highest point of this hill is 330 feet above O.D. The Upper Sands which cap this hill appear to be a continuation of those of The Ridges, not an outlier of them, as mapped by the Geological Survey.

2. A pebble-bed (2 feet thick) at the base of these sands is exposed, at 300′ O.D., at the first turn of the road behind the White Horse Inn and north of the church. It was proved ($1\frac{1}{2}$ foot thick) at 280′ O.D., 500 yards south-east of this point, by excavations made for me in the roadside, giving a dip S.E. of 1 in 71†, or rather less than 1°. In both cases the pebbles are imbedded in clay, and the underlying bed is clay. In The Ridges the clay of No. 5 seems generally to thicken and cut out the loamy sands of bed No. 4 of the College sections.

3. The lane turns sharply north of west from the above-mentioned point for 120 yards and descends 20 feet (as determined by levelling) to the small alder-swamp, fed by springs evidently from the base of the Upper Sands. This gives a dip of about 1 in $17\frac{1}{2}$ (*i. e.* from 3° to 4°) in this direction.

4. From this point the lane runs due west on these clays along the hill-flank for nearly 300 yards (showing absence of any

* The discovery of a discrepancy of some 20 feet in the levels around the crest of this hill as they are given on the older and the newer six-inch maps has necessitated the re-writing of this portion of the paper after communication with the Director of the Ordnance Survey, whose courtesy I have the pleasure of acknowledging here.

† Correcting this for the true dip, presumably towards the Blackwater, we get about 1 in 50, or rather more than 1°.

general dip in this direction), when we come to Section S (see below); but at the white gate an occupation-road strikes almost due north down the steep flank of the hill, evidently crossing the unexposed green earthy beds of Section S, since, at a distance of 275 yards, by the map, and at an altitude of 238′ O.D. by levelling, the clays of the California type, referred to Nos. 9 and 10, crop out, and these can be traced a good distance along a clean ditch to the north. They are seen again in the lower part of the lane leading east to Warren Lodge; and they are well exposed in the cutting on the Nine-mile Ride (referred to above, p. 173), 300 yards further to the north, with their base exposed in a ditch-section at 207′ O.D., below which the fine quartz-sands (No. 11) crop out plainly enough. I draw particular attention to the approximate agreement of levels of the clays which crop out beneath the green-earth series on the north flank of this western spur of the hills with those of the same clays in the California clay-pits (Section Q).

In considering the above facts, we have to choose between three possible explanations of the altitude (300′ O.D.) of the pebble-bed at the corner of the lane north of the church. Either (1) the clays of the horizon, No. 5, are suddenly developed to a thickness of from 30 to 40 feet; or (2) a clay with a strong pebble-bed occurs 20 feet or more above the base of the Upper Sands; or (3) there is a strong local northerly dip on the north flank of this hill. Opinions may differ: I prefer the third explanation as most probable. Such a local feature might easily result from some post-Eocene faulting in the Secondary Rocks below and a consequent flexure of the more yielding Eocene beds. Assuming the true dip here to be north, I have estimated, from approximate data, a dip of 1 in 6·6, or nearly 9°, in the upper hill-flank, the dip diminishing as we descend the hill.

Section S. *In lane north of Finchampstead Church.*

	feet.	
a. Strong clay, distinctly laminated at the base	3	(No. 5).
[Thin layer of bog-iron-ore.]		
b. Green earthy sands, laminated purplish seams of clay, and below these strong loamy sands, with much green sand in pipes and layers, as in bed *f* Section P..	$18\frac{1}{2}$	(Nos. 7 & 8).
c. Clays and loams * (more clayey in upper part)......	?	(Nos. 9 & 10).
	30 feet or more.	

The lane trends from this point nearly due north to Nine-mile Ride, within a quarter of a mile of the open pit in London Clay mentioned above. Taking into account the depth of the water-bearing line in the wells in the neighbourhood, and the altitudes of the respective outcrops of the Lower Sands (No. 11) and of the London Clay, the sands below No. 10 cannot be here much more

* These, it will be observed, crop out on the same level as at 300 yards to the east, and as at California, nearly 1 mile to the east.

than about 30 feet thick, as compared with the 92 feet of the College-Well Section, a marked instance of attenuation.

Obviously enough the determination of this horizon is very important, so far as concerns the actual thickness of the lower quartz-sand series (Nos. 11 and 12) on the margin of the area; and, as I showed in my former paper, the lithological character of bed No. 10 varies sufficiently within certain not very wide limits to introduce an element of uncertainty, if inferences were drawn from a few disconnected and small exposures taken at random. But I think it must also be equally obvious to any one who peruses carefully this and my former paper, that the lithological evidence is strengthened and controlled by the stratigraphical, the beds recognized as on the horizons of Nos. 9 and 10 of the typical well-section being found either cropping out from beneath the green-earth series or in direct stratigraphical alignment with beds that do thus visibly crop out from beneath them.

Section S will be seen to be on the same contour with Section P at Wick Hill. Finchampstead Rectory, at 250′ O.D., is on beds which crop out also on the same contour from beneath the Upper Sands, which cap the Church Hill, and the well here (50 feet deep) showed that the green beds become very feeble also in that direction, very little green sand having been brought up in the digging of it, within the lifetime of the present Rector *. At the foot of this hill beds Nos. 9 and 10 crop out, and they can be traced all along the road to near Eversley Bridge. There are many exposures of these in small sections; they are cut through by a small transverse valley of erosion between the Rectory and Bannister's Farm, which stands on an outlier of them, and some fifteen years ago they were worked for bricks near the lower road, at about the 200-foot contour. Their passage down into the dirty fine quartz-sands of No. 11 is well shown in some rather large ditch-sections in the fields below the Curate's house, only a few feet above the Blackwater, and above the place where the London Clay is marked on the Survey Map.

On the south flank of The Ridges the clays of No. 5 crop out in the road-cutting below Sunnyside, and continue down to East Court. The green earthy sands (Nos. 7 & 8) crop out next below, and below these the clays and loams (Nos. 9 & 10) are exposed in many small sections about the village. In 1886 a new well was dug at the village school by John Walter, Esq., of Bearwood, who kindly drew my attention to it.

Section T. *Well at Village School, Finchampstead* (210′ O.D.).

	feet.	
a. Laminated hard clayey sand	10	(No. 10).
b. Dirty blackish-green quartz-sand, with pyrites.	5	(No. 11).
c. The same dirty sand mixed with black clay ...	5	
Total.........	20	

* The assignment of the beds in the Rectory Hill to the Upper Bagshot (Geol. Mag., January 1885) was a mistake based on the reported non-appearance of green sands in the well-section.

The apparently excessive thickness of the Middle Group on this hill-side is explained by a dip towards the Blackwater Valley, of which evidence is given above.

Bearwood Hills.—In addition to the facts already described (Geol. Mag. dec. iii. vol. iv. pp. 111 *et seq.*) the following require consideration. (*a*) The flank of the hill is very much obscured by a vast amount of *débris* (mixture of sand and pebbles) from the higher beds, the phenomena presented at St. Anne's Hill, Chertsey *, being here repeated. There are several old, overgrown gravel-pits, in which these materials have been worked in former years.

(*b*) In the latter part of the summer Mr. Walter was good enough to have a second and deeper square pit dug through the pebble-bed. On descending the pit by a ladder, I made the following observations and measurements, while the section was fresh and not obscured by rain-wash.

Section U. *Pit on the flank of Barkham Hill* (260′ O.D.).

	ft.	in.
a. Drift (coarse sand and flint fragments)	2	0
b. Loamy sands	3	0
c. Pebble-bed in greenish and brown sand	5	0
d. Coarse brown loam		3
e_1. Clay, tough, hard, pale grey, laminated }		
e_2. Clay, more compact, chocolate-coloured }	2	6
e_3. Clay, tough, hard, drab-coloured, laminated }		
f. Coarse irony sand, with clay-laminæ, like *e*		6
g. Coarse sand, irony (similar to bed *f* in Section P, without the green sand)	3	6
Total exposure	16	9

The excavation was stopped by water, probably thrown out by beds of the horizon of Nos. 9 and 10, which may include the bed exposed in a pit in the wood 300 yards north-west of this spot. The beds *e* to *g* of this section I consider to be the attenuated equivalents of the beds *c* to *g* of Section P (Wick Hill) †, on the other side of the Barkham Valley, since in no other section have I met with clays so precisely similar in character to the 2½ feet of clay in this Barkham section as the clays which in the Wick-Hill section are inti-

* Quart. Journ. Geol. Soc. vol. xliii. pp. 376, 377.

† In revising this paper for the press (March 5) I append the following note with the specimens from the Wick Hill and Barkham pit sections *arranged in parallel series on a tray before me*, the specimens of both series being equally desiccated:—

Bed *d* (Sect. U) lithologically identical with bed No. 5, as exemplified by two specimens from that bed as it is exposed in the railway-cutting at Wellington College and in the adjoining brick-field.
Bed e_1 (Sect. U) lithologically identical with clay-seams of bed *c* (Sect. P).
Bed e_2 (Sect. U) lithologically identical with bed *d* (Sect. P).
Bed e_3 (Sect. U) lithologically identical with bed *e* (Sect. P).

Bed *d* of Section U is seen on the south face of the pit, and thins away to nothing in the transverse pit-face. The position of this bed is, so far as it goes, in favour of assigning the pebble-bed to horizon No. 3.

mately associated with the green earths. On these grounds the beds *e* to *g* of this section may be assigned with some probability to the horizon of Nos. 7 and 8. That they are not part of the London Clay is well shown by the position of the bed *g*, and the caution with which I first described them is fully justified. This leaves it an open question whether the pebble-bed *c* of this Barkham section is on the horizon of No. 3 or No. 6 of the College-Well section. Compare also Sections K, L, O.

Fuller details of the structure of these Bearwood Hills are given in a previous paper (Geol. Mag. *loc. cit.*). I see no reason to depart from the view therein expressed, that these hills are capped by an outlier of the Upper Sands, although the horizon of their base is at a rather lower level than the corresponding horizon in the Finchampstead Church Hill, the elevations of the beds in that hill having been, I venture to think, sufficiently accounted for. A section along the eastern flank of Finchampstead Ridges would show the correlation of the beds in the Barkham Hill to be in reality a very simple matter.

Farley Hill, to the west, cut off from the Finchampstead Hills by a valley along which London Clay is exposed, has, I believe, from exposures on its cap and flanks, a similar capping of Upper Sands, the Middle Group being mainly represented by strongly developed clays and loams of horizons Nos. 9 and 10, which appear to overlap the quartz-sand series found on the south side, and to come directly on the London Clay further north. Further exploration is needed here *.

Results.

It will be seen that there is a general but very irregular attenuation of the quartz-sand series along this line of country †. While they thin out entirely in the Bracknell Hill at Wokingham and Barkham, and admit of the overlap of beds Nos. 9 and 10, they thicken to 80 feet or more in the Ascot Well ‡, thinning again to from 10 to 15 feet on the north side of Englefield Green. The most probable explanation of this is that about Ascot we are on the site of the influx of an important Eocene river, which was an affluent to the main river-mouth in which these sands were deposited. We have similar evidence of an affluent of less magnitude from the north-west in the fluviatile sands found on the north side of the tongue of London Clay on which St. Paul's Church, Wokingham,

* I have estimated 30 ft. for the quartz-sands at Woodbury, the residence of W. Simonds, Esq. (March 27).

† Prof. Prestwich (Quart. Journ. Geol. Soc. vol. xliv. p. 107) suggests Eocene denudation as the cause of this attenuation; but I venture to think that the evidence taken altogether shows rather that it is due to conditions of original deposition.

‡ The rectified reading of this section given in my last paper was based on the following data:—(1) specimens which came into my possession after the first account of it was published; (2) the discovery of the dip of the London Clay at Warfield; (3) some notes by Mr. Whitaker; (4) some calculations made by Mr. R. S. Herries.

stands. See fig. 1 of my former paper (vol. xliii. of the Quarterly Journal).

Having roughly mapped the stretch of country dealt with in this part of the present paper, I am the more strengthened in the view which is put forward. It is my intention to present a copy of the map to the Society's Library when the details of it are complete. It should be noted that the boundary of the Middle Group was marked provisionally with a broken line from the South-Eastern Railway to near Sunninghill on the earlier editions of the Survey Map.

Part II.—The Highclere Section.

My attention was first drawn to this by F. J. Bennett, Esq., F.G.S., of H.M. Geological Survey, and in particular to that portion about half a mile south of Highclere Station. Prof. T. Rupert Jones has kindly furnished me with a sketch of part of the section in the cutting north of the Station through Tot Hill. This was made in 1882, when the construction of the line was in progress. A short notice of the same section was furnished by him to the 'Geological Magazine' (dec. iii. vol. i. pp. 122, 123). The general dip, as measured by him in this section, is 3° S., the same dip being observed in the London Clay in a cutting north of the Enbourne; while the general dip of the Bagshot Beds in the cutting further south is about 10° N., as measured by Mr. Bennett and myself. These facts point plainly to the existence of a synclinal flexure*, the axis of which, east and west, runs along the valley to the south of the Station (see fig. p. 179). On my first visit, in company with Mr. Bennett, I detected the green earthy sands of the Middle Bagshot exposed in the cutting-slope for some distance at the northern end of the southern cutting. These are succeeded southwards by the clayey series, which everywhere forms the basement of the Middle Bagshot, and must be claimed as such in this section, although Mr. Bennett first drew my attention to them as clays of the Lower Group. They are about 30 ft. thick, and furnish a striking example of the way in which not only these but also the higher clay-beds of the Middle Group are sometimes found to thicken at the expense of the more sandy members of the series, as we approach the London Clay, in tracing them across the country†. These clays, with which towards the base considerable bands of ironstone are interbedded, are succeeded downwards by a fine quartz-sand, which at lower horizons becomes rather loamy. Attention should be drawn to the remarkable lithological similarity (making allowance for differences in thickness) of the several beds and the order of their succession to that already recorded for the beds No. 7 to 12 of the Wellington-College district‡. Mr. Bennett informed

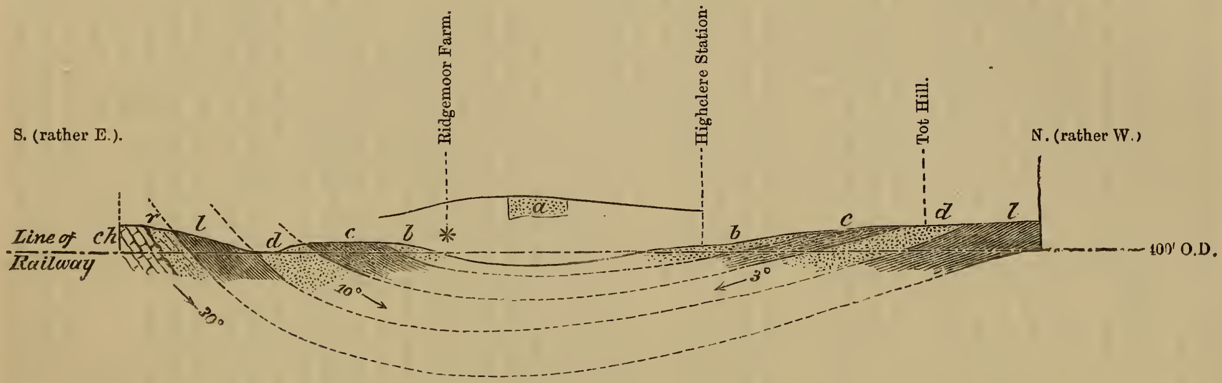
* Probably a westerly extension of the "Farnborough Syncline," Quart. Journ. Geol. Soc. vol. xli. p. 506.

† *E. g.* in the section in the Swinley brick-yard (*supra*, p. 165).

‡ Quart. Journ. Geol. Soc. vol. xli. p. 494, &c.

Section of Eocene Beds, Didcot and Winchester Railway.

(Scale: horizontal 2 in. = 1 mile; vertical 1 in. = 200 feet.)



a. Upper Bagshot Sands (18 ft. exposed in sand-pit) ¼ mile west of section.
b. Green earths and sands. } Middle Bagshot.
c. Lower clay-series with ironstone and irony sands. } Middle Bagshot.
d. Fine quartz-sand, more loamy below. Lower Bagshot.
l. London Clay.
r. Reading Beds, with green-coated flints and *Ostrea bellovacina.*
ch. Chalk.

me that the sandy beds at the south end of this cutting graduate down into the London Clay. On a second visit, in the month of August, in company with H. W. Monckton, Esq., F.G.S., a closer examination was made. Unfortunately a line of erosion occurs just across this place, and we could find no exposures showing the junction; but a little further to the south unmistakable London Clay is exposed in the railway-cutting, though not enough to prove the dip; and this passes down into the mottled clays of the Woolwich and Reading series. The junction of the last-named beds with the Chalk is very easily found. This formation dips here to the north at an angle of 30°, and on its eroded surface (as at Reading) rests the Basement-bed of the Reading series with *Ostrea bellovacina*, green-coated flints, and many black grains. The thickness of the Woolwich and Reading beds we estimated at about 60 ft, that of the London Clay not much more, certainly under 100 ft. The cutting in Tot Hill has been less minutely examined. This has been rendered unnecessary, as the examination of the fresh section by Prof. Rupert Jones was much more complete than any examination could be now that the cutting-slopes are overgrown. Near the southern end of this cutting, however, which does not appear to have been open at the time, we recognized the green earthy sands of the Middle Group in a somewhat advanced stage of oxidation; and a bed which corresponds very well with the upper clayey bed (No. 5 of my tabulation) of the Middle Group is exposed in the bank at the Station.

I venture to think that the Officers of the Geological Survey can hardly feel much difficulty or surprise at the identification of beds of the Middle Group in this section across a piece of country mapped as "i. 4," when they consider that a little further to the west, in Highclere Park and at Woodhay, they have mapped outliers of this group "i. 5."

The interest of the section, however, does not end here. If we follow the railway across the valley south of Highclere Station and look westwards, we can see an open sand-pit, $\frac{1}{4}$ of a mile off, near the top of the hill above Ridgemoor Farm (see fig. p. 179), exposing beds which cannot be brought very well into stratigraphical alignment with the beds of either of the cuttings, when the now-ascertained dips of the beds in those cuttings are taken into account. They clearly occupy a higher horizon, since they are above the axis of the syncline, and at a considerably higher altitude than the beds in the cuttings. On visiting this sand-pit with Mr. Monckton, I could not fail to recognize the strong lithological facies of the Upper Sands; and although my companion was unwilling at first to admit this unreservedly, he was soon converted to my view by finding an irony cast of a bivalve*. There are about 18 feet of these Upper Sands exposed in this pit. They are also exposed in gullies in the lane just north of the pit, though much obscured by angular flints, the downwash of the

* Mr. R. S. Herries, F.G.S., exhibited at the Society's meeting a number of such casts which he has succeeded in finding in this pit. See 'Nature,' vol. xxxvii. pp. 104, 128.

gravel-capping, to which the hill owes its preservation. The ridge of this hill is traversed by the Whitway, on the west of which is Highclere Park.

Results.

When it is observed that the Upper-Bagshot outlier is about 18 miles due west of those places (Shapley Heath and Bramshill) which mark the extreme westerly limit of previous records of beds of that group, the importance of their identification becomes apparent. It appears that the marine estuary, in which the Upper Sands were deposited, extended over the region of Chertsey and Sandhurst for miles in a long narrow arm to the west, partly along what is now the valley of the Kennet and the Enbourne*, and it seems to offer support to the view, which I have long held on general grounds, of the great antiquity of this arterial line of drainage of southern England. In the light of such evidence we are perhaps justified in dating back its existence at least to Eocene times, thus giving a high antiquity to the great Kennet-Thames line of drainage, compared with which the drainage of the Isis basin into the Lower Thames, by the cutting of the Pangbourne gorge across the strike of the Chalk, may almost be spoken of as a recent event in the physical history of the South of England.

Another interesting point is the sharp dip of the Chalk on the north of the Kingsclere axis of elevation (equalling that of the Hog's Back), while the great attenuation of the London Clay to the west, as shown by a comparison of its thickness at Highclere with its thickness at Aldershot and Ash, seems to suggest a partial elevation of the Kingsclere axis during the London-Clay period. On the other hand, the pretty constant thickness of the Woolwich and Reading Beds seems to forbid the assignment of an earlier period than the London Clay to the Kingsclere upheaval.

Again, the high dip of the Chalk at Highclere (30° N.), as compared with the more moderate dip of the Bagshot Beds (10° N.), as shown in our section (p. 179), affords evidence of very considerable pre-Bagshot elevation of the Kingsclere axis†. Whether the whole of the Bagshot series was equally affected by later movements is a question which, with our present data, cannot perhaps be answered; and with the results of Lieut. Lyons's work in the Aldershot district‡ before us, we seem as much in the dark as ever as to the extent and duration of any communication between the London and Hampshire Basins, after the close of the period represented by the Woolwich and Reading Beds. Perhaps the work of the officers of the Survey in Hampshire may bring to light some evidence of attenuation or overlap, which may go some way towards settling this

* This obviously necessitates a reconsideration of the stratigraphy of the intermediate country, and more especially that of the Bagshot Beds of the district about Banghurst and Ramsdell.

† See Barrois, 'Recherches sur le terrain crétacé supérieur,' 1876, pp. 114, 115; also fig. 8 of the plate appended to that monograph.

‡ Quart. Journ. Geol. Soc. vol. xliii. August 1887, pp. 432–441.

interesting question. At present I think we must say with Dr. Barrois (*op. cit.* p. 115), "Je ne sais comment on pourrait reconnaître ici l'importance de ce qui a été enlevé par les dénudations."

The General Syncline.—We have seen that there is evidence of the "Farnborough Syncline" * being continued to the west, at least as far as Highclere. A glance at the map shows, by the trend which the *general strike of the Tertiary Beds* makes to the north-east from Guildford to about Ewell, that the axis of this syncline must pass nearly through Woburn Park, near Chertsey. This is quite enough to account for the low altitude of the strongly-developed clays which are mapped (and, I believe rightly) as belonging to the Middle Group there, and at Ongar and Row Hills.

On Mr. Hudleston's last paper † we note therefore :—(i.) that the apparent abnormal thinness of the Lower Sands about Chertsey is but an instance of that slight unconformity for which he had himself contended in his previous paper ‡; (ii.) that the identity of the horizon of the clays in the Hatch brick-yard with that of certain intercalated patches in the Walton cutting requires more evidence than has been yet adduced for it to be generally accepted ; (iii.) that the dark-coloured laminated sandy clay (Mr. Hudleston's 'No. 4 Bagshot') bears a striking resemblance to the higher beds of the London Clay exposed in the Aldershot brick-yards, where a very similar succession may be studied, and (until the contrary is proved by excavation) may be maintained to be only an inlying portion of the London Clay, a result of that previous local erosion of the surface of that formation of which the section nearer the Station gives us good evidence.

It is with much pleasure that I find the *general* relationship which I have all along insisted upon between the London Clay and the Lower Bagshot ('fluviatile sands') borne out, not only by the well-sections published by Lieut. H. G. Lyons, R.E., F.G.S. §, but also by the more extensively-informed judgment of Prof. Prestwich. This relationship of the 'London Sands,' as he now proposes to name them (as the equivalents of the Upper Ypresian), is seen on comparative grounds and from palæontological evidence obtained in other Eocene areas, to be closer than has been generally supposed, notwithstanding marginal erosion and local unconformities on the northern flank and in the Walton cutting. Now that the variability of the thickness of the Lower Sand Series is admitted, there is really no serious difference between us. Whether or not this amounts to an unconformability along the northern margin, or is only a marked instance of "contemporaneous erosion" (Jukes), is a question on which there is room for difference of opinion. That the movements which gave a slight accentuation to this great pre-Eocene

* Quart. Journ. Geol. Soc. vol. xli. As a piece of evidence for estimating this syncline, the new well at Minley Manor (1886) at 250′ O.D. gave 62′ of uniform Upper Sands without reaching the pebble-bed or the Middle Clays.

† Quart. Journ. Geol. Soc., August 1887. ‡ Ibid. May 1886.

§ Quart. Journ. Geol. Soc., August 1887; see also paper by the author, "The Bagshot Beds and the London Clay," Geol. Mag. for September 1886.

estuarine line of drainage, admitting of the simultaneous silting up of the more central parts and local erosion along the margin, were not a simple movement tending to produce a mere synclinal flexure, but rather a series of movements connected with the later Eocene physical history of central Mercian England, is, I think, an inference which is justified by the data before us.

Additional Note on the Green-earth Series.

Taking into account such facts as the following—(i.) the attenuation of the green-earth series towards the north; (ii.) the solitary instance (Wellington-College Well) in which the series of beds between the two principal clays are made up (or said to be made up) wholly of green earthy sands and pebbles, while even there, in the well at the West Lodge, 1 ft. of light grey quicksand was proved at the base of the green sands, representing several feet of a similar sand in the Wick-Hill Section, other beds being often in the deep-well sections intercalated with the green earths (*e.g.* 13½ ft. of 'light sandy clay' at the Bagshot Orphan Asylum, 20½ ft. of other strata in the well at the South Camp, Aldershot, while the green earths scarcely occur at all in the Brookwood Well); (iii.) the possibility of their decoloration by slow oxidation in long-exposed sections—we cannot admit the mere presence or absence of green earths in small sections as a *test of horizons of the Middle Group* (as has been persistently urged in some quarters), although the evidence is undoubtedly strengthened by the presence of the green earths.

Again, it follows from their northerly attenuation (which is a stratigraphical fact) that either the beds at higher horizons must be unconformable to them (owing to contemporaneous denudation), or else a gradual subsidence of the more central parts of the estuary (which is far more probable) allowed of the gradual accumulation of these green earthy deposits in extensive lagoons. In either case the southerly dip of beds at lower horizons must, of necessity, be greater than that of beds at higher horizons: and obviously any application of stratigraphical methods of calculation which ignores this consideration must be so far misleading.

Then as to the common presence in them of well-rounded wind-worn quartz-grains, to which attention was drawn in my last paper *, a little reflection enables us to see in this fact additional evidence of the lagoon-origin of these green beds, the shifting of sand-dunes by the wind subjecting the sand to a vast amount of æolian attrition †.

The Middle Group, then, with its lagoon-deposits coloured frequently with organic salts of iron, its freshwater Diatoms, its pebble-beds at more than one horizon, and its two persistent clay-

* Quart. Journ. Geol. Soc. vol. xliii. p. 380.

† For a remarkable example of this, within the present century, on the shores of the Baltic (Kurische Haff), see Credner, 'Elem. der Geol.' 6th ed. (p. 271, fig. 83).

beds, was certainly deposited in a region of debatable ground between sea and land—the pebble-beds probably recording marked inroads of the sea * accompanied by the drifting inland of portions of the "chesil-beaches" piled up by ordinary tides along the seaward margin of the delta. Ultimately the area was converted by regional subsidence into a tidal arm of the sea (probably in connexion also with the Hampshire Basin) or marine estuary, in which the Upper Sands were deposited, to a thickness of which we have now no direct evidence, the only remains of the younger strata being perhaps the displaced Sarsens † and the reconstructed loamy sands intercalated in places with the plateau-gravels.

Discussion.

The President said that he had received a letter from Prof. Prestwich expressing regret at being unable to attend. Prof. Prestwich thought that, probably, Mr. Irving's view as to the Lower Bagshots being of irregular thickness is correct; this would help to confirm his own opinion as to its being Lower Eocene. It had struck him that, in some of his former papers, the Author might have mistaken a surface-drift of green earth, pebbles, and clay for the Middle Bagshots.

Mr. Monckton would express no opinion on the general remarks. Referring to the Newbury district, he had been with Mr. Irving when they visited the sand-pit shown towards the centre of the section. These sands he at first believed to be Lower Bagshots, but from certain lithological peculiarities, and also from the presence of forms like the casts of bivalve shells, he was forced to the conclusion that the beds were Upper Bagshot. This supposition suited very well with appearances on the south side of the syncline, but he would like further to examine the northern side.

He next referred to the Wellington-College and Finchampstead sections, which he criticised adversely. The question was whether the several beds therein described were similar beds, or a recurrence of a similar state of things on different horizons. At the doubtful points there are neither fossils nor green-sand beds, and the Author had referred beds in dispute very differently in his several papers, as instanced by his change of opinion at Bearwood and in the Ascot well-section. Correlations based upon altitudes could be of no value unless the beds were horizontal, whereas there was abundant evidence of a dip to the south ‡.

Mr. Herries disagreed with the Author's views as to the Wellington-College sections, and considered that he had not added much

* The prevalent discoid form of the flint pebbles (as one sees them in the Chesil Beach at Portland, and in the older Triassic "chesil-beach" at Budleigh-Salterton) in some of our pebble-beds speaks strongly for shore-action. It is not improbable that many of them have been derived from the Chalk of Norfolk, or even of more distant regions.

† See paper by the author on the "Bagshot Beds of the London Basin and their associated Gravels," Proc. Geol. Assoc. vol. viii. 1883.

‡ In connexion with Mr. Monckton's remarks see note * p. 173.

to last year's paper. He thought the Highclere section correctly represented; the Chalk and Woolwich and Reading Beds had a dip of more than 30 degrees to the N., and there was room for the London Clay and Lower and Middle Bagshots with that dip. The existence of recognizable fossils and the character of the beds, such as the absence of false-bedding, were strong evidence that the sand-pit in which the fossils had been found was of Upper Bagshot age.

Mr. Drew pointed to a remarkable case of thinning in Bearwood Hill, where the whole of the Middle Bagshots are represented as having suddenly disappeared.

The Author said that the thinning-out referred to by Mr. Drew would excite no surprise when drawn on a true scale. To Mr. Monckton his reply was that his work had not ignored the elementary rules of stratigraphy. The results, when mapped, were different from those shown on the Survey Map, but they were derived from evidence based on field-observations, and he was quite prepared to have them tested on the ground.

16. *On* Insoluble Residues *obtained from the* Carboniferous-Limestone Series *at* Clifton. By Edward Wethered, Esq., F.G.S., F.C.S., F.R.M.S. (Read February 8, 1888.)

[Plate VIII.]

The Carboniferous-Limestone rocks at Clifton are well known and have been the subject of several communications to the Geological and other Societies. Among the authors of such communications I may mention Sir H. de la Beche, Sir A. Ramsay, Dr. Buckland, Mr. Conybeare, Mr. Etheridge, Mr. Tawney, and Mr. Stoddart; the papers and monographs written by the investigators just named deal mostly with the physical, stratigraphical, or palæontological problems which the rocks of the gorge of the Avon have presented for solution: I am not aware that any one has examined the residues obtained from the limestone after boiling portions in strong acid.

Outlines of the Formation.

The thickness of the Carboniferous-Limestone series at Clifton is thus stated by Sir H. de la Beche *:—

	feet.
Upper mixture of Sandstones, Marls, and Limestones	400
Central portion of series	1438
Lower Shales	500
	2338

Professor Hull †, in his classification of the Carboniferous series, puts the Bristol and Somersetshire coal-fields under one head, and gives the thickness of the Limestone as follows:—

	feet.
Stage C. Yoredale Shales (thin)	100
Stage B. Carboniferous Limestone	2330
Stage A. Lower Limestone Shales	100
	2530

Professor Hull's classification of the Carboniferous series seems to me to be the most comprehensive yet produced; but there may be some difference of opinion as to the term Yoredale when applied to the Upper Limestone of the Bristol and Somersetshire coal-fields. If Professor Hull means, by the term Yoredale, the beds which mark those physical conditions which closed the Limestone Period and ushered in the Millstone Grit and Coal-measures, then he is correct in saying that there is at Clifton a series of deposits, represented by a thickness of about 100 feet, which mark the close of the Limestone Period and the coming in of the Millstone Grit. They

* Mem. Geol. Survey, vol. i. p. 129.
† Quart. Journ. Geol. Soc. vol. xxxiii. p. 631 (1877).

are the beds referred to by Sir H. de la Beche as "Upper Mixture of Sandstones, Marls, and Limestones."

Hitherto the limestones known as the "Black Rock" have been regarded as the base of the Middle Series of Limestones, and it is with reluctance that I propose to alter the existing arrangement. I am, however, compelled to remove the "Black Rock" from the Middle Limestones and include it with the Lower Limestone Shales under the term of Lower Limestones. My reason for doing so is that the Black-Rock beds have no claim to be a part of the Middle Limestones, on the ground that the organisms, chiefly Encrinites, which contribute to the structure of the rock are more allied to those in the Lower Limestone Shales than to the fossils which occur in the Middle Limestones. At the top of the Black-Rock series there is clear evidence of an alteration of conditions under which the limestone was being deposited; this is indicated by a thickness of about 100 feet of oolitic limestone which closed what may be termed the "local Encrinite Period," and preceded conditions extending over a length of time difficult to estimate, during which a great thickness of strata was deposited in which crinoidal remains are few in number and small in size.

Professor Hull has certainly underestimated the thickness of the Lower Limestone Shales; and as my measurement corresponds closely with that of Sir H. de la Beche, I accept his statement of 500 feet.

In this paper, then, I shall refer to the Carboniferous-Limestone series at Clifton in the following divisions and estimated thicknesses.

	feet.
Stage C. Upper Limestones	100
Stage B. Middle Limestones	1620
Stage A. Lower Limestones, including (i.) Black Rock, 490 feet, (ii.) Lower Limestone Shales 500 feet	990
Total	2710

It will be observed that, at Stage B, I have put down "Middle Limestones" in the place of "Carboniferous Limestone." I do this because the whole should be classed as Carboniferous Limestone, an opinion apparently held by Sir H. de la Beche, for he speaks of that portion of the series marked by Stage B as "the central portion of the series.

The Limestone-forming Organisms.

Lower Limestones.

(i.) *Lower Limestone Shales.*—These beds rest conformably on sandy strata which in turn lie conformably on the Old Red Conglomerate. The lowest beds of true limestone are made up largely of Ostracoda and Corals, among which latter *Monticulipora tumida*, Phill., is conspicuous. Small Crinoids are numerous in some beds,

o 2

and shell-fragments occur; but these do not contribute to the structure of the rock to any great extent.

(ii.) *Black Rock.*—These limestones have been made famous from the fact that it was from these beds that Agassiz obtained some of the fish-remains which he figured in his book on fossil fishes; and some of the originals are now preserved in the Bristol Museum. Fish-remains are still to be found in the "Black Rock," especially at the base. Under a microscope thin sections of the limestone exhibit the spines of *Productus* and *Spirifera*, shell-fragments, valves of Ostracoda, and Polyzoa; but by far the greater portion of the rock-structure consists of the joints of Encrinites.

Middle Limestones.

Passing from the Lower Limestones, we come to the base of the Middle Series, which is represented by the oolitic limestone before referred to. In the majority of instances the nuclei of the granules, when recognizable, are Foraminifera; but in one thin section of the rock a joint of an Encrinite was discovered as the centre in two granules.

The beds which follow the oolitic limestone appear to rest unconformably on these below; but this is not real, and is due to false-bedding in the oolitic limestone. The succeeding stratum is, however, of a very different character from that upon which it rests, and is defined by a sharp demarcation as though the alteration of conditions had been rapid and without gradual passage. Thin sections show the rock to contain a few Foraminifera, valves of Ostracoda, and a number of circular objects measuring from ·003 to ·012 of an inch in diameter. These calcareous bodies, whatever they may be, are very numerous, and exist throughout the Middle Limestones above the oolitic beds. But the most important form of life, as distinguishing these beds from others, is the occurrence of the genus *Mitcheldeania*, which, so far, appears to be limited to this horizon. Following the *Mitcheldeania*-Limestones, as I propose to call them, we come to the most important development of the Carboniferous Limestone at Clifton, which extends as a bold line of cliffs for a distance of nearly a mile along the Gloucestershire side of the gorge of the Avon, and on the Somersetshire side appears as wooded slopes. It would not be correct to say that the whole of this great thickness of limestone is built up of Foraminiferous ooze, but that certainly may be said of some portion. Taking it as a whole, the rock is made up of Foraminifera, the small circular bodies referred to in the *Mitcheldeania*-Limestones, occasional valves of Ostracoda, shell-fragments, and some other organisms which have not yet been described.

Upper Limestones.

Towards the top of the Middle Limestones the strata become more arenaceous, until beds are met with which contain as much as 81 per cent. of siliceous residue; with these true limestones occur, some of them of oolitic structure, the nuclei of the granules being mostly detrital quartz-grains and Foraminifera. Finally the limestone disappears and becomes replaced by true Millstone Grit, which yields from 97·4 to 98·39 per cent. of insoluble siliceous residue.

The Insoluble Residues.

The method adopted for procuring the residue was to place a lump of the limestone in an evaporating-dish ; concentrated hydrochloric acid was then poured into the dish, and, after a time, a little water. When carbonic anhydride ceased to be evolved on the addition of more acid, the solution was boiled and then allowed to cool. The solution was next poured off, and the residue washed with distilled water. At first the residue was transferred to a small flask and again boiled with concentrated hydrochloric acid ; but examination of the residues, before and after that operation, proved that this last process was not required.

To estimate the quantity of residue, typical samples were ground to a fine powder in an iron mortar, and well mixed. One gramme was then weighed out, boiled in a small flask with concentrated hydrochloric acid, transferred to a filter, and washed with hot distilled water so long as nitrate of silver produced any reaction on addition to some of the washings collected in a test-tube. The following table shows the percentage.

Percentages of Insoluble Residues given in ascending order.

Lower Limestones.		Middle Limestones.			Upper Limestones.
Lower Limestone Shales.	Black Rock.	Oolitic Beds.	*Mitcheldeania*-beds	Main Portion.	No Divisions.
11·2	1·9	·8	2·67	10·6	11·3
	22·5		3·70	10·0	10·0
	7·0		5·20	2·3	2·5 (oolitic).
				2·2	81·6
				3·0	
				1·1	
				2·2	
				1·9	
				1·4	

In the case of the large proportion of residue in the first two estimations of the main portion of the middle series, it should be stated that the limestone contained an unusual proportion of organic matter, and doubtless the high percentage is to some extent due to the ash of the organic substance.

Description of the Residues.

In describing the residues I shall follow the plan already adopted of commencing with the Lower Limestones and proceeding upwards.

Lower Limestones.

i. *Lower Limestone Shales.*

No. 1. Mostly detrital quartz-grains averaging about ·001 of an inch in diameter. There are also dark siliceous objects present which are not entirely negative to polarized light.

No. 2. Detrital quartz (Plate VIII. fig. 1), averaging about ·003 of an inch in diameter. A few grains of felspar, tourmaline, and zircon.

No. 3. Detrital quartz, averaging ·005 of an inch in diameter, some zircon and amorphous silica, which polarizes around the edges.

No. 4. Detrital quartz averaging about ·006 of an inch in diameter, some of the grains containing cavities. Grains of tourmaline, zircon, felspar, and amorphous and chalcedonic silica are also present.

No. 5. The specimens were taken from the rock which the late Mr. Stoddart, some years ago, described * as the "Microzoal bed". He treated the limestone with cold hydrochloric acid, and obtained a residue consisting of "casts or else pseudomorphs composed of peroxide of iron and silica." Mr. Stoddart rightly states that the casts are those of the joints of Crinoids and remains of Polyzoa; but, in addition, I have found those of corals. An examination of the sections of the rock, under a microscope, shows that the calcareous skeleton of the Corals and Polyzoa are generally preserved, and it is the portion of the organism occupied during life by organic matter which has been filled with oxide of iron. With the remains of Crinoids it is different, as the whole skeleton appears to be replaced by oxide of iron, and that too without destroying the areolar structure characteristic of the Echinodermata. On treating the residue left by the cold acid with boiling acid the whole of the ferruginous constituents disappear, and a siliceous residue remains (fig. 2). This residue consists of casts of Crinoids and other organisms, chalcedonic silica, detrital quartz, and a few grains of tourmaline.

ii. *Black Rock.*

No. 1. Residue composed of siliceous flakes.

No. 2. Detrital quartz, chalcedonic silica, a few micro-crystals, and some tourmaline.

No. 3. Detrital quartz, around some of which a slight secondary crystallization has commenced, a few grains of tourmaline and zircon, and some pyrites.

No. 4. Much detrital quartz, tourmaline, zircon, and a quantity of pyrites which, when viewed by reflected light, seems, in some instances, to be pseudomorphic.

* Ann. & Mag. Nat. Hist. 3rd ser. vol. viii. p. 487.

Middle Limestones.

i. *Oolitic Limestones at the base.*

By far the greater proportion of the residues consists of well-rolled detrital quartz-grains, averaging ·008 of an inch in diameter, but occurring as large as ·013 of an inch. A fragment of felspar and some tourmaline.

ii. *Mitcheldeania-Beds.*

No. 1. A few detrital quartz-grains and a quantity of chalcedonic silica.

No. 2. Detrital quartz, averaging about ·003 of an inch in diameter, around some of which a slight secondary deposit of silica has commenced.

No. 3. Chiefly flakes of chalcedonic silica.

No. 4. Mostly chalcedonic silica, well-rounded grains of detrital quartz, as large as ·011 of an inch in diameter, tourmaline, and zircon. The chalcedonic silica occurs in the form of fragmentary pieces, and also as circular objects which average about ·004 of an inch in diameter, but some are considerably larger. Some of these objects are isolated, but in other instances two or three are seen attached together. A reference to a thin section of the rock shows that the structure is much obliterated, but that the limestone is made up of calcareous circular bodies. Some of these are concretions, with Foraminifera as nuclei; but others are definite organisms, and correspond with the chalcedonic objects in the residue. As to what these organisms are, does not enter into the province of this paper; it is enough for us to know that the circular forms in the residue are casts or pseudomorphs of the calcareous objects which form the limestone.

iii. *Main Portion of the Middle Series.*

No. 1. Earthy brown limestone. Flakes of amorphous and chalcedonic silica, apparently associated with organic matter.

No. 2. Dark siliceous masses, mixed with organic matter. To test this, the organic matter was estimated and found to be 12·8 per cent. of the rock. It may be well just to mention that the structure of the rock at this horizon is much obliterated, which may be due to the action of organic acids given off from organic matter. If we allow for loss by decomposition, the proportion of organic matter originally present in the limestone must have been considerable.

No. 3. Detrital quartz and a quantity of chalcedonic silica. Seen by reflected light, the latter appears as dark-brown and snow-white objects. Pyrites plentiful, in the form of minute balls, measuring ·002 of an inch in diameter, and also apparently as pseudomorphs of organic structure. In some cases the dark appearance of the chalcedonic silica is due to the admixture of pyrites.

No. 4. Rolled detrital quartz-grains measuring as much as ·015 of an inch in diameter. Chalcedonic sponge-spicules and other fragments of silica in the same form, among which are casts and spherical objects measuring about ·015 of an inch in diameter.

No. 5. Chiefly microscopic crystals with nuclei and fragments of chalcedonic silica. The nuclei of the crystals are undoubtedly detrital quartz-grains, and the crystals have been formed by the deposition of secondary silica upon the surfaces of original quartz-crystals, as described by Dr. Sorby, F.R.S.*

No. 6. Detrital quartz, some tourmaline, chalcedonic silica, and pyrites.

No. 7. Oolitic limestone; residue consists of detrital quartz and a very little chalcedonic silica.

No. 8. Detrital quartz, on the surface of which secondary silica has been deposited, and in some cases a perfect crystal has formed around a quartz-grain as a nucleus. Some of the micro-crystals are very perfect and larger than previously observed, one of which is represented in Plate VIII. fig. 3 A, and measures ·015 × ·009 of an inch. There is also present a considerable quantity of chalcedonic silica.

No. 9. Chiefly micro-crystals measuring ·007 × ·003 of an inch, with detrital quartz-grains as nuclei; also detrital quartz-grains which are not entirely enveloped in a deposit of secondary silica. The crystals are especially important, as besides the inorganic nuclei, they contain the minute globules seen in amorphous silica, which points to the conclusion that the secondary deposit was derived from amorphous and chalcedonic silica associated with the detrital quartz in the limestone.

No. 10. Masses of amorphous and chalcedonic silica, some of which are crystallized around the edges. In some instances portions represent three stages of structural transition; the centre portion is amorphous and is surrounded by chalcedonic silica, and this, again, passes into the crystalline condition (see woodcut, p. 194). There are also micro-crystals; some of these have detrital quartz-nuclei, but in others it is difficult to make out any nucleus at all, with the exception of a minute globular structure similar to that seen in amorphous organic silica.

No. 11. Chalcedonic and amorphous silica, some of which appears to be casts. A few grains of detrital quartz, tourmaline and zircon. Some nucleated crystals also present.

No. 12. Micro-crystals with detrital quartz-nuclei, averaging about ·003 × ·007 of an inch in size (Plate VIII. fig. 4).

No. 13. Clusters of micro-crystals without recognizable inorganic nuclei. Apparently the objects are crystallized chalcedonic silica.

No. 14. Brown siliceous fragments, which seem to be casts or pseudomorphs. Small pieces of chalcedonic silica; detrital quartz and micro-crystals with inorganic nuclei.

No. 15. Fragments of chalcedonic silica, among which are casts

* Presidential Address to the Geological Society, February 1880, p. 62.

of Foraminifera, and a quantity of spicules of sponges (Plate VIII. fig. 5).

No. 16. Detrital quartz in quantity; small fragments of chalcedonic silica; chalcedonic spherical objects, measuring from ·002 to ·004 of an inch in diameter (Plate VIII. fig. 6).

No. 18. Small pieces of amorphous and chalcedonic silica; detrital quartz-grains averaging about ·002 of an inch in diameter, and some tourmaline.

No. 19. Detrital quartz and tourmaline; pieces of amorphous and chalcedonic silica; micro-crystals, some of which measure ·003 × ·004 of an inch.

Upper Limestone.

No. 1. Detrital quartz with secondary silica deposited on the surfaces, and a few perfect crystals.

No. 2. Fragments of chalcedonic silica, among which spicules of sponges were detected, dark siliceous objects, some of them casts or pseudomorphs; pyrites, detrital quartz, and tourmaline.

No. 3. Detrital quartz; micro-crystals with detrital quartz-nuclei; chalcedonic silica and tourmaline.

No. 4. Oolitic limestone; the residue contains detrital quartz, averaging about ·008 of an inch in diameter.

No. 5. Oolitic limestone; with residue consisting of detrital quartz, chalcedonic silica, siliceous pseudomorphs or casts, and a quantity of pyrites which also appear to be pseudomorphs.

Review of the Residues.

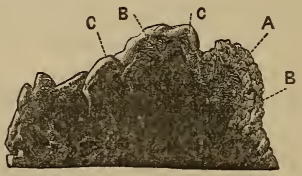
The residues derived from the Lower Limestone Shales consist mostly of detrital quartz, occasionally associated with amorphous and chalcedonic silica, some of which is in the form of casts and pseudomorphs of organisms. With the detrital quartz are fragments of tourmaline, zircon, and felspar.

The Black-Rock limestone yields residues made up of a large proportion of detrital quartz, distinguished from the same residue in the Lower Limestone Shales by a slight secondary deposit of silica on the surfaces; and in some cases complete crystals have been so formed with an original quartz-grain as a nucleus. Amorphous and chalcedonic silica is more plentiful than in the limestone below; and the minerals tourmaline, zircon, and pyrites are frequently met with.

Coming to the base of the Middle Limestones, that is to the oolitic beds, the residue is made up of rolled detrital quartz-grains and a few fragments of felspar and tourmaline. Above this horizon the residue undergoes a change, and becomes more typical of the Middle Limestones. Detrital quartz-grains occur, but not to the same extent as in the residues previously examined; on the other hand, the proportion of chalcedonic silica has increased. The residues of the Middle Limestones may be said to consist of detrital quartz, micro-crystals of quartz, amorphous and chalcedonic silica, and, less frequently, pyrites, tourmaline, and zircon. From some beds the residues obtained were little else than micro-crystals of quartz. Among the fragments of amorphous and chalcedonic silica may be seen sponge-spicules, casts and spherical bodies. Towards the top of the Middle Limestones the proportion of detrital quartz in the residues increases, and the deposition of secondary silica on the surfaces of the grains becomes less marked, until, as before stated, the calcareous beds become replaced by the Millstone Grit.

Form in which the Silica occurs other than that of the Detrital Quartz.

The silica exists in three forms—(1) Amorphous; (2) Chalcedonic: (3) Crystalline. These three stages are frequently seen in the same fragment, as represented in the woodcut. The crystal-



A fragment of amorphous silica passing first into the chalcedonic or crypto-crystalline condition, and the latter into the crystalline. From the Middle Limestone. ×40 diam. A. Amorphous, B. Chaledonic, C. Crystalline Silica.

lizing process commences around the edges and proceeds towards the centre, a process which is well illustrated in the figure, and also in one of the objects (B.) in fig. 3, Plate VIII. At times we get masses of crystals, as though the crystallizing process had been completed. In the amorphous silica we appear to have a practical proof of the tendency of an unstable substance to return to the stable, or original condition, after having served a purpose for which it is no longer required. There are also the micro-crystals with nuclei which might be treated under this head; but I prefer to take them separately, and I shall also make further reference to those without nuclei.

Formation and Origin of the Micro-Crystals of Quartz.

The finding of quartz-crystals in limestone rock is no new discovery, but previous observers do not mention the nuclei. Mr. Thomas Wardle records them* as occurring in the Mountain Limestone of Caldon; Professor A. Renard speaks† of them in the same

* Presidential Address to the North Staffordshire Field-Club, 1873, p. 42.

† "Recherches lithologiques sur les Phthanites du Calcaire Carbonifère de Belgique," footnote, p. 15. Bulletin de l'Académie Royale de Belgique.

formation in Belgium; and Professor Sollas figures * two micro-quartz-crystals from the Caldon Lower Limestone of Derbyshire. On another occasion Professor Sollas states † that he has seen them "in the Silurian limestone of Hamilton, Ontario, in the Devonian limestone of Newton Abbot, the Carboniferous of North Wales, and the Lias of Sutton, South Wales; and in all but the Devonian limestone they were obviously associated with remains of siliceous organisms," a statement which quite corresponds with my observations at Clifton. Speaking of the origin and formation of the crystals, Professor Sollas considers that the silica became dissolved and then crystallized out. "In these crystals," he continues, "we have an instance, disentangled from all complication, of the simple crystallization of quartz from a siliceous solution; and the notion that deposition of silica from diffused solutions could not take place without the presence of an organic nidus is thus completely disposed of." Before further considering Professor Sollas's theory, let us look at the possible origin of the crystals which I have found in the Carboniferous Limestone at Clifton. The possible origins may be reduced to four:—

i. Are they detrital?

ii. Are they the result of simple crystallization of silica from a siliceous solution?

iii. Have they originated from secondary crystallization around rolled or broken fragments of an original quartz-crystal?

iv. Are they the result of the crystallization of amorphous and chalcedonic silica?

With regard to the first of these propositions I can find nothing to justify such a conclusion. The crystals are well defined and show no signs of water-action. Much the same may be said of proposition No. ii.; all the evidence is against crystallization from a siliceous solution. As I have several times, in describing the residues, remarked, many of the crystals show nuclei of detrital quartz (Plate VIII. figs. 3 and 4), and thus the third proposition becomes possible. Dr. Sorby has referred ‡ to the deposition of crystalline quartz around the broken angles of quartz-grains in sandstone rocks, the silica being deposited continuously with the nuclei. Dr. Sorby's observations have received confirmation from other observers, most notably from Mr. R. D. Irving §, of the United States Geological Survey. An examination of the crystals with nuclei, which I have obtained from the limestone at Clifton, can lead to no other conclusion than that they have originated from the deposition of secondary silica around the broken angles of quartz-grains. In the limestone, however, the process appears to have been carried to greater perfection than in the instances investigated by Dr. Sorby and Mr. Irving, for, as in fig. 3 and in fig. 4, Plate VIII., perfect crystals have been constructed around quartz-grains; moreover such instances are nume-

* Ann. & Mag. Nat. Hist. ser. 5, vol. ii. p. 361 (1878).
† *Loc. cit.* ser. 5, vol. vi. p. 446 (1880).
‡ Quart. Journ. Geol. Soc. vol. xxxvi., Proc. pp. 62, 63 (1880).
§ Fifth Annual Report United States Geol. Survey, pp. 219–226.

rous in the residues from the Middle Limestone. As to the source whence the secondary silica has come, there may be some room for speculation. Has it been deposited from solution in the sea-water, or, as I should prefer to express it, extracted from solution by the molecular affinity between the silica of the detrital quartz and the silica in solution? This appears to be the probable explanation of the matter; but there is the fact that in the secondary silica, and especially around the nuclei, are frequently to be seen remnants of amorphous silica; this feature is well shown in the crystal represented in fig. 3, Plate VIII., and in some of those in fig. 4. The fact tends to show that in some instances the secondary silica may have been derived by contact direct from amorphous silica associated with the detrital quartz.

So far I have referred only to those micro-crystals which show detrital quartz-nuclei. There are, however, others in which no such nuclei can be detected, and these I believe to have originated from the crystallization of chalcedonic silica. These crystals can be seen in process of formation around the edges of chalcedonic in the woodcut (p. 194). We have only to imagine such crystals to become detached to account for those which do not show detrital quartz-nuclei. The facts which I have produced, in connexion with the origin of the micro-crystals, seem to show that the theory advocated by Professor Sollas must at least be modified.

Origin of the Amorphous and Chalcedonic Silica in the Limestone.

In dealing with the origin of the amorphous and chalcedonic silica, I am led up to a very interesting controversy between Dr. Hinde and Professor Hull as to the origin of chert. The essence of the controversy is as to whether the Carboniferous chert in Ireland is of organic or inorganic origin.

In 1878 a paper was published * in which Professor Hull and Mr. Hardman speak of chert as a pseudomorphic deposit which has resulted from the sea-water becoming highly charged with silica. This water percolated through the limestone before it became consolidated, and the calcareous structure of the organisms became replaced by the silica in the sea-water before the overlying Yoredale beds were deposited. "It does not appear," says Professor Hull †, in his fifth general conclusion as to the origin of chert, "that the case of silicious sea-bottoms, such as that of the great depths discovered by the soundings of the 'Challenger' in the Southern Ocean, affords an example of the phenomena here described—the sea-bottoms referred to being directly due to animal organisms secreting silica, such as Diatomaceæ, Polycystineæ, and the spiculæ or skeletons of sponges. The silicious material here described can only be considered as a secondary product, due to the replacement of lime carbonate by silica." From these remarks it appears that Professor Hull regards the pseudomorphous silica as of inorganic,

* Scientific Trans. Royal Soc. of Dublin, vol. i. N. S. pp. 71–94 (1878).
† *Loc. cit.* p. 84.

and not of organic origin. This view of the matter was contested by Dr. Hinde in 1885*, who argued that the irregular masses of chert in the Upper and Lower Greensand had been derived from the silica of sponge-remains; and from the same source had also originated the silica which in many deposits had replaced the tests of Mollusca and other calcareous organisms. Professor Hull replied to Dr. Hinde, and, in doing so, said†: "My argument will be based on the fact that the development of sponge-life in the seas of the Carboniferous period was insignificant, and quite inadequate to account for the existence of bands and masses of chert, sometimes constituting almost a half or a third of the entire mass of the Upper Limestone." Dr. Hinde replied ‡, bringing forward further proof of his proposition, to which Professor Hull wrote an answer§, in which he said: "Dr. Hinde's recent investigations undoubtedly show that siliceous sponge-structures enter far more largely into the composition of Carboniferous chert than has hitherto been suspected." "But," he continued, "I am not prepared to go to the full length of Dr. Hinde's demands, as I understand them, nor to abandon as untenable the proposition that much of the silica of Carboniferous chert has been derived by a transmutation process from the waters of the ancient seas." My observations of the insoluble residues do not support the idea that the siliceous constituents were derived directly from the sea-water, that is to say, from inorganic silica, but from siliceous organisms, with the exception, of course, of the detrital quartz. What, then, were these organisms which contributed the silica? That sponge-life was abundant in the Carboniferous sea there can be no doubt; but it is difficult to estimate to what extent, on account of the disintegration and changes which these remains appear to have undergone. Dr. Hinde states ‖ that the silica of siliceous sponges may be either "(*a*) amorphous or in the colloid state; (*b*) chalcedonic or cryptocrystalline, or (*c*) crystalline." This description certainly applies to the siliceous remains which I have obtained from the limestone at Clifton; but I am not prepared to say that other organisms besides sponges have not contributed. I think, however, we may conclude that the amorphous, chalcedonic, and crystalline siliceous constituents in the residues are of organic and not inorganic origin.

My thin slides of the limestone, together with the residues, afford evidence which points to the conclusion that the greater portion of the Carboniferous Limestone at Clifton was deposited in the form of material not unlike that of the Chalk and the calcareous mud now being deposited, in which siliceous organisms occur. Professor Huxley once spoke¶ of the Atlantic mud as "modern chalk;" I regard the Middle series of the Carboniferous Limestone at Clifton as Palæozoic Chalk, though I am not sure that it was a deep-sea deposit.

* Phil. Trans. part 2, 1885, p. 433. † Proc. Royal Soc. vol. xlii. p. 304.
‡ Geol. Mag. vol. iv. N. S. dec. 3, pp. 435–446.
§ Geol. Mag. vol. iv. N. S. dec. 3, pp. 524–526.
‖ Pal. Soc. vol. xl. p. 55. ¶ 'Saturday Review,' 1858.

EXPLANATION OF PLATE VIII.

Fig. 1. Detrital quartz, from the Lower Limestone Shales. ×40 diam.
2. Another residue from the Lower Limestone Shales, consisting of detrital quartz, siliceous pseudomorphs of portions of Crinoids and amorphous silica. ×40 diam.
3. Micro-crystal (A) and a fragment of amorphous silica (B) passing into the chalcedonic or crypto-crystalline and the crystalline conditions at the outer portion. From the Middle Limestone. ×80 diam.
In the centre of the crystal is a nucleus consisting of a grain of detrital quartz surrounded by a substance having the structure of amorphous silica.
4. Residue from the Middle Limestone, consisting of micro-crystals of quartz with detrital quartz-nuclei. ×80 diam.
5. Residue from the Middle Limestone, consisting of grains of detrital quartz, chalcedonic spicules of sponges, and other fragments of chalcedonic silica. ×40 diam.
6. Residue from the upper portion of the Middle Limestone, consisting of detrital quartz, amorphous silica in very small fragments, and chalcedonic spherical bodies, the nature of which is not clearl known. ×40 diam.

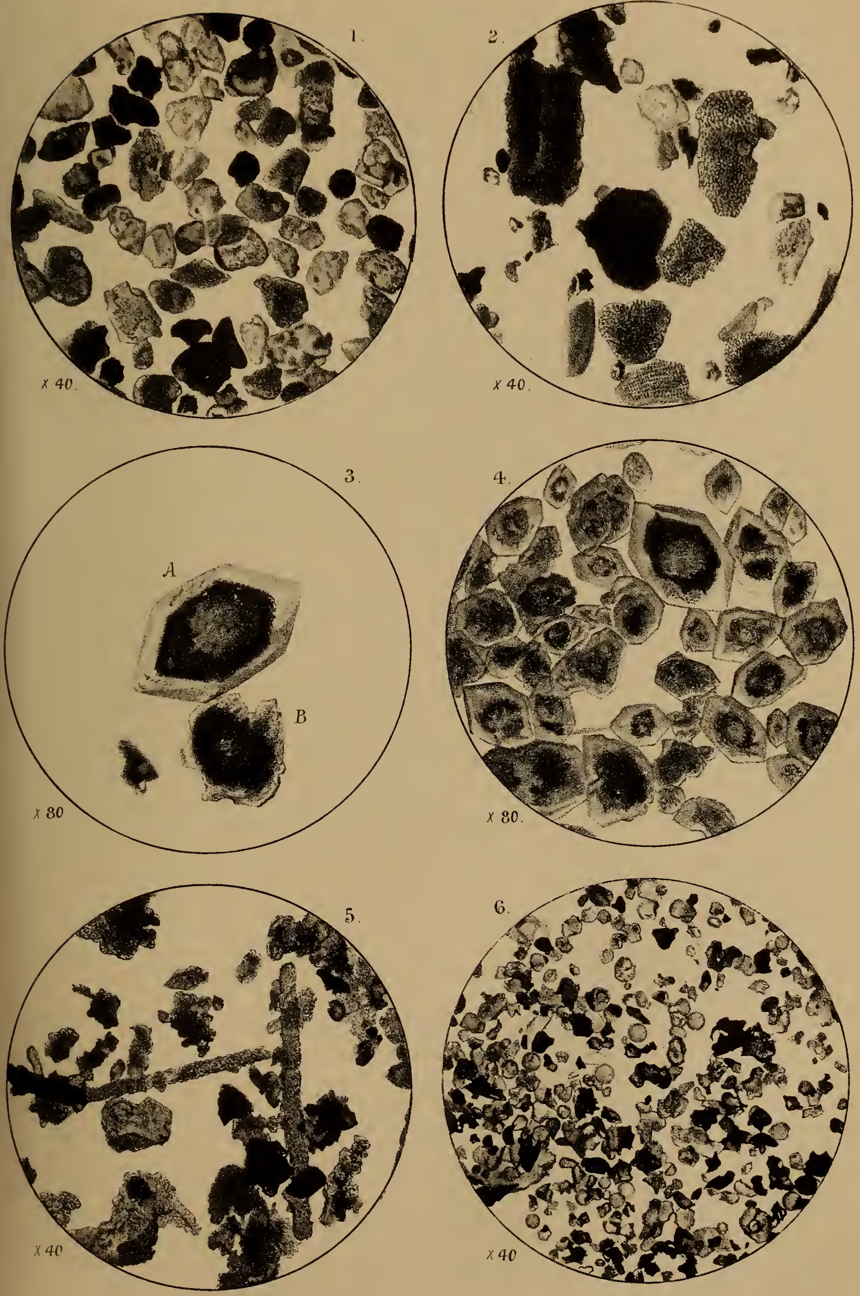
Discussion.

The President observed that while the fact of the occurrence of quartz-crystals in limestones was well known, a number of points had been brought forward by the Author for the first time. It was clear that the several members of the Carbouiferous-Limestone series must have undergone changes of different kinds, but some of the differences observed might be due to peculiarities in the original composition of the rock. The existence of nuclei of fragmental quartz in the crystals, such as had already been described in certain sandstones, and the indications of a gradual passage of amorphous silica into chalcedony and so into quartz had not before been noticed.

Prof. Bonney said that the President had already touched upon the salient points of Mr. Wethered's investigations, so that there was little more for him to do than to express his sense of their value; among other things the paper was interesting as throwing additional light on the formation of flints and cherts. He believed that the sponge-spicules indicated the source of much of the silica. There might also have been chemical precipitation, though not directly, from the water which had taken up silica from more soluble organisms in percolating the rock; so that, as it were, the more powerful organism steals the silica from the weaker ones.

Dr. Hinde was obliged to the Author, whose work confirmed his own views, and had been executed in a careful manner. Silica in the rocks is constantly passing towards the stable condition of quartz. He should like to know what was the evidence of the amorphous character of the silica in the centre of the quartz-crystal. He referred to the various stages of erosion which may be observed in sponge-spicules, prior to final solution, which in many cases has taken place.

Mr. Etheridge also complimented the Author, and spoke of the importance of determining the species of the Foraminifera together



W H Crowther lith.

Mintern Bros. imp.

CARBONIFEROUS-LIMESTONE RESIDUES.

with the Corals. Where *Lithostrotion* and other corals abound the Foraminifera occur in every oolitic grain in the detrital condition of the coral-reef. The Foraminifera were different in different oolitic beds. The Ostracoda occur mainly in the Lower-Limestone shales. The unknown body with the spines he suspected to be Radiolarian. He demurred to the position assigned to the Black Rock. He suggested that Mr. Wethered should take up the subject of the distribution of Foraminifera along with the Corals.

Mr. Winwood spoke of the specially encrinital nature of the Black Rock, but he thought that the Mollusca also should be taken into consideration. He had recently had sections made of the oolitic limestone from another locality without discovering any nuclei other than quartz.

Mr. Topley reminded the Author that in his abstract he had omitted mention of the zircons and tourmalines found in the residues, and referred to the researches of Mr. Dick in this connexion. He had used a wise discretion in not making use of the term "Yoredale Beds." Although the Black Rock might be the "Encrinite Bed" of that particular district, such accumulations did not constitute a palæontological horizon. The typical "Encrinite Bed" of the north is higher in the scale.

The President observed that, with respect to zircons, all sedimentary rocks have been shown to yield them in considerable quantity.

The Author, in reply, thanked the President and Fellows who had discussed his paper, and especially Prof. Bonney, at whose suggestion he had commenced the investigation, and who had aided him with advice in carrying it on. Mr. Etheridge had misunderstood the position assigned by him to the Black Rock; their views were identical. He had queried the *amorphous* silica in the quartz-crystals mentioned by Dr. Hinde. To Mr. Winwood he replied that in the oolitic beds the quartz-grains are well worn. The zircons and tourmalines found throughout are generally angular. He hoped to deal with the calcareous organisms in another paper.

17. *On the* History *and* Characters *of the Genus* Septastræa, D'Orbigny (1849), *and the* Identity *of its* Type Species *with that of* Glyphastræa, Duncan (1887). By George Jennings Hinde, Ph.D., F.G.S. (Read February 8, 1888).

[Plate IX.]

The circumstances which have given origin to the present paper are as follows:—On December 1, 1886, Prof. P. M. Duncan, F.R.S., read before the Society a paper entitled "On a new Genus of Madreporaria—*Glyphastræa*, with remarks on the *Glyphastræa Forbesi*, Edw. & H., sp., from the Tertiaries of Maryland, U.S."*, and exhibited specimens of the form described as the type of a new genus. The statements made by this author and the characters depicted on his diagrams did not appear to me to be borne out by the corals exhibited, and I determined to find out for myself, by an independent and thorough investigation of all the specimens of the form which could be obtained, whether the history and character of the species, *Septastræa Forbesi*, Edw. & H., supported the description given of it in the paper in question, and justified the removal of it from the genus *Septastræa*, in which it had been originally placed by the French authors, to the new genus *Glyphastræa*, proposed by Prof. Duncan.

The specimens which have been studied by me for the purposes of this paper are:—first, the acknowledged type of *Septastræa Forbesi* in the collections of the British Natural History Museum, South Kensington, and several other examples of the same form preserved with it; also microscopic sections of the type form which, at my request, the authorities of the British Museum kindly had prepared for me to ascertain its internal structure; secondly, two beautifully preserved examples of the same species, belonging to the Scarborough Museum, which have been lent to me through the kind offices of Mr. C. Fox Strangways, F.G.S.; thirdly, a specimen from the Museum of the Academy of Sciences, Philadelphia, forwarded to me by Prof. Angelo Heilprin, through Dr. C. A. White, of Washington; fourthly, the specimen labelled as *Septastræa Forbesi*, in the Museum of the Society; and, fifthly, the type specimen of *Columnaria* (?) *sexradiata*, Lonsdale, now in the Museum of King's College, London †.

My investigations have led to the following conclusions, which I may here state briefly, and the reasons for which will appear in the sequel:—1st. That *Septastræa Forbesi*, E. & H., which Prof.

* The abstract of the paper appeared in No. 495, Abstracts of the Proceedings of the Geol. Soc. of London, pp. 18, 19. The paper itself (materially altered and added to subsequent to its reading before the Society) was published in the Quart. Journ. Geol. Soc. vol. xliii., Feb. 1887, pp. 24–32, pl. iii.

† Through the kind permission of the Curator of the Museum, Prof. J. W. Groves, F.L.S., to whom I am also indebted for having a section made from this specimen to allow of a comparison with that from *S. Forbesi*.

Duncan has made the type of his new genus *Glyphastræa*, has been claimed by d'Orbigny, and, I think, rightly, as identical with the type of his own genus *Septastræa*; consequently *Glyphastræa* is only a synonym; 2nd. That some of the characters assigned by Prof. Duncan to *Septastræa Forbesi* may be otherwise interpreted; 3rd. That the minute structure of this species exhibits important features of considerable interest in connexion with the nature of corals generally, which do not appear to have been hitherto known or noticed.

Taking first in order the history of the genus *Septastræa*, it appears that the original diagnosis of it, by d'Orbigny, was published in 1849 in a small pamphlet, independently issued, bearing the title, 'Note sur les Polypiers Fossiles.' I have sought in vain for a copy of this pamphlet in the scientific libraries in London, but through the kindness of Dr. P. Fischer, of the Muséum d'Histoire Naturelle, Paris, I have ascertained that the text of the description is as follows:—

"*Septastræa.*—C'est un *Goniastræa* sans columelle et sans palis, dont les douze cloisons simples viennent se réunir au centre de calices profonds; muraille compacte. On connaît une seule espèce de l'étage Falunien. Exemple: *S. subramosa* d'Orbigny."

Dr. Fischer further informs me that there is no description of the proposed type species, *S. subramosa*, but that in a manuscript catalogue the author states that it was obtained from Southampton, Virginia, U.S.A.

In the same year (1849) Messrs. Edwards and Haime* accept the genus *Septastræa* as valid, and they give the following extended and more precise definition of it:—

"Polypier de forme massive ou subdendroïde. Calices polygonaux, à bords soudés à ceux des calices voisins mais montrant ordinairement une ligne de séparation extrêmement fine. *Multiplication* par fissiparité? † Cloisons bien développées paraissant constituées par des lames parfaits. Ni columelle ni palis. Traverses bien développées. Ce genre comprend des espèces fossiles des terrains tertiaires, qui paraissent différer des Goniastrées par l'absence de columelle et de palis; mais il est possible que la multiplication soit submarginale, et que les cloisons soient entières, ce dont nous n'avons pas pu nous assurer."

Following the generic definition, MM. Edwards and Haime include the four species, *Septastræa ramosa*, Defrance, sp.; *S. Forbesi*, E. & H., n. sp.; *S.? multilateralis*, Mich., sp.; and *S.? hirtolamellata*, Mich., sp. The first of these, *S. ramosa*, Defrance, is stated to be identical with d'Orbigny's nominal type, *S. subramosa*. But a reference to Defrance's ‡ description at once shows its

* "Recherches sur les Polypiers," Ann. des Sciences Naturelles, 3e série, t. xii. p. 163.

† In the translation of this passage given in Prof. Duncan's paper, Q. J. G. S. vol. xliii. p. 24, the note of interrogation after fissiparity has been accidentally omitted, and no reference is made to the subsequent remark that it was possible that the mode of increase of the coral was submarginal.

‡ Dictionn. des Sciences Naturelles, t. xlii. p. 381 (1826).

utter worthlessness as a specific diagnosis, and there is no apparent ground for the above assertion, that this probably recent (non-pétrifiée) coral, of uncertain derivation, is the same as d'Orbigny's type from the Miocene of Virginia.

The second species, *S. Forbesi*, is here described for the first time from specimens from Maryland; the originals were stated to be in the collection of the Geological Survey at London*, and in the Museum at Bonn. The description of this form is so similar to that given of the mythical *S. ramosa*, that it is difficult to find wherein the difference consists, more especially as there are no figures of either form. The distinction alleged is that in the last-named form the septa of the first and second cycle are said to be equal, whereas in *S. Forbesi* they are unequal in length. But in the same specimen of *S. Forbesi* there are plenty of corallites in which both these features are present, so that, as specific characters, they are worthless.

D'Orbigny's reference to *Septastræa* in the 'Cours élémentaire de Paléontologie' (1849), vol. i. 3rd part, p. 170, is nearly a verbatim reproduction of the description given in the 'Note sur les Polypiers;' but instead of one species, d'Orbigny follows Edwards and Haime, and includes therein four species, one from the Etage Parisien, and the others from the Etage Falunien, therefore all Tertiary forms.

Three years later, in 1852, d'Orbigny again refers to the genus in the 'Prodrome de Paléontologie,' vol. iii. p. 146, and requotes his original description, with the addition of the words "ensemble dendroïde." D'Orbigny again places his nominal species *S. subramosa* as the type of the genus, describing it as a "Belle espèce presque dendroïde;" and he places *Septastræa Forbesi*, E. & H., as a synonym of *S. subramosa*. At the same time he regards *S. ramosa*, E. & H., as a distinct species.

It is therefore evident that d'Orbigny claimed the *S. Forbesi*, E. & H., as merely a synonym of his *S. subramosa*; and comparing the descriptions of these two forms given by Edwards and Haime, the claim appears to be well founded. But the further question arises, whether, accepting the species as synonymous, d'Orbigny could justly claim that it should bear the prior name. *S. subramosa*, seeing that this was not accompanied by either description or figure, whereas the later name, *S. Forbesi*, has the specific definition attached to it. It must be conceded that on this ground the name given by d'Orbigny cannot be retained, and that whilst recognizing the identity of *S. subramosa* with *S. Forbesi*, this latter name must stand as that of the type species of the genus *Septastræa*. Independently of the propriety of this course, there is the further advantage that the authenticated type specimen of *S. Forbesi* is in the British Museum, and from it the generic characters can be definitely ascertained; whereas I am informed by Dr. P. Fischer that the original of d'Orbigny's *S. subramosa* cannot now be found in the collection of his fossils in the Muséum d'Histoire Naturelle at Paris.

* The specimen here referred to has since been handed over to the British Natural History Museum, South Kensington.

Tracing the subsequent history of the genus, we find that in their great work, 'Histoire Naturelle des Coralliaires,' MM. Edwards and Haime again give nearly the same diagnosis of *Septastræa** as in the Ann. des Sci. Nat. in 1849. They state that the absence of columella and pali distinguish it from *Goniastræa*, and that the genus is from Tertiary rocks. Four species are again enumerated, but it is very significant that no mention whatever is made of the claim of d'Orbigny that *S. Forbesi* and *S. subramosa* are synonymous †.

De Fromentel, in his 'Introduction à l'étude des Polypiers Fossiles' ‡, mainly copies the generic and specific descriptions relating to *Septastræa* from Edwards and Haime's work, but he also introduces into the genus three species of Jurassic corals. It should be noticed that the species previously placed in the genus were exclusively of Tertiary origin. These new Mesozoic species, as will be shown in the sequel, have no generic affinity with the Tertiary type-forms of d'Orbigny and Edwards and Haime.

Prof. F. B. Meek §, in 1864, placed in *Septastræa*, but with a query, the *Columnaria* (?) *sexradiata*, Lonsdale, and with it the *S. Forbesi*, E. & H., as corals occurring in the Miocene strata of North America. As no mention is made of the nominal *S. subramosa*, d'Orbigny, which came from Virginia, it is probable that this author did not recognize the validity of the species-name, and accepted in its stead *S. Forbesi*.

Prof. P. M. Duncan, in the 'Supplement to the British Fossil Corals' (1867), does not give a diagnosis of the genus, but refers to that of Edwards and Haime, and says ‖:—"The genus *Septastræa* resembles *Isastræa*; but there is fissiparous growth in the calices of the first, and never in the calices of the last-named genus. The peculiar calicinal gemmation of *Isastræa* never produces septa which crossing the calice divide it off into separate individuals. The walls of *Septastræa* are not so perfectly united as in *Isastræa*. The genus is found in the Lias and in the Tertiary Coral-fauna."

This author further places in the genus three new species from the Lias of this country, and also retains one previously described by Fromentel. It will be shown that these species are not congeneric with the *Septastræa* of Edwards and Haime, and that the generic characters given above are not supported by an examination of the typical species of these authors.

Later writers on corals appear to have accepted the definition of *Septastræa* given by d'Orbigny, without particular comment. Thus Quenstedt ¶ states that it occurs only in Tertiary strata; and Prof. v. Zittel ** that it is similar to *Goniastræa*, except that it does not

* Vol. ii. (1857). p. 449.

† Similarly, this fact is also unnoticed in the paper by Prof. P. M. Duncan.

‡ (1861) p. 174.

§ "Check List of Invertebrate Fossils of North America, Miocene." Washington, Smithsonian Institution, p. 1.

‖ Pal. Soc. pt. iv. pp. 5, 6 (1867).

¶ Petrefacten Deutschl. Heft vi. 1878. p. 1015.

** Handb. der Pal. vol. i. 1879, p. 254.

possess either columella or pali. De Fromentel, in the 'Paléontologie Française'*, again repeats the diagnosis of the genus, with the addition that the lamina, which sometimes occurs in the centre of corallites about to divide, is only the extension of a long septum. The two species from the Cretaceous rocks of France which he introduces into the genus do not, however, any more than the Liassic species, properly belong thereto.

In the "Revision of the Families and Genera of the Madreporaria"†, Prof. P. M. Duncan gives a definition of *Septastræa*, similar in the main to that of Edwards and Haime; but the columella is stated to be rudimentary or absent, and there is "fissiparity of calices"‡. The genus is included with three others in the "Alliance Goniastræoida," which consists of massive fissiparous Astræidæ, having, with other features, dentated septa. It will be noted that this author, in opposition to Edwards and Haime, asserts that there may be a rudimentary columella in the genus, and further that the mode of growth is by fissiparity of the calices, whereas the French authors are doubtful on this latter point, and state that the growth may possibly be submarginal, *i. e.* by budding.

In the paper in the Quarterly Journal of Feb. 1887, p. 25, treating of the new genus *Glyphastræa*, the same author again reverts to *Septastræa*, and requotes the definition given of it by Edwards and Haime. He further states that the Mesozoic species introduced into the genus by himself and de Fromentel do not agree with the Tertiary species originally placed in the genus by d'Orbigny and Edwards and Haime, and he therefore takes the original species of the genus for the type of a proposed new genus *Glyphastræa*, and leaves in *Septastræa* those Liassic forms which, according to his own confession, do not belong to the genus as originally constituted.

But in those cases in which species have been erroneously included in a genus, the established and common-sense rule is to regard the species which the author of the genus originally included in it as its type, and if other species are subsequently introduced into the genus either by the same author or by other writers which do not agree generically with the type form, these subsequent species should be removed from it and placed elsewhere. But Prof. Duncan has actually reversed this order; for instead of removing from *Septastræa* the Jurassic species, which, by himself and Fromentel, have been erroneously placed in it, many years after it had been established, and which, as acknowledged by himself, are not congeneric with the original Tertiary forms, he severs from the

* Tome viii. livr. 28, Juin 1879.

† Linnean Society's Journal, Zoology, vol. xviii. (1884), p. 103.

‡ Prof. Duncan states, in his paper on *Glyphastræa* (Q. J. G. S. vol. xliii. p. 25), "the only important modification I made in revising the genus [*i. e. Septastræa*] was to introduce the necessary statement that increase took place by gemmation as well as by fissiparous division of the corallites," and he refers to p. 103 of the "Revision" in the Linn. Soc. Journal. On turning to the reference given, however, I do not find any mention whatever of the statement about gemmation therein.

genus the original Tertiary species of d'Orbigny and Edwards and Haime, on which its characters were originally based, and which from 1849 to 1861 were the only species included in it.

It would have been quite in accordance with precedent to have amended the diagnosis of *Septastræa*, if the type specimen showed that the definition given of it by d'Orbigny and by Edwards and Haime was not so full or so accurate as it ought to be; but it is a decided violation of the ordinary rule, and does great injustice to the author of a genus to appropriate what he claims to be the type species for a new genus, and to leave in its place species which are not generically related to the forms which the author proposed to include in it. It seems to me, therefore, that the genus *Glyphastræa*, being based on *Septastræa Forbesi*, the type species of d'Orbigny's genus *Septastræa*, cannot be regarded as valid, and must therefore lapse.

The principal object which I have had before me in thus tracing out in some detail the history of *Septastræa* is to show that, whatever may be the characters of the genus, they have been based upon corals from the Miocene formation of Virginia and Maryland, and, further, that *Septastræa Forbesi*, E. & H., is the type species, and one of the original specimens of it is in the British Natural History Museum. I now purpose giving a detailed description of the type form, comparing it also with the other specimens which have been lent to me, so as to place the characters of *Septastræa* on surer ground than hitherto. I may remark that most of the specimens are in excellent preservation, retaining their structures as perfectly as in recent corals, and in certain respects better adapted than recent corals for the study of minute structural details. Their mineral constitution appears to be likewise unaltered*.

Septastræa Forbesi.—Outer Form. This is variable in different specimens, which are for the most part upright, cylindrical, or compressed, palmate stems or expansions, from which short, stumpy branches, with rounded blunted extremities, proceed irregularly. The branches are either simple or dichotomous. In one compressed palmate specimen the uneven margins merely show small depressed cavities from which branches have evidently been broken off. No specimen which I have seen is complete; the basal portion of the corallum is always wanting, so that the mode of attachment and the character of the young form cannot be known. In all the specimens of *S. Forbesi* the entire surface exposed, with the exception of the fractured portions, is covered with the summit walls and calices of the corallites, which are all approximately in the same general surface-plane and in contact with each other. The lateral walls of the corallites are only shown in the fractured portions of specimens.

Mode of Growth and Increase.—The exclusive mode of increase,

* Prof. Duncan has indeed stated that the Maryland specimen which he examined is *siliceous* (Quart. Journ. Geol. Soc. vol. xliii. p. 25); but on testing this same specimen with acid, I find every indication that it is of carbonate of lime, the same as the type and other specimens in the British Museum.

as shown in *S. Forbesi* and *S. sexradiata*, is by buds, which are produced on the surface of the corallum in the interspaces between the margins of the corallites. The commencement of this process is clearly shown at and near the apex of the growing branches in the type specimen of *S. Forbesi*; on one branch of this example there are ten distinct buds or young corallites (Pl. IX. fig. 1 *b*). At the interspace formed by the junction of fully developed corallites there is first seen a smooth, shallow depression, bounded by a slightly raised edge, about one third or one half the size of the mature calices. At a further stage, slightly raised ridges, representing the septa, extend from the margins of this space towards its centre. These incipient septa are irregularly developed; in some cases only four or five are present, and it is only exceptionally at this early stage that a complete cycle of six septa makes its appearance. The further growth of the young corallites can be traced in the fractured ends of branches; and the number and disposition of the septa is very variable (Pl. IX. fig. 4). In the course of growth, the corallites, near the apex of the branches, follow a generally vertical direction in the axial portion of the stem or branch for some distance, and they then curve and diverge outwards until their calices are nearly at right angles to the axis. Other corallites are very short and at right angles to the direction of the stem throughout. Thus, in direct transverse fractures or sections of the corallum, the corallites in the central portion are seen in cross section, whilst near the margins their lateral walls or longitudinal sections are exposed. The corallites appear to reach their full width very rapidly. It is only on the surface of growing or incipient branches that buds make their appearance.

In all the examples of *Septastræa Forbesi* and *S.* (*Columnaria*) *sexradiata* which have come under my notice, there is not a single decisive instance of increase by fissiparity to be met with, either on the surface of the corallum or in the exposed fractured interior. It is difficult to understand how these corals could have been described as fissiparous. It is true that d'Orbigny does not, in the original definition, mention the mode of increase; but the genus *Goniastræa*, with which he compares *Septastræa*, is a decidedly fissiparous genus, though Prof. Duncan* states that gemmation occurs in it as well. Edwards and Haime†, indeed, are not decisive as to this character, but they frankly say that they had not determined the point, and that it was possible that the corals, instead of being fissiparous, might increase by submarginal buds, which is really the case.

Prof. Duncan, however, in the 'Revision of the Madreporaria,' p. 103, states, without qualification, that *Septastræa* is characterized by "fissiparity of calices," and in *Septastræa Forbesi* he finds ‡ that "fissiparity is exceptional, but occurs." But in a single specimen of *S. Forbesi* this author § figures from a fractured stem

* Revision of the Madreporaria, p. 102.
† Ann. des Sci. Naturelles, 3[e] sér. t. xii. p. 163.
‡ Quart. Journ. Geol. Soc. vol. xliii. p. 26.
§ *L. c.* pl. iii. fig. 2.

three instances of fissiparity to a single case of budding; and in another part of the same specimen * three corallites, in two of which fission is stated to be in progress. Judging from these examples, it might be concluded that fissiparity was the rule and budding the exception; but after a careful examination of the original specimens figured †, it is my opinion that the phenomena represented are quite unconnected with fission, and that they are merely examples, by no means uncommon in this genus, of the irregular development of the septa in the corallites.

Reference is also made in the same paper to a so-called very remarkable and suggestive instance of fission in a section ‡ made from Edwards and Haime's type specimen now in the British Museum. In this section there is an additional corallite interpolated in the short distance between the part cut off and the surface of the corallum, which is regarded as a new form resulting from the fission of one of the adjoining corallites. The figures given of it (*l. c.* pl. iii. figs. 4, 4′) exaggerate the reality in favour of fission, and do not properly represent the surroundings. The fact that the supposed parent corallite is not in any degree larger than the normal ordinary adjoining corallites, and that it is nearly entirely filled up with stereoplasm, are strong points against its fission. There is also a distinct interspace at the margin of this corallite, precisely similar to those from which new buds are developed; and as careful measurements show that the new coral exactly fills this interspace, it seems to me much more probable that it has grown in the ordinary way from a bud than that it has been produced exceptionally by fission.

Character of the Corallites.—The individual corallites, as seen in transverse section in the interior of the corallum, vary from nearly circular to polygonal, according to the degree in which they have been modified by mutual pressure. On the surface of the corallum, when mature, the corallites are all polygonal; their summit walls are thickened, so that there is a well-marked, generally level space between the individual calices; in the median line of this there is, in the best-preserved examples, a slightly elevated ridge, consisting

* *L. c.* pl. iii. fig. 3.

† Prof. Duncan may also be quoted against himself on the point; for whilst in the explanation of fig. 3 he states that fission is in progress in two of the corallites represented, he nevertheless says, in the text, p. 27, "that these appearances may be the result of irregular corallite growth under the influence of pressure from crowding."

‡ Quart. Journ. Geol. Soc. vol. xliii. p. 27. The description of this section is given as part of the original paper, read on December 1, 1886; but it is quite impossible that it could have appeared in that paper, since the section described was not even in existence at the time. This identical section was made at the British Museum, at my request, to enable me to ascertain if the statements made when the paper was read would be verified or not by a section of the coral; therefore some time subsequent to the reading of the paper in which this description of it professes to have been included! The section was shown to Prof. Duncan, who introduced a description of it into his original paper, without any note or bracket to indicate that the matter was a subsequent addition.

of small tubercles; more frequently, however, the median line consists of a shallow but distinctly impressed linear furrow (Pl. IX. figs. 1, 6). The general surface of the summit-walls and the upper margins of the septa are likewise covered with minute blunted tubercles.

In certain portions of the surface of the corallum in some specimens the corallite walls are much thinner and sharp-edged, indicating that they had not reached the same stage of mature growth as the thick-walled individuals.

The bounding walls, or so-called theca, of the corallites are originally extremely thin and delicate, and it is only by subsequent deposition on their inner surfaces of calcareous material, to which Lindström * has given the name of "stereoplasm," that they become thick and solid in the later stages of growth. The walls of adjacent corallites are distinct † and separate from each other, though in close contact; at the immediate surface of the mature corallum the partition is only indicated by the linear furrow between the calices. The distinctness of the walls is most clearly shown in fractured branches and stems, the division usually taking place *between* individual corallites, each retaining its own wall. In transverse sections, also, each corallite exhibits a distinct wall.

Septa.—In their early stages of growth the septa are thin, delicate plates, of the same character as the bounding wall or theca; in fact they are formed by infoldings of the outer wall or, rather, in other terms, as the septa are first in order of growth, the theca or wall is merely the exterior continuation of the septal laminæ (Pl. IX. fig. 8). This point will be referred to more in detail when treating of the minute structure of the septa. The septa are extremely variable in their development. In some young corallites, as seen in sections of branches of the type specimen, only four are present, in others there are eight septa. In some nearly matured corallites. under apparently abnormal conditions of growth, there may be only two septa, forming a single partition across the centre of the corallite, in others there are four or five, unequal in length. In normal mature corallites twelve septa are shown in the interior, some or all of which may extend to its central axis, where their free lateral margins unite, and frequently are slightly intertwisted together (Pl. IX. fig. 5). Not unfrequently some of the septa slightly curve about halfway between the wall and the centre of the corallite, and unite by their margins with the sides of adjoining septa (fig. 7). Two short adjoining septa also occasionally unite, so as to form a closed loop inside the theca, quite independent of the other septa in the same corallite. I have not observed more than twelve septa in the lower and central portions of any of the corallites; the only indications of a third cycle of septa are slightly impressed vertical lines

* "Förteckning på svenska undersiluriska Koraller," p. 30. Öfvers. af Kongl. Svenska Vetensk.-Akad. Förh. 1873.

† Prof. Duncan states (*l. c.* p. 26) that "the union is so decided, that the corallites are, and always were, inseparable," which is not the case in the type or any other specimen that I have seen.

on the exterior of the theca, and this is the case even when the septa of the third cycle are developed at the summit of the calices, as in *S. sexradiata*. It also often happens that even when 12 septa are fairly well developed in the interior of the corallites there are only six clearly shown in the calices, the other septa of the second or third cycles being only faintly indicated by slight projections at the margins of the calices.

The calices in the mature corallum are generally shallow (in extreme instances nearly level with the surface of the corallum, in other cases from 1 to 3 mm. in depth). The floor is, in mature corallites, complete and usually gently elevated at the centre, so as to form a slight dome; it is radially divided by the septal upper edges, which project slightly above it. In some instances the floor conceals the central union of the septa; in others their junction is distinctly shown. The septa within the calices of mature corallites are much more regular than in the lower and central portions; they are for the most part 6 or 12 in number, but they may range from 4 to 24. In certain cases two opposite septa extend quite across the corallum, and are more prominent than the others; but this feature is by no means general, and in some specimens is hardly noticeable (Pl. IX. figs. 2, 3, 3 *a*, 3 *b*, 6).

When the corallites have not reached their full limit of growth, or, perhaps, in some cases owing to abnormal conditions, the calices are much deeper, and the floors are incomplete and limited to the central portions of the corallites. In weathered specimens also the basal floor of the calices may disappear, and they are then open for a considerable depth.

In the interior of some calices, more particularly in those which are less filled up with stereoplasm, there are delicate linear grooves within the wall, extending vertically from the summit margin, one on each side of the principal septa (Pl. IX. fig. 17). Sometimes the line is not continuous, but instead of it there are closely arranged minute holes. These structures are probably connected with the insertion of the muscles of the mesenteries* of the living polyp. In the interior of the calice of the existing *Flabellum patagonichum*, Moseley, there are similar rows of small holes on either side of the septa; these do not penetrate through the theca. Prof. Lindström† has described apparently similar rows of dots or small holes in the recent *Schizocyathus fissilis*, Pourtales.

By the junction of the inner margins of the septa with each other the internal cavity of the corallites is divided into a series of closed longitudinal chambers or interlocular spaces, and each of these is independently partitioned off at irregular intervals by the transverse

* I am not aware that these structures have been previously noticed in fossil corals; they would evidently afford greater hold to the mesenterial muscles, and explain the statement of Prof. Moseley, that these are attached with such firmness that when the corallum is broken away small pieces of it hang tenaciously to the muscular shreds. Report of H.M.S. 'Challenger,' vol. ii. p. 163.

† "Actinology of the Atlantic Ocean," p. 15. Kongl. Svenska Vetensk.-Akad. Handl. Bd. xiv. no. 6, 1877.

dissepiments. These are extremely thin plates, stretching, in this genus, nearly horizontally across the interlocular spaces. The dissepiments are sometimes developed at the same height in the different septal chambers of a corallite; often, however, they are not produced contemporaneously.

For the greater portion of their length the corallite-walls and the septa retain their thin, delicate characters; but in the upper portion of the corallites, for a short distance below the surface of the corallum, when the corallites have attained their limit of growth, there is a deposition of solid calcareous tissue or stereoplasm, in successive layers, on the interior surface of the wall, the septa, and the uppermost dissepiment, which gradually fills up the upper portion of the corallites, until, as already mentioned, the floor of the calices is almost level with the surface of the corallum, and, as calices, they are nearly obliterated. As a rule, the infilling of the corallite by stereoplasm commences abruptly immediately above the uppermost dissepiments, the wall and septa below these being extremely thin; in some cases, however, a partial deposit of stereoplasm takes place below the last dissepiment. In longitudinal sections of the corallites (Pl. IX. fig. 14) the layers of stereoplasm are clearly shown as wavy lines dipping down from the sides to the centre of the interlocular spaces. Prof. Duncan has described this stereoplasm as numerous, closely striated dissepiments; but the mode of its deposition and its dense structure appear, in my opinion, to show that it is distinct from the true horizontally placed dissepiments.

Pseudocolumella.—It has been already mentioned that the more prominent septa extend to the centre of the corallite, and then either unite evenly by their free inner margins or curve round each other to a slight extent, thus forming a structure to which the name of pseudocolumella has been given by Edwards and Haime* and by Prof. Duncan†. In fractured surfaces and sections the character of this axial structure is very distinctly shown, and there is no doubt that it is produced entirely from the septal laminæ, and that there are no indications of a *columella propria* in the sense in which the words are used by Edwards and Haime. In the upper portion of the corallites the central areas, in common with the interlocular spaces, are infilled with the deposition of stereoplasm; but this has nothing in common with a genuine columella, which, if developed at all, would not have been limited to the upper portion of the corallites merely.

I fully agree with d'Orbigny and Edwards and Haime, that in the type species of *Septastræa* there is no columella in the proper acceptation of the word. Prof. Duncan, however, made this structure one of the distinctive characters of his new genus, which was based

* Histoire nat. des Coralliaires, vol. i. p. 61.

† An excellent and concise definition of this structure is thus given by Prof. Duncan:—"False columellæ are formed by the soldering together of the inner ends of two or more septa, by the twisting of the inner ends of several septa, and by the presence of endotheca close to the septal inner margin."—British Fossil Corals, Suppl., Pal. Soc. 1866, pt. i. p. 12.

on the same type species, *Septastræa Forbesi*. In his original paper, read before the Society, the presence of a columella is categorically asserted, and in the published Abstract* we find it mentioned as a "columella," "a narrow linear columella," and "a narrow ribbon-shaped columella." In the subsequently modified and augmented paper in the Quarterly Journal we find the same structure alluded to under various terms on every page, but with the significant addition that it is sometimes absent. Besides the simple appellation "columella" †, it is likewise defined as "a trabecular and non-essential columella, it often being reduced to a mere lamina which is in the path of two opposed large primaries" ‡; "a narrow discontinuous columella, which is ornamented in the same manner as the septa, but which, in some instances, has a raised edge" §; "a columella which sections prove to be occasionally discontinuous and always non-essential in its method of growth" ‖; "columella small, parietal, lamellar or ribbon-shaped, uniting opposite primaries, or several septa sometimes absent" (*sic*).

After a careful examination of all the specimens described and figured in the paper quoted above, I am unable to discover any of the different varieties of columella which they are stated to possess. They all may, in my opinion, be readily traced to the union and partial involution of the inner margins of the septa in the axis of the corallites, producing the structure known as a pseudo-columella. Nor do the figures accompanying the paper (so far as they are true to nature and not diagrammatic) show structures beyond this. The figures given of the section made at the British Museum (pl. iii. figs. 13, 14) to determine this point conclusively show that a true columella is not present ¶.

Minute Structural Features of Septastræa.—As already mentioned, the effects of fossilization on the examples of *Septastræa* from North-American Miocene strata have been the reverse of what generally happens in fossil organisms; for instead of destroying or obliterating structural features, it has revealed some details more clearly than in many recent corals, and thus thrown fresh light on the nature of the thecal wall, the septa, and the so-called costæ of the corallites and their mutual relation to each other.

Structure of the Septa.—On examining, under the microscope or a strong simple lens, a fractured edge or transverse section of a stem or branch of *S. Forbesi*, the individual septum of the central full-grown corallites, though of great tenuity, not exceeding the thickness

* No. 495, 1886–7, pp. 18, 19.

† *L. c.* p. 24.

‡ *Ibid.* p. 26.

§ *Ibid.* p. 28, pl. iii. figs. 3, 6, 9, 10.

‖ *Ibid.* p. 28.

¶ My justification for thus entering with so much detail into the nature of the asserted columella may be best expressed in the following words of Prof. Duncan respecting this structure:—"Playing a very important part in the economy, and being in relation both with the septa and the pali, the columellæ are structures whose variations in form are of generic import" (Brit. Fossil Corals, Suppl., Pal. Soc. 1866, pt. i. p. 14).

of ordinary writing-paper, will be seen to consist of two laminæ, which are so closely apposed that to ordinary sight they appear as a simple thin plate. Closer examination shows that between these laminæ there is a delicate central linear interspace. The bilaminate septum can be traced to the periphery or bounding wall of the corallite, and it does not then terminate, for one of the laminæ bends round sharply and is continuous with, and forms the theca or corallite-wall on the one side, and the other lamina of the septum similarly forms the thecal wall on the opposite side*. On tracing these lateral extensions further on both sides, we find the same process repeated at the next septum, for there is a similar sharp inflexion to form the septal laminæ, and the same structure is repeated all round the corallite (Pl. IX. figs. 7, 8, 16).

The bilaminate nature of the septa is still more clearly shown in longitudinal fractures which occur in broken extremities of the stems and branches of different specimens. In these cases the septa, though only of paper thickness, individually split up longitudinally into distinct symmetrical halves, and the median plane passes through the centre of that delicate interior structure already noticed, so that each of the two laminæ of the septum consists of two distinct layers of material, an outer and an inner; the two inner layers being very intimately united, so that they have hitherto been regarded as forming a single distinct central layer in the septum. That this median septal structure consists of two distinct halves is further shown from the fact that in several cases corallites actually split along the median plane of the septa, and not in the interspaces between them (Pl. IX. fig. 9).

The inner or median face of each of the laminæ of the individual septum is a nearly plane calcareous membrane, exhibiting somewhat broad, curved, transverse growth-lines, which are highest at the peripheral margin of the septum, next the outer wall, then curve downwards and again rise slightly to the axial or inner margin (Pl. IX. fig. 9). These transverse growth-lines have much the same general appearance as those which usually occur on the outer surface of the theca in most ordinary corals, and are generally known as epitheca. In immediate connexion with the transverse growth-lines there is a delicate layer, consisting of well-marked linear ridges, slightly flexuous, and parallel with each other, which are either vertical or oblique in direction, so as to be at right angles to the transverse growth-lines (Pl. IX. fig. 10). Between the vertical ridges there are very minute linear furrows, which in the best-preserved specimens are crossed transversely, so as to produce a linear series of minute holes, thus giving this layer a lattice-like appearance (fig. 11). On the split face of certain septa, the surface layer of transverse growth-lines is not preserved, and only the vertical linear ridges are shown on each half of the septum.

The ridged or lattice-like inner layer of the septal lamina is not

* This extension appears to be uninterrupted, and I have failed to discover any sutural line between the septal laminæ and the thecal extension.

compact, but consists of minute, dull, whitish grains of calcite, which have a powdery, incoherent appearance. There is a well-marked contrast between this and the compact structure of the outer layer of the lamina; and from a comparison with the structure of the inner septal layer in other corals, it seems probable that the powdery, incoherent material in the fossils is not the original condition of this layer, but results from subsequent change or disintegration during fossilization.

Exterior to the lattice-like layer, and in intimate union with it, is the outer layer of the septal lamina, which is composed of compact, minutely fibrous, calcareous tissue, known as stereoplasm. This fibrous layer gives lively prismatic colours when viewed between crossed nicols. The fibres are deposited in continuous, excessively thin layers, which are indicated by slightly darker lines or breaks. The microscopic appearance of the stereoplasm in sections of the fossil *Septastræa* varies but little from that of recent corals of the genus *Flabellum*, for example.

The outer or exposed surface of the septal lamina, formed by the stereoplasm, is smooth, solid, and compact, and has the appearance of polished ivory. Even in the thinnest septa the stereoplasmic layer forms the largest part of the septal laminæ; and in the process of growth, and more especially in the mature corallites, it is thickened* by repeated depositions of the same material. The inner or lattice-like layer of the laminæ, on the other hand, does not receive any subsequent additions of growth.

In transverse sections it not unfrequently happens that the central or inner layer of the septum is only represented by an empty space enclosed between parallel layers of stereoplasm, thus showing the less resistant nature of the substance of the central layer in comparison with the stereoplasm.

Structure of the Theca or Corallite-wall.—It has been pointed out that the wall of the corallite is merely the outer extension of the laminæ of the septa; and its minute structure, in the main, resembles that of the laminæ. The exterior or lateral surface of the corallite-wall in *S. Forbesi*, as seen in fractured specimens, exhibits a series of parallel, vertical, slightly depressed lines or furrows, with slightly rounded or nearly plane longitudinal interspaces, or pseudo-costæ †. Examined by a strong lens, these interspaces are seen to consist of closely arranged, directly transverse or slightly arched ridges or

* Prof. Duncan suggests that the axial or parent corallites, as he styles them, have undergone some diminution in the bulk of their walls and septa, probably during the life of the polyps (*l. c.* p. 25); but I can see no evidence that the stereoplasmic layers have been removed after having been once formed, or that the wall and septa of the lower portion of the corallites have been originally thicker than they are now.

† The term "costæ" has been applied to the edges or margins of the septa which project on the exterior of the theca or corallite-wall, and they are merely the distal edges of the septa. But septa, formed on the type of *Septastræa* and *Flabellum*, do not project beyond the so-called theca, and the spaces, where they appear on the exterior, are depressed linear furrows instead of projecting ridges or true costæ. The flattened or rounded interspaces between the septa of these corals, which stand out slightly in relief, are generally termed *pseudo-costæ*.

growth-lines, which dip deeply downwards at each vertical furrow, and, apparently, only extend from furrow to furrow (Pl. IX. fig. 12). At the depressed lines or furrows these transverse growth-lines of the exterior of the theca are continuous with the growth-lines which, as already mentioned, form the inner or median plane of the septal lamina. The vertical furrows, therefore, are coincident with the median line of the septa, and the thecal surfaces between the furrows or pseudo-costæ are between the septa. The transverse growth-lines of the outer wall of the theca are, however, much stronger than the growth-lines of the septal laminæ with which they correspond.

Within the growth-lines of the thecal wall there is a lattice-like tissue of the same nature, but more delicate than that of the septal lamina; and, united to this, is a layer of stereoplasm, which is continuous with that forming the outer layer of the septa.

The constitution of the thecal wall is therefore similar to that of the septal laminæ; there are first, from without inwards, the transverse growth-lines which, in connexion with the vertical lines of the lattice-like tissue, form the primary layer of what is now a powdery, incoherent material, and next, the layer of stereoplasm. In the wall of the theca the primary layer is exterior to the corallite, whereas in the septa the primary layer of each lamina is in the central or inner portion.

The stereoplasmic layer thus forms a complete interior or lining to the corallites. In the young corallites, as well as in the full-sized forms which have not attained their full growth-limits, the stereoplasm forms a simple thin covering to the delicate interior membrane; but when the full growth-limit of the corallites is reached, this material is deposited in successive layers within the interlocular chambers above the uppermost dissepiment until they are filled nearly to the surface of the corallum (Pl. IX. figs. 13, 14). The deposit is, in all cases, laid down from within; the close apposition of the corallites prevents any addition to the exterior of the walls.

The horizontal dissepiments which extend across the interseptal loculi and successively form the basal floor to the living polyp appear to consist primarily of a single, delicate, calcareous membrane, of a fibrous structure, which grows from the margins of the loculus towards the centre (Pl. IX. fig. 15). Whether this primary layer is of the nature of the primary layer of the septa and theca, or whether it is of stereoplasm, I have not been able to determine; in either case it becomes subsequently thickened by stereoplasm in common with the other skeletal tissues.

The nature of the septa and theca in recent corals and their relation to the tissues of the living polyp have lately been carefully studied by several German and English authorities, and the facts shown by the fossil *Septastræa* have an important bearing on the subject. In the study of the minute structure of recent corals, transverse microscopic sections have been almost exclusively relied on. The septa of such forms as *Flabellum*, *Lophohelia*, and *Mussa* show, when viewed by transmitted light, a central dark line or layer, of a confused appearance, which is surrounded on both sides by a lighter fibrous layer of calcareous material, regarded as stereoplasm. Likewise the thecal wall exhibits a similar dark layer, which, in *Flabellum*, is next the exterior and connected with the dark layer of the septa, and, further, has the slighter fibrous stereoplasm on one side only, that is, on the interior. In the other genera mentioned above, the dark layer of the septa does not directly connect with the dark layer of the thecal wall,—at all events as regards the principal septa—but when present in the theca it has a layer of lighter stereoplasm on both the exterior and interior surfaces. The nature of this dark layer in recent corals has not yet been determined; it is known as the primary layer or centre of calcification, and appears to be distinct in character from the stereoplasmic layer which encloses it, though there is no well-marked line of division between them. There can be no doubt that the transverse growth-lines and longitudinal ridges and furrows constituting the inner layers of the septal laminæ and the outer layer of the theca, in *Septastrea*, correspond to the darker primary layers in the recent corals mentioned above. Unfortunately the fossil coral is less adapted for microscopic investigation than the recent forms, owing to the incoherent nature of the primary layer; and it is only where the corallites are now solidified by stereoplasm that it is possible to obtain transparent sections. These show, less distinctly however, the same minute structure as in the recent corals.

Two partially conflicting views as to the nature of the septum in Aporose Corals have hitherto been maintained. Thus Edwards and Haime * cursorily state that in the most highly developed septa there are two parallel laminæ, which are either fused together directly or by an intermediate tissue. This view seems to be still held by Prof. Duncan †, who says of the present form, *S. Forbesi*, "The septa are bilamellar and the evidence of a very irregular and narrow interlamellar space is apparent, sometimes superficially and invariably in microscopic sections of corallites near the calices."

Prof. Lindström ‡, on the other hand, has advanced the view that the normal septum in living and fossil corals, whether palæozoic or neozoic, consists of a narrow, central, primary lamina enclosed on both sides by a layer of stereoplasm, or endothecal structure, and that this primary lamina is virtually the septum and possesses a different structure from the enclosing stereoplasm. This view of the nature of the septum is also supported by Dr. G. von Koch §, one of the foremost authorities on living corals; Dr. Fowler || and Mr. Bourne ¶

* Histoire nat. des Coralliaires, vol. i. 1857, p. 57. † *Loc. cit.* p. 28.

‡ "Contributions to the Actinology of the Atlantic Ocean," Kongl. Svenska Vetensk.-Akad. Handl. (1877) Bd. xiv. no. 6, p. 17. Also "Om de palæozoiska Formationernas Operkelbärande Koraller," Bihang till K. Svenska Vet.-Akad. Handl. Bd. vii. no. 4 (1882), p. 86.

§ "Ueber das Verhältniss von Skelet und Weichtheilen bei den Madreporen," Morpholog. Jahrb. Bd. xii. (1887), p. 156, pl. ix. fig. 4.

|| "The Anatomy of the Madreporaria.—III.," Quart. Journ. Micros. Sci. vol. xxviii. (1877), p. 7, pl. i. figs. 4, 5.

¶ "On the Anatomy of *Mussa* and *Euphyllia*, &c.," ibid. vol. xxviii. p. 23, pl. iii. figs. 2, 3.

likewise point out, in many existing corals, the dark line in the centre of each septum as the centre from which calcification has taken place, therefore the primary layer.

The structure of the septa in the fossil *Septastræa* fully confirms the view of Lindström that the central or dark layer of the septum is distinct from the enclosing or lighter layers; but the fossil coral proves the further fact, which does not appear to have been previously ascertained either in fossil or recent corals, that the delicate central dark layer in the septum is really divided by a median plane, and consists of two distinct halves or laminæ, and that the structure of each of these, with its outer envelope of stereoplasm, is similar in this genus to that of the theca, which, indeed, in this and some other genera is merely a lateral extension of the septal laminæ.

This median division of the primary layer of the septum likewise accords with the view, enunciated more particularly by von Koch, that the septa, in common with the other hard skeletal tissues, are formed by a secretion of the ectodermal layer of the living polyp, and that, morphologically, the skeleton is exterior to the soft tissues of the animal. To within a recent period the statement of Edwards and Haime * that the septa and theca were produced by the mesodermal layer of the polyp was generally accepted; but v. Koch has conclusively shown that the septa are developed within longitudinal folds of the ectoderm by modified cells, technically known as "chalicoblasts" †.

The discovery of the median division of the primary layer in the septa of *Septastrea* led to an examination of other genera of fossil corals, and I find a precisely similar structure in fossil species of *Flabellum*, *Ceratotrochus*, *Trochosmilia*, and *Paracyathus*. There is but little doubt that the same structure is present also in *Conosmilia*, Duncan; but I have been unable to examine examples of this coral ‡.

In many respects there is a close correspondence in the structure of the septa and theca of *Septastræa* and that of the recent and fossil genus *Flabellum*. The septal laminæ of this latter genus are continued laterally outwards to form the theca; the transverse growth-lines of the primary layer of each lamina are similar in both genera; and there is a precisely similar deposition of stereoplasm, which forms a solid infilling in the basal portion of *Flabellum*, as in the upper portion of the corallites of *Septastræa*. These resemblances in the fundamental structures of the septa and theca appear to me to indicate a closer relationship than mere similarity in the number or disposition of the septa or other superficial characters; and there is some reason for believing that a thorough investigation of the minute microscopic structure of fossil and recent corals will afford a more satisfactory basis for their classification than that now in

* Hist. nat. des Coralliaires, t. i. p. 34.

† See von Heider, 'Sitzungsber. kaiserl. Akad. d. Wiss. Wien,' 1882, p. 651.

‡ This genus was described in the Ann. & Mag. Nat. Hist. 1865, vol. xvi. p. 184, and three species included in it. The type specimens were stated by Prof. Duncan to be in the Collection of the Geol. Soc. They were redescribed and refigured in the Quart. Journ. Geol. Soc. vol. xxvi. 1870, p. 305. by the same author; but the originals can no longer be found in the Geol. Society's Museum.

existence. At present there is great confusion, and some of the leading authorities * differ widely even as regards the characters which constitute a coral.

From the foregoing description of the type species, *Septastræa Forbesi*, it is evidently necessary to revise the definition of the genus given by D'Orbigny and by Edwards and Haime, and I therefore propose the following diagnosis:—

MADREPORARIA APOROSA.

Family ASTRÆIDÆ.

Genus SEPTASTRÆA, d'Orbigny (1849), emend. Hinde.

Syn. Septastræa, d'Orbigny; Edwards & Haime, in part; Fromentel, in part; Meek; Zittel; non Duncan. *Glyphastræa*, Duncan.

Generic Characters.—Corallum compound, massive, palmate or subramose. Corallites prismatic at surface of corallum, subcylindrical in the interior, their walls in close contact with, but distinct from each other. Septa in normal corallites varying from 6 to 24, usually either 6 or 12 fully developed; septa of the third cycle not reaching the centre of the calice. Occasionally two opposite septa, much more prominent than the others, meet in the centre and extend across the calice. The septal laminæ extend laterally at the periphery to form the theca. The inner margins of the septa unite with each other to form closed loculi, and they are occasionally intertwisted, so that a pseudo-columella is produced. Dissepiments nearly horizontal. The septa and thecal walls are thin and delicate in the lower part of the corallites; but in the upper portion, when full-grown, the interior of the corallites is filled with a deposit of stereoplasm, so that the calices are very shallow, and in mature forms there is a complete floor to the calice. Increase by gemmation in the interspaces between the corallites.

Type species: *Septastræa Forbesi*, Edw. & H. (=*S. subramosa*, d'Orbigny, nominal).

Loc. Fossil: Miocene Tertiary, North America.

The Mesozoic forms placed in the genus by de Fromentel and Duncan do not properly belong to it.

As the mode of increase of this genus is clearly by gemmation, it can no longer remain in the tribe of the Faviaceæ, in which it was placed by Edwards and Haime, nor in the alliance Goniastræoida of Prof. Duncan.

* As an instance of this may be cited the fact that whilst Mr. J. J. Quelch merges the Madreporaria Rugosa as a single group with the Madreporaria Aporosa ('Challenger' Report, vol. xxi. 1886, p. 57), Prof. P. M. Duncan states that it might be regarded as doubtful whether the Rugosa are Corals at all! (Quart. Journ. Geol. Soc. vol. xl. 1884, p. 506). The same author, again, in treating of the Fungidæ, writes, "One might speculate upon the impossibility of the occurrence of mesenteries, and wonder whether these forms are really corals" (Linnean Soc. Journ. vol. xvii. 1883–4, p. 146).

In the minute structure of the septa and the formation of the theca by the extension of the septal laminæ, *Septastræa* still further differs from *Favia*, *Goniastræa*, and their allied forms ; and pending a more complete rearrangement of the Aporose Corals it may provisionally be taken as the type of a new subfamily, the Septastræinæ.

SEPTASTRÆA FORBESI, E. & H. (Pl. IX. figs. 1–5, 7–15, 17.)

1849. *Septastræa Forbesi*, E. & H. Ann. des Sci. Nat., 3e sér. t. xii. p. 164.

1849. *Septastræa subramosa*, d'Orbigny (nominal), Note sur les Polypiers fossiles, p. 9.

1852. *Septastræa subramosa*, d'Orbigny, Prodr. de Pal. vol. iii. p. 146.

1857. *Septastræa Forbesi*, E. & H. Hist. nat. des Corall. vol. ii. p. 450.

1861. *Septastræa Forbesi*, de Fromentel, Introduction, &c. p. 174.

1864. *Septastræa Forbesi*, Meek, Check-list Invertebr. foss. N. American Miocene, p. 1.

1886. *Glyphastræa Forbesi*, Duncan, Abstract Proc. Geol. Soc. London, no. 495, p. 18.

1887. *Glyphastræa Forbesi*, Duncan, Quart. Journ. Geol. Soc. vol. xliii. p. 29, pl. 3.

Corallum of large flattened masses with lobate or digitiform extensions, or of rounded or compressed stems with short rounded branches. Mode of attachment unknown. Entire surface of corallum covered with calices in close contact. In normal corallites 12 septa developed, but frequently only six extend to centre of corallite. The septa of the third cycle only indicated by slight vertical ridges. In abnormal corallites the number of the septa may be reduced to 2, 4, or 5, or increased to 16 and even to 36. The fully mature calices are shallow, from 1 to 3 millim. in depth, polygonal, with thickened margins, an impressed line or linear rows of tubercles marking the division between individual calices; the upper surface of the wall and the septal upper edge likewise covered with tubercles, but the surfaces of the septa in the interior of the corallites are smooth. Floor of calice in mature corallites entirely closed, the upper edges of the septa slightly projecting above the floor, which has a dome-shaped elevation in the centre. In calices not mature the walls are thin, the floor is incomplete near the periphery, but usually filled up in the central portion to a varying extent.

Dissepiments very thin, irregularly developed, occasionally at the same level in the different interloculi, usually from 1 to 2 millim. apart, the uppermost dissepiment forming the base to the infilling of solid stereoplasm. No indications of a genuine columella. Fresh buds formed at the interspaces between the walls of adjoining mature corallites : no instances of real fission present.

The largest specimen (incomplete) is 160 millim. in height, 120 in width, and from 20 to 50 millim. in thickness. The corallites vary from 4 to 6 millim. in diameter, their average width is 4·5 millim.;

abnormally large forms reach to 8·5 millim. in width, but show no signs of fission.

This species is distinguished from *Septastræa sexradiata*, Lonsdale, sp., by the non-development in the calices of the third cycle of septa.

Distribution. Miocene Tertiary, Southampton, Virginia, and Maryland, United States of America. The type specimen is in the Brit. Museum Nat. Hist., South Kensington.

SEPTASTRÆA SEXRADIATA, Lonsdale, sp. (Pl. IX. figs. 6, 16.)

1845. *Columnaria* (?) *sexradiata*, Lonsdale, Quart. Journ. Geol. Soc. vol. i. p. 497, figs. *a*, *b*.

1845. *Columnaria* (?) *sexradiata*, Lyell, ibid. p. 416.

1857. *Astrangia* ? *bella*, E. & H. Hist. nat. des Corall. vol. ii. p. 615.

1861. *Astrangia* ? *bella*, de Fromentel, Introduction &c. p. 237.

1864. *Septastræa* (?) *sexradiata*, Meek, Check-list Invertebrate Fossils N. American Miocene, p. 1.

1887. *Glyphastræa sexradiata*, Duncan, Quart. Journ. Geol. Soc. vol. xliii. p. 30.

Corallum forming large masses of a similar character to those of *S. Forbesi*, the lower portion of the corallites varying, in transverse section, from approximately circular to polygonal, and their walls are thin. In the lower portion the corallites have usually 12 septa, but frequently only six are present and reach the centre of the corallite. The septal surfaces in the interior are smooth. The inner septal margins occasionally intertwisted, so as to form a pseudo-columella, as in *S. Forbesi*; but there are no indications of a true columella. The nature of the septa and of the theca precisely as in *S. Forbesi*, and the upper portion of the corallites similarly filled with stereoplasm. The calices shallow, with their central portions from 1 to 2 millim. below the margins. The upper surface of the corallite-walls and the septal edges in the calices covered with minute blunted tubercles. The floor of the calices completely closed with a film of stereoplasm, save in a few immature calices, in which the interlocular septal spaces are open. The septa in the calices are slightly elevated blunted ridges; they sometimes disappear before reaching the centre, and the axial space, when perfect, is covered with minute tubercles.

In the calices 24 septa are clearly shown, of which 4, and sometimes 6, are markedly prominent, and these generally reach to the centre; as a rule 12 septa extend nearly or quite to the axial area, and the intermediate 12 septa of the third cycle reach about halfway and then either bend and unite with the larger septa, or more frequently remain free. Though the 12 septa of the third cycle are thus plainly developed in the calices, they cannot be distinguished in the lower portion of the corallites, where only the 12 septa of the first and second cycles are present.

The dissepiments are horizontal, and from 1·5 to 2·5 millim. apart.

There are no traces of fission, and increase is by gemmation, the same as in *S. Forbesi*.

The typical specimen (incomplete) is 140 millim. in height, 150 in extreme width, and 44 millim. in thickness. The corallites vary from 3 to 6 millim. in diameter, but their average width is 4·7 millim.

The above description of this species is taken from the type form, described and figured by Mr. Lonsdale in the Quart. Journ. Geol. Soc. vol. i. p. 497. After considerable inquiry in various quarters * I ascertained that this valuable specimen was in the Museum of King's College, London: but until I called attention to the fact, it had not been recognized as the specimen figured by Mr. Lonsdale, and at the time of my first seeing it, it was labelled *Glyphastræa Forbesi*.

It is very evident that in form, mode of growth, and in every other feature but one, this species is closely similar to *Septastræa Forbesi*. The one feature in which it differs is the greater development of the third cycle of septa within the calices. This feature, curiously enough, is limited to the calices, for in the lower part of the corallites only the 12 septa of the first and second cycles are developed, as in *S. Forbesi* so that specimens in which the surface features are partially obliterated cannot be distinguished from this latter species. I have serious doubts whether this one feature may not, after all, be due to a more favourable condition of growth or environment to which this particular specimen has been exposed. It is somewhat remarkable that of the 13 specimens of *Septastræa* which have come under my notice, this is the only one which exhibits such a development of the third cycle of septa in the calices; in all the others this cycle is only indicated by marginal ridges. There is a certain amount of variation in this respect in the specimens referred to *S. Forbesi*, for in some only 6 septa are developed in the calices, in others 12, and yet no specific distinction can be made; since in certain specimens both conditions are present. It might therefore be urged that, as Lonsdale's specimen is undistinguishable in every other respect from *S. Forbesi*, the difference in this variable feature does not possess specific value. Whilst admitting the force of the argument, I think it is preferable provisionally to allow the difference to be specific, and if further evidence should show that it must be regarded as merely due to external conditions, and that there is only one species, then this species must bear Lonsdale's name of *sexradiata*, since this has the priority of Edwards and Haime's name, *Forbesi*.

Lonsdale's description of this species is remarkably complete, precise, and accurate, and cannot be improved upon at the present day. He even noticed that the individual septum was formed of two united laminæ, and that the extension of these formed the walls; the thickening of the wall and septa is pointed out, and the solid infilling of the upper part of the corallites is compared with that in

* In this connexion I beg to express my thanks to Leonard Lyell, Esq., M.P., F.G.S., for searching for this specimen in the Collection of the late Sir Charles Lyell, now in his possession.

Oculina. The increase by gemmation and not by fission is described, and the fact that the central axial structure is merely produced by the union of the septa. And even in placing the form in the genus *Columnaria*, Goldfuss, Lonsdale showed a true insight into its relations; for there is no doubt that *Columnaria*, though Palæozoic, belongs to the Family Astræidæ. As Lonsdale's work has, by some later authors, been unjustifiably neglected in favour of that of Edwards and Haime, I venture to point out that in this case it is far superior to that of the French authors.

In 1857 *, Edwards and Haime placed Lonsdale's species as a synonym of *Astræa bella*, Conrad, in the doubtful genus *Astrangia*. These authorities could have paid but little attention to its description, or they would not have relegated it to a genus whose characters are, as remarked by Prof. Duncan †, so very different. I have endeavoured to ascertain if there is any ground for the assertion that *Columnaria sexradiata*, Lonsdale, is really a synonym of *Astræa bella*, Conrad ‡. The description given by Conrad of his species is exceedingly meagre, but, so far as it goes, it indicates a coral quite distinct from Lonsdale's *C. sexradiata*, which is not incrusting, does not possess unequal cells, and its septa are not denticulate, as is stated to be the case in *A. bella*. The late Prof. Meek § likewise regarded *A.* ? *bella*, Conrad, as quite distinct from *C. sexradiata*, Lonsdale; and Prof. Verrill ||, another competent authority, has placed *A. bella*, Conrad, in the subgenus *Cœnangia*, thus quite distinct generically from *Septastræa* (*C.*) *sexradiata*. Through the kindness of Dr. C. A. White, of Washington, and Prof. A. Heilprin, of Philadelphia, I have been enabled to study examples of *A. bella*, Conrad, and I can myself testify that they are markedly different from Lonsdale's species. It is therefore evident that Edwards and Haime were in error, alike in placing Lonsdale's species in the genus *Astrangia*, and in regarding it as a synonym of *A. bella*, Conrad.

Prof. Meek ¶ appears to have been the first to recognize that *Columnaria* (?) *sexradiata*, Lonsdale, belonged to the genus *Septastræa*; but he inserts a query, probably because this latter genus had been wrongly stated to be fissiparous, whereas Lonsdale's species undoubtedly increases by gemmation.

Prof. Duncan ** asserts that *Septastræa* (or *Glyphastræa*) *sexradiata* †† shows a small columella, that there is union between some of the tertiary septa and the secondaries, which does not occur in the calices of *S. Forbesi*, and that, "moreover, the open condition of the

* Hist. nat. des Corall. vol. ii. (1857), p. 615. † *Loc. cit.* p. 30.

‡ Journ. Acad. Nat. Sci. Phil. vol. viii (1842), pt. 2, p. 189. The description is as follows:—"*Astræa bella.* Incrusting, thick, cells unequal, pentagonal, rays numerous, minutely and beautifully denticulate, frequently alternate in length. Occurs near Newborn, N.C." No more is stated, and there is no figure.

§ 'Check-list of the Invertebrate Fossils of North America,' 1864, p. 1.

|| Trans. Connecticut Acad. Arts & Sciences, vol. i. pt. 2, 1867–71, p. 530.

¶ *Loc. cit.* p. 1.

** Quart. Journ. Geol. Soc. vol. xliii. (1887), p. 20.

†† Lonsdale makes no mention of a columella, and his figure merely shows that central union of the septa which he states is present.

interseptal spaces of the immature calices of Lonsdale's species is not seen in *G. Forbesi*; nevertheless the alliance of the species is very close." As regards the columella, there is absolutely no difference between this structure in the two species, in both it is only a pseudo-columella; it is also a fact, though not, apparently, noticed by Prof. Duncan, that the immature calices with open interspaces, which he claims as a particular feature in *S. sexradiata*, are equally present in *S. Forbesi*, and the differences between the two species are, as stated above, reduced to the further development of the tertiary septa and the union of some of them to the secondaries in the former species.

How close the alliance of the species really is may be judged from the fact, already mentioned, that Prof. Duncan unwittingly pronounced the typical figured specimen of Lonsdale's *S. sexradiata* to be a specimen of *S. Forbesi*.

Distribution. Tertiary: Miocene. Evergreen, James's River, Petersburg, Virginia, U.S.A.

The original specimen is in the Museum of King's College, London; it was probably presented by Sir Charles Lyell*, who collected it himself, and stated that, lying on the beach of James's River, were masses of the coral upwards of two feet wide, which had been washed out of a shell-marl.

The above are the only species which can be strictly included in the genus *Septastræa* as amended; there are several other species which have been placed in it by various authors, and I propose briefly to point out the reasons for excluding them from the genus.

SEPTASTRÆA MULTILATERALIS, E. & H.

1847. *Astræa multilateralis*, Mich. Icon. Zooph. pp. 61, 311, pl. 12. fig. 10.

1850. *Septastræa multilateralis,* E. & H. Ann. des Sci. Nat. 3e sér. t. xii. p. 164.

1857. *Septastræa geometrica*, E. & H. Hist. Nat. des Corall. t. ii. p. 450.

There is a very excellent example of this species in the British Natural History Museum; it agrees with *Septastræa* in its principal characters, but there is no thickening and infilling by stereoplasm of the upper portion of the corallites (a distinguishing feature of *Septastræa*), further, the dissepiments are not horizontal and they are vesicular. The original specimen is from the Miocene strata, near Bordeaux, France.

SEPTASTRÆA (?) HIRTOLAMELLATA, E. & H.

1847. *Astræa hirtolamellata*, Mich. Icon. Zooph. p. 162, pl. 44. fig. 5.

1850. *Septastræa* (?) *hirtolamellata*, E. & H. Ann. des. Sci. Nat. 3e sér. t. xii. p. 165.

The descriptions given of this species are very slight, but it is evident that the upper portion of the corallites is not infilled with

* Quart. Journ. Geol. Soc. 1845, vol. i. p. 416.

stereoplasm, and that the septa are strongly dentated. The type form is from Eocene strata at Parnes and Grignon, France.

SEPTASTRÆA RAMOSA, E. & H.

1849. *Septastræa ramosa*, E. & H. Ann. des Sci. Nat. 3e sér. t. xii. p. 164.

1850. *Septastræa ramosa*, d'Orbigny, Prodr. d. Pal. vol. iii. p. 146.

This species has never been figured. The *Astrea ramosa*, Defrance *, on which it is based by Edwards and Haime, is a very doubtful form, of uncertain origin, and it is not definitely known whether it is fossil or recent. The description given of the species by Edwards and Haime is equally vague, and there is no appreciable difference between it and that of *S. Forbesi*. These authors claim that the *A. ramosa*, Defrance, is synonymous with *Septastræa subramosa*, d'Orbigny, but there is not sufficient evidence to support this view. D'Orbigny, on the other hand, whilst holding that the *S. ramosa*, E. & H., may be included in *Septastræa*, denies that it is synonymous with his *S. subramosa*, which he asserts is the same as *S. Forbesi*, E. & H. At present it is impossible to determine, in the absence of figures, whether *A. ramosa* properly belongs to *Septastræa*, or if it does, whether it can be separated from *S. Forbesi*.

SEPTASTRÆA EXCAVATA, de Fromentel.

1861. *Septastræa excavata*, de From. Introduction &c. p. 175.

1867. *Septastræa excavata*, Duncan, Brit. Foss. Corals, Suppl. Pal. Soc. pt. iv. no. 1, p. 32, pl. i. figs. 6, 7.

Accepting as correct Prof. Duncan's reference to and figures of this species, it is very evident that it does not belong to *Septastræa*; for there is no infilling of stereoplasm, the calices are deep, and the increase is by fissiparity. The species is from the Lias of Brocastle, S. Wales, and Pont d'Aisy, Côte-d'Or, France.

SEPTASTRÆA DISPAR, de Fromentel.

1856. *Isastræa dispar*, de From. Bull. Soc. Géol. France, 2e sér. t. xiii. p. 801.

1861. *Septastræa dispar*, de From. Introduction &c. p. 175.

The characters assigned to this form are entirely insufficient to determine the genus to which it belongs. It does not seem to have been figured. It is stated to have been derived from Portland strata at Marcey-sur-Saône, France.

SEPTASTRÆA EXPLANATA, de Fromentel.

1861. *Septastræa explanata*, de From. Introduction &c. p. 175.

As in the preceding case, the scant description without a figure is altogether valueless to establish either the species or the genus to which the form belongs. It is said to come from Bajocian strata at Mantz and Voucourt (Haute Marne), France.

* Dictionn. des Sci. Nat. vol. xlii. p. 381.

SEPTASTRÆA HAIMEI, Duncan.

1858. *Isastræa Haimeii*, Wright, Quart. Journ. Geol. Soc. vol. xiv. p. 35.

1867. *Septastræa Haimei*, Duncan, Brit. Foss. Corals, Suppl. Pal. Soc. pt. iv. no. 1, pp. 5, 6, pl. i. figs. 1–5.

This form is of a type quite distinct from *S. Forbesi*, and it is evident that it does not belong to the same genus, *Septastræa*. The upper portion of the corallites is not filled with stereoplasm, the septa only occasionally reach the centres of the calices, and they are stated to grow by fissiparity, produced by two large septa stretching across the calices and uniting. Dr. Wright states that the form is from the Lower Lias, near Evesham, Warwickshire; whereas Prof. Duncan * asserts that it is from Street, in Somersetshire, and that Dr. Wright is answerable for its discovery in this locality (*l. c.* p. 6, note).

SEPTASTRÆA FROMENTELI, Terquem et Piette.

1865. *Septastræa Fromenteli*, T. & P. Mém. Soc. Géol. de France, 2e sér. t. viii. p. 129.

1867. *Septastræa Fromenteli*, Duncan, Brit. Fossil Corals, Suppl. pt. iv. no. 1, p. 37, pl. x. fig. 5.

This species is closely allied to the previous one, and for the same reasons it will have to be excluded from the genus *Septastræa*. It occurs in the Lias of Marton, near Gainsborough, and other localities.

SEPTASTRÆA EVESHAMI, Duncan.

1868. *Septastræa Eveshami*, Duncan, British Foss. Corals, Suppl. pt. iv. no. 2, p. 52, pl. xiii. figs. 5–7.

This species also is allied to *S. Haimei*; the walls are thin throughout, the corallites not filled above with stereoplasm, and increase is stated to be by fission; in all these features it differs from the true *Septastræa*. The specimen is from Lias strata, at Evesham, Warwickshire.

SEPTASTRÆA CRASSA, de Fromentel.

1879. *Septastræa crassa*, de From. Paléont. Française, livr. 28, t. viii. p. 486, pl. 123. fig. 2.

The description and figures only relate to the surface-characters of the form; these, however, are sufficient to indicate that it is distinct from the Miocene *Septastræa*. The form is from the Neocomian at Sault (Vaucluse), France.

SEPTASTRÆA AMBIGUA, de Fromentel.

1879. *Septastræa ambigua*, de From. Paléont. Franç. livr. 28, t. viii. p. 486, pl. 133. fig. 1.

* The type of this species is now in the Brit. Museum Nat. Hist., and I have the authority of Mr. Etheridge, F.R.S., for stating that it bears no evidence of having been derived from the Lias of Street.

Nothing is stated of the internal characters of the corallites of this species, which, so far as can be determined from the figures, is allied rather to the Lias forms wrongly placed in the genus than to the type forms of *Septastræa*. The form is from the Cenomanian of Le Mans, France.

It would have inordinately increased the limits of this paper, and would have involved an extended microscopic investigation, to have determined positively the genera to which the Lias and other corals belong, which I have shown cannot remain in *Septastræa*. I have further refrained from this task since I have learned, whilst engaged on the present paper, that Mr. R. F. Tomes, F.G.S., has undertaken an investigation of these Liassic species, of several of which he is fortunate enough to possess the type specimens.

Summary.

The following are the main facts and conclusions arrived at in the foregoing paper:—

1. The genus *Septastræa*, d'Orbigny (1849), is based on the characters of a coral from the Miocene strata of Virginia, which the author named *S. subramosa*, but did not describe. The same form was subsequently named *S. Forbesi*, by Edwards and Haime; d'Orbigny claimed this name as the synonym of *S. subramosa*; but owing to this latter being merely nominal the claim cannot be recognized, and the type species of *Septastræa* must bear the name *S. Forbesi*, Edw. & H.

2. The original specimen of *S. Forbesi*, E. & H. (= *S. subramosa*, d'Orbigny), is in the British Nat. Hist. Museum, and from it the characters of the genus can be satisfactorily ascertained.

3. In 1861 de Fromentel, and in 1867 Prof. Duncan placed in the genus *Septastræa* several species of corals from the Lias Formation of England and France; but these are not generically related to the original types of the genus from the Miocene Tertiary of America.

4. Prof. Duncan, in 1887, takes out of *Septastræa* the type species *S. Forbesi*, and makes it the type of a new genus, *Glyphastræa*, leaving in the former genus those Liassic species placed therein by himself and Fromentel at a later date, and which have no generic relation to d'Orbigny's and Edwards and Haime's original types of the genus. As the same species cannot be the type of two distinct genera, the name *Glyphastræa* becomes obsolete.

5. In the genus *Septastræa*, as based on *S. Forbesi*, amongst other features enumerated, the corallites have separate walls, the theca is formed by an extension of the septal laminæ, the lower portion of the corallite-walls and the septa are thin, but the upper portion of the corallites is infilled with stereoplasm, so that the calices are shallow. There is no true columella, only a pseudo-columella formed by the union and partial involution of the inner septal margins. The increase is exclusively by marginal gemmation; fission does not occur. Linear perforations between the septa for

the insertion of the mesenterial muscles are shown in some specimens.

6. The septa in *Septastræa* consist of a central layer, which in microscopic sections is dark and enclosed on both sides by lighter layers of calcareous tissue. The dark central layer is divided in the median plane, so that each lamina of the septum consists of a primary dark inner layer and an outer lighter layer of stereoplasm. The inner dark layer consists of transverse growth-lines and delicate longitudinal ridges and grooves of a powdery, incoherent material; its present character is probably due to change in fossilization. The enclosing lighter layer of stereoplasm, on the other hand, is compact, fibrous, subcrystalline, and of an ivory-white appearance. The thecal wall is merely an extension of the septal laminæ, and has a similar minute structure.

7. The structure of the theca and septa in *Septastræa* corresponds closely to that of the recent and fossil genus *Flabellum*.

8. Only two species are included in *Septastræa*, as now defined, viz., *S. Forbesi*, E. & H., and *S.* (*Columnaria*?) *sexradiata*, Lonsdale, sp.

EXPLANATION OF PLATE IX.

Fig. 1. Upper portion of the type specimen of *Septastræa Forbesi*, E. & H. (now in the Brit. Mus. Nat. Hist.), showing the disposition of the corallites and the interstitial buds (*b*) at the growing ends of the branches. Nat. size.

2. Corallites from the surface of a specimen of *S. Forbesi*, showing the early stage of growth of a young individual (*b*), in which mere traces of septa appear in a shallow, triangular depression between full-grown calices. Enlarged five diameters. Specimen in Brit. Mus.

3, 3 *a*, 3 *b*. Three calices of *S. Forbesi*, showing variations in the septal development. Enlarged three diameters.

4. Four corallites from the interior of a specimen of *S. Forbesi*, showing great variation in the disposition of the septa. Enlarged three diameters.

5. A transverse section of a corallite from the interior of a specimen of *S. Forbesi*, showing curved and intertwisted septa. Enlarged five diameters.

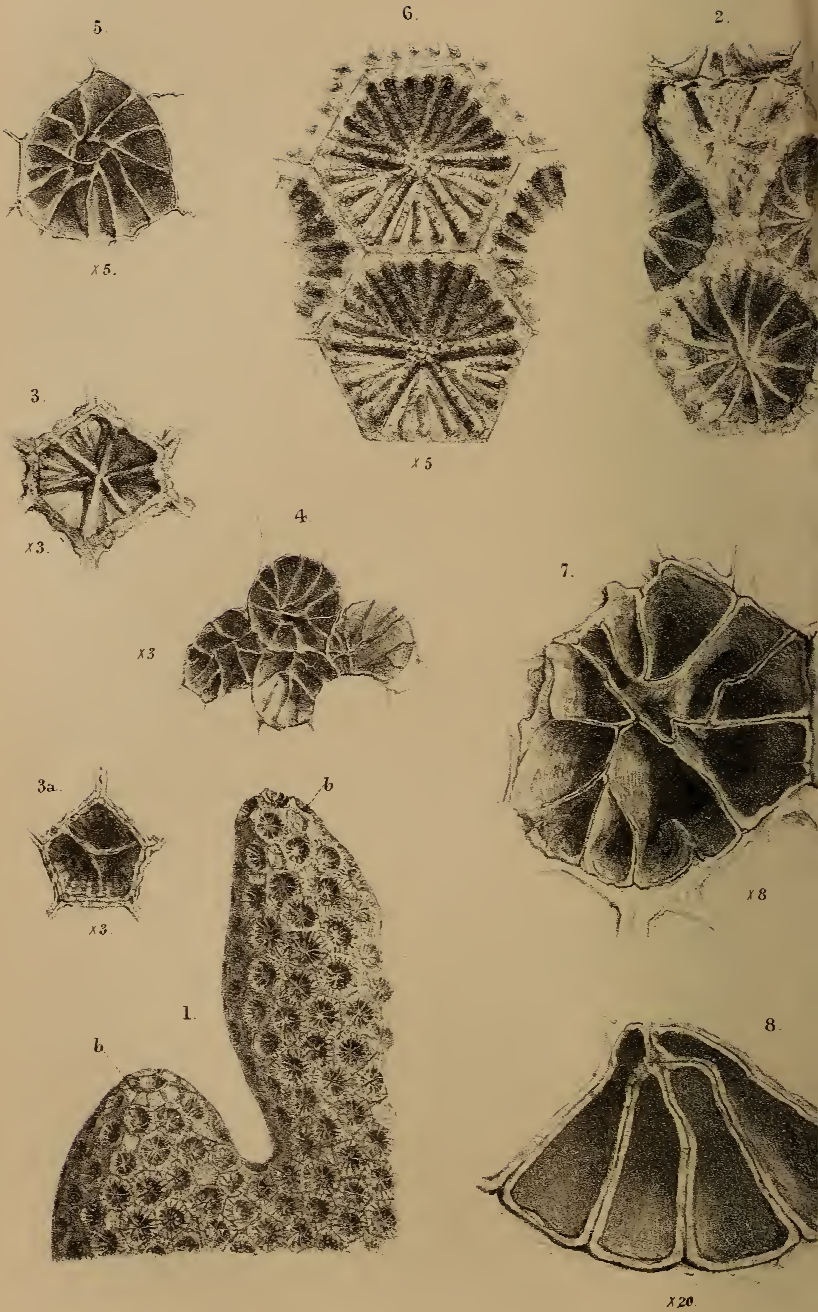
6. Calices from the type of *Septastræa sexradiata*, Lonsd., sp. (now in the Museum of King's College, London), showing the development of the third cycle of septa. Enlarged five diameters.

7. A corallite from the interior of *S. Forbesi*, showing the bilaminated character of the septa, and their mode of union with each other. Enlarged eight diameters.

8. A portion of the interior of a corallite of *S. Forbesi*, showing the divergence of the septal laminæ to form the wall or theca, and the extension of the dark primary layer or centre of calcification in the median line of the septa, to the exterior of the wall. Enlarged twenty diameters.

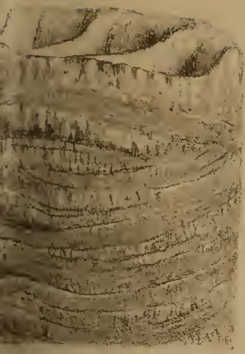
9. A portion of a septum of *S. Forbesi*, which has split along its median plane, and shows the smooth inner face of the septal lamina with the transverse growth lines, and traces of the longitudinal ridges. Enlarged fifteen diameters.

10. A portion of the inner layer of a septal lamina of *S. Forbesi*, showing the longitudinal ridges and grooves immediately beneath the transverse growth-lines. Enlarged forty diameters.



F. H Michael del. et lith.

9.



x 15.

12.

x 20.

15.

x 15.

13.

x 20.

10.

x 40.

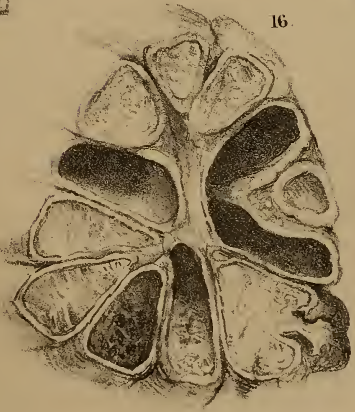
3b.

x 3.

17.

x 6.

16.



x 16

11.

x 40

14.

x 7.

ÆA.

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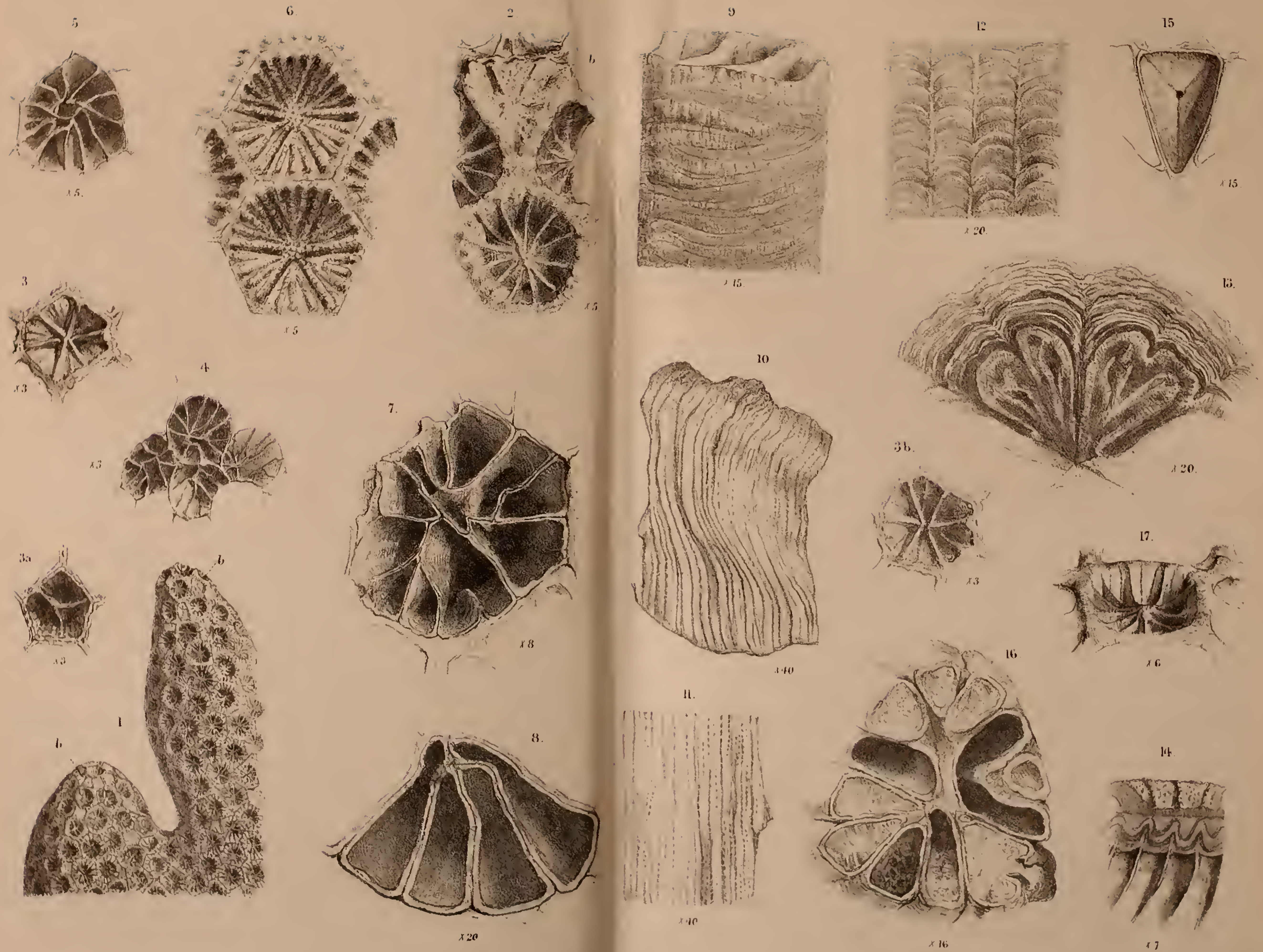

F. H. Michael del. et lith.

SEPTASTRÆA.

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Fig. 11. Another portion of the inner layer, showing small holes in the spaces between the ridges. Enlarged forty diameters.

12. A portion of the exterior, lateral surface of the wall or theca of a corallite of *S. Forbesi*, showing transverse growth-lines crossing the pseudo-costal spaces, and the longitudinal furrows along the lines of the septa. Enlarged twenty diameters.

13. Part of a transverse section of the upper portion of a corallite of *S. Forbesi*, showing the disposition of successive layers of stereoplasm, with which the interlocular spaces are completely filled. Enlarged twenty diameters. From the type specimen in the British Museum.

14. A longitudinal section of the upper portion of a corallite of *S. Forbesi*, showing the limitation of the deposit of stereoplasm to the space immediately above the uppermost horizontal dissepiments, and the arched lines of deposition of this material within the corallite. Enlarged seven diameters.

15. A single interlocular space in a corallite of *S. Forbesi*, viewed from beneath, showing the development of the horizontal dissepiment from the bounding walls of the septa, and the sutural lines at the meeting of the membrane. Enlarged fifteen diameters.

16. A transversely fractured corallite of *S. sexradiata*, viewed from beneath, showing the complete enclosure of the individual interlocular spaces by the septal laminæ. Enlarged sixteen diameters.

17. A calice of *S. Forbesi*, showing impressed longitudinal grooves in the inner surface of the wall, between the principal septa, for the insertion of the mesenterial muscles. Enlarged six diameters.

Discussion.

The President remarked upon the complicated question of nomenclature which was raised in the case brought before the Society by the Author. The latter part of his paper added valuable information on the structure of corals, and was a striking instance of the aid that might be afforded by palæontological research to the studies of biologists.

Mr. Alfred Foord said the drawings in Prof. Duncan's memoir had been carefully made from the original specimens, and that the existence of a columella in *Glyphastræa* was distinctly visible, as shown in several of the figures.

Mr. Etheridge was well acquainted with the specimens, and called attention to the great difficulty there was in correctly determining their species from the appearances presented. The research relative to the present species was almost unprecedented. Dr. Hinde had taken great pains in unravelling the history of these corals, and his investigation of their microscopic structure was of great importance, and would probably lead to valuable results in the future classification of the Cœlenterata.

Dr. Woodward agreed with Dr. Hinde as to the distinctive characters of *S. Forbesi* and *S. sexradiata*, and complimented him on the clearness of his description.

Dr. Hinde, in reply, said he had not questioned the general accuracy of Mr. Foord's drawings; but in two instances, in the plate referred to, the figures were admittedly diagrammatic, and the crucial feature in another figure had been exaggerated, no doubt unintentionally on the artist's part. The speaker considered the use of the microscope essential for the correct determination of coral structure.

18. *On* Ailurus anglicus, *a new* Carnivore *from the* Red Crag.

By W. Boyd Dawkins, F.R.S., Professor of Geology and Palæontology in Owens College. (Read January 25, 1888.)

[Plate X.]

§ 1. Introductory.

In the fine collection of fossils from the Crag of Norfolk and Suffolk, presented to the Museum of the Yorkshire Philosophical Society at York by Dr. Reed, is a battered and water-worn specimen, which is of singular interest, because it carries the range of one of the most restricted of the genera of the Oriental Province far to the west and to the north of its present habitat. It is a small fragment of the right lower jaw, with the last true molar in position, found in the Red Crag of Felixstowe, the rest of the ramus and the angle and articular and coronoid processes being broken away (see figs. 1 and 2).

§ 2. Description and Comparison with Ailurus fulgens.

After a long and careful study, I find that the lower jaw in question differs in a marked degree from all the European fossil Carnivores, and presents no important points of difference when compared with the series of jaws of recent *Ailurus* in the British Museum.

The last true molar in the fossil is implanted in the jaw by two fangs, the anterior being the smaller, and supporting the anterior cusps, A and D of figures 1, 2, 3, 4. The multicuspid crown is composed of three small, obtusely pointed cusps, A, B, C of figs. 1, 3, and 4, on the outer side, while the inner (figs. 2 and 3) is occupied by the large cusp D and a smaller hind cusp F, connected by a line of low tubercles, from which the enamel has been stripped. The outer series of cusps is separated from the inner by a shallow longitudinal groove (fig. 3) traversing the crown nearer the inner than the outer side, and causing the inner cusps to be narrower than the outer. They are also the higher. The crown is also divided by two transverse valleys into three lobes (figs. 3, 4), of which the anterior, A, D, is the higher and larger. In all these points the fossil agrees with the living *Ailurus* (figs. 5, 6, and 7), with the exception that the longitudinal depression is not so strongly marked in the former.

Nor are differences of any value to be noted on a comparison of the fossil specimen with the recent teeth cusp by cusp. The antero-outer cusp A of figs. 3 and 4 occupies the greater part of the front lobe, and has in front a small talon or tubercular cingulum. In five specimens of living *Ailurus* the cusp A is in the same relative position (figs. 6 and 7), and a tubercular cingulum or slight talon is traceable in four. The accessory cusp A′ of figs. 3 and 4 is present in the interspace between A and B, in both the fossil and the recent (figs. 6 and 7). The cusp B of the fossil is obtusely pointed and separated by a cleft from the third cusp C. Behind this cleft in the fossil is a small accessory cusp B′ (fig. 4), which I have only been able to note as a mere rudiment in one recent tooth belonging to an *Ailurus* shot by Mr. B. H. Hodgson in Nepaul. The third cusp, C, is small and mapped off from the back cusp F by a slight valley. In all these points the fossil agrees with the recent specimens. On the inner side, the front lobe D of fig. 3 is mapped off from A by a cleft, and bears a talon in front. In the living *Ailurus* (fig. 6), the talon has developed into a basal cusp D′. The fractured surface of the tooth (figs. 2 and 3) behind D renders it impossible to compare the inner margin minutely with the recent specimens; enough, however, remains to prove that it is composed of small tubercles running from D to F, like those in *Ailurus fulgens* (fig. 6, E). The cusps of the fossil are, as a whole, larger, blunter, and less clearly defined from one another than in recent *Ailuri*.

On a comparison of the fossil with the recent jaws of *Ailurus*, the only marked point of difference is that the *dental foramen* is situated further back in the former than in the latter. These differences are not, in my opinion, of more than specific value; and I therefore propose the name of *Ailurus anglicus* for the fossil, from its discovery in East Anglia.

§ 3. Measurements.

The following Table gives the comparative measurements of the teeth and jaws of the fossil and recent *Ailuri* in inches and tenths.

True Molar 2.

	Ailurus anglicus, Dawkins.	Brit. Mus. *Ailurus fulgens*, 226. h.	Brit. Mus. *Ailurus fulgens*, 226. g.
Length	0·70	0·48	0·45
Breadth of front lobe	0·40+	0·23	0·22
Breadth of middle	0·32+	0·20	0·22
Breadth of back	0·38+	0·15	0·15

The Lower Jaw.

	Ailurus anglicus, Dawkins.	Brit. Mus. *Ailurus fulgens*, 226. h.	Brit. Mus. *Ailurus fulgens*, 226. g.
Depth behind m 2	0·95	0·81	0·75
Circumference	2·5		
Depth in front of m 2	0·87	0·61	0·58
Circumference	2·4		

From these measurements it is clear that the *Ailurus* from the Crag was a larger and more powerful animal than any of the recent *Ailuri* in the British Museum.

§ 4. The Range of Ailurus in Space and in Time.

The living *Ailurus*, the "Wah" or "Panda," is a carnivore belonging to the Arctoidea, and standing, according to Flower *, between the Ursidæ and Procyonidæ. It is, according to Hodgson †, of exceedingly restricted range, being found in the sub-Himalayas, in which it lives in the deserts, between 7000 and 13,000 feet above the sea, ranging northwards on the flanks of the mountains as far as the forests extend, in Thibet, Nepaul, Sikkim, and Bhotan. It is described by Anderson ‡ as inhabiting the high and dry country to the north-east of Darjeeling §. It ranges also as far to the east as Yunnan ||.

The discovery of the lower jaw described above extends the range of the genus, restricted at the present time to high altitudes in the regions north and east of India, to the shores of western Europe in the Pliocene age, and offers new evidence in support of the view ¶ that the Pliocene Mammalia of Europe are closely related to those now living in the far East, in the Oriental Region. Of the associated genera found in the Red Crag, four—*Ailurus*, *Tapirus* (*priscus*), *Cervus* (*suttonensis*), and *Rhinoceros* (*Schleiermacheri*)—are represented by living forms in the Oriental Region, while two extinct genera, *Hipparion* and *Hyænarctos,* are common to the Pliocenes of India and Britain. From these facts I should conclude that the Oriental Region has offered a secure place of refuge to some of the Pliocene genera, in which they have survived the changes in their surroundings that have caused them to disappear from Europe and the rest of Asia.

EXPLANATION OF PLATE X.

Fig. 1. *Ailurus anglicus*, Dawkins, right lower jaw, outer side. Nat. size.
2. The same, inner side.
3. The same, molar tooth, m. 2, surface of crown. ×2.
4. The same, $\overline{\text{m. 2}}$, outer surface. ×2.
5. *Ailurus fulgens*, F. Cuv., lower jaw, outer side. Nat. size.
6. The same, molar tooth, $\overline{\text{m. 2}}$, surface of crown. ×2.
7. The same, molar tooth, $\overline{\text{m. 2}}$, outer surface. ×2.

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* Flower, Proc. Zool. Soc. 1869, p. 37, 1870, p. 752; Encyclop. Britann. Article Mammalia; Section *Arctoidea*; Fam. 1, *Mustelidæ*; Fam. 2, *Procyonidæ*; Fam. 3, *Ailuridæ*; Fam. 4, *Ursidæ*.

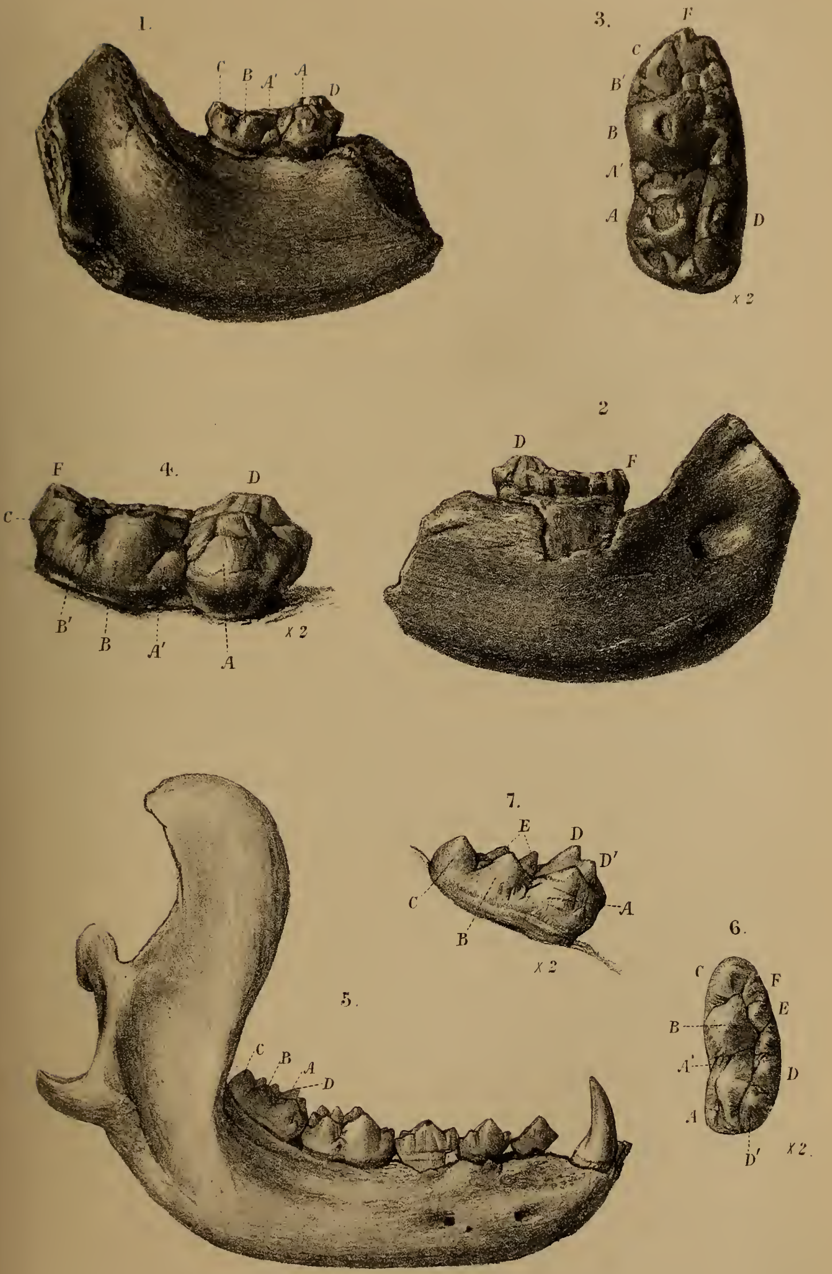
† B. H. Hodgson, Journ. Asiatic Soc. Bengal, vol. xvi. p. 1113 (1847).

‡ J. Anderson, Proc. Zool. Soc. 1869, pp. 278, 408; 1871, p. 561.

§ For other information see Mivart, Proc. Zool. Soc. 1882, p. 135, and Bartlett, Proc. Zool. Soc. 1870, p. 769.

|| Anderson 'Anatomical and Zoological Results of the Yunnan Expeditions,' Introd. p. xx. For this reference to its eastern range I am indebted to the Referee.

¶ Dawkins, 'Early Man in Britain,' pp. 79, 89.



F H Michael del. et lith.

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AILURUS ANGLICUS.

Discussion.

The President remarked that seldom had a fact of greater interest in its bearing upon geographical distribution in past times been brought before the Society.

Mr. Lydekker said that he had not much doubt as to the correctness of the identification; at any rate, the fossil seemed to indicate a genus closely allied to *Ailurus*. As shown by the molar, it could not apparently belong to any other group, no known Artiodactyle being like it. He rather differed as to the question of range. There is no trace of *Ailurus* in the Miocene or Upper Eocene of Europe, and he thought it more probable that the genus had reached Europe from India whilst missing Africa.

Prof. Seeley said that although the tooth was worn, he considered that its crown was traversed by two longitudinal parallel grooves, defining three rows of denticles or cusps, while in *Ailurus* there was only a median groove between the denticles. He considered that the mode of grouping of the denticles in the recent and fossil types was different, so as to suggest even greater divergence in the other teeth which were not preserved. Differences of this kind were usually regarded as generic, and might have a family value. They are supported by differences in the coronoid process, in the way in which it arises, and in the form of the bony substance of the jaw. The fossil specimen was one third larger. So that, while he regarded the affiliation to *Ailurus* as a legitimate indication of affinity, he thought that the facts justified caution in making a generic determination, and that this was the more necessary if new views on geographical distribution were based upon the interpretation.

Mr. Newton, while admitting that it is desirable to be cautious before giving names, said he could find nothing like this tooth in the Crag, while its agreement with the corresponding tooth of *Ailurus* was very close indeed, excepting in the unimportant matter of size. With regard to the distribution, he referred to the Gazelle from the Upper Crag, which also found its nearest allies in Asiatic rather than in African forms.

Mr. Blanford expressed his surprise at the discovery. The fact of the tooth being worn was of no importance. There was not much to be inferred from the Gazelle mentioned by Mr. Newton, as it represented an entirely different fauna. *Ailurus* was now confined to the Eastern Himalaya, and was, in fact, an Asiatic raccoon. If this fossil was really *Ailurus*, the range of the raccoons must have been more extended, and yet no other fossil species had been found in the Old World, nor was there any representative of *Ailurus* in Africa. On the evidence, Prof. Dawkins was possibly right; but one tooth was not much to go upon; and, on the whole, the determination would require confirmation.

19. *Note on the* Movement *of* Scree-Material. By Charles Davison, Esq., M.A., Mathematical Master at King Edward's High School, Birmingham. (Read February 29, 1888.)

(Communicated by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.)

The slope of screes being, as a rule, not much under the greatest angle at which it is possible for their component material to rest, it follows that a very slight force is in general required to put the surface-stones in motion*. This is evident, too, from the number of stones dislodged when a block falls down from above; also from the difficulty experienced by persons in trying to cross them. "Every movement," says Scoresby, describing the descent of a mountain covered with loose stones in Spitzbergen, "was a work of deliberation. The stones were so sharp that they cut our boots and pained our feet, and so loose that they gave way almost at every step, and frequently threw us backward with force against the hill. We were careful to advance abreast of each other, for any individual being below us would have been in danger of being overwhelmed with the stones, which we unintentionally dislodged in showers" †.

The instability of scree-material being so great, the causes of its motion are consequently numerous. Many have at various times been pointed out, more especially in considering the origin of different accumulations of angular débris, such as the limestone-breccias of Gibraltar or the stone-rivers of the Falkland Islands, the main difficulty in these cases being, however, to account for the transport of the material over surfaces inclined at a small angle. References to these well-known discussions are perhaps hardly necessary, it being the object of this paper to call attention to one other cause of movement which, at least in the present application of it, seems to have passed unnoticed.

While sitting near a shale-heap some time ago on a dry warm summer day, I was surprised by the fall close beside me of several blocks of shale, followed by a number of smaller pieces dislodged by their movement. And, again, in a slate-quarry, I have noticed fragments of slate on a waste-heap tumbling down and carrying others along with them in their course. In neither case, so far as I could see, was there any visible reason for the disturbance. All around being still, the movement could only be attributed to the expansion of the stones by the sun's heat during the day ‡.

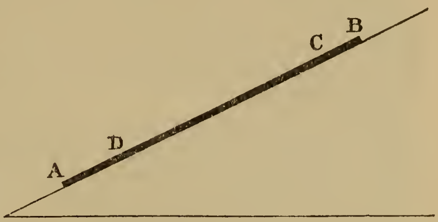
* Mr. Ruskin has given a useful list of the angles of screes observed by him in different parts of Switzerland in his 'Modern Painters,' vol. iv. p. 317. In making the experiments of the first kind afterwards described, I found that when the bricks rested at angles nearly equal to the angle of friction, the tremors due to carts passing at a distance of 8 or 9 yards were sufficient to shake them down. It was for this reason that I afterwards made the experiments with angles so low as 20°.

† Arctic Regions, vol. i. p. 129.

‡ Does not the fact that so many stones on the surface of screes are *just on the point* of slipping show that the cause of movement is not, as a rule, paroxysmal, but continuously acting and gradual in its effects?

The creeping of the lead on the roof of Bristol Cathedral through a distance of 18 inches in less than two years is well known, and arose, as Canon Moseley proved*, from the alternate expansions and contractions of the lead during changes of temperature taking place mainly downwards, being assisted by gravity in that direction.

Let AB represent a bar of lead or other substance resting on an inclined plane. When the temperature rises the bar expands; but, since it requires a less force to push a body down, than up, an inclined plane, the part, AC, pushed down the plane, is longer than the part, BC, pushed up it. Again, when the temperature falls the bar contracts, and the part, BD, pulled down the plane, is longer than the part, AD, pulled up it. In both cases, then, the descent of one end is greater than the rise of the other, and therefore the bar, as a whole, descends.



Let a feet be the length of the bar, μ the coefficient of friction between it and the plane, α the inclination of the plane, and e the coefficient of expansion of the bar for a rise of 1°; then, if the temperature rise τ°, and fall subsequently by the same amount, the total descent of the bar, Canon Moseley shows, will be

$$\frac{a\, e\, \tau \tan \alpha}{\mu}$$

feet †. Hence the descent is greater the longer the bar, the greater the coefficient of expansion and the range of temperature, the higher the slope of the plane, and the less the coefficient of friction.

Canon Moseley also tested his theory by a simple experiment. A sheet of lead, 9 feet long and $\frac{1}{8}$ of an inch thick, was placed on a flat wooden surface inclined at an angle of 18° 32′. The average daily movement, from the 16th of February until the 28th of June, was ·1745 inch. The movement was found to be greatest on those days when there were cold winds or passing clouds, there being then many changes of temperature during the day ‡.

It appeared to me that, in the same way, all stones free to move on the surface of screes must be slowly creeping downwards, and that this might be the explanation of the fall of the stones in the two instances given above. But it yet seemed desirable to make further experiments with slabs of stone, instead of with lead-sheeting: first, because the granular surfaces of rocks might offer effective

* "The Descent of Glaciers," Roy. Soc. Proc. (1855), vol. vii. pp. 333–342.

† *Ibid.* pp. 334, 335.

‡ "On the Descent of a Solid Body on an Inclined Plane when subjected to Alternations of Temperature," Phil. Mag. (1869), 4th series, vol. xxxviii. pp. 99–118.

resistance to a motion so minute; and, secondly, because, on account of their greater thickness, the changes of temperature might not sufficiently penetrate the stones in the short periods during which such changes sometimes take place. The experiments were of two kinds—the first qualitative, the second quantitative. I will now give an example of each.

Experiment 1.—The object of this experiment was to discover if any downward motion took place in a stone lying upon an inclined plane, and, if so, whether the motion were to be attributed to the alternate expansions and contractions of the stone during changes of temperature*.

A brick (B) was fixed with its upper surface inclined at an angle of 20° towards the south-west. On this was laid another brick (A) whose movements, if any, were to be observed by means of a level, resting at one end on the upper edge of the brick A, and at the other on a support made of similar brick. If the brick A did not move relatively to B, the vertical components of the expansion or contraction of the supports at either end of the level would be the same, and the level would indicate no change of position. If, however, the brick A did move in the way anticipated, the nature and manner of the movement should be in conformity with the theory given by Moseley.

The level was read frequently during the day, generally every half-hour. The temperature was also observed at the same times. As the experiment was intended to show the nature only of the movement, I did not attempt to determine the value in angular measurement of each division of the level. The following conclusions were brought out very clearly by this experiment:—

1. The upper end of the brick rises slightly with a rise of temperature, but descends beyond its first position with a corresponding fall of temperature.

2. The movements accompany, or take place a short time after, the changes of temperature.

3. The total downward movement is least on those days on which the sky is clouded and the range of temperature small.

A similar experiment might have been made to determine the motion of the lower end of the brick, by resting the level on a projection near the end and on a brick support near it. But the above experiment, several times repeated, seemed to me to show conclusively that stones resting freely on an inclined plane will gradually creep down the plane owing to the expansions and contractions of the stones, due to changes of temperature, taking place mainly downwards under the influence of gravity.

* [Since this paper was read, it has been pointed out to me that "in Canon Moseley's experiments ...... the lead which moved had an expansibility different from that of the wood on which it rested," and that if the two bricks in Experiment 1 "had expanded equally no motion could have resulted." The movement in this, and the following, experiment must therefore be attributed to the unequal heating of the upper and lower stones. The distinction is important, though it does not affect the subsequent results.—*Note added* March 24, 1888.]

Experiment 2.—In this experiment, the object was to determine the actual distance which a stone of given length lying on a given slope will descend in a given time.

Two slabs of a fine-grained sandstone (called York stone by the mason) were cut, each 3 feet long, 5 inches broad, and 2 inches thick. One face and one side of each were smoothed. One of the stones was fixed, so that its upper surface sloped at an angle of 17° towards the south. The other was placed on this, the smoothed faces being in contact, and the ends of both stones in line at starting. Fine scratches were cut in the same straight line on the smooth sides of the stones, in the middle and at either end, their subsequent displacement determining the amount of the movement. The whole was well protected by a light wooden framework covered with wire-netting. It was exposed to sunshine for about five hours a day at the commencement of the experiment, diminishing to about two hours a day at the end. Readings were, as a rule, taken once a week, at the same hour in the afternoon, and, except at these times, no artificial shadow was ever allowed to fall upon the stone.

The experiment began on May 5, 1887, and ended on September 22. In this time the total descent was $5\frac{5}{6}$ mm.*, *i. e.* an average of ·00164 inch per day, or ·599 inch per year. The period of the experiment was naturally divided into three intervals, the first from May 5 to June 9, the second from June 10 to August 25, and the last from August 26 to September 22. During the first interval there were 14 days on which rain fell, the sky was usually overcast and on one day only was fairly free from cloud: the average daily range of temperature was 12°·0 F., and the average daily descent of the stone ·00187 inch. The second interval was remarkable for its prolonged summer weather, rain fell but seldom, and the sky was cloudless for days together: the average daily range of temperature for the first eight weeks of this interval was 18°·3 F., and the average daily descent for the whole interval ·00119 inch. During the last interval there were 8 days on which rain fell, and on half the days the stone was frequently shaded by passing clouds: the average daily range of temperature was 14°·7 F., and the average daily descent ·00258 inch. From this experiment we may conclude that:—

1. The descent is greatest on those days on which there is bright sunshine intercepted frequently by passing clouds.

2. Rain slightly increases the rate of descent†, probably, though perhaps not entirely, by diminishing the friction between the stones.

Assuming the average rate of descent throughout the year to be that above given, namely, ·00164 inch per day, the upper stone will, by the creeping movement alone, have advanced far enough to fall over the lower one after a period of about $29\frac{1}{2}$ years. This is, of

* This distance being correct to within one sixth of a millimetre, it follows that the error in the average daily descent is less than ·00004 inch.

† This follows from a comparison of the movements during the first and second intervals.

course, a slow movement, almost imperceptibly slow, but, as it will be seen, far from unimportant.

Apart from the resistance to motion offered by vegetation and earthy matter, the stability of scree-material depends largely on the form and lie of the stones and the slope of the surface, these conditions being themselves connected. If the stones be nearly cubical in form, they will be found to lie at all angles, often with their edges leaning on surfaces sloping in opposite directions. The stability is naturally great in such a case, unless the stones be small. On the other hand, if the stones be flat-shaped, as in most slaty screes, they rest with their flat surfaces on the edges and faces of those below, inclining outwards and downwards at angles more or less approaching that of the scree-talus. Large blocks are more stable than small ones, not only on account of their greater weight, but also because they are generally imbedded amongst a number of smaller stones, and thus can hardly be regarded as surface-stones. Still, it is far from unusual to meet with blocks five feet or more in length lying quite on the surface of screes and in a position suitable to creeping.

A good example of a case in which the conditions are favourable to movement, and especially to creeping, occurs near the top of Hindscarth, a mountain in Cumberland, 2385 feet in height. On the west side of this mountain, not far below the cairn, are several sheets of loose fragments of well-cleaved slate. The sheets may be a foot or more in depth, and are inclined at an angle of about 20°. The pieces of slate are of all sizes up to a foot or a foot and a half in length, and are generally very thin, the largest not being more than about an inch in thickness, and even this amount is unusual. They lie with their flat surfaces on the bare hill-side or resting on those of other stones, nearly all inclined at the same angle as the slope. They are mostly long-shaped, and, with few exceptions, both large and small stones *lie with their longer axes pointing down the slope*, showing that, during motion, they have placed themselves in the position of least resistance.

Such conditions are I suppose unusual; but, as a general rule, the majority of the stones on the screes with which I am acquainted slope outwards and downwards, and are therefore in a position for creeping. The effects of creeping, moreover, are not confined to the mere descent of the stones. The movement of a stone in this way may withdraw its support from others resting on it. It may easily be imagined also that the stones may be of such a form and so arranged that a very slight movement in one may cause both it and some of those in contact with it to topple over; and, once in motion, they will drag many others along with them before they finally come to rest.

Again, the entire surface of screes is exposed to every change of temperature, and, throughout their whole extent, every stone that is free to move will make, with every change of temperature, a small slip downwards. The importance of this will be best shown by an example.

Let us consider a scree-talus one mile in horizontal length: let the average height measured along a line of slope be 1000 feet, and the average thickness of the surface-stones 6 inches. Let us suppose that the stones on one half only of the scree-surface are in a position to creep, and that, on the average, every stone on this half creeps downward one-thousandth of an inch a day. Then, the total amount of movement is equivalent to 1320×1000 cubic feet moving through one thousandth of an inch, or 110 cubic feet through one foot, every day.

This is of course a mere approximation; but it will serve to indicate the order of magnitude of the movement contemplated. If we had similar numerical estimates for the other moving agencies, we should be able roughly to compare them in efficiency. The importance of each cause varies, however, with the climate and so many other conditions that it would be difficult to assert at any time and of any screes that one cause is more efficient than another. In all probability, creeping is very far from being the most important cause of movement, yet it is possible to imagine conditions under which it might in time be most effective, as in the stone-rivers of the Falkland Islands, and at least one case where it may be almost the only agent at work.

I refer here to the conditions which probably obtain on the surface of the moon, where, as is well known, there are no seas, no appreciable trace of an atmosphere, and where the most diligent telescopic search for many years has failed to detect the slightest sign of present volcanic action. Deprived of the most potent agents of geological change, there remain the effects which can be produced by sudden alterations of temperature. The change from the intense heat of the lunar day to the cold of the lunar night or shade being untempered by any intervening atmosphere, the strain that results from the sudden cooling will be amply sufficient to break up the surface of any known rock. In this way, screes must accumulate on the mountain-sides, and the surface blocks that are free to move will creep gradually downwards, perhaps more rapidly than they would do on the earth, owing to the absence of vegetation and disintegrated rock upon the moon and the great range of temperature, long though its period be, to which its surface-rocks are exposed. Unbalanced by volcanic action, the actual rate of degradation may even be greater than on the earth; but, whether this be the case or not, there can be little doubt that in great and sudden alterations of temperature there exists a very important source of change upon the surface of an otherwise dead world.

Discussion.

The President expressed some surprise that the observations had not been made before, and congratulated Mr. Davison on the neatness of his demonstration.

Prof. Bonney agreed with the Author that changes of temperature do cause many stones to change their level, and considered the investigation a valuable one. It had often occurred to him that there were more minute movements in loose materials than was generally recognized, and that frequently a stratification was produced in this way, as could frequently be seen in talus from excavations.

Rev. Edwin Hill agreed that we were indebted to Mr. Davison. He suggested that besides surface-motion an internal rearrangement of the scree-stones was produced by such movements.

The President called attention to observations by Newbold upon musical sand-hills, which showed that the sliding-down of the sand whereby a musical note was produced was due to the sun's heat.

20. *A* CONTRIBUTION *to the* GEOLOGY *and* PHYSICAL GEOGRAPHY *of the* CAPE COLONY. By A. H. GREEN, M.A., F.R.S., Professor of Geology and Mathematics in the Yorkshire College, Leeds. (Read January 25, 1888.)

IN the year 1882 I was commissioned by the Colonial Government to examine and report upon the Coals of the Cape Colony. My attention was of course chiefly directed to this special object; but, to carry out my task successfully, a clear comprehensive view of the geology of the Colony as a whole was needed, and this I did my best to arrive at. I was able to devote about four months to the work, and during that time I traversed a very large part of the Colony. But it is an extensive tract, and travelling over it is very slow, and it was obviously impossible in so short a time to do more than get a broad general notion of its geological structure. Two things stood me in good stead. First, the great physical features are so strongly marked that they stare you in the face as you go along; and, owing to the leisurely rate at which you travel, they remain in view long enough to be stamped on the memory; while the barren ruggedness and bare stony character of much of the country enable the observer, as he passes along, to note even from afar the character and lie of the rocks, the clear dry atmosphere making this possible at distances where, in our climate, all distinctness would be lost in haze. It is at first very striking, for instance, to find that you can distinctly trace the outcrop of a trap-sheet along a hillside ten miles or more away, and assure yourself that in some places it is running parallel to the beds and in others cutting across them. Secondly, the ground had been very largely cleared for me by the labours of previous observers. As far back as 1852, Andrew Geddes Bain drew in with a bold firm hand all the leading lines in South-African geology*. The masterly sketch, which he then put forward†, and which has required but little in the way of addition or correction since, was the work of a man who had no special geological training, but who had a good eye for a country, strong common sense, sound judgment, great enthusiasm, and untiring industry, every quality that is wanted to make a first-rate pioneer, and he will always stand high among the pioneers of geology. That some of his theories savoured of the extravagant cannot be denied; but this is excusable in a man who had had no special scientific training. In matters of fact or observation he was very seldom at fault. Among the South-African geologists who have followed him, I may mention Mr. E. J. Dunn as the one whose work I have had most frequently to refer to. Labouring with indefatigable perseverance, often under very

* Mr. Wyley published, in 1859, 'Notes of a Journey in two directions across the Colony in 1857–58.' I have had no opportunity of seeing this, and know only the abstract given by Mr. R. Tate, Quart. Journ. Geol. Soc. vol. xxiii. (1867), p. 172.

† Trans. Geol. Soc. of London, 2nd ser. vol. vii. pp. 53, 175.

discouraging circumstances, he has materially enlarged our knowledge of the detailed geology of the Cape Colony *.

But though I was all along following the footsteps of such able forerunners, I believe I have succeeded in adding some little to the stock of our knowledge in South-African geology, and have done something towards clearing up points which were heretofore doubtful. In this belief I now offer the results of my work to the Society.

The grouping of the South-African rocks which I have been led to adopt is as follows:

9. Stormberg Beds { Volcanic Beds, 9 *d*. / Cave Sandstone, 9 *c*. / Red Beds, 9 *b*. / Molteno Beds, 9 *a*. }
8. Karoo Beds.
7. Kimberley Shales.

Great Unconformity.

6. Ecca Beds.
5. Dwyka Conglomerate.

Unconformity.

4. Quartzites of the Zuurbergen, Zwartebergen, and Wittebergen.
3. Bokkeveldt Beds.
2. Table-Mountain Sandstone.

Great Unconformity.

1. Slates and intrusive Granite of the neighbourhood of Cape Town (Malmesbury Beds).

* Prof. T. Rupert Jones, who has a very wide acquaintance with the literature of South-African geology, points out to me that other observers besides those mentioned in the text have written on this subject, and mentions specially W. B. Clarke (1841), Dr. Atherstone, G. W. Stow, J. Shaw, W. Prosser, R. N. Rubidge, Hübner, Hochstetter, and others. The last two words show that even with these additions the list is incomplete. It would indeed be hardly possible to compile a bibliography which should be even approximately satisfactory; for many of the contributions to the geology of South Africa are scattered through newspapers or Colonial periodicals which are difficult or impossible of access to the English reader. The same friendly critic remarks that many facts are recorded without acknowledgment in the following pages which have been noticed by previous observers, and that a false impression may thereby be created in the minds of my readers that I claim these as discoveries of my own. I am very thankful for the warning, and have done my best to guard against the mistake which it was intended to prevent by availing myself freely of the copious list of references which my friend has supplied. To make my story complete, I have had repeatedly to supplement my own observations by those of previous workers in the same field. In the larger matters I trust that I have been able to indicate the sources from which I derived my information. There are besides points of minor importance, which have been commented on over and over again. I should not have thought it necessary, under any circumstances, to call attention to every writer who has mentioned these; for the reason just given this would not always have been possible.

Besides the above, there is a vast amount of intrusive Trap over the country occupied by groups 7, 8, and 9. Some, but not so much, in the Ecca Beds.

Of the four lowest of these subdivisions I can scarcely say anything, and practically my story will begin with the Dwyka Conglomerate. The portions of my sections which cross the rocks beneath that horizon are taken from Bain or other authors, supplemented by such passing observations as I was able to make *en route*; but I think I saw enough on my journey into the interior to be convinced of their general accuracy.

I. Lithological Description of the Rocks.

(1, 2.) The slates, granite, and some dykes which traverse them, of the neighbourhood of Cape Town (the "Malmesbury Beds"), have been described by Dr. Cohen (Neues Jahrbuch für Mineralogie &c., 1874, p. 460, 1880, vol. i. p. 96), and he also gives some account of the Table-Mountain Sandstone, which, as far as I made its acquaintance, I found to be a coarse massive grit. See also Darwin, 'Voyage of the Beagle,' part 2, p. 148.

(3.) The Bokkeveldt Beds are described by Bain as slates and sandstones. The fossils which he sent to England from these beds are described by Sharpe and Salter (Trans. Geol. Soc. 2nd ser. vol. vii. pp. 204–224). They both agree in thinking that their analogies are with the Devonian of Europe.

(4.) This group consists mainly of massive white quartzites, with bands of more thinly bedded quartzite and shale. I heard that thin streaks of anthracite have been noticed in it near Grahamstown. It is certainly very barren of fossils, and I could not get on the spot any definite trustworthy account of fossils from it. But there are reports that *Lepidodendron* and other Carboniferous plants have been found. Bain says (*loc. cit.* p. 54) that a few vegetable impressions and casts from these beds, first discovered by Dr. G. Atherstone, appear to belong to *Lepidodendron*. He also mentions (p. 184) numerous specimens of Carboniferous plants from near the Kowie River; and it is stated (p. 184, note) that there is in the Museum of the Geological Society a specimen of micaceous schistose rock from the Kowie River with *Lepidodendron*-like impressions.

[For the following notes I have to thank Prof. Rupert Jones. Specimens from the Kowie were pronounced by Mr. R. Etheridge to be Carboniferous plants, and are so described in a letter from Mr. H. W. Bristow addressed to the Crown Agent, 2nd May, 1870; also in the Cape Town 'Standard Mail,' Nov. 18, 1869, Mr. Neate mentions *Sigillaria*, *Stigmaria*, *Lepidostrobus*, *Halonia*, *Selaginites*, in micaceous fissile shales, from Port Alfred. Prof. Jones also tells me of *Knorria* from the Kowie Mouth at the Geological Society and British Museum. He further refers to Prosser, Trans. Phil. Soc. of South Africa, vol. i. (1878) part 5.]

(5.) For this rock I adopt Dunn's designation of "Dwyka Conglomerate" in place of the old names of "Claystone-Porphyry"

(Bain) and "Trap-Conglomerate" (Wyley). These names imply that it is of volcanic origin, a point which is by no means certain.

From its very remarkable nature and from the many and varied opinions, some of them of the wildest and most extravagant character, which have been held as to its origin, it has been a great centre of attraction to all who have paid attention to South-African geology. It is a great mass of breccia and conglomerate of variable character, but very coarse in places. My first introduction to this rock was at Grahamstown, under the guidance of Dr. Atherstone, from whom I received not only the heartiest welcome, but also an amount of information and help which was most useful at the outset of my explorations. The rock here has the following character:—A dark grey, closely grained, hard matrix, thickly set with many small angular fragments and rounded grains of quartz. The larger included blocks not very numerous, the majority angular or subangular, but some well-rounded pebbles; the largest fragment I saw, of granite, measured 19 inches by 11 inches, and was quite angular. A whitish granite, rich in quartz, was by far the commonest rock among the fragments, but quartzite and other rocks occur. In many places no bedding is discernible, but where the rock has been exposed it has a bedded look, parallel bands making their appearance on the weathered face, differing from one another in colour, and some weathering faster than others; along the outcrop too it weathers in a very peculiar way which suggests bedding. Slabs which look something like rudely shaped tombstones stand up in long parallel rows all along the hillside, and it looks very much as if these were hard beds, and that the spaces between had been occupied by something softer. Under the microscope the matrix is seen to consist of a greenish-black opaque substance, set with transparent fragments of all sizes, from the tiniest dot, only just visible under a power of 200 diams., up to bits 1 mm. across, with a few two or three times that size. The fragments are markedly angular and of all shapes, most unmistakable chips. They are very nearly all limpid quartz containing dust and fluid-cavities. The fractured nature of the outline of many of the quartz-grains comes out most beautifully under a tolerably high power; but often other parts of the edge in the same grain are smoothed and softened off as if by the action of some solvent. Besides the quartz-chips there are scattered sparingly about bits of plagioclase (one of microcline) and decomposed doubtful chips, some of which are probably felstone, and some may be basic traps*.

I again saw the Dwyka Conglomerate in two localities, in company with Mr. Thomas Bain, the son of the first African geologist, who inherits his father's geological tastes and enthusiasm, and who gave me the benefit of his genial companionship and great local knowledge during the last three weeks of my

* Dr. F. H. Hatch, of the Geological Survey, who kindly examined my slides, has detected the following minerals in addition to those mentioned in the text:—orthoclase, chlorite, magnetite, saussurite, epidote, mica, garnet, zoisite, augite, and olivine. He also notes that, penetrating the quartz-grains, are hair-like needles of rutile.

stay in Africa. The first was on the northern flank of the Wittebergen, north of Willowmore. The rock had here the same general character as at Grahamstown, but at some spots it contained very few blocks; at others they were numerous, and principally of a quartzite that I could not distinguish from the quartzite of the adjoining mountains (no. 4 of the table on p. 240). In a slice, cut from a specimen from this neighbourhood, rock-fragments are plentiful: among them are one showing micropegmatitic structure and a bit of Chiastolite-rock. At Prince Albert, my next locality, the conglomerate contained a large number of good-sized boulders, many angular and subangular, rounded pebbles, many small fragments, and the usual quartz-chips. Many of the large boulders were of various kinds of crystalline schist, and there were a fair number of quartzite-blocks. I had by this time got to know the quartzites of the Wittebergen fairly well, and, if it were not that all quartzites are a good deal alike, I should have said without hesitation that the quartzite-blocks in the conglomerate had come from these mountains. I also noticed bits of a jaspideous breccia exactly like a rock that I had been shown from the Rhinoster River (in the Transvaal), and amygdaloids like those occurring in the gravels of the Vaal River. The matrix, under the microscope, was the same as in the specimen from Grahamstown, but there were recognizable chips of granite and quartzite.

I also saw the conglomerate in the valley of the Buffels River, but noticed nothing new in it there.

The matrix of the rock has all the look of mashed-up granite mixed with fine mud *. Many different rocks have contributed to furnish the boulders; among these we may safely put the Witteberg quartzites, granite, and rocks apparently very similar to the crystalline series of the Transvaal. The size and angularity of the boulders suggest the action of ice. I have a pebble from the conglomerate of Prince Albert, which might pass for an ice-scratched block in a country known to have been glaciated; but such scratches as the block shows are not necessarily ice-marks; and this is all the evidence I could gather on this point during my hurried examinations.

The notion I formed as to the origin of this rock was that it was a coarse shingle formed along a receding coast-line (see p. 267). Both Dr. A. Geikie and Dr. Hatch have suggested to me that it has very markedly the *aspect* of a volcanic breccia, and its strongly fragmental character under the microscope is in favour of the view that this is its nature. But though in this respect it is scarcely possible to draw any distinction between the Dwyka Conglomerate and some undoubted tuffs, its resemblance to such rocks as the "Dolomitic Conglomerate" of Bristol, and the "Brockrams" of the Vale of Eden, is equally close. Dr. Hatch also lays some stress on

* Dr. Cohen has contributed to the 'Neues Jahrbuch' (Beilage-Band v. p. 193, 1887) an elaborate account of the rocks of the Cape Colony, from the Dwyka Conglomerate upwards. He finds that the cement of this conglomerate contains a considerable amount of soluble silica.

the great freshness of the felspar-fragments as supporting this interpretation. The absence, *so far as we know*, of any associated lava-flows, and of lapilli in the slides, tells somewhat the other way; but these points of negative evidence do not count for much in the present limited state of our knowledge.

(6.) The Ecca Beds consist very largely of hardened sandy clays *without lamination*, which I will call "mudstones," to distinguish them from laminated clays or "shales;" these are generally purplish or mottled, but occasionally of other colours. Shales do occur, but they are comparatively rare. The group also contains much sandstone; many of the sandstones are highly quartzose, finely grained, compact and hard, approaching quartzites; some of the sandstones exhibit very marked spheroidal weathering, so perfect indeed, that any one looking at them from a little distance would unhesitatingly pronounce them to be basalt or dolerite. The first instance I saw of this was in the Ecca Pass; it was so marked in its character and the resemblance to weathered basalt was so close, that I could scarcely believe my eyes, when, on breaking into the rock, I found it only sandstone. In some places, as between Prince Albert and Prince-Albert-Road Station, sandy limestones occur in the Ecca Beds.

There is a most magnificent section of this group in the Ecca Pass, to the north-east of Grahamstown, which I saw under the kindly guidance of Dr. Atherstone, all but clean cut from top to bottom, and showing nearly 4000 feet of beds. This is not the full thickness, for the formation extends some way further to the north-east; but as the beds are there repeated in folds, it is not easy to estimate the additional thickness.

I could hear of no fossils from the Ecca Beds. I believe reptilian remains have been picked up in the country occupied by them; but, from all I could learn, I came to the conclusion that these were found in loose blocks on the surface, stray remnants of the sheet of Karoo Beds, which once spread over the country but which has been denuded away. Bain states that at Ecca Heights (north of Grahamstown) a stratum occurs, nine inches thick, entirely composed of vegetable remains (*loc. cit.* p. 54). I think the rock of this locality belongs most probably to the Ecca Beds; but I am not sure, it may be a bed in the Zwarteberg quartzites. He also mentions a bed, near the base of the group, which contains abundance of plant-remains (*loc. cit.* p. 187); but I have not been able to learn that any of these have been determined. Cohen states that grauwacke-like sandstones with indistinct plant-remains occur in the Ecca Beds (*loc. cit.* p. 209).

(7.) The beds which I have placed in a separate group under the name of "Kimberley Shales" consist principally of grey and dark sandy shales and mudstones; some thin bands, more sandy than the generality of the beds, approach sandstones; but true sandstones are either absent or rare. Thin layers of argillaceous limestone are not uncommon. I shall be better able further on to explain my reasons for thinking that these beds are sufficiently important and persistent to deserve being treated as a separate subdivision with a distinctive name.

I think this group is practically the same as the "Olive Shales" of the late Mr. G. W. Stow *. It would appear from his observations that these shales extend northwards across the Vaal River and abut unconformably against the old crystalline rocks of the Transvaal. Resting on these old rocks, and forming a basement-bed to the "Olive Shales," is a conglomerate formed out of the underlying rocks, called by Mr. Stow "Ancient Conglomerate" †; I shall speak of it as the "Basement Conglomerate of the Kimberley Shales." From the description of this bed it seems to me to resemble very closely the Dwyka Conglomerate, and I have my suspicions that it has been confounded with that rock; but there will be more to be said on this point further on. Mr. Stow also describes conglomerates and sandstones interbedded among the Kimberley Shales on the north. It seems that these are thickest along the line where the Transvaal crystalline rocks rise to the surface and that they thin away rapidly to the south, which indicates that we are here near the edge of the basin in which the Kimberley Shales were deposited.

Plants are found in the Kimberley Shales, and they occasionally contain lenticular beds or nests of coal. I saw a specimen of one of these found at Kimberley; it consisted of thin laminæ of coal alternating with thin bands of black shale; the patch from which it was taken, I was told, had been worked all round, and proved to thin away on all sides; its maximum thickness was six inches, maximum breadth about twenty feet. Even in the hand specimen the laminæ of coal were not continuous, but lenticular in shape. I was told also that reptilian bones had been met with in the Kimberley Shales, but I was not able to learn any particulars as to these or the plants. The probability seems to be that the fossils of the Kimberley Shales are similar to those of the Karoo Beds.

(8.) I have used the term "Karoo Beds" to indicate only a portion of the great group of strata that were originally included under this name. In this limited sense the Karoo Beds consist of alternations of sandstones and shales.

The sandstones are finely grained, and the majority of them contain a large amount of decomposed felspathic matter, so they incline to be soft. Occasionally more quartzose and harder beds occur; but it is very rarely, if ever, that we meet with anything approaching the compact quartzite-like sandstones of the Ecca Beds. There is a tendency in the Karoo sandstones to spheroidal weathering, but it never reaches the perfection of some of the Ecca sandstones, and no one would ever run any risk of mistaking a Karoo sandstone for basalt (see p. 244). The weathered outside of the Karoo sandstones is usually of a pale buff colour, but occasionally they are red or purplish.

The majority of the Karoo clays are shales (but mudstones do

* Quart. Journ. Geol. Soc. vol. xxx. (1874), p. 610 *et seq.* † *Ibid.*

occur), frequently red with greenish bands and blotches (recalling forcibly our English New Red Marls), or dark greyish-purple or buff. It is useful for purposes of identification to note that the shale-bands in the Karoo Beds are, as a rule, much thicker than the sandstones. Bain mentions (*loc. cit.* p. 55) that the Karoo Beds contain nodules of greyish-blue argillo-ferruginous limestone, which often contain reptilian remains. I saw such near Burgersdorp in a bed in which Dr. Kamemeyer had found many reptilian bones.

There is a gradual passage from the Kimberley Shales into the Karoo Beds. The shales become more sandy and harder, beds of sandstone put in and become gradually more numerous, and so we pass from a group which is practically all shale to one in which sandstone is an important item. Cohen states that the matrix of the Karoo sandstones and shales contains carbonate of lime (*loc. cit.* p. 218). When we remember that great deposits of calcareous tufa cover a large portion of the Karoo country, it seems not unlikely that this ingredient is not original, but has been introduced by infiltration.

The fossils of the Karoo Beds which have attracted most attention are the reptilian remains discovered by Bain. These have been described by Professors Owen and Huxley.

Bain mentions shells from this formation at Mankaza Port, twenty miles north-east of Fort Beaufort (*loc. cit.* p. 55), and also some shells from Graaf Reinet (*loc. cit.* p. 225), which have been doubtfully referred to freshwater genera. *Estheria* is quoted by Prof. Rupert Jones *.

Ferns (*Glossopteris*, *Rubidgea*, ? *Dictyopteris*), with *Phyllotheca* and other plant-remains, are recorded by various authors †; but, so far as I know, these have not been fully described and tabulated.

The evidence is imperfect and partly negative; but, so far as it goes, it points to the conclusion that the Karoo Beds are a freshwater deposit.

(9 *a.*) The Molteno Beds are, like the Karoo Beds, made up of alternations of sandstones and shales, but there are several very marked points of difference between the two groups. The sandstones of the Molteno group are some of them finely grained and undistinguishable from those of the Karoo Beds; but many of them are very coarse grits, made up to a considerable extent of large grains of glittering quartz, and with very little felspathic matter. These grits frequently pass into conglomerates containing pebbles of white vein-quartz. Still coarser conglomerates are occasionally met with, in which there are boulders of quartzite larger than a man's head. The shales of the group are for the most part grey or dark-coloured; red shales are not entirely wanting, but they seem to be very rare. Also, while in the Karoo Beds the shale-bands are, as a rule, thicker than the sandstones, the reverse is the case in the Molteno Beds; in them the bulk of the subdivision consists of thick beds of massive grit, and the shale-bands which lie between them

* Geol. Mag. [2] vol. v. p. 100.
† Quart. Journ. Geol. Soc. vol. xxiii. (1867), p. 140.

are comparatively thin and form only a very subordinate part of the group.

The only fossils that I know of from the Molteno Beds are the remains of land-plants; ferns are said to be plentiful. Mr. Carruthers has examined specimens from Dordrecht. "One," he says, "seems to be a species of *Danæopsis*, a second a *Sphenopteris*, and I know not what fossil genus I could refer the third to. With these are associated what appear to be fragments of a Monocotyledonous plant, which are undeterminable" *. Mr. Dunn quotes *Pecopteris*, *Odontopteris*, *Cyclopteris cuneata*, *Tæniopteris Daintreei* †. I obtained a few specimens from the neighbourhood of Molteno. These, Dr. Williamson informs me, belong, with one doubtful exception, to the genus *Odontopteris*, which, he adds, "is confined, so far as we know at present, to the Carboniferous and Lower Permian (Lower New Red Sandstone) beds." Fragments of silicified wood are extremely abundant in some places; a specimen from Dordrecht was determined by Mr. Carruthers to be coniferous ‡. Fossils sent to England by Dr. G. Grey, described as from the north-eastern margin of the Stormberg Range, have been determined as *Lepidodendron*, *Sigillaria*, *Pecopteris*, *Alethoptoris*, *Asterophyllites*. It is very unfortunate that the locality of these fossils is not more accurately defined.

So far as I have been able to learn, the fossils of the Molteno Beds have yet to be collected and described.

It is probable that the Mammal *Tritylodon longævus*, described by Sir R. Owen (Quart. Journ. Geol. Soc. vol. xl. 1884, p. 146), came from Molteno Beds.

It may be useful to summarize the main characters by which the Ecca, Karoo, and Molteno Beds may be distinguished; they are shown in the following table:—

	Ecca.	Karoo.	Molteno.
Sandy Rocks.	Very quartzose, compact, and hard. Marked spheroidal weathering in some.	Much felspathic matter, finely grained, not massive, as a rule. Feeble tendency to spheroidal weathering in some.	Coarse quartzose grits and conglomerates common, often in massive beds.
Clayey Rocks.	Mudstones predominate; shales rare.	Shales, few mudstones; red, purple, and mottled beds common.	Shales, few mudstones, grey or dark; red beds rare.
		Sandstones thin compared with the shale bands.	Shale bands for the most part thin compared with the sandstones.

* Quart. Journ. Geol. Soc. vol. xxvii. (1871), p. 525.
† Report on the Stormberg Coal-field (1878), p. 19.
‡ *Loc. cit.*

Corresponding to these lithological distinctions, there are differences equally well marked in the physical features of the tracts occupied by the three groups.

The Ecca Beds have been bent into a number of folds, whose axes range approximately east and west, and they consist of alternations of hard and soft beds. The usual result in such a case is to produce a country traversed by long parallel ridges running along the outcrops of the hard beds, and intervening valleys following the outcrop of the softer beds. Such is the character of much of the country formed of the Ecca Beds. But other parts of this country are very flat and featureless. The well-known Karoo deserts are on the Ecca Beds, and they are the most monotonous stony plains that can be imagined. I had suspicions, in some cases where the Ecca country was so destitute of feature, that the flatness might be due to there being a thin sheet of Kimberley Shales remaining, and that this levelled over the inequalities in the surface of the Ecca Beds; but I was never able to verify this conjecture, because these flats are usually deeply buried in superficial sand and débris of sundry kinds.

The Kimberley Shales form immense rolling plains, generally grassy, and the only marked inequalities are made by outcrops of Trap sheets or dykes.

The beds of the Karoo and Molteno subdivisions are nearly flat. In such a case alternations of hard and soft beds give rise to terraced hill-sides; and such is the character of the hills made of these rocks. But there is always a difference, which instantly catches the eye, between a hill-slope formed of Karoo Beds and one formed of Molteno Beds. In the Karoo Beds the sandstones are thin compared with the intervening belts of shale, and consequently the steep steps formed by the outcrop of the sandstones are narrow compared with the gently sloping terraces that run along the outcrops of the shales; and the result is that the hill-side, when viewed from a distance, has a striped appearance, and looks as if it were ruled across by a number of thin parallel horizontal bands. In the Molteno Beds, on the other hand, where the shales form a comparatively subordinate item, the great massive grits make lofty, precipitous, and rugged "kranzes," and the shale-terraces are so narrow and so cumbered with grit-débris, that they are scarcely recognizable a little way off. In both the Karoo and Molteno Beds the boldest edges and hill-caps are formed by the escarpments of the great intrusive sheets of trap.

Coals of the Molteno Beds.—The only workable coals yet discovered in the Colony are found in the Molteno Beds. Detailed sections will be found in the Official Reports mentioned in the note *, and

* Colonial Mining Engineer's Report on the Coal-field of the Stormbergen. By F. W. North. Presented to both Houses of Parliament by command of His Excellency the Governor. Cape Town, 1878.—Report on the Stormberg Coal-fields. By E. J. Dunn. Presented to both Houses of Parliament by command of His Excellency the Governor. Cape Town, 1878.—Report on the Coals of the Cape Colony. By A. H. Green. Presented to both Houses of Parliament by command of His Excellency the Governor, 1883.

need not be reproduced here; but the following points are of general interest.

It was only in a very few instances that I was able to get a sight of the floor of the coal-seams; but whenever this was the case, I found nothing below the coal which in any way resembled a "seat-stone" with roots or rootlets. At the Indwe Colliery the coal rested directly on a hard, closely-grained, laminated, micaceous sandstone. There were a few vegetable impressions on the planes of bedding; but I could see nothing like rootlets. In another case the floor was formed of an irregularly bedded, micaceous, sandy shale; at Cypher Gat the floor was well-bedded shale; in neither case could I detect any sign of rootlets. This absence of a seat-stone suggested to me the possibility that the coal was of subaqueous origin.

There are other peculiarities in the coals which seem to me to lend some support to this view.

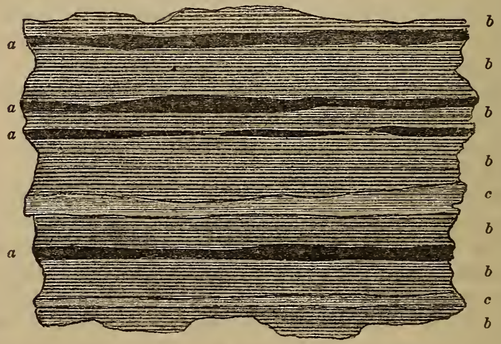
All the coals which have been analyzed are extremely impure; they contain from 21 to 30 per cent. of ash.

Again, all the coals that I saw are more or less finely laminated. Some of the layers appear to be all coal, often bright and lustrous; but even the cleanest-looking leaves a large amount of ash when burnt. Other layers are black shale. As far as these two sets of layers go there is nothing to distinguish the South-African from many other coals. But there is a third kind of layer, the like of which I do not recollect to have seen in any but these South-African coals. The layers of this third class are dull, and each is made up of a number of subordinate laminæ, often of excessive thinness. If we split a block parallel to one of these laminæ, the surface is so dull and earthy that no one, looking at it alone, would ever believe that he had a piece of coal in his hand: nothing like coal is to be seen; but the appearance is exactly that of the surface of a bedding-plane of rather dull black shale. It would seem that these layers are complicated in their structure; that they consist of a large number of very thin laminæ of coal, and numerous still thinner films of hardened black mud, which coat the surface of each coal-lamina and separate it from the laminæ above and below it. Fig. 1 illustrates in a diagrammatic way the structure just described; (*a*) are layers of bright coal, (*c*) are layers of black shale, (*b*) are layers consisting of very thin alternating laminæ of coal and black mud films.

The finely laminated layers were shown in a very pronounced form in the coal worked at Cypher Gat. Mr. Cuttell managed to cut me a section of this coal which was fairly transparent round the edges. The laminæ were too numerous to be counted exactly, but at least six were distinguishable in a thickness of ·07 millim.; some of these were again subdivided into subordinate laminæ not more than ·003 millim. thick. In parts the laminæ ran remarkably true and rectilinear; in other parts they were wavy and broken; but they were everywhere sharply defined. Some were quite transparent and yellow or yellowish brown (? pure resinous vegetable matter);

others less transparent and of a darker brown (? vegetable matter mixed with mud); others deep black and opaque (? mud-films); these last were most sharply defined. I made comparisons with the following coals, sections of which were kindly lent to me by Mr. E. T. Newton:—Newcastle; Babington Colliery, Notts; Moira; Wharncliffe

Fig. 1.—*Diagram illustrating the Structure of the South-African Coals.*



Silkstone, Barnsley. More or less lamination was recognizable in all these, but in all it was inferior in fineness, distinctness, and evenness to the lamination of the Cypher Gat coal. I also noticed the effect of increased enlargement on the different sections. Under a power of 200 diameters the lamination of the Cypher Gat coal is more sharp than with lower powers, and the fine black stripes especially stand out more conspicuously. The reverse was the case with the English coals; under the higher power their lamination became confused and indistinct. In the English coals, too, the laminæ did not differ so much in transparency as in the Cypher Gat coal, and there were none of the fine black laminæ.

The differences are not great, but they are such as might well arise if the African coals were formed under water into which vegetable matters and mud were discharged. Even when the vegetable matter was in excess, there was still mud enough present to cause the coal to contain a large percentage of ash; at other times the supplies alternated in rapid succession, so that only very thin laminæ of impure coal were deposited, and on the top of each a thin film of black mud was spread out.

Other singularities are presented by coals from Van Vyk's Farm near Burgersdorp, and Van Zyl's Farm near Molteno. The analyses of these coals and of the coal from the Indwe are subjoined :—

	Van Vyk *.	Van Zyl *.	Indwe †.
Carbon	69·72	63·74	61·021
Hydrogen ...	2·98	2·81	3·208
Oxygen ... }	4·96	4·65	2·178
Nitrogen }			2·190
Sulphur......	0·97	0·76	0·434
Ash	22·34	28·80	30·320

The composition of all these coals, excluding the ash, is almost exactly the same. The Indwe coal is free-burning; the other two coals light with so much difficulty that it is said they will not burn at all. I hope that I have got some way towards detecting a peculiarity in physical structure which may account for this difference. Some of Van Vyk's coal was coarsely powdered and heated in a platinum spoon before a blowpipe. It burnt slowly without flame, and left a light-brown residue, the fragments being unaltered in shape by the heating. Under a power of 40 diameters the brown fragments are seen to have a curious reticulated structure. There are a number of thin wavy plates which enclose lenticular cavities or boxes. Some boxes are empty, others contain a black substance; this is probably the carbonaceous part of the coal, which has been burnt out of the empty boxes, while in the case of the others the combustion has been incomplete. It looks as if the carbonaceous matter had been broken up into small fragments each of which is enclosed in a box of incombustible material ‡. Such a result would be produced if vegetable matter floated in water long enough to be disintegrated, and if each fragment, as it sank slowly, became invested with a coating of mud. I did not succeed in detecting any similar structure in Van Zyl's coal; but the experiment is one in which success is attained only by somewhat of a lucky combination of accidents; pounding too roughly or an excess of heat would be very liable to destroy so delicate a structure.

In the hope of getting some further insight into the nature of these mud-films, the surface of one was scrubbed with a clean brush and hot distilled water. The mud obtained was dried and ignited for five hours in a platinum crucible over a Bunsen-burner. The incombustible residue consisted of two parts. One consisted of dull whitish, tufaceous-like shreds, which dissolved with effervesence in cold dilute hydrochloric acid. In view of the large deposits of calcareous tufa which cover so much of the surface in this part of

* Analyses by Mr. C. H. Bothamley, Assistant-Lecturer in Chemistry, Yorkshire College, Leeds.

† Mr. North's Report (quoted above), p. 10.

‡ Professor Williamson was good enough to attempt a microscopic examination of this coal, but he was unable to grind a section thin enough to be transparent.

the country, I look upon this as a deposit thrown down from infiltrated water. There were besides a number of transparent, colourless, doubly refracting grains that scratched glass; most were imperfectly rounded or angular, some few better rounded. They ranged in size from $\cdot 1 \times \cdot 1$ millim. to $\cdot 3 \times \cdot 6$ millim., about $\cdot 3 \times \cdot 3$ millim. being an average size. Some contained what looked like liquid-cavities. I have scarcely any doubt that they are clastic grains of quartz. Similar grains were visible in the slice of the Cypher Gat coal already mentioned; and I found them in the ash of other of the South-African coals. The English coals which I took as standards of comparison contained similar grains, but not in such large numbers as the African coal. In the case of the English coals these grains are probably wind-blown dust, and this they *may* be also in the African coals; or, if these were subaqueous, they would be water-borne débris.

The evidence is far from conclusive, but it is not incompatible with the view that the South-African coals are of subaqueous origin.

Adopting this view, my notion of the way in which these coals were formed is somewhat as follows. The great lake in which the Molteno Beds were laid down became largely filled up. A swampy surface was formed, dotted over with pools and small lakes of various sizes and depths. In these basins, or in some of them, alternating layers of vegetable matter and mud were laid down.

A further point of interest is that the coals in some cases seem to have suffered from contemporaneous denudation before the beds next above them were deposited. In my Report (pp. 11, 12, 13) I have given details of one such instance. When we look at the coarseness of the grits and conglomerates that so frequently lie almost immediately above the coal, this is only what might be expected. The wonder is that any coal at all survived under the conditions that must have prevailed shortly after its formation. It is common to find at a very short distance above the coals a coarse grit containing pebbles and well-rounded boulders of quartzite, the latter often larger than a man's head, and in some cases as much as two feet long; usually there is between the bed and the coal some small thickness of shale, but at Molteno it rested in places directly on the seam. Wherever they came from, these boulders must have travelled a considerable distance; and it is scarcely believable that there were currents in the lake strong enough to move them, except in the neighbourhood of the mouths of rivers. They may have floated entangled in the roots of trees, but even on this supposition it is hard to see why they are so numerous and widely distributed.

One most important practical conclusion follows from a review of our present knowledge of these South-African coals. Sanguine speculators, on the strength of having seen outcrops of coal at a few widely separated spots, have assumed that at least one unbroken sheet of coal spreads beneath the large area covered by the Molteno Beds, and have framed most encouraging estimates of the coal-resources of South Africa. It will be most gratifying if these calculations turn out to be correct, but it must be confessed that all we know as yet on the subject is directly in the teeth of such a result. We do know that the coals vary enormously in thickness and value from place to place; for instance there is good reason to think that the worthless coal of Van Zyl's Farm belongs to the very same bed which yields at Molteno, only about a mile off, a marketable coal. There is some reason to think that the coals were originally deposited in detached patches. It is certain that in some cases they were largely mutilated by contemporaneous erosion very shortly after their deposition. In view of these facts, such an assumption as is involved in the estimates in question is wholly unjustifiable, and any attempt to appraise the value of the coal-deposits of South Africa must be altogether premature.

(9 *b*, 9 *c*, 9 *d*.) Of these subdivisions I have scarcely anything to say, for I saw them only at one spot, on the slopes of Vaal Kop, the highest point of the Stormbergen, about 12 miles to the east of Molteno.

Here, above beds of decided Molteno type, we find a group of shales, with sandstones neither thick nor coarse, of a deep red colour, and above them more massive reddish sandstones. These are the "Red Beds" of Mr. Dunn. He puts them down as 600 feet thick and says that reptilian remains occur in them. Next follows a finely grained, light-coloured sandstone, which weathers white, about 150 feet thick, Mr. Dunn's "Cave Sandstone." It is extremely massive, no planes of bedding being visible through its whole thickness; and it forms magnificent precipitous escarpments along the hill-sides. Miles away these lines of white cliffs stand out in the clear atmosphere sharp and distinct; or an outlier, capping an isolated hill-top, makes a landmark, visible over all the country side. I saw from a distance just the same white cliffy scarps running along the slopes of the Draakensberg; and again when I was at Winburg in the Orange Free State my eye was caught by mountains well away to the south with the same white capping. In the Club at Burgersdorp there were some very clever sketches of the Basuto Mountains, not drawn by a geologist, but there was no mistaking the Cave Sandstone in them. No rock that I ever saw makes such characteristic features. On the farm Wonder Hoek, at the foot of Vaal Kop, the Cave Sandstone gives rise to wild and striking scenery. There is a ramification of valleys and the escarpment winds in and out of each of them in rugged undercut precipices of from 100 to 150 feet high, the slopes above and below being comparatively gentle. The precipitous escarpments are very largely undermined by the weather, and thus enormous rock-shelters or "caves" are formed, whence the name of the rock. Above the Cave Sandstone comes a group of bedded amygdaloidal lava-flows and tuffs, the "Volcanic Beds" of Mr. Dunn. A peculiarity in these are the so-called "Pipe Amygdaloids," in which the rock is traversed by a number of vertical, winding, tubular cavities, filled in with a zeolite. These are described by Dr. Cohen, 'Neues Jahrbuch für Mineralogie,' 1875, p. 113, 1880, vol. i. p. 96. My specimens of these lavas are described on p. 255.

Further details about the Red Beds, the Cave Sandstone, and the Volcanic Beds will be found in Mr. Dunn's Report on the Stormbergen Coalfields (Cape Town, 1878).

Intrusive and Contemporaneous Traps.—The whole of the country occupied by the Kimberley Shales and the Karoo and Stormberg Beds is seamed with almost innumerable dykes and intrusive sheets of trap. They are thicker in some quarters than in others, but you cannot move far anywhere without coming across more or less of them. The following, which I have examined microscopically, seem all very similar in character *.

Intrusive Sheet, at the Reservoir, Beaufort West. Thick Sheet, Colesberg.—An interlacing mass of lath-shaped crystals of plagioclase (·2 to ·3 millim. across) and augite; little olivine; ilmenite; very fresh. The felspar crystals penetrate the augite, but hardly to such an extent as to produce marked ophitic structure.

Sheet on top of Hangklip †, near Queenstown.—Very marked ophitic structure; broad plates of augite penetrated by lath-shaped crystals of plagioclase (·07 millim. across). Granules of olivine, some enclosed in the augite; little ilmenite; very fresh.

The rock is columnar, and the base of the sheet clearly cuts across the bedding of the shales on which it rests.

Intrusive Sheet, Dordrecht.—Exactly like the last; plagioclase laths 1·7 to ·8 millim. across.

East of Vet River, Winburg, Orange Free State.—Very similar to the last two; olivine somewhat decomposed; plagioclase laths ·3 to ·5 millim. across.

Sheet at top of the De Beer's Mine, Kimberley.—Laths of plagioclase, ·1 to ·5 millim. across; olivine; ilmenite; felspar penetrates both augite and olivine; some olivine enclosed in the augite.

Sheet on slope of Hangklip, near Queenstown.—About three quarters of the slice is occupied by laths of plagioclase, ·01 to ·03 millim. across, with ragged, ill-defined boundaries. The spaces between are filled in with a green fibrous decomposition-product, in which comparatively unaltered augite and olivine can be detected here and there.

Thick Sheet in Kimberley Mine.—Laths of plagioclase ·05 to ·1 millim. across; viridite and opacite; plagioclase penetrates the other constituents. It is not clear what minerals have given rise to the decomposition-products. If these were augite and olivine, the rock must have been originally very similar to that last described.

Spheroidal and columnar structures are common in these traps. Some of them also show in a very marked way curvi-tabular structure; the rock is traversed by curved planes of division, running parallel to each other, the weathered surface is commonly formed by one of these curved surfaces, and we have along the outcrop a series of bosses with gently rounded tops, which bear a considerable resemblance to *roches moutonnées*. It looked in some cases as if the intrusion of the trap had bent up the overlying beds into a flat

* For further details and analyses see Dr. Cohen's paper already quoted.

† Quart. Journ. Geol. Soc. vol. xxvii. (1871), p. 531.

dome, after the fashion of the laccolites of the Henry Mountains described by Mr. Gilbert. The planes of division produced by contraction would then naturally run parallel to the curved upper surface.

Besides sheets and dykes there are also intrusive masses of trap, some of which cover areas of many square miles and form great hill-groups. One very large mass forms the hills known as the Andries-Bergen, about 18 miles N.N.W. of Queenstown *. The rock is very similar in appearance to that of the sheets and dykes, only on the whole somewhat coarser in grain. It consists of laths of plagioclose (·2 to ·6 millim. across), augite, olivine, and ilmenite. The plagioclase penetrates both the augite and the olivine; the olivine is in large crystals. The rock bears a very close resemblance to that of the intrusive sheets of Beaufort West and Colesberg; the main points of difference are that the felspar-crystals are larger and there is more olivine. The coarser grain may very reasonably be attributed to a slower rate of cooling due to the larger bulk of the mass.

I also brought away specimens from a small intrusive mass close to Burgersdorp. The specimen from the centre of the mass is very similar to the rock of the intrusive sheets of the top of the Hangklip and Dordrecht in its microscopical character; there is rather a larger proportion of plagioclase and the crystals are larger in size, ·2 to ·3 millim. across. A specimen taken close to the edge of this mass is much more closely grained than the preceding. Under the microscope it is seen to be a finely felted mass of small felspar-microliths, and grains, probably of augite, in a black opaque ground-mass. Scattered about are larger crystals of plagioclase, up to ·6 millim. across, shattered and broken, plates of augite up to ·1 millim. across, and blebs of what seems altered olivine.

I have already mentioned that I saw the subaerial lavas, which form the highest subdivision of the Stormberg Beds, only on Vaal Kop. The three specimens I brought away from there have the following characters. They are more closely grained than the intrusive traps and decidedly vesicular or amygdaloidal. No. 1 is very similar to the rock of the sheet on the top of Hangklip. No. 2 contains many laths of plagioclase ·04 millim. across on an average; the space between these is filled in by viridite and small transparent granules, some of which appeared to be augite and some possibly olivine. A few larger crystals of plagioclase, shattered and corroded, are scattered about. It is very like the thick sheet in Kimberley Mine, but the plagioclase laths are smaller. No. 3 is very like No. 2, only the plagioclase laths are smaller and the other constituents more decomposed and more difficult to identify. It contained large fragmentary crystals of plagioclase, augite, and olivine.

So far as the evidence goes, the resemblance between the lava-flows and the intrusive igneous rocks is fairly close, so that both may well have come from the same source.

* The large and prosperous farm of Carnarvon, belonging to Mr. Halse, stands just on the edge of this mass, and I recollect with pleasure the hospitable welcome we received there.

The fresh unaltered state of the minerals in these slices is very noticeable, all the more so that my specimens were taken close to the surface. The dryness of the climate and the scantiness of the vegetation have probably much to do with this.

II. Lie of the Rocks and Physical Structure of the Country.

In its broad outlines the geological structure of the southern end of Africa is extremely simple. The strike of the beds runs roughly parallel to the coast, and in the part of the country with which we are now specially concerned is nearly east and west. The general dip is from the coast towards the interior, so that in the district now under consideration it is northerly.

The country falls naturally into two divisions, sharply contrasted with one another in geological structure; the one on the south is a district of disturbed, the one on the north of undisturbed beds; the distinctive characters of each will be recognized by a glance at Horizontal Sections nos. 1 & 2 (figs. 4 and 5, facing p. 270).

The southern belt of folded and contorted rocks includes the formations up to the top of the Ecca Beds. The southern half of this belt is occupied by the formations up to and including the Witteberg quartzites (No. 4 of the Table at p. 240), and its physical structure is very much the same throughout. More or less interrupted hill-ranges, with a general easterly and westerly trend, separated by longitudinal valleys, and cut across by transverse gorges, are the features which it everywhere presents. The separate hill-ranges of this zone are numerous, and each has a name of its own; the Zwartebergen and Wittebergen may be taken as types of all of them. The maximum of contortion and elevation is found along a zone running east and west through the centre of the contorted belt. Both to the north and south of this zone the folds open out, and the contortion gradually decreases in intensity.

We have here all the distinctive characters of a true mountain-chain, of a somewhat mild type perhaps, and worn down by denudation to a moderate elevation.

The northern part of the southern belt is occupied by the Dwyka Conglomerate and the Ecca Beds. It varies a good deal in its physical aspect; some of its chief characteristics have been already mentioned, and will be described further on.

To the north of the contorted belt lies a broad spread of country, in which the Kimberley Shales, the Karoo Beds, and the Stormberg Beds come on, one above the other. The rocks lie in a great saucer-shaped basin; but the saucer is so flat that the strata are everywhere practically horizontal. This country is bounded on the south by a belt of lofty ground formed by a number of hill-ranges, with a general easterly trend, of which those known as the Nieuwveldt and Camdeboo Mountains may be taken as types; but these are hills of denudation, and have no right to the title of mountains in the geological sense of the word, though, if wildness and ruggedness may give them a claim to the name in its popular acceptation, they are quite as much entitled to the appellation as the Zwartebergen and the Wittebergen.

This great group of horizontally bedded rocks abuts on the north against the mass of crystalline schists that range from Bushmansland into the Transvaal (see northern end of Section 2, fig. 5).

To pass to details, the general structure of the country south of the Zwartebergen and Wittebergen range is shown on Section 2 (fig. 5). This part of the section is mainly taken, with some modifications, from Bain; but I was able, during the railway-journey across the country which it traverses, to observe enough to assure me of its general correctness. It makes no pretensions however to be anything more than a mere hand-sketch.

In the south of this strip of country the hills run up to some 3000 or 4000 feet above the sea, and the beds undulate in broad saucer-shaped basins. As we go northwards the ground rises, the folds become sharper till they pass into what may fairly be called contortions, and we reach the zone already mentioned, in which contortion and elevation reach their maximum. It is a long mountain-belt formed by the Zwarteberg Quartzites, the highest points of which run up to between 6000 and 7000 feet above the sea. I made four traverses across this range: between Aberdeen road and Port Elizabeth; between Port Elizabeth and Grahamstown; on my road from Aberdeen into the valley of the Oliphants River; and on my return from that valley to Prince Albert. The physical structure was everywhere the same: long lines of rugged and lofty hills formed of very contorted synclinals of quartzite, cut across every here and there by deep transverse gorges, and between the hill-ranges great longitudinal valleys, which run along very contorted anticlinals of shales and sandstones on which the Quartzites rest.

I think there is little doubt that these shales and sandstones belong to the Bokkeveldt Beds. Mr. T. Bain told me that the fossils of that group had been found in them, and I noticed badly preserved shells in them near Willowmore. I have therefore represented them as Bokkeveldt Beds on the sections. Section No. 3 (fig. 6) will give a good general notion of the structure of the Quartzite-belt.

By far the finest section which I saw was in Meirings Poort, between Prince Albert and the valley of the Oliphants River. This is a narrow precipitous gorge, in parts almost deserving the name of cañon, trenching one of the great quartzite-ridges down to its very base. The sides run up in a succession of steep steps to heights which must be, in places, several thousand feet above the floor of the gorge, and in the vertical walls at the bottom an almost unbroken section is laid bare. The thickly-bedded Quartzites stand up for the most part nearly on end, and are only moderately folded; but interbedded bands of more thinly-bedded sandstones and shales are crumpled in the most violent manner, and often so mashed up that it was not possible to follow any single bed for even a moderate distance.

I did not see enough of the country which has been so far described to enable me to decide whether or not the Table-Mountain Sandstone, the Bokkeveldt Beds, and the Quartzites follow one another in conformable succession. But I think I obtained evidence which points to a very decided unconformity between the Quartzites and the Dwyka Conglomerate. No sections that I saw gave much information on this point. Dr. Atherstone very kindly guided me to several places in the neighbourhood of Grahamstown where he hoped we might find a junction between these two formations, but the sections were none of them satisfactory. This was also the case when I crossed the junction near Vogel-struis-Laagte, on my road from Aberdeen to Willowmore. In both cases I believe the Conglomerate was folded in among the Quartzites in the way shown in Sections 3 and 4; and even if an actual junction had been visible, the disturbance was so great that it is doubtful whether it would have been possible to decide whether it was a conformable junction or not.

At one spot only, about two miles south of Prince Albert, was I lucky enough to see the Conglomerate actually in contact with the underlying rock, here Bokkeveldt Beds. There were here strong indications that the Conglomerate rested on an eroded surface of shale; but the exposure was far to small to allow of any general conclusions being drawn from it. But, though my sections were inconclusive, the following considerations, I think, will establish my point. Boulders of a rock which I could not distinguish from the Quartzite of the Wittebergen are plentiful on the Conglomerate; and the Conglomerate rests sometimes on Quartzite and sometimes on Bokkeveldt Beds. These facts make it pretty clear that there must have been very large denudation of the underlying rocks before the formation of the Conglomerate.

The next question that presents itself is whether the Ecca Beds are conformable to the Dwyka Conglomerate. I saw the actual junction between these two formations only in the section given in fig. 2, to which I was guided by Mr. T. Bain. There could be no doubt that at the point marked A the Ecca shales rested on a very wavy and uneven surface of Conglomerate. But this obviously proves nothing in the case of a rock like the Conglomerate, liable to be thrown down in heaps; and the apparent discordance is quite as likely to be due to original irregularity of deposition as to subsequent denudation.

The only other section I saw which at all bears on the question is on the north of Grahamstown, at the 10th milestone on the Queen's Road, just at the top of the Ecca Pass, which I examined in company with Dr. Atherstone. My reading of this section is given in Section 4 (fig. 7), and shows Ecca Beds resting directly on rocks belonging to the Quartzite group without any Dwyka Conglomerate between the two. The Conglomerate is seen in great force not 20 yards away, so that its absence can hardly be owing to irregular deposition, and would seem to indicate unconformity; but my visit to the spot was made quite at the beginning of my trip, before I had become familiar with the South-African rocks, and I do not insist on my interpretation. The section deserves careful study by local geologists.

The question, then, for the present remains open, but I am inclined to look upon the Dwyka Conglomerate as the basement-bed of the Ecca group, and I shall have more to say as to the method of its formation further on.

This finishes all I have to tell about the southern half of the belt of folded and contorted rocks that runs across the south of the Cape Colony; the northern half of that belt is occupied by Ecca Beds, and varies very much from place to place in its surface aspect. In the so-called Karoo Deserts a plain that looks, and is almost, a dead flat stretches away on all sides as far as the eye can reach, in parts all strewn over with loose stones, in parts overspread with a coating of sand. A scanty growth of shrivelled spiny bushes covers the ground, and enhances rather than abates the general parched and arid aspect of the whole. The only relief is afforded by long winding lines of refreshingly green trees, which grow alongside the river-courses, the beds of which, except after a heavy downfall of rain, are for the most part dry, though moisture enough is present in the subsoil and in a few scattered pools to keep alive a fairly vigorous vegetable growth. Elsewhere the Ecca Beds form moderately hilly country, the hard bands giving rise to long parallel ridges, and the softer to intervening valleys.

The boldest country I saw on this formation was on the first part of my journey from Grahamstown to King-William's Town. Here the country is strongly diversified by hill and valley, and covered by a luxuriant growth of Acacias, prickly pears, Euphorbias, and other plants.

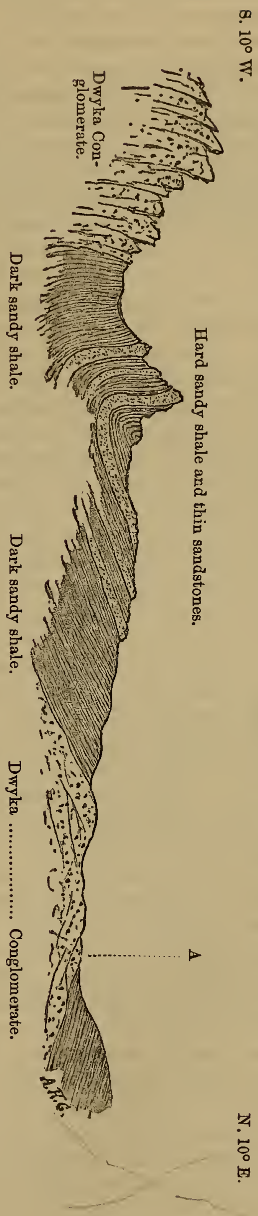


Fig. 2.—*Section in the Valley of the Buffels River, about five miles below Buffels-River Station, showing the junction of the Dwyka Conglomerate and the Ecca Beds.* (Length of section about half a mile.)

We now pass to the great saucer-shaped basin of Kimberley Shales, Karoo Beds, and Molteno Beds which occupies the northern part of the country under description.

These three formations are conformable to one another, and are separated from the underlying Ecca Beds by a most marked unconformity. Nothing perhaps arrests the attention of the geologist who is traversing the country for the first time more forcibly than this unconformity. As you move leisurely along over many of the tracts of Ecca Beds, you feel that the ground over which you are driving is neither more nor less than a great geological map. The state of the roads is not such as to promote easy travelling, but is admirably calculated to reveal the geological structure of the country. A rude jolt tells you that you have driven over the outcrop of a hard bed which stands up in a little reef across the road, and a glance over the side of the cart tells you which way the bed is dipping. You may be tired and a little remiss, but these reminders come too often to allow of your neglecting your geology; you note that the strike is steadily east and west, that the dip is now to the north, now to the south, now steep, now gentle; and so you realize that the beds you are crossing lie in a long succession of folds. From time to time you cast your eyes towards a long line of bold hills which bounds on the north the plain you are traversing, and stretches away both to the east and west as far as the eye can follow it. The long level stripes which bar the slopes of these hills plainly show that the rocks composing them are horizontal; and, though you may be miles away from the junction, you have a conviction that these rocks must rest unconformably on the folded beds of the plain. No one accustomed to read great physical features can fail to come to this conclusion. Later on you come to know that these hills are formed of Karoo Beds.

I saw the actual junction of the Karoo and Ecca Beds only on the farm of Mr. Rabies, about a two hours' drive to the north of Aberdeen. There could be no question here about the unconformity. The section which showed it most distinctly is given in fig. 3.

The hills just mentioned are a part of that long strip of elevated ground which runs right across the country and forms the southern boundary of that northern tract of undisturbed rocks of which we are now treating. It is one of the most conspicuous of the physical features of South Africa, with an aspect everywhere most marked and everywhere the same. Plenty of panoramic views may be obtained from the higher points, and they all show a country traversed by interrupted ranges, trending generally east and west, and dotted over with isolated eminences. The hills are formed of Karoo Beds, and show the horizontal striping already described as so characteristic of that formation. Here and there a hill-range is crowned by an escarpment of unusual height and boldness, formed by one of the great intrusive trap sheets, or an isolated hill has a capping of trap, which makes it a landmark for miles round. Trap sheets project elsewhere along the slopes of the hills, readily distinguishable by their ruggedness from the narrow bars that mark the out-

Fig. 3.—*Section north of Aberdeen, showing the Junction of the Karoo and Ecca Beds.*

(3) Buff soft sandstone, containing much decomposed felspar; breccia at base, with fragments of (1)............................	Karoo Beds.
(2) Sandy shale and thin sandstones....................................	
(1) Grey, purple, red, and mottled claystones........................	Ecca Beds.

crop of the sandstones; and in the clear air the course of these sheets can be easily followed by the eye, and their intrusive character established. Between the hills lie broad flat-bottomed valleys and extensive plains, deeply buried in rich alluvial soil, which rain has been for ages sweeping down on to them. I have very little doubt that in many cases the floor of these flats is formed of Kimberley Shales; and in crossing them I had my suspicions constantly aroused that denudation had cut down into Ecca Beds; but the superficial covering was so thick that I never got a section which showed conclusively what was beneath it.

Among the most important of the hill-ranges of the belt are the Nieuwveldt mountains, north of Beaufort West, one point of which is 7300 feet above the sea: the Camdeboo mountains, north of Aberdeen; and the Compass-Berg, north of Graaf-Reinet, 7800 feet. In the Stormbergen, to the north of Queenstown, which is a continuation of this belt, the whole of the Stormberg beds come on, and a height of 7250 feet is reached in their culminating point, Vaal Kop, about 12 miles east of Molteno. Further to the north-east, in the Draakensberg, still greater elevations are attained.

The absolute elevation of the highest points of this belt above the plains on the north and south will be, in the Cape Colony, between 3000 and 4000 feet; they are all of them purely hills carved out by denudation, and they stand as speaking witnesses of what denudation can do, and of the enormous lapse of time during which it must have been at work in this country*.

It is also interesting to note how thoroughly the work has been done, and how completely the Karoo Beds have been cleared away off the country to the south and north; outliers do occur in the immediate neighbourhood of the main range, but, with one possible exception, I saw none at any distance from it. That one possible exception was a very conspicuous hill, known as the Schoorstein

* Rubidge, Geological Magazine, vol. iii. (1866), p. 88.

Berg, close on the northern flank of the Wittebergen, north of Willowmore. The capping of this hill showed in such a marked way the striping characteristic of hills formed of Karoo Beds that it seemed to me just possible that an outlier of Karoo Beds still survived there. I could not verify my conjecture by climbing to the top, but I hope some local geologist will do so (see north-eastern end of Section 3, fig. 6, p. 270).

To the north of the belt of elevated ground we have been just describing there stretch away interminable plains, composed of Kimberley Shales. It was here that I first became alive to the importance of this subdivision, though, as will be seen shortly, I had previously had suspicions of its existence. Mr. Dunn has, in his last Report* on the geology of the Cape Colony, advanced the view that the Kimberley Shales of the north are identical with the Ecca Beds; with this view I cannot agree, and I think I shall best show why, if I give the steps by which I was led to my present opinion. I left Middleburgh, which is well in the heart of a country of Karoo Beds, by coach for Kimberley, crossed the Kikvorsch Berg, and ran down into the basin of the Orange River. As we descended, a gradual change came over the aspect of the country; we passed from a hilly district of most pronounced Karoo type, first to ground much flatter, but diversified by detached eminences formed of Karoo Beds, and then to a country composed entirely of broad, rolling, grassy flats, in which the only approach to hills were low ridges formed by the outcrop of trap sheets and dykes. The flats were much obscured by superficial deposits, but wherever I found a section in bedded rocks they were grey or dark shales with some harder and more sandy beds, but no sandstones; not unfrequently the shales contained bands of clayey limestone of a "cement-stone" character. There could be no question that these shales came out from underneath the Karoo Beds, and I named them provisionally "Kimberley Shales." This type of country continued all the way to Kimberley. From Kimberley I made an excursion to Winburg, in the Orange Free State. To within about 15 miles to the west of Brandfort our road was over rolling grassy flats, and all the sections seen were in beds agreeing exactly in character with the Kimberley Shales; hills, formed of Karoo Beds, then rose out of the flats, and some 10 miles east of Brandfort the Karoo Beds were overlain by rocks agreeing in character with the Stormberg Beds. Again, on my return journey from Kimberley by Hope Town and Victoria West, Kimberley Shales were continuous for some distance to the south of Hope Town, and then were overlain by Karoo Beds. This division, then, is certainly persistent over a very large area on the north of the Nieuwveldt and Camdeboo Range; if it is, as I believe, a thing distinct from the Ecca Beds, it ought to crop out along the southern slope of that range.

Here unluckily my opportunities for observation were limited, and most of them occurred before I had suspected the existence of the Kimberley Shales as a distinct subdivision; but certain facts,

* Report on a supposed extensive deposit of Coal underlying the Central Districts of the Colony. Cape Town: 1886.

which puzzled me very much at the time when they were noticed, became intelligible when I came afterwards to learn that there was such a subdivision.

On my journey from Grahamstown to King William's Town the geology, to a point some way beyond the Keiskama River, was as plain as could be—abundant sections in Ecca Beds, and a country traversed by parallel ridges with dip-slopes and escarpments, and thickly clothed in bush and scrub. At the point mentioned, however, we entered a totally different country—broad, rolling, grassy, treeless plains, slightly varied by low, rounded hills, in which all the sections seen were in beds corresponding exactly in character with the rocks I afterwards came to know as Kimberley Shales on the north. Some distance before reaching King William's Town we passed on to Ecca Beds again. I have little doubt now that we crossed here an outlier of Kimberley Shales, and have introduced such an outlier in Section 4 (fig. 7).

Again, on the railroad journey from King William's Town to Queenstown, I noticed a tract between Blaney Junction and Kee Road with just the same physical features, and showing in occasional sections just the same kind of rocks as I afterwards came to look upon as distinctive of Kimberley Shales; and on the strength of this I have introduced an outcrop of this subdivision on the south side of the great hill-range formed of Karoo Beds, which Section 4 just runs up to.

I had one more chance of testing my views, viz. on the south side of the Nieuwveldt mountains to the north of Beaufort West. I must confess that after having been jolted in a "coach" through a sleepless night across the hills, the comparative luxury of a railway truck was more provocative of sleep than of geological observation; but I did notice that, after we got clear of the hills, the ground ran down with a smooth, gentle slope, and the sections seen on it were in shales like the Kimberley Shales, and that still further to the south we passed on to decided Ecca Beds.

I feel therefore that though the evidence I could collect is not so conclusive as I could wish, what there is is decidedly in favour of the Kimberley Shales being present on the southern slope of the Nieuwveldt and Camdeboo Range, and of their being a distinct thing from the Ecca Beds.

In the section north of Aberdeen, given in fig. 3 (p. 261), there are no Kimberley Shales, but their absence may be due to their being here overlapped by the Karoo Beds in the manner suggested in Section 1 (fig. 4, facing p. 270).

A further confirmation of my reading would be furnished if it could be shown that any of the deep river-valleys which traverse the plains of Kimberley Shales on the north cut down into Ecca Beds. I cannot bring any positive proof that they do; but I have a strong suspicion that Ecca Beds come out in the valley of the Orange River to the north of Hope Town. I saw in Hope Town flagstones, which I was told came from quarries between the town and the river, that were totally unlike any beds I ever came across in the Kimberley Shales, but resembled very closely flagstones obtained from the Ecca Beds near Beaufort West. I have accordingly ventured to show Ecca Beds rising to the surface in the valley of the Orange River, where it is crossed by Section 2 (fig. 5).

Mr. Dunn's main argument in favour of the Kimberley Shales being identical with the Ecca Beds is that he has succeeded in tracing the Dwyka Conglomerate northwards up to the neighbourhood of Kimberley, and that the Kimberley Shales there lie directly upon it. If this point be substantiated, it will tell very strongly in favour of Mr. Dunn's view. But I must say that I distrust his identifications.

For instance, the sides of the Kimberley Diamond Pipe show the following section:—

	feet.
Surface and debris	24
Shale	277
Breccia	3
Dolerite, not bottomed in 1882, about	100

The Dolerite has been already described (see page 254), and has all the characters of the intrusive sheets so common in the Kimberley Shales; I saw no reason to think it was anything else. Mr. Dunn however calls it "Ancient Diabase," and believes that the thin band of breccia above it is the representative of the Dwyka Conglomerate. I do not think he will find many supporters in this view.

There is further the possibility that the conglomerate identified by Mr. Dunn with the Dwyka Conglomerate is what I have called "The Basement Conglomerate of the Kimberley Shales." I know this bed only from Mr. Stow's description*; but his account is very clear, and seems to show that this conglomerate not only lies underneath, but is partly interbedded with his "Olive Shales." The materials of the two conglomerates must have been derived from the crystalline rocks of the Transvaal, so they would necessarily be hard to tell one from another. My notion of the relation of the two conglomerates to one another is shown at the northern end of Section 2 (fig. 5).

The considerations just adduced and others of a similar character show that there is much that is uncertain in Mr. Dunn's reading. But the point on which I rely is, that I believe that beds having all the characters of the Kimberley Shales crop out on the southern side of the Nieuwveldt and Camdeboo Range, between the Karoo and Ecca Beds. If this belief turn out to be well founded, Mr. Dunn is certainly mistaken.

III. Miscellaneous.

Conglomerates of the Oliphants River (Section 3, fig. 6).—Mention must be made of some red sandstones and conglomerates which I saw in the valley of the Oliphants River. They lay at various levels, and rested on Bokkeveldt Beds. All the pebbles I saw in the conglomerate were of quartzite, like that of the adjoining hills, the majority

* Quart. Journ. Geol. Soc. vol. xxx. (1874), p. 598, pl. xxxix. fig. 2.

not above six inches long and well rounded; but large subangular blocks were not uncommon. The conglomerate is sometimes very massive and makes fine mural escarpments; sometimes unconsolidated, when it weathers into rounded gravelly hills. Lenticular bands of fine sandstone are interbedded with it. The only fossils I heard of from it were bits of carbonized wood; it contains lenticular beds of lignite. It has the character of a lacustrine deposit, formed at a time when the configuration of the country was not very different from what it is at present, but when the valley in which it lies was occupied by a lake. I know of nothing that would give a clue to its age.

Superficial Deposits.—These are very varied and extensive and offer many points of interest. They have received notice at the hands of sundry geologists; but, for reasons already given, I have not appended detailed references to previous descriptions. The great plains of the Ecca Beds and Kimberley Shales are often overspread with sheets of red sand, and this frequently contains a considerable quantity of black metallic-looking particles, which I found in one case to be ilmenite. I think there is no doubt that the sand is formed by the decomposition of the Trap sheets and dykes, and spread about by the wind. I have frequently noticed as many as a dozen little whirlwinds careering over the extensive plains at the same time, each one marked by a cloud of sand spinning through the air.

Great deposits of calcareous tufa are also common on the plains, the material for which, I believe, is furnished by the decomposition of the lime-felspars of the traps. The carbonate of lime, however, is carried far away from the source from which it is derived, and often spread out in extensive sheets. I fancy this has been brought about somewhat in this way:—the violent torrential downpours of rain for which the country is so notorious will in a quarter of an hour convert a parched plain into an almost continuous sheet of water. When the surface-water has run off, the subsoil remains saturated, and the water, percolating about, gradually rises to the surface, is evaporated, and deposits the carbonate of lime it has taken up during its underground journey.

The Cape Flats are covered with very mixed material; part of it is obviously decomposed granite; it also contains a large number of rounded quartz-grains, which may well have come from the Table-Mountain Sandstone; and part is sand blown in from the coast. The whole seems to have been mixed and distributed by wind. Alongside the rivers this mixture has been arranged in a rudely bedded form, and contains layers of carbonized twigs, branches, and roots, forming a poor kind of lignite. Near Cape Town there is a good deal of lumpy stuff, called "gravel," and looking not unlike gravel. When one of the lumps is broken it is seen to be composed of quartz-grains cemented by limonite, or of clayey matter stained and bound together by a similar cement.

At the tenth milestone from Cape Town, on the Maitland road, a very curious boss of rock sticks up through the loose superficial covering. It is composed of white sandstone, some so soft as to crumble under the hammer, some reminding one of English grey-wether, and some almost hard enough to be called quartzite. It contains reed-like stems, but some specimens that I submitted to Professor Williamson are so badly preserved that he could not determine them. Professor Rupert Jones tells me that specimens in the British Museum are casts of the stems and leaves of aloes. Its isolation makes it impossible to determine the relations of this mass to any of the neighbouring rocks, but it is perfectly possible that it may be only a mass of the sandy superficial deposit bound together by a siliceous cement.

IV. Summary.

It may seem bold in me, my conduct may be thought to deserve even a harsher epithet, if, on the strength of a few months' scampering over the country, I take upon myself to construct a geological history of South Africa from the time of the formation of the Table-Mountain Sandstone to the present day. But speculations that had their birth when I was on the ground, and have kept cropping up every now and then since, have gradually blended into a story, which, I trust, hangs fairly well together, and furnishes a tolerably consistent and reasonable explanation of the facts that have come within my knowledge. This I will now give for what it is worth; if it serve merely as a string on which to thread these facts together, it may have some use as a working-hypothesis.

The oldest rocks of South Africa come out to day on the north in the Transvaal, where they are largely crystalline in character, and on the south around and on either side of Cape Town, where they are mainly clay-slate with intrusive masses of granite. In both cases the formations that rest upon these old rocks are marked off from them by the strongest possible unconformity. Whether the crystalline rocks of the north and the clay-slates of the south are parts of the same great group, our present knowledge will not enable us to say; but it is not unlikely that this is the case, and that beneath the sedimentary rocks which I have been describing in this paper, there stretches an unbroken floor of much older rocks very largely crystalline in their character. Not unlikely; because in such a case the geological structure of South Africa would correspond in this respect with what is now coming to be generally accepted as the geological structure of Europe, America, and, indeed, every country whose geology has been sufficiently gone into. I do not care to push the parallel further, and, by dubbing these old rocks "Archæan" or any similar name, to force a correlation between them and the fundamental rocks of other countries: it is enough for me that they are very probably there, and I will speak of them as the "Basement Rocks."

We may look back, then, to a time when South Africa formed part of a continent made up of these "Basement Rocks;" subsidence began on the south, and a tract was lowered beneath water which at last extended itself northwards about as far as the line of the Zwartebergen, Wittebergen, and the other ranges included in that chain. The country north of this line still remained above water. In the basin so formed the Table-Mountain Sandstone, the Bokkeveldt Beds, and the Zwarteberg Quartzites were deposited. Whether these formations were laid down without interruption during a long period of unbroken subsidence, or whether during the time of their formation there were intervals of upheaval and denudation, we cannot say until the geology of the country they now occupy has been worked out in detail. The former supposition has this in its favour. These rock-groups now form a number of parallel ranges, which, in spite of their present moderate elevation, have all the characteristic structure of a true mountain-chain, and it is well known that the production of a mountain-chain has generally been preceded by continuous sedimentation during a long period.

Earth-movements set in after the deposition of the Zwarteberg Quartzites; the rocks were folded and largely denuded. The proof of this lies in the fact, noticed by Bain, that the Dwyka Conglomerate, the formation that follows next in order, rests sometimes on the Quartzites and sometimes on Bokkeveldt Beds, and contains boulders of the Quartzite.

The continent now presented a great mountain-chain running across it from east to west on the south, and a broad tract formed of the Basement Rocks spreading away to the north.

Afterwards the land again began to go down. The mountains very likely sank, but not enough to lay them beneath water. But the tract to the north became submerged, and a great basin was eventually established, the southern shore of which was formed by a line of quartzite mountains and the northern shore of Basement Rocks. But the submergence was gradual, beginning on the south and pushing its way step by step northwards. There was thus at first only a narrow belt of shallow water fringing the quartzite mountains, and into this blocks and boulders from the quartzite on the one side, and from the Basement Rocks on the other side were rolled down, and piled up in shingly heaps which are now the Dwyka Conglomerate. The fans of gravel now forming at the mouths of the Himalayan valleys furnish instances of a similar process; if these were discharged into the sea instead of being thrown down on land, they would be spread out into a sheet of conglomerate and breccia. As the water worked its way northwards, similar deposits would form along the receding coast-line, and the whole bottom of the basin would become covered with a sheet of conglomerate. But as soon as any portion of the basin became deep enough, it would become the receptacle of finer sediment, and so a great thickness of shale, sandstone, and limestone, the present Ecca Beds, accumulated above the conglomerate.

The formation of the Ecca Beds was brought to a close by another series of powerful earth-movements. These acted with greatest energy on the south, along the old lines of disturbance: and accordingly we find there the Ecca Beds, Dwyka Conglomerate, and Quartzites folded in among one another in sharp and closely packed convolutions. But the contortion diminishes rapidly in intensity as we go northwards, the folds open out, and the Ecca Beds soon come to lie in a succession of broad rolls, though among these closely compressed arches with steep dips are not uncommon.

The next scene introduces us to a very long period of steady depression, by which a large freshwater lake was formed. In this lake the Kimberley Shales, Karoo and Stormberg Beds, Red Beds, and Cave Sandstone were laid down in conformable succession. During the formation of these beds volcanic forces seem to have been gathering head underground. Probably they did not succeed in forcing open roads to the surface during this long period, for no contemporaneous lava-flows are known in any of the above-mentioned groups. But doubtless, before any subaerial outburst took place, lava was actively burrowing about underground; and we may reasonably suppose that many of the intrusive sheets and dykes that abound among these rocks were injected while the beds among which they occur were in process of formation, and when there was only a small thickness of rock overhead to oppose their motion. We can thus explain the very trifling amount of disturbance which the intrusive masses produce in the rocks which they traverse.

But after the formation of the Cave Sandstone, the pent-up lava burst its way up to day, and great flows and beds of tuff bespeak a period of volcanic eruptions. Of its products, denudation has left us only the merest shreds, but these occur scattered over so wide an area as to leave no doubt that the outbursts must have been of no small magnitude.

It often crossed my mind, as I vainly endeavoured to number up the sheets and dykes I had come across in the course of a day, that it is only in a country like this that we can form any adequate estimate of the underground work of volcanic forces. Over an area certainly 120,000 square miles in extent, and probably much larger, dykes, sheets, and huge masses of trap meet one at every turn. Sometimes, as for instance near Burgersdorp, there are tracts in which you may go for several miles and see nothing but trap, so close together do the intrusive masses run; elsewhere they are more scattered, but no part of the area is free from them.

The upheaval that finally lifted the rocks last described into the air must have been of a gentle character; for they are but very slightly disturbed from the horizontal. Since it took place South Africa has probably continued dry land down to the present day; for the scraps of Jurassic, Cretaceous, and Tertiary formations that it possesses lie close to the coast and apparently were formed at no great distance from the shore. During this long period subaerial denudation has had ample time to clear away the many cubic miles of rock that must have been removed to form the present surface.

A certain similarity between the scanty fossils of the Karoo Beds and the almost equally scanty fauna and flora of the Lower Gondwana system of India has been often made the subject of remark; and an intermittent boulder-bed in the Talchir, the lowest subdivision of the Gondwanas, has been parallelled with the Dwyka Conglomerate. The presence of a basement-conglomerate is far too common an occurrence to be made in itself a ground for correlation; and now that the Dwyka Conglomerate is known to be no part of the Karoo Beds, but to be separated from them by a strong unconformity and some 4000 feet of Ecca Beds, this part of the parallel falls to the ground.

The similarity, so far as their few fossils go, between the Karoo and the Lower Gondwana, however, still holds good; the point is discussed in Messrs. Medlicott's and Blanford's 'Geology of India' (vol. i. p. 121). One statement made by them, that "true Carboniferous deposits, with *Lepidodendron*, *Sigillaria*, &c., underlie the Karoo series unconformably," requires confirmation. They probably mean the Quartzites of the Zwartebergen; but the existence of Carboniferous fossils from these beds rests upon evidence too vague to be altogether satisfactory.

Discussion.

The President said it was a great advantage that so good a stratigraphical geologist as Prof. Green had visited South Africa, and cleared up some of the difficulties connected with the geology of that area. Mr. Smith Woodward's contribution was also valuable.

Prof. Rupert Jones remarked that this was almost the first personal account given to the Society of South-African geology. He remarked on Dr. Rubidge's section of the Witteberg Quartzite at Ceres. *Lepidodendron* had been found in this quartzite in the Eastern Province, but not in the Karoo Beds. The "Dwyka Conglomerate" ought, he thought, to retain its old name of "Ecca Conglomerate." The confirmation of the previously reported unconformity of the Ecca Beds was valuable. The occurrence of Dicynodont fossils, derived from the Karoo Beds, scattered over the Ecca Beds, was well explained by the Author. It is doubtful whether any of these fossils come from the Author's "Kimberley Shales." Plants, however, certainly occur, as they do also in the Ecca Beds. Fishes had been found by Mr. Stow in the Cave Sandstone. The non-publication of his great sections was to be regretted.

Mr. Blanford noticed that the term Karoo would be better applied to the whole system from Ecca to Stormberg than restricted to a subdivision not found on the Karoo plains. He pointed out some of the resemblances between South-African and Indian beds, especially the similarity of the Talchir and Ecca Conglomerates to a decomposed basalt, the laminated character of the coals, the absence of underclays, and the erosion of the coal-seams; and he contended that the beds were of fluviatile rather than of lacustrine origin. With regard to Mr. Smith Woodward's paper, the occurrence of a *Cleithrolepis* in the Stormberg Beds and in Australia tended rather to increase the probability of the Stormberg subdivision being Post-Triassic; for the genus occurred in the Wyanamatta as well as in the Hawkesbury Beds, and the former were probably Jurassic.

Dr. Geikie remarked on the superficial resemblance of the fragments of Dwyka Conglomerate to a volcanic mud. The intrusion of sheets of lava between beds of rock without disturbance, to which the Author had referred, would depend mainly on the energy of eruption.

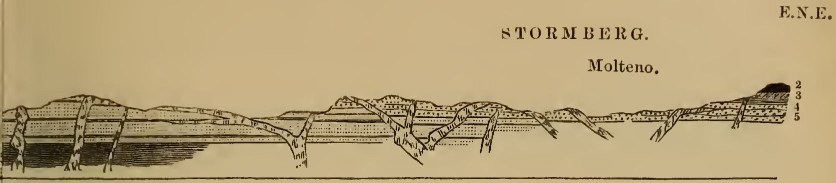
Mr. Clement Reid pointed out some differences in the character of the striation between boulders from the Boulder-clay and the fragment from the Ecca Conglomerate exhibited by Prof. Green. He had seen similar striation on Septaria in tumbled ground, and attributed the markings to moving mud or landslips.

Prof. Hughes would refer the striation exhibited to movements of the mass after consolidation, pointing out that the striations enter the embayed portions and small indents in the stone in a manner never produced by glacial or sliding movements.

Mr. Irving also agreed in the last remarks. It was a subject to which he had himself drawn attention. Inclining to Mr. Blanford's view as to the origin of the coal, he asked if the structure of the ash did not suggest silicified vegetable tissue.

Prof. Green said it was difficult to select the names for South-African subdivisions, and he had been unable to determine exactly what Beaufort and Koonap Beds were. He had explained in the paper the question of the presence of Kimberley Shales to the southward. He had been unable to find out what the supposed *Lepidodendra* were. In referring to the intrusive basalt, he had especially noted the small disturbance of the overlying beds. The structure of the coal to which Mr. Irving had referred did not appear to be organic. The speaker further explained the origin of the Ecca Conglomerate by gradual subsidence.

Mr. Smith Woodward said he had avoided calling the fish-remains Triassic; and considered that, if really Triassic, they must be very high in the system.



a Beds on Dwyka
Conglomerate.

9
Kimberley Shales on Ecca Beds and on Crystalline Rocks.

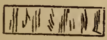
ATION OF SYMBOLS.

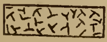
11.  Bokkeveldt Beds.

12.  Table-Mountain Sandstone.

13.  Malmesbury Beds and Crystalline Rocks of the Transvaal.

14.  Peridotites and Agglomerates of the Kimberley Diamond-pipes.

15.  Intrusive Dolerite.

16.  Granite.

te-

[To face p. 270.

Fig. 4.—*Section No. 1, showing the general Geological Structure of the Cape Colony from the Zwarteberg to the Stormberg Mountains.* (Horizontal scale 15 miles to 1 inch; vertical scale about five times as great.)

Fig. 5.—*Section No. 2. Generalized Section from Cape Town to the Transvaal. General Direction* S.W.–N.E. (Horizontal scale about 25 miles to 1 inch; vertical scale about five times as great.)

Fig. 6.—*Section No. 3, to show the position of the Conglomerate of the Oliphants Valley.*

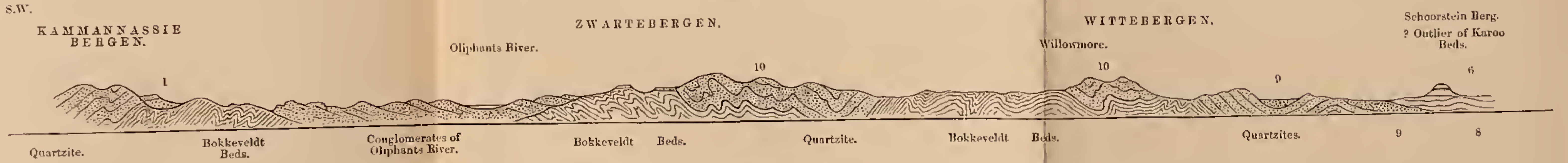
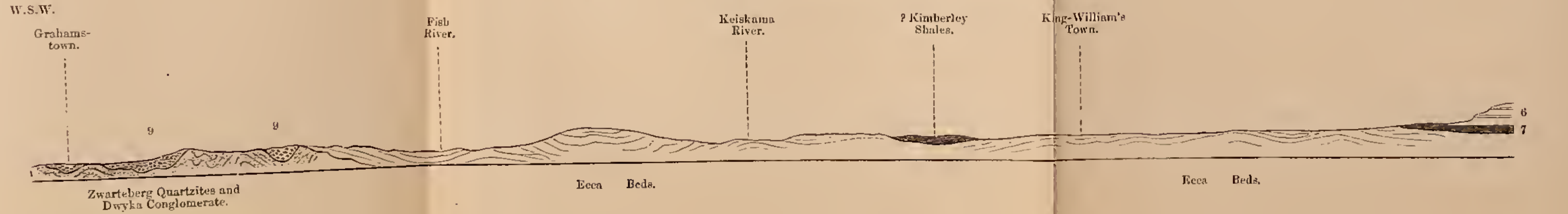


Fig. 7.—*Section No. 4. Through Grahamstown and King-William's Town.*



EXPLANATION OF SYMBOLS.

1. Conglomerates of Oliphants River.
2. Volcanic Beds.
3. Cave Sandstone.
4. Red Beds.
5. Molteno Beds.
(2–5: Stormberg Beds.)
6. Karoo Beds.
7. Kimberley Shales and Basement Conglomerate.
8. Ecca Beds.
9. Dwyka Conglomerate.
10. Quartzites of the Zwartebergen and Wittebergen.
11. Bokkeveldt Beds.
12. Table-Mountain Sandstone.
13. Malmesbury Beds and Crystalline Rocks of the Transvaal.
14. Peridotites and Agglomerates of the Kimberley Diamond-pipes.
15. Intrusive Dolerite.
16. Granite.

21. *On the* Cambrian *and associated* Rocks *in* North-west Caernarvonshire. By Prof. J. F. Blake, M.A., F.G.S. (Read December 21, 1887.)

Introduction.

The area to which the present memoir refers has for a long time attracted the attention of geologists, partly because within it may be found the oldest portion of the Cambrian series, and therefore the supposed base of our known stratified rocks, and partly because, of late years, there has been an expectation of finding here some representatives of still older series.

The most recent observers, indeed, agree in regarding the whole of the mass coloured as porphyry between Bangor and Caernarvon, and some part of that coloured altered Cambrian, as belonging to a Pre-Cambrian epoch, and the felsite of Llyn Padarn and Moel Tryfaen they treat in the same way. There is no difference of opinion between them on this latter area, but as to the former, though all divide the mass into three parts—the mass near Caernarvon, the mass near Dinorwic, and that near Bangor,—Prof. Hughes considers all three a connected series of "beds," Prof. Bonney regards the Caernarvon rock as very old, and the other two as connected, while Dr. Hicks regards them as representing three independent and unconformable groups. Again, Prof. Bonney and Prof. Hughes differ as to the stratigraphy near Bangor, with the effect that the former considers much more to be Pre-Cambrian than the latter does. All three views are diametrically opposed to that of the Survey, not only as to theories but as to many of the facts. Nor has the Survey given way. Prof. Ramsay, in 1881 *, says the proposed changes are made on purely theoretical grounds; and Prof. A. Geikie, in 1883 †, certainly accepts no change of view, on the ground that, if the Survey maps are to be corrected, it must be done in the same style as that in which they were constructed.

It will be probably admitted therefore that there is need for further observation and proof one way or the other.

I have been led personally to the study of this area from its relation to the rocks of Anglesey. If the schists of that island are really Pre-Cambrian, this fact must be proved, if possible, by tracing the base of the Cambrian, or of some older rock, across from the mainland into contact with them.

It will be well at the outset to state clearly the position to which this study has led me. I find that, though there *may* be Pre-Cambrian rocks in this area (and I am inclined, from considerations derived from other areas, to think there are), yet the evidence on the ground itself is not sufficient to justify this conclusion. In other words, the views of the Survey, exception being made of certain "convictions" with regard to metamorphism, most clearly approxi-

* Mem. Geol. Surv. vol. iii., new edition.
† Quart. Journ. Geol. Soc. vol. xxxix.

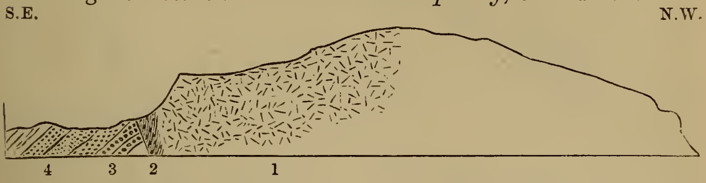
Fig. 1.—*Map of the district between Bangor and Caernarvon.* (Scale $\frac{2}{3}$ in. = 1 mile.)

mate to the natural interpretation of the then known facts. New facts, more careful observations, and improved methods lead to a modification of these views; but the wholesale upsetting of their conclusions by later writers seems certainly to be due to a "disregard of the evidence by which the officers of the Survey" were led to adopt them.

Bangor and Caernarvon Area.

It will be well to begin our examination at Caernarvon, where matters are simplest, and where we may find a key to interpret the rest. The "field-quarry" at Twt Hill has been the scene of much controversy, and two interpretations now stand before us for choice. On the one hand, Prof. Bonney declares that the conglomerate there seen rests on the "granitoid rock," and cannot be younger than

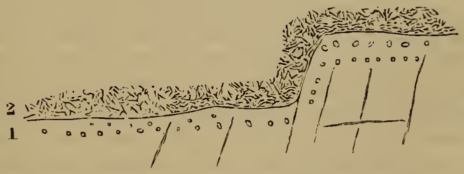
Fig. 2.—*Section at Twt-Hill Field-quarry, Caernarvon.*



1. Quartz-porphyry.
2. Finer band of the same.
3. Conglomerate.
4. Grit.

basal Cambrian; on the other hand, the Survey make this conglomerate Ordovician, and the "porphyry" intrusive. I have examined this quarry many times, with the care that is due to its importance. (The section from S.E. to N.W. is given in fig. 2.) To my eyes the conglomerate does *not* rest on the "granitoid rock," but the porphyry cuts across the edges. A knife can be inserted into the plane of junction. The *edge* of the bed in contact (not its base) is discoloured for about half an inch, suggesting the action of heat, and the porphyry for the nearest foot from the junction-plane is of much

Fig. 3.—*Plan of junction of Porphyry and Conglomerate.*

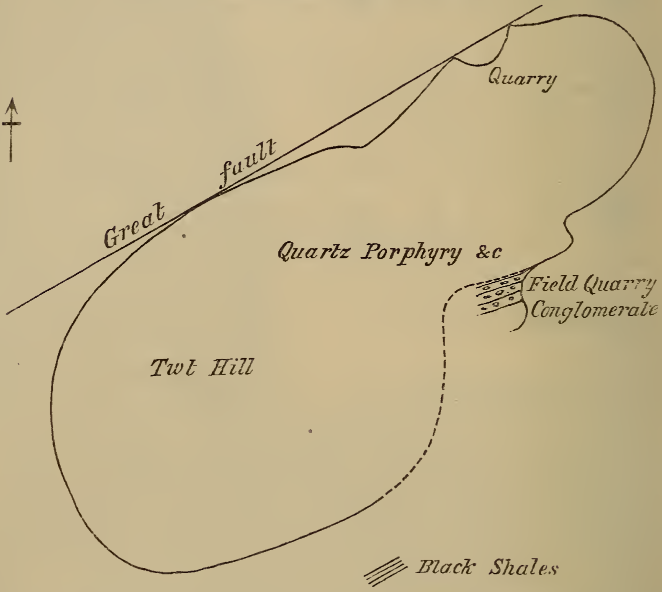


1. Conglomerate. 2. Finer band of porphyry.

finer texture, insomuch that I at first took it for a dyke. This suggests ore rapid cooling at the edge. Again, the surface of junction is not plane or undulating, but has in one place a step in it (see fig. 3).

Again, the strike of the beds, which is nearly parallel to the surface of junction, runs right into the hill (see fig. 4). There must therefore be another great irregularity of junction, throwing the conglomerates to the south-east, between this and the new church, where they occur again, as noted by Prof. Hughes. Then there is the quarry mentioned by that author by the side of a new road at Yscuborwen*, which I have not found. Here, as at Twt Hill, the

Fig. 4.—*Ground-Plan of Twt Hill.*



conglomerate runs obliquely against the porphyry along a line running S.W. to N.E., and the edges of the beds are cut off by a perpendicular line. Here the conglomerate is said to dip, as at Twt, to E.S.E. At a disused quarry in a field by Tygwyn is another exposure of conglomerate and grit, here dipping at 45° to the S.S.E., the line of strike leading directly to the Menai Straits, while the porphyry is seen eight yards away towards the north.

The surface of junction, therefore, curves about in a most extraordinary manner; and seeing that the porphyry has the aspect of an intrusive rock, these observations would certainly suggest an intrusion. Nevertheless they could not have led the Survey to their conclusions, since the line is incorrectly drawn on their map. The alternative hypothesis is a rather complicated group of faults. Other considerations must be brought to bear upon the question before we can decide it.

The most important of these is the nature of the Twt-Hill rock.

* Quart. Journ. Geol. Soc. vol. xxxv. 1879.

Prof. Hughes boldly writes down "Twt-Hill beds," and speaks of "the most conspicuous divisional planes suggestive of bedding." On this I must point out that if a bedded rock could be so metamorphosed as to produce a quartz-porphyry, the first thing to disappear, as such, would be the planes of bedding; and if there are any such planes to be found in a metamorphic rock, we must look for them, not in the most conspicuous, but in the most obscure subdivisions of the rock-mass. Prof. Bonney brings the microscope to bear upon the question, and declares he can distinguish between a granite and a granitoid rock. The only points of difference that can be tested are given in a note in Quart. Journ. Geol. Soc. vol. xxxv. p. 306. One is that in a granitoid rock the quartzes and felspars show more irregularity in their outlines, size, and distribution; and another that an indefinite felsitic matrix may be seen. This latter point is surely more suggestive of a porphyry, and there is little use in discussing the former, since it does not cover half the structures found in rocks of the Twt-Hill type. In various parts they put on various aspects, but it is impossible to trace the changes; they come in sporadically and die out gradually, after the manner of a granitic intrusive mass, varying its character according to its circumstances of cooling, and so merging into a quartz-porphyry. From the great similarity of the structures to those in undoubtedly intrusive masses, I conclude that the Twt-Hill rock *must* be of an intrusive character. But that it was intrusive into the conglomerate is another matter altogether. True, the edge of the conglomerate *looks* burnt in the Twt-Hill field-quarry, but under the microscope this is shown to be due only to infiltration of ferric oxide along the junction. Again, the lowest portion of the conglomerate here is very remarkable. Its quartz-fragments are quite angular, and even irregular; they are sometimes complex, as if they had come from such a rock as the neighbouring granite, and then show signs of very severe pressure. There are fragments also of quartz-schist* and other altered rocks, while the matrix is composed of secondary quartz and sericite. The rock would certainly appear to be derived from others in the immediate neighbourhood, one of which would have to be practically identical with the granite here exposed.

We must also consider what is the true age of the conglomerate. It is always spoken of as the Cambrian conglomerate, though at Twt-Hill field-quarry the succeeding rocks are scarcely exposed: but the same conglomerate is, or was, seen, by the new church, and not fifty yards away, down the sloping street, black shales are seen (fig. 4), and these are continuous for the rest of the distance to the point, quite close at hand, where Mr. Marr found Arenig fossils †. Any fault supposed to lie between Arenigs and Cambrians here is entirely hypothetical, and when the beds are traced north is found to be practically impossible. Hence it is that I conclude that this conglomerate cannot be of Cambrian, but must be of Arenig age.

* Callaway, Geol. Mag. 1881.

† Quart. Journ. Geol. Soc. vol. xxxii. 1876.

So it is coloured by the Survey, and every consideration tends to prove them right. It is at the base of the Arenig that palæontologists have suggested a break in the strata. It is the base of the Arenig that contains the overlapping conglomerates in Anglesey and Ireland *, and this is the lowest series that is most widely spread in Europe †. Hence it is nothing extraordinary that Arenig rocks should here have a conglomerate at their base, and should be associated with the porphyry (all Cambrian rocks being absent), and so it is that we find here the key to the interpretation of the district. My explanation, therefore, of the rocks near Caernarvon is as follows:—The granite is intrusive into older rocks than the Arenig, now hidden from view, though perhaps their fragments may be recognized in the conglomerate. This conglomerate once rested on the surface of these rocks, perhaps not far from the curved and bay-like line which now forms the junction with the granite; but in the upheavals of the district the union has been broken, and slippings have taken place, producing faults.

Passing now to the north-east of Caernarvon, the undulations of this base-line of the Arenig are found to be very considerable. They are traced on the Map, fig. 1, p. 272. The conglomerate almost cuts out the porphyry behind Ty-coch, where it actually dips towards it. It then passes rapidly eastward, to be found near the river-side south of Pengelli. It then apparently curves back till it runs nearly north to Careg Goch, and all the fields to the east are covered with the Ordovician shale. Then we come to the great grit-beds south-south-east of Tan-y-maes, and the conglomerate, which must be almost welded to the porphyry at the cottages, and certainly overlies it. East of this we find it thrown out to the farm at Wern, where the junction with the shale is seen. It must then be thrown east again, to curve round the farm at Cefn and undulate along the road to Gorsbach. Here we come upon a different set of underlying beds, and the conglomerate gets finer and gradually degenerates into a grit—we find this grit in the valley to the east of Gorsbach, to the south-west of Ty-mawr, and further on in a quarry near the cross roads on the western side. I have not traced it for the next 1½ mile to the north, but find it again at Caer-hun, in quarries to the east of the road, again on the west of Pen-yr-allt, and on the east of Cae Seri, then cutting the road by the "i" in "Bryniau," and after crossing this it rises into a good escarpment of massive grit in a wood running parallel to the road which branches off to the right. After the crossing of the next lane, and so on to the Holyhead road, very little sign of grit can be found—it may be concealed or have died out, or there may be a slight fault here. In tracing this line it will be perceived that the portion on the Bangor sheet is very accurately laid down on the map, but the part on the Caernarvon sheet has not previously been surveyed with precision. It will be seen also that the conglomerate and grit base of the series is much thicker south of Gorsbach, where it is in contact with the

* See Ramsay, Mem. Geol. Surv. vol. iii.
† See Hicks, Quart. Journ. Geol. Soc. vol. xxxi. 1875.

igneous rock, than to the north, where it abuts against the sedimentary, and is thickest in the bays of the curve, probably indicating that this curve is near the true line of deposition. The most critical part of this line is at Gorsbach, where an older conglomerate comes in, which we are only prevented from mistaking for the Arenig by carefully tracing the line on both sides and comparing the character of the rock step by step, as is done below.

We have thus marked off for our study a definite area of rocks, of which as yet we only know that they are Pre-Arenig. This area we must now examine.

The southern portion, as marked off by Prof. Bonney*, is certainly distinct from the rest, but it loses its character as we pass northwards. Thus, at Ty-coch the section shows a coarse-crystalled granite, only cracked and disturbed. As we pass into the so-called "Crug beds" of Prof. Hughes, *i. e.* at Crug Farm, we find a beautiful radiating granophyr, much cracked and filled with quartz. In the ravine west of Tan-y-maes the rock is porphyritic, with idiomorphic quartz-crystals, and a matrix partly micropegmatitic, partly mosaic; and at the extreme tongue by Tafarn-y-grisiau only the latter matrix is left, and the whole is very dirty. All these have a family likeness, and may well be considered parts of the same intrusive mass. In the side of the main road south of Dinorwic, between the two branches of the road which goes over the hill, is seen the rock into which we may suppose this porphyry intrudes. It has a dirty unstratified aspect, like an indurated mud, but really consists of irregular fragments of quartz, in a quartzose but dusty matrix, much lined and infiltrated. Immediately we cross Prof. Bonney's line and pass to the east over Dinorwic, the change in the character of the rock, as seen under the microscope, is marvellous and complete. Whether close above Dinorwic or at Pant-yr-fallan-fach, on the eastern slope of the hills, or in the valley to the east, or still further east near Tan-yr-allt, every rock is a fresh quartz-porphyry, whose ground-mass is crowded with streaming microliths, exhibiting fluxion-structure to perfection. The contrast between these and the Caernarvon group of rocks is all the more marked from the latter being in their most altered state and the former in their freshest, where they are found side by side. The subdivision, therefore, of the great mass of quartz-porphyry in this district into two distinct parts, of different ages, we owe entirely to the microscopic researches of Prof. Bonney.

I do not think that these felsites all belong to one outburst, whether as an intrusion or a flow: first, because there are varieties of the porphyry, some containing only scattered quartzes, others crowded with quartz and felspar, and some, as in the ravine near the "d" of the Tyn-y-coed, with a spherulitic matrix. Moreover, as pointed out by Prof. Hughes, there are breccia-beds, though I have only found one, running north-eastwards by Tan-yr-allt.

Probably the most important point to determine with regard to this porphyry is the nature and cause of the long tongue which is

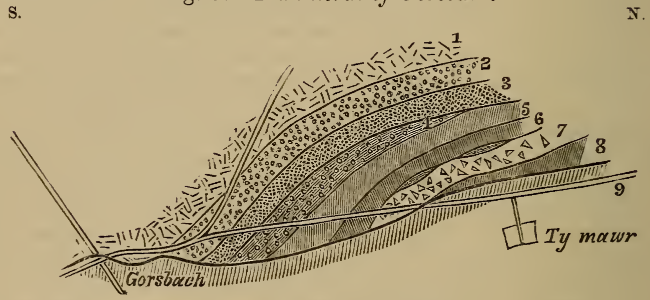
* Quart. Journ. Geol. Soc. vol. xxxv. 1879.

drawn on the Survey Map running up from Pen-y-swintan to Friddod (see Map, fig. 1), as its distribution would suggest intrusion. This tongue is not correctly laid down in the map either of Prof. Bonney or of Prof. Hughes, but is drawn on the Survey Map with considerable accuracy.

I think, however, the probability is that it is not intrusive. In the first place the structure of the rock, as obtained at Pen-y-swintan or at the extreme end at Friddod, is not that of a dyke, which such a tongue would practically be, but the matrix shows flow-structure, and it is crowded with crystalline fragments, the rock itself not being much fractured, thus suggesting a faulted original flow. Again, as will be seen by the stratigraphy of the higher beds, the country here must be much broken up by faults, one of which, on its north-western side, might easily bring it to its present position; and lastly, it is followed in several places on the south-east side by a small conglomerate, some fragments in which, in one specimen at least, are similar in structure to the porphyry.

The beds, however, which lie between the porphyry and the Arenig grit are perhaps the most important, at all events in their relation to the rocks of Anglesey. They are divided into two areas by the fault which runs along the Bangor valley; and if we can be certain of them in one area, the stratigraphy of the other becomes more of a geological puzzle than a matter of general interest.

Fig. 5.—*Plan north of Gorsbach.*



1. Felsite.
2. Quartz-felspar grit.
3. Grit.
4. Felsite conglomerate.
5, 8. Green Bangor Beds.
6. Hälleflinta.
7. Breccia.
9. Arenig grit.

Taking the eastern area, we find the first incoming of these beds just north of Gorsbach, near Llandeiniolen, where the geology is rather complicated. The ground-plan is given in fig. 5*. On the western side of the Arenig grit, which can be traced all along here, we find, next to the porphyry, a coarse quartz-felspar grit, which forms a knob at Fachell, and is scarcely to be distinguished from the porphyry, except under the microscope; next comes a band of grit, and then the dark muddy conglomerate, full of large pebbles of red felsite. Higher still is a thick mass of compact green-banded rock, such as occurs so abundantly at Bangor, and then finer material

* The Map, fig. 1, is not quite accurate here.

still, with lines curving about almost like a vitreous lava, but actually a hälleflinta. The beds above are breccias, and finally a green-banded rock again. We seem to have here, in miniature, the whole series as seen further north near Bangor, but this may not be so really. The red felsite-conglomerate, indeed, appears to die out, no trace of it appearing in the fields a little to the north as we walk across the strike of the series.

Seen under the microscope, Nos. 2, 5, 6, 7, seem all of the same type, the fragments in the several rocks differing only in size. Most of them are mineral fragments, but there are some characteristic rock fragments of a basaltic type, consisting of long transparent crystals scattered irregularly in a black opaque ground-mass. I know of no rock in this district, except in Anglesey, from which such fragments could be derived. The red felsites in No. 4 are very like those below; but one fragment I take to be an altered pumice, since it contains long cavities drawn out into fantastic shapes, and lined by a coat of inward-growing crystals; if such is its nature, it no doubt formed the surface of the felsites.

Passing north we come to the region so carefully examined by Prof. Bonney. I have, I trust, examined it with equal care, and can fully confirm the accuracy of his observations, particularly in those points in which he differs from Prof. Hughes. I have traced the quartz-felsite grit by Rhos fawr, Brithdir, round by Wern into the valley, where it curves westward round the edge of the felsite. Then the green laminated beds on the summit of the hills, and the porcellanites by Penhower, as far as the commencement of the Tair-ffynon lane; then the great agglomerates, jasper conglomerates, and grits at Tair-ffynon, and the quarry by the side of the main road, where, however, the dip is turned round, probably in the neighbourhood of the fault; then the finer beds at Perfeddgoed, which include a quantity of purple slate, near Caer-hun and to the north of it; then a bluish breccia at the corner south of Cae Seri, which may be well matched at the poor-house, and another to the north, which may or may not be the same as that at Hendrewen; and finally the great hälleflintoid mass which, commencing with Mniffordd and Nant Gwtherin, forms the western slopes of Bryniau Bangor. I have nothing to add in this region to the proofs adduced by Prof. Bonney in support of his statements of the succession, which, to those who have examined the ground, should be perfectly convincing. (See the Map, fig. 1.)

Here, however, we part company. There lies to the north a conglomerate of large stones which, for some reason I have never discovered, has been called by everyone in latter days the basal Cambrian conglomerate. Now the last few of the grits having had a pretty persistent strike of N.N.W., we find in the fields by Nant Gwtherin another coarse grit, its strike still N.N.W. This seems to have been identified with the so-called "Cambrian conglomerate" by Prof. Hughes; but a careful survey will show that this cannot be right, for we can follow this grit for some distance along its strike, and find to the east of it, *i. e.* above it, in the sequence, some more hälleflintoid rock (well shown in a quarry by the roadside), and we must go to the east again to find the conglomerate of large stones in the nearest spot of the adjacent field. This can scarcely be brought about by a fault, since the Arenig is undisturbed; and moreover the coarse grit does not resemble the conglomerate, but resembles more closely a grit seen where its continuation should be, to the west of the conglomerate on Bryniau Bangor. The great conglomerate appears to die out on the south, as conglomerates do; but we may trace it from a knob at about the "n" of Bryniau, in a north-north-west direction, to the west of, and nearly parallel to, the road; and this strike leads exactly to the spot where it is found in the road, as noticed by Prof. Hughes. It is therefore strictly conformable to the underlying beds. It is just near its southern termination, but on the opposite side of the road, that the escarpment of Arenig grit is seen striking N.N.E., in other words making an angle of 45° between the two. There is therefore no conformity with the overlying beds. Moreover, if the great conglomerate were the base of a new series, the beds above ought to be decidedly different. There are certainly a few purple beds in the road, but so there are far away to the south; but the main mass is difficult to distinguish from the hälleflinta below—so difficult, it appears, that Prof. Bonney, by curving round the conglomerate, has made beds, which really lie *above* it, appear to lie *below*, thereby unconsciously testifying to their identity.

I can therefore regard this so-called *basal* Cambrian conglomerate as nothing else than another and the most remarkable of the series of conglomerates which characterize these "Bangor beds." It is clear, then, that above the porphyry we have an ascending conformable series of conglomerates, grits, and more or less banded hälleflintas, alternating with each other and overlapped unconformably along their eastern side by the Arenig grit.

I have also carefully examined the country on the western side of the fault, but I am afraid it is more or less labour lost; we learn nothing further as to the succession, and cannot hope to tell whether a rock is conformable or not, especially when, like the great conglomerate, it changes its strike by more than 45° in the course of its 1½ mile run. But I am not in the least certain that this is on the same horizon as the great conglomerate on the other side of the valley. To begin with, the pebbles are not the same, those on the east being far more quartzose; but the rock is most like *one* of the beds at Tairffynon and the dark conglomerate of Fachell, a correlation made by Prof. Hughes. It would require the least number of faults to bring this about, and the beds actually seen below it are similar to those which occur below the Tairffynon conglomerate, while the beds above are more comparable on the two sides of the valley than they would be if we identified it with the conglomerate of Bryniau Bangor. I think the most *probable* stratigraphy here would be to draw a line of fault with an upthrow on the east, making a very small angle with the main fault, and running from near the "Inn," opposite Treborth, to beyond the Baths at Garth, thus bounding the felsite on the west, and running through the corner of the road where the great conglomerate changes its strike. A small fault *does* come out on the shore between the Baths and the Ferry. Thus the general strike of the beds on the east side of this fault would be to the east of north, instead of to the west of north, as on the other side of Bangor valley. But if my view be correct, all this is a matter of little consequence. The puzzle is to account for the very large pebbles of felsite and other volcanic products when the felsite near at hand must have been covered up by earlier deposits, and there is none other near to choose from.

Thus the Pre-Arenig rocks near Bangor form one indivisible series, but what is their age? Are they also Pre-Cambrian? The supposed proof of this has rested on the *assumption* of a basal Cambrian conglomerate, and the assumption is not justified. With Prof. Ramsay the only question was between what we now call Upper or Lower Cambrian, *i. e.* between "*a*" and "*b*," and he concluded, from a comparison of these rocks with others in Glynlifon Park, that they were Cambrian rather than Lingula-flags. Another reason that led him to this conclusion was the similarity of the conglomerates near Bangor to those near Llanberis, which are undoubtedly Cambrian. Any difference between these was accounted for by metamorphism. We can, however, dispense with much metamorphism, and yet compare these rocks with Cambrians. There is little to choose, microscopically or otherwise, between some of the rocks near Gorsbach and some near Llyn Padarn, nor between some varieties near Bangor and the rocks in the heart of the Cambrian near Llandwrog, nor between the grits north of Perfeddgoed and some west of Dinas Dinorwic. The included fragments may be somewhat different, but they are exactly the same type of rock. The great peculiarities of these Bangor beds are their great total thickness without reaching the great workable slates, and the presence of numerous and various conglomerates. They are called volcanic, but they are arranged in beds after the manner of subaqueous deposits, and can only be said to be volcanic as having been derived from the denudation of volcanic products. They are, of course, of later date than the volcanic eruption whose remains are seen in the porphyries. Thus their general features attach them to the Cambrian, and their peculiarities are what we might expect at the base of such a series. Is not the cause of any minor differences from other Cambrian rocks simply that we never see the base of the Cambrian elsewhere in North Wales?

This opens up another question, and forces us to the study of the rocks by Llyn Padarn, since these are supposed to represent the basal Cambrian, and to lie upon a Pre-Cambrian axis.

Llyn Padarn and Moel Tryfaen.

The great conglomerates which lie on the east of the masses of porphyry, on either side of Llyn Padarn, are considered by every one to be the base-bed of the Cambrian. According to Prof. Ramsay, as

I understand him, the conglomerates first lay on the hidden land from whose denudation they are derived. Then came an eruption of porphyry, which crept between the two and absorbed into its substance the lower part of the conglomerate. According to Prof. Bonney and Dr. Hicks, the porphyry was poured out as a lava, and the conglomerate was derived from its denudation. The proofs of this latter view are numerous. First, there are the abundant pebbles of felsite found in the conglomerate, which are certainly like the porphyry below; and it seems unnecessarily going out of the way when Prof. Ramsay says they are like some Bala felsites. Another argument may be derived from the way in which these conglomerates cling to the porphyries all along their range. They are seen in contact on Clegyr and on the south of Llyn Padarn, and though Dr. Hicks *supposes* there are some schists between them at Moel Tryfaen, his dark porphyritic-looking rock, which comes in the adit next the felsite, has been recognized by Prof. Bonney as the conglomerate itself; and in a small cutting of the slate railway on the west-south-west of the summit of the hill, the conglomerate is actually seen side by side with the felsite, neither passing into it, as supposed by Prof. Ramsay, nor unconformable to it, since there is no bedding in the felsite.

Furthermore Prof. Bonney has pointed out the flow-structure in the porphyry. I may add that, as observed by Prof. Hughes, to the west of Clegyr, and in immediate contact with the conglomerate, there are great masses of agglomerate, and these are repeated in connexion with another flow at a lower level, having a nose of breccia at its termination near Llys Dinorwic. We can scarcely, therefore, hesitate to admit, in the light of such observations, that these are really, practically at least, subaerial flows, and that the conglomerates have been derived in part from their denudation.

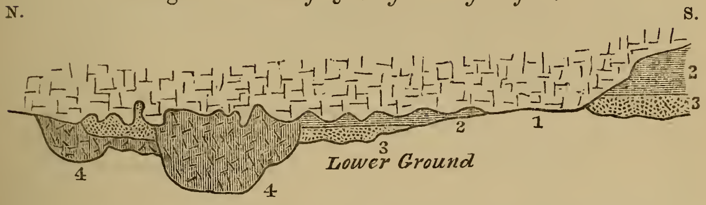
But the next question is, what is the age of the porphyry? in other words, what did it flow upon? Prof. Bonney and Dr. Hicks do not seem to have inquired into this. They take it to be Pre-Cambrian, and are apparently hopeless of finding any base or floor for it. If such a floor is to be found, it must be on the western side, since the conglomerate lies to the east; but here there is a great mass of Cambrian strata, and it is the relation of the felsite to these which we must examine. In some parts the junction is marked as a fault, but in the rest it is not. On examining the ground we soon find that the western boundary is for the greater part hypothetical, as it is confessed to be in the explanatory memoir*. The ground is covered by drift, and no junction can generally be seen. The only exception to this is on the north-east side of the river Rothell, where the drift is absent. This, then, is the crucial spot. If there is a fault here, our question must remain unanswered; but if there is not, and the felsite is older than this western Cambrian, as well as the eastern conglomerate, then the beds on the western margin must turn up and be found lying upon, or dipping away from it, and so

* Mem. Geol. Surv. vol. iii. 1866.

Prof. Ramsay and, after him, Dr. Hicks draw the section, though they introduce a fault as well.

But is this so? On the north-west side of the felsite there is a low alluvial valley, about 200 yards wide. On the opposite side, quite close to the valley, there are exposures of rock; but it is *not* a conglomerate, but ordinary fine slates, with vertical cleavage, but dipping towards the felsite at an angle of about 20°. This is suggestive, but affords no certain datum; our only chance is on the edge of the felsite itself. It is ill founding a determination on one section, but in this case a single proof could scarcely be more decisive. On the west side of the road from the bridge to Bryn Efail, and exactly on the letter "E" of that word in the map, there is a quarry in the felsite, which here shows a precipitous face towards the valley. The plan of this quarry is shown in fig. 6. The edge of the felsite

Fig. 6.—*Plan of Quarry at Bryn Efail.*

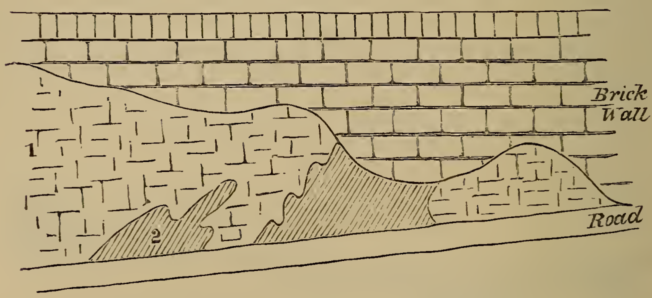


1. Porphyry. 2. Slate. 3. Grit. 4. Greenstone.

is ragged and irregular, but perfectly clean. In the centre of the quarry it runs against a boss of greenstone, and cuts it into promontories and twisting tongues. At the sides of this the junction is, for the most part, with a vertical bed of slate, which is followed on the west by a bed of grit, with which also the felsite occasionally comes in contact. The strike of these beds is nearly parallel to that of the Cambrians just noticed. The felsite is so welded with the slate that it is easy to obtain a junction specimen, and two such have been examined. In one the line of junction is perfectly straight. The felsite shows the quartz-crystals somewhat broken and exhibiting signs of pressure, and the ground-mass is crypto-crystalline and of varying coarseness; the whole is singularly like the band at the edge of the Twt-Hill mass in the Field-quarry, and I have no doubt they were formed under similar circumstances. Towards the junction both felsite and slate are infused with ferric oxide, which produces a coloured band in the slate of about $\frac{1}{8}$ inch in width. In the slate are developed abundant crystals of chiastolite, to judge from their long shape, their rhombic cross-section, and their dark line down the centre, and their being broken up into an infinitude of small low-polarizing crystals, which refuse to extinguish as a whole. There are also a number of small high-polarizing crystals which I cannot identify. In other words, the slate is altered by contact with the felsite. The same phenomena are observable in the other specimen, where the felsite runs in veins into the slate.

In the road outside the quarry, beneath some cottages, there are again phenomena which point to the same conclusion (see fig. 7). In the mass of rock, on which a brick wall is built, are seen the felsite and baked slate running into each other in a way which proves intrusion, in this case, of course, on the part of the felsite.

Fig. 7.—*Section in Road near Bryn Efail.*



1. Porphyry. 2. Baked Slate.

This spot is so important in its teaching as to the age of the felsite, that I can only suppose that it has escaped the attention of previous observers. It provides a crucial test, and thus a decisive proof, that this great flow of acid lava was, like the 99 per cent. of which Prof. Sedgwick speaks*, contemporaneous with the Cambrian rocks amongst which it is found. The Cambrians to the west are of earlier, and those to the east of later date than this. The question being thus apparently settled, it is necessary to see how this conclusion fits with other facts that may be observed in the neighbourhood. In the first place, the conglomerates ought to contain not only felsites, but also fragments of the Cambrian rocks to the west. At Clegyr, where the top of the felsite is an agglomerate of felsitic fragments (and nothing would be easier than to round them into pebbles), the conglomerate is mostly, though not entirely, made of such stones. But at Moel Tryfaen, where the top of the felsite, for some reason, is clean, the majority are slate. On this, Prof. Ramsay says†, "the pebbles of purple slate resemble those of the very strata amidst which they are found; the quartz-rock and jaspers resemble some of the metamorphic rocks of Anglesey." It is remarkable that Dr. Hicks‡, who thinks this conglomerate is derived from Pre-Cambrian rocks alone, omits all mention of the purple slates, and enumerates only "quartz, quartz-felsites, porphyritic rocks, and schists." Now these fragments of slate are large and scarcely

* Quart. Journ. Geol. Soc. vol. iii. 1847.
† *Ibid.* vol ix. 1853.
‡ *Ibid.* vol. xxxiv. 1878.

rounded, and cannot have come from far; and no such *large* slate-fragments, as far as I have been able to discover, are to be found in any of the conglomerates of Bangor, which must be nearer to their source if they come from Anglesey. The quartz- and jasper-pebbles at Moel Tryfaen, on the contrary, are rounded and not so large; and when we remember the large quartz-pebbles at Bangor and the jasper-fragments at Tairffynon, and also at Llandwrog, we may well believe that these pebbles have come from their original home by two stages, and that their previous resting-place was in the earlier Cambrian conglomerates. It is true that the majority of these "slates" are so indurated and compact that they are more comparable to the lower beds near Bangor, which are regarded by Dr. Hicks as Pre-Cambrian; but among them there is a minority showing that peculiar banding of purple and green which can scarcely be matched in any bed near Bangor, but only further up the series. Thus, in any case the pebbles are consonant with, and they may be considered to confirm the Mid-Cambrian age of, the conglomerate, and therefore the possibly still Cambrian age of the Llyn-Padarn and Moel-Tryfaen porphyry. But on the ground of a supposed unconformity, a long interval is claimed to have elapsed between the two rocks: and this idea is likely to militate against the view of these porphyries and their companions being mere incidents in the Cambrian succession. As, however, the underlying beds are volcanic breccias, they are naturally irregular, and I will therefore quote the words of Prof. Green in describing them:—"The unconformity . . . does not necessarily indicate any great difference in age . . . The breccias are of volcanic origin, and the irregular and restricted upheavals and disturbances, which are always liable to occur where volcanic activity is going on, are quite competent to bring about unconformities quite as marked as those of the present section." I may quote also the words of Prof. Hughes, which exactly express my view of the matter:—"In the Llyn-Padarn section the fragmants in the agglomerates are much rounded, so as to suggest that towards the close of the period of volcanic activity a larger and larger proportion of the volcanic ejectamenta got worked up by the action of the sea, until, at a subsequent (but perhaps not long subsequent) period, they were all sea-washed and rolled, forming, with the waste of rocky shores, the coarse conglomerate which we have taken for the base of the Cambrian." These words are just as true, whether we take the conglomerate as the base of the Cambrian, or as a bed some distance up in the series.

But, again, if the beds, as we find them, are approximately in chronological order, the series to the west of the porphyry ought to be distinct from the series on the east. As to this there is a difference that must at once strike every one; on the west side there is not that great mass of workable slate which is so remarkable on the east, and which clings so closely to this old porphyry, coming in with it at Penrhyn and going out with it at Nant-y-llef. To go further it is necessary to enter into some detailed stratigraphy, especially as I regret to find myself in disaccord with the distinct words of Prof. Ramsay, who says* that the beds "on the west of the porphyry are the same in number, arrangement, and lithological character as those on the east."

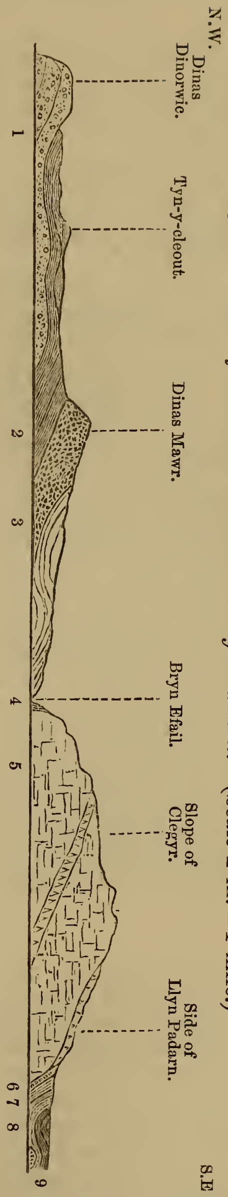
This point, therefore, must be carefully considered. Prof. Ramsay draws a section from Dinas Dinorwic to Clegyr (fig. 55), in which the two lowest members of the Cambrian undulate at low angles for two miles from Dinas as far as Bryn Efail, where they are cut off by a fault, and these two lowest members are also found on the top of Clegyr. In spite of the undulations, however, he has to make the western portion seven times as thick as the eastern to make a section at all. Then we have seen that the beds nearest Byrn Efail do not dip west, and that there is no fault. At Dinas Dinorwic Dr. Hicks says he has found large one-inch pebbles in a conglomerate. This is not mentioned by Prof. Ramsay, and after twice knocking all over the hill, I failed to find it. If it be there, it is followed by a tough grit, almost like a felstone, which forms the mass of the hill, and must be of great thickness. There is a dip of 70° inserted on the map. Then at Tyn-y-cleout we have a mass of purple-banded slate, not unlike the Bangor series, which appears to continue a long way. Then we reach the mass of Dinas Mawr, a lofty hill composed of coarse jasper-grit, most like that near Brithdir; to the east of this we have purple slates again, with interbedded grits, gently undulating for the first time, but on the whole not turning up again. Such is the western series (see fig. 8); the eastern has been described by Prof. Bonney. On the railway-section north-east of Llyn Padarn he supposes a fault between the porphyry and the conglomerate; but there is really none; the two may be traced clinging to one another in an irregular line up on to the western slope of Clegyr. On the railway the conglomerate is not so distinct from the agglomerate as above (perhaps there is no agglomerate here), and under the low anticlinal further east there is only left a fissile breccia to represent it. After a greenstone-dyke comes a remarkable series of beds, namely, banded hälleflinta, as seen at Bangor, perhaps 50 feet, becoming more slaty at the top, then a remarkable false-bedded band, the lines being made of purple grains and the matrix felsite dust. This is so compacted that it looks quite like a felsite. It is intensely cleaved across the bedding and false-bedding. This is followed by a one-foot band of purple-slate conglomerate pulled out into lenticules, and interosculating with finer material. Then are seen for 100 ft. greenish slates, getting purple by degrees, and often containing another thin band of cleaved felsite-grit, and then the purple slate, which, after an interrupting fold, is seen to be the base of the great roofing-slates. There is not, therefore, really much between the conglomerate and the roofing-slate, and when we compare it with the western beds, the series could not well be more distinct, considering that they are both Cambrian. It is interesting also to note that hälleflinta is not peculiar to the rocks near Bangor, but is rather in relation, as it appears, with a previous volcanic outburst.

* Mem. Geol. Surv. vol. iii. 1886, p. 154.

From this examination I cannot understand on what Prof. Ramsay's statement is based. I fear it cannot be maintained. Much of the mapping, too, here is acknowledged to be hypothetical, and leads, as I conceive, to too great importance being attached to these felsites. Thus the porphyry west of Clegyr, which itself consists of two different flows, separated here and there by deposits of slate *, is never seen to cross the road at Llanbabo, and its occurrence beyond, together with the fault, is entirely conjectural, as the whole country is covered deeply in drift, a circumstance in itself suggestive that the underlying rock is not likely to be so hard a rock as felsite. Then the felsite of Moel Gronw is not apparently connected with the former, nor can it be traced beyond the road called Cefn-y-waun. The basal conglomerate does not wrap round it, but forms a band clinging to the east of Clegyr only, and leaving Moel Gronw some distance further east. The Moel-Gronw felsite is thus a later outburst, which is separated from the purple slate above by only a band of grit, which *perhaps* is represented in the form of a thin band of conglomerate seen in the railway at a higher level than the great one. The limits of the felsite, as actually seen, are also very much smaller than drawn on the south-west. The line is carried out as far west as Glanrafon, on the Gorfai River, where there is an exposure of rocks in the deep river-gorge; but these are quite different from those of Moel Swtan, which is the nearest exposure of the true Llanberis

* See Bonney, Quart. Journ. Geol. Soc. vol. xxxv. p. 312.

Fig. 8.—*Section from Dinas Dinorwic to Llyn Padarn.* (Scale 2 in. = 1 mile.)



1. Lowest compact grit.
2. Banded slate.
3. Coarse grit.
4. Slate.
5. Porphyry with agglomerate.
6. Coarse conglomerate.
7. Hälleflintoid rock.
8. Green slates.
9. Roofing-slate.

felsite. There are three varieties, close together and of small size, probably insignificant intrusions. Then the mapping round Moel Tryfaen is shown by the adit and cutting on that hill to be wrong. There can be no fault between the conglomerate and the slate. The great mass of felsite represented as occurring to the west is all under drift-covered country, while the conglomerate wraps round the felsite between Moel Tryfaen and Pen-y-groes. These corrections would curtail the importance of the porphyry and make a great fault unnecessary.

Thus the Cambrian age of this mass of porphyry, as determined by the nature of its under and its upper surface, is consonant with, and confirmed by, the other tests to which the conclusion can be submitted.

We must now apply this determination to the question of the age of the rocks near Bangor. Since the conglomerates of Llyn Padarn and Moel Tryfaen are *not* the base of the Cambrian, there is no reason why they should correspond with any particular band in the series at Bangor, either towards the top or at the bottom. But if these Padarn conglomerates are not the base, where is it? *Nowhere* in this particular area. We go downwards as we go westwards till interrupted by a pair of trough faults, letting down the Ordovician. When we get over this and come upon the older beds again, what should they be but the continuations westward of the Cambrian series? There is scarcely a bed amongst them that we cannot match somewhere or other in the higher parts of the series, though on a smaller scale. Considering the lateral changes that may take place in rocks, and the frequent dying-out of conglomerates, we cannot safely say that all the Bangor beds underlie all those from Dinas Dinorwic east: the correlation of bed with bed, or the proof of their independence, if it were thought of importance, would require a further long series of stratigraphical researches. All we can say is, that we see to the south of Bangor the base of the Cambrian down to a great felsite lava-flow; but whether this, like that at Llyn Padarn, was contemporaneous and followed below by earlier deposits still, or was erupted at a date that may be fairly separated from the Cambrian period, there is not enough evidence in this district to show.

Conclusions.

The results of the examination in the areas between Bangor and Caernarvon, and from Llyn Padarn to Moel Tryfaen, of the rocks which are found within them, are not very confirmatory of the views of recent observers, but lead us back, with certain important modifications, to the earlier teachings of the Survey on the district. They may be summarized as follows:—

1. In the Bangor to Caernarvon area: three distinct conglomerates have been confounded together. The only one which, by its unconformable overlap, sets an upper limit to the age of the rocks below

is of Arenig, *i. e.* of Ordovician age, and can only be called Cambrian by the misleading use of the term, which embraces all rocks up to the Bala series.

2. The rocks of the southern and central portion are essentially of igneous origin.

3. These may clearly be distinguished into two groups, of which the southern is probably intrusive, and the northern is certainly eruptive.

4. There is an interval of time between their production; but how great an interval, there is no evidence to show. That the southern mass is of later date than the Arenig, and intrusive into it, is a tenable hypothesis; but that it is of earlier date and overlain by the northern portion, is far more probable.

5. The Bangor beds are derived from the denudation of the volcanic series and of rocks which may have been associated with it.

6. These beds contain a series of conformable conglomerates, of which the great conglomerates near Bangor are members.

7. They are the continuation downwards of the Cambrian rocks seen to the east, and have not undergone very serious alteration compared with the latter.

8. The porphyries of Llyn Padarn and Moel Tryfaen are contemporaneous lava-flows in the midst of the Cambrian series, the overlying conglomerates being derived from them and from the Cambrian sedimentary rocks to the west.

And hence, finally, there is no certain proof of there being any Pre-Cambrian rocks in the whole district, though there is great probability that the rock near Caernarvon belongs to a distinct epoch anterior to the Cambrian.

I may add that nothing here observed invalidates former conclusions as to the essential independence of the group which lies below the true basal Cambrian conglomerate in the St. David's district. That group does not bear sufficient resemblance to the series in north-west Caernarvonshire to justify their correlation, and the unconformity there observed is of a totally different order, and comparable rather to the overlap of the Ordovician beds in this district.

Discussion.

Prof. T. McK. Hughes said the question was too large and intricate to discuss thoroughly at so late an hour. His reading of the stratigraphy of the Twt-Hill quarry and of the sections near Llandeiniolen and Bangor differed altogether from that of Prof. Blake, whose correlation of the various conglomerates appeared very doubtful.

Dr. Hicks felt the same difficulty. In his opinion Prof. Blake had misunderstood the beds and had not sufficiently considered the effects produced by the faults. The pebbles of felsite in the Cambrian conglomerates showed a cleavage produced before they were broken from the parent rock. At Llyn Padarn the Cambrian conglomerates rest on the cleaved edges of the underlying felsitic rocks, therefore the latter cannot be intrusive in the Cambrian.

Prof. Blake, in reply, said he had the advantage of having read Prof. Hughes's and Dr. Hicks's papers. He showed that if Prof. Hughes's view of the Twt-Hill quarry-section were correct, the change would not be opposed to his (Prof. Blake's) contention. Some other objections were answered in detail.

22. *An* Estimate *of* Post-Glacial Time. By T. Mellard Reade, Esq., C.E., F.G.S., F.R.I.B.A. (Read February 29, 1888.)

Of late several attempts have been made to show that the close of the Glacial period was very recent*.

Having personally devoted considerable attention to what is called Post-glacial or "superficial" geology, I am much struck with the imperfect knowledge with which the question of Post-glacial time is frequently approached.

The writers seem to be unaware of, or to insufficiently appreciate, the grand sequence of events recorded in the deposits on the Lancashire and Cheshire coasts which have taken place since the snow and ice of the Glacial period disappeared †.

On the borders of the coast-line between the Dee, the Mersey, and the Ribble, the student who cares to pursue the subject can do so with great advantage. But through the horizontality of the deposits, and their general low level, none occurring above the level of the 25 feet Ordnance datum and all reaching down to below the level of the lowest spring-tides, the study has to be pursued through the medium of excavations and borings. This I have done in observations extending over many years, and I now propose to show their bearing upon the absorbing question of recent geological time.

Denudation of the Low-Level Marine Boulder-clay.

The whole of the country to which these notes specially refer was formerly entirely covered with a mantle of Low-level marine Boulder-clay and sands. These I have described at length in several papers ‡.

That the valleys of the Dee, Mersey, and Ribble were at one time filled with Low-level marine Boulder-clay, we have, I think, indubitable evidence. The ancient or Pre-glacial course of the Mersey was, as I have shown, under the site of the town of Widnes in Lancashire, and, as numerous borings have disclosed, it is now, with the exception of some superficial deposits of estuarine mud, entirely filled with Low-level marine Boulder-clay and sands. There is strong reason to believe that even here a considerable amount of Boulder-clay was removed before the deposit of the recent silt; but,

* Professor Prestwich estimates that the final melting away of the ice of the Glacial period took place within from 8000 to 10,000 years of the present time (Q. J. G. S. vol. xliii. 1887, p. 407). Mr. Mackintosh estimated it at not more than 6000 years (see Geol. Mag. 1883, p. 189 and pp. 191, 192).

† Professor James Geikie, in 'Pre-historic Europe,' is one of the few who appear to have made themselves acquainted with the remarkable and important changes it is attempted in this paper to explain.

‡ "Drift beds of the North-west of England," Q. J. G. S., part 1, 1874, part 2, 1883. See also C. E. De Rance, Q. J. G. S. vol. xxvi. p. 657; 'Memoirs of the Geological Survey,' &c.; G. H. Morton, 'Geology of the Neighbourhood of Liverpool;' and various papers by D. Mackintosh, Robert Bostock, Dr. Ricketts, and several local archæologists and geologists.

in the present course of the river, the Boulder-clay has been scoured out in places down to the bed-rock. That the Mersey Valley was filled with Boulder-clay, at least to the level of that in the pre-glacial channel at Widnes, will not, I think, be disputed by anyone who knows the locality. There can be little doubt that the Boulder-clay originally filled up the channel of the estuary between Liverpool and Birkenhead. A remnant of it lying in a Pre-glacial channel, the existence of which I ventured in 1872 to predict, was bored through in 1884 by the Mersey Tunnel Works.

That Wallasey Pool, now occupied by the Birkenhead Docks, was formerly levelled up with Boulder-clay is equally evident. The Boulder-clay also exists, or formerly existed, in a thickness sufficient for brickmaking, at Edgehill, on the Lancashire side of the Mersey, at a level of 200 feet above Ordnance datum.

When we consider the proximity of this locality to the Mersey, and the tendency of deposits to work down to and accumulate at lower levels, together with the proved instance of levelling up at Widnes, we can hardly refuse to believe that the Mersey Valley was formerly filled with Boulder-clay. To be assured that such a levelling up takes place in a sea-bottom, we have only to examine a chart of the Irish Sea, which represents a slightly undulating floor or vast plain having no irregularities of level even approximating to those of the valley of the Mersey. That there exist in this sea-area, could we bare it down to the bottom rock, river-valleys or considerable irregularities of contour, is shown by the "ditch" opposite Wigtonshire, where the tide, which here flows very fast, has scooped out a channel from 400 feet to 600 feet deep. The evidences that the Mersey Valley was once levelled up with Boulder-clay is further confirmed by the boring at Halewood, about three quarters of a mile from Hunts-Cross Railway Station, which penetrated 137 feet of drift presumably lying in a former tributary of the Mersey, of which there was no evidence on the surface.

The same may be said of that at Hooton, Cheshire, which went through 169 feet of drift, lying in a valley. A bore-hole at Ilchester wharf, Birkenhead float, penetrated 166 feet of alluvium and drift, and I have little doubt that these are only a few out of many examples of the general levelling up that took place during the submergence of the Glacial period.

It is thus quite clear that an enormous mass of glacial deposits has been swept out of the Mersey Valley. That this was mainly done by subaerial agents, when the land was at a higher level than at present, is proved by the numerous tributary streams which branched into it and are now partially filled with Post-glacial deposits. Everywhere below the Post-glacial deposits, to be presently described, the Glacial beds are deeply eroded and show evidences of long subaerial waste.

How much time can be reasonably put down for these changes will be presently discussed.

Post-glacial Beds.—In a few places on the Boulder-clay surface are found remains of vegetation, and above them a series of estuarine deposits containing marine shells, such as *Tellina*, *Mytilus*, *Turritella*, &c., and in certain laminated clays *Scrobicularia piperata* in the vertical position in which it lived. These Post-glacial deposits, where they occur, have levelled up the inequalities produced by the previous subaerial erosion of the Boulder-clay, and they cover an extensive area amounting to some 75 square miles between the Ribble and the Mersey. It is difficult to say what their maximum thickness is, but they are known to be, in places, 50 feet deep. The deposits thin out landwards towards the ancient shore-line, so that the borings in the centre of the Moss-lands show less than this thickness *.

None of these deposits, which are very general and are found even as high up the river as Warrington, reach above the level of the 25 feet Ordnance contour. It is manifest that they represent a period of subsidence probably long continued. Mammalian remains are found in these beds, but no extinct animal is represented.

Lying upon these silts and blue laminated clays is a very extensive peat-bed containing the stools of trees with the roots ramifying into the clays or silts below. They are mostly oak, birch, and pine. That these trees have grown in the position in which they are now found we have ample evidence. It therefore follows that the Post-glacial estuarine beds in which they are rooted, after being laid down, were elevated sufficiently for the efficient drainage of the land, and there is strong reason to believe that at this time Great Britain was united to the continent of Europe. Similar submarine forests can be traced all round Great Britain and Ireland, the Isle of Man, and the north coast of France, and I believe that most of them are synchronous with our Lancashire and Cheshire submarine forests. These forests represent, then, a period of general elevation extensive in area, but of unknown vertical range.

Since the growth of these extensive forests, there has again been a subsidence, so that many of them became submerged beneath the sea, and it is to this cause that we owe their partial preservation. Along the littoral margin they are frequently found beneath blown sand, and have, in places, recent estuarine silts deposited upon them.

That all these changes occurred, there is evidence amply sufficient to satisfy any unprejudiced mind. I know of few events in geology more clearly recorded than those just detailed †.

The channel of the Mersey, as proved by borings made during the opposition to the Manchester Canal, is largely filled with Post-glacial gravels. The precise age of these it is difficult to determine, but probably they are the remnants of the Boulder-clay washed out during the subaerial excavation of the present channel. Some of

* See "Borings on the Southport and Cheshire Lines Extension Railway," Proc. of Liverpool Geol. Soc. 1884–5, p. 93.

† See "Post-glacial Geology of Lancashire and Cheshire," Proc. of Liverpool Geol. Soc. 1871–2; "The buried valley of the Mersey," ibid. 1872–3; "On a section at Hightown," ibid. 1881–2; "The Mersey Tunnel, its Geological Aspects and Results," ibid. 1884–5; "Some further Notes on the submarine forest at the Alt Mouth," ibid. 1877–8; "A problem for Irish geologists in Post-glacial Geology," Scientific Proceedings of the Royal Dublin Society, 1879.

the gravel may have been reworked up by the sea. Borings from Weston Point to Hale Head showed the presence of gravel, peat, and sand below the present bottom *.

Length of Time represented by the foregoing Post-glacial Geologic Changes.

That these changes represent a very considerable lapse of time, seems to me almost self-evident; but how can we obtain a true scale with which to measure it? In making the attempt it will be better to reverse the order in which we have described the events, and begin with the latest deposits.

In a paper on "The date of the last Change of Level in Lancashire" †, I have attempted to show, from observations made of the rate of accumulation of blown sand at Blundellsands, that the minimum time required for the accumulation of the 22 square miles of blown sand between Liverpool and the Ribble must be put down at 2500 years, and that no appreciable change of level has taken place in the coast-line within that period. History does not go quite that far back; but so far as it does (that is to the time of the Roman occupation of Britain), there is no evidence of any value pointing to any change of level having taken place; nay, what evidence there is is strongly the other way. The Roman fords on the river Dee show plainly that the state of things then was much as it is now ‡.

The Roman remains found at Hoylake came from a stratum of soil above the peat-and-forest bed. It is evident from this that the peat-and-forest bed was in existence in Roman times in much the same condition in which it appears now. It is in consequence of being buried by blown sand that such numerous evidences of Roman tenancy have been preserved at Hoylake. The Roman station was probably situated just inside of the sand-dunes, which have since encroached upon it and entombed its remains. I know of no implements or other evidences of human handiwork having been found either imbedded in the superior peat or in the silts below, but I have found them in the superficial layers lying on the peat. I am satisfied that 2500 years is a reasonable minimum limit to the beginning of the present condition of level of land and water; but it may be much older. The superior peat-and-forest bed represents, as I have attempted to show §, a continental connexion with these islands, and if so, the land must have subsided not less than 200 ft. since the connexion existed.

Now comes our difficulty: What rate must we allow for the sub-

* "The Mersey Tunnel, its Geological Aspects and Results," Proc. of Liverpool Geol. Soc. for 1884–5.

† Quart. Journ. Geol. Soc. Aug. 1881, vol. xxxvii. pp. 436–9.

‡ See paper by the late Mr. R. Bostock, Proc. of Liverpool Geol. Soc., March 8th, 1870. An examination of the Roman Wall lately disclosed by excavations in the Roodeye has satisfied me that the level of Chester, in relation to the sea, is practically now what it was in Roman times.

§ See "Post-glacial Geology of Lancashire and Cheshire," before referred to.

sidence? We have really very little evidence to go upon excepting that regional changes of land and sea are extremely slow. If we put it down at 2 feet per century, the subsidence would be completed in 10,000 years; let us, however, be generous and say 4 feet per century, which would give 5000 years.

But then land-movements are not always going on; we have seen that the land has been practically stationary for the last 2500 years. If we allow another 2500 years for a pause before the subsidence began, we shall, I think, make a very low estimate.

The elevation of the estuarine silts (Formby and Leasowe beds) must have preceded the depression, and as they were mainly laid down at approximately the same relative level of land and sea as now obtains, we shall have to allow 5000 years for the elevatory movement, estimated at the same rate as the subsidence *. Working backwards from the present time we arrive at the conclusion that (2500 + 5000 + 2500 + 5000 =) 15,000 years is a very moderate estimate for the time which has elapsed since the completion of the laying down of the Formby and Leasowe estuarine silts. Working still backwards in time, if we allow another 2500 years for the pause during which the estuarine silts underlying the peat- and forest-bed were laid down, a parsimonious estimate I consider, we shall arrive at a total of 17,500 years for the time occupied by the Post-glacial changes represented by the Formby and Leasowe and accompanying forest-beds.

But, as I have indicated, the denudation of the Boulder-clay upon which these deposits lie is very great and represents a much greater lapse of time. Measured in the centre of the valley, at least 100 feet, and probably more, of glacial deposits had been swept out of the Mersey Valley before these Post-glacial beds were laid down. Again we are in a difficulty for a time-modulus to apply to the excavation of the valley, which would be more rapid than the general lowering of average ground, the rate of which may be taken at 1 foot in 4000 years †. Let us assume that the valley was swept of its deposits at the mean rate of 1 foot in 400 years, or 10 times the general mean rate; the time occupied in the denudation of 100 feet would be 40,000 years. Considering that the Mersey Valley was widened out to nearly its present extent before the estuarine beds were laid down, a mean rate of 1 foot in 400 years is, to my mind, very rapid. As there are no indications of glacial action during the course of these events, I think that the estimate of 57,500 ‡ years (17,500 + 40,000), say in round figures 60,000 years, for Post-glacial time a reasonable one and, as represented by these changes, well within the mark.

The calculation includes the time occupied in the elevation of the glacial deposits from beneath the sea, as it is assumed that the

* There are no known instances affecting so large an area of a rate of elevation or subsidence so great as this. The observations in Sweden showed a mean rise of 3 ft. 6 in. in 134 years. 'Nature,' Dec. 18, 1884, p. 150.

† "A Delta in miniature," Quart. Journ. Geol. Soc. May, 1884. "Denudation of the two Americas," Presidential Address, Liverpool Geol. Soc. 1884–5.

‡ Dr. Croll, from entirely different data, estimates it at 80,000 years.

denudation went on *pari passu* with the elevation. It may be urged that the mean lowering of the ground in a Boulder-clay area would proceed much more rapidly than in average ground composed of a variety of rocks. I am not prepared to admit this. Boulder-clay is a very tenacious substance, and, if only attacked from the top surface, takes long to denude.

The valleys would be excavated at a greater rate than in rock, provided there were a sufficient gradient, as the clay is more readily undermined. This I have allowed for in the increased rate of valley-excavation. No ordinary rock would be worn down so quickly as 1 foot in 400 years. Again the rate of vertical excavation by a river would not be uniform; it would proceed with greater rapidity at first and decrease as it reached the base-level of erosion, then it would cease entirely.

All this time the valley would be widening and would continue to widen, though the vertical excavation ceased. Other things being alike, the widest valley must be the oldest. The Mersey Valley is distinguished for its width in the upper estuary, and, in this, tidal action has helped. When we look at the River Ribble below Ribchester, we cannot help being impressed with the idea that there has been little change since the Roman times. I found in 1882 Roman tiles 3 feet below the surface-soil, on the river-cliffs, resting on the Boulder-clay. There are Boulder-clay cliffs on either bank, so that the lateral movement of the river at this part since Roman times cannot have been great.

It is quite apparent that there has been in the area under consideration considerable general denudation of the Boulder-clay. Rocky knolls once covered have been laid bare. Here and there we find patches of Boulder-clay as indications of its former presence. The surface of the clay below the soil is full of ramified channels and holes filled with the sand left from the destruction of the clay above *. Unfortunately there are no *zones* in the clay by which we might be enabled to say how much of it has been removed in particular areas. We are thus driven to the valleys for an answer. They are in many cases remarkably wide, with Boulder-clay at the bottom and on the plateau above, while the flanks often display the rock surface. This is the case at many points in the Mersey Valley and in its tributaries.

When we consider that at the rate of 1 foot in 4000 years the *mean general lowering* would only amount to 10 feet in 40,000 years, we may well consider our estimate based on valley-denudation a moderate one.

When first investigating the Post-glacial deposits of south-west Lancashire and Cheshire, I was much impressed with the great lapse of time they indicate; and a long acquaintance with this class of geological investigation has not lessened the impression.

As I have before stated, in none of the Post-glacial beds have any remains of extinct animals been found. If at a future time any

* See "Subsoil Denudation of Boulder-clay," Geol. Mag. 1882, p. 265.

should be found, it will probably be below the estuarine beds on the surface of the Boulder-clay.

There is little doubt that this surface was occupied by a fauna now partially extinct; but the subaerial conditions, which lasted so great a length of time, were apparently unfavourable to the preservation of their remains. Sir Charles Lyell states that the skulls of two Mammoths were taken out of the excavation made for the Holyhead Railway, near the harbour, two feet below the surface of a bed of peat, which was covered with stiff blue clay. This peat was continuous with that exposed at low water in the harbour of Holyhead, in which were seen stumps and roots of trees *.

The basis on which we have had to construct our estimate is naturally imperfect; but against any possible overestimate of time which may have crept in from the imperfection of the time-measures applied to the events, is to be set the possibility of other events having happened which are unrecorded or unreadable in the deposits which we have been considering.

Discussion.

The President anticipated a considerable amount of discussion on a question which had already engaged the attention of so many writers.

Prof. Prestwich thought the sections of much interest, but wanted to know the terms of the discussion. What was meant by the so-called post-glacial deposits indicated in the column? There was no evidence of their being of post-glacial age, either in the presence of extinct Mammalia or of boreal Mollusca.

The Author explained that all the deposits between the Marine Low-level Boulder-clay and the recent deposits were included in his "post-glacial."

Prof. Prestwich remarked that these deposits contain only recent shells: they are in fact merely ordinary alluvial deposits with the submerged forests, so common round many of our coasts. The dates the Author proposed to assign to these neolithic deposits were founded on estimates entirely his own. But little reliance was to be placed on the thickness of beds accumulated at the mouth of a river.

Mr. De Rance observed that his first paper before the Society dealt with this area and subject. It was a satisfaction to him to agree with Mr. Reade's descriptions, though their conclusions were at variance. The Mersey was a case of a valley within a valley, a pre-glacial valley filled in with glacial deposits, a post-glacial one fringed with river-terraces. The case was somewhat different as regards the Ribble, west of Preston. He pointed out the great thickness of the drift in the Fylde, its base being below sea-level for many miles. He described the position of the peat-bed and its vertical range, and the amount of excavation effected in the valley since the period of the Upper Boulder-clay, the several stages being marked by terraces,

* 'Principles,' 10th ed. vol. i. p. 545.

the last being the alluvial flat. He corroborated Mr. Reade's statement as to the small change of level since the time of the Romans, but thought that in arguing with respect to the amount of time, he was reckoning without his host; for the valleys had reached their negative gradient before the Roman period. There were no links for the calculation of time for the formation of deposits older than the Roman era.

Dr. EVANS had himself abstained from reducing geological time to years, but he admired the Author's ingenuity. However, he had left out of his calculation certain stages. There was no evidence as to the time elapsed between the Boulder-clay and the base of these deposits, and very little as to whether they were marine or alluvial. If marine shells are absent these beds are probably alluvial and comparatively modern. He contrasted the estimate of the time required for their deposition with the short period allowed by some recent authors for the interval between the Glacial epoch and the present day.

Mr. CLEMENT REID remarked that there was a very similar succession in the deposits of the Humber. A rough calculation had shown that the highest buried forest in that district may have been submerged about 3000 years ago; and the pile-dwelling at Ulrome seemed to prove that it occurred before part of the Neolithic period. He thought that the Author had overlooked the fact that when the land was higher, denudation, and consequently deposition, would be more rapid. This seemed to invalidate any calculations based on the present rate of deposition of silt. He had found it impossible to make any estimate of the time represented by the deposits below the highest submerged forest.

Mr. WHITAKER thought that Mr. Reade's post-glacial beds were newer than the valley-gravels of the south-east of England. The terms post-glacial and glacial have a different meaning in different places; some of the post-glacial drift of one district may be as old as some of the glacial drift of another district; thus southern post-glacial drift may be as old as the Boulder-clay in the column. He spoke of the rapid accumulation of alluvial marsh-clays and peat-beds, as at Tilbury Docks.

Mr. TOPLEY pointed out that the beds under discussion, which upon any view of the case represented a long period of time, were later in date than those of the Cae-Gwyn Caves.

Prof. PRESTWICH remarked that there was considerable correspondence between Mr. Reade's section and that at Tilbury Dock, but at the latter place the alluvial deposits were under 100 feet thick, and rested, not on Boulder-clay, but on the latest of the valley gravels, or true so-called post-glacial beds.

The AUTHOR scarcely expected that any one would fully agree with him on the question of lapse of time. There had been some misapprehension amongst the speakers, who had confined their remarks mainly to the time occupied in the formation of what he called the post-glacial deposits. But he had largely relied upon the time occupied in the clearing out of enormous quantities of marine

Boulder-clay in the valleys of the Mersey, Dee, and Ribble. This post-glacial erosion preceded the deposition of the estuarine and Peat- and Forest-beds, which lie on the denuded surfaces of the remnants of Boulder-clay now occupying the valleys. His estimate of 1 foot in 400 years for the valley-erosion was not excessive, being ten times more than the present general rate of denudation. He referred to the proofs of the surface of the Boulder-clay being much eroded. He only pretended to give an approximate estimate, which was really below the mark. He thought it possible to apply a time-scale to certain beds.

23. *On some* Additional Occurrences *of* Tachylyte.

By Grenville A. J. Cole, Esq., F.G.S. (Read February 29, 1888.)

[Plate XI.]

Since the spring of 1883, when I had the honour of being associated with Prof. Judd in a paper on the Basalt-glass of the Western Isles of Scotland *, a few additional occurrences of tachylyte in the British Isles have come under my notice in the field. Specimens have been thus collected from Ardtun in Mull, Kilmelfort in Argyll, from near Bryansford, County Down, in Ireland, and among certain older rocks of the Welsh border. I am also enabled, by the kindness of my friend Mr. A. W. Dymond, to give an account of the microscopic characters of the tachylyte of the Quiraing in Skye.

The Duke of Argyll, in his classic description of the leaf-beds of Ardtun in Mull †, refers to a glassy layer between two of the basaltic masses of the headland; and the same occurrence was mentioned by Mr. Koch during the discussion on the paper dealing with Scottish basalt-glass. Mr. J. Starkie Gardner, who called my attention to the rock upon the ground itself, has described and figured the course of an intrusive sheet that forms a very conspicuous feature at Ardtun ‡. At its most accessible portion it is about 8 ft. thick, and in the centre still retains, as shown by microscopic examination, a considerable amount of colourless glassy matter. In this matrix cumulites and belonites are developed; plagioclase felspar is abundant, interspersed with brown prismatic augite, while the magnetite is collected into crystals that are often well defined. On a sea-face so exposed the rock has naturally suffered, and the black lustrous specks visible in it to the naked eye prove to be soft products of alteration §. It does not appear, however, that they are pseudomorphs after olivine, a mineral which is in this case rare, if not altogether absent. On the other hand, the few specks of quartz that occur are clearly of secondary origin.

The upper and lower surfaces of this intrusive sheet have, by rapid cooling against the surrounding basalt-flows, become coated with a black glassy selvage, which is seldom more than an inch in thickness. This tachylyte adheres more firmly to the contact-rocks than to the mass from which it was developed; but microscopic examination opposes the idea that an intermingling through fusion has taken place along the planes of junction. The crystals of the overlying basalt are, indeed, seen to be sharply broken through, and abut unaltered against the intrusive glass.

The tachylyte itself is fairly fresh, though traversed by the numerous joint-planes characteristic of this class of rock. Its

* Quart. Journ. Geol. Soc. vol. xxxix. p. 444.
† *Ibid.* vol. vii. (1851), p. 94.
‡ *Ibid.* vol. xliii. (1887), pp. 271, 272.
§ Compare the chlorophæite of Macculloch, 'Western Islands of Scotland,' vol. i. p. 504.

colour is a rich blue-black. Its high specific gravity, which reaches 2·83, may be explained by the crowding of spherulites in many parts and the consequent approach to a crystalline condition. The rock, however, that forms the centre of the intrusive sheet has a specific gravity of only 2·79, as determined both by the chemical balance and by Attwood's instrument on a large and representative specimen. This anomaly parallels the examples cited by Delesse *, who himself recognized how the density of different portions of an intrusive mass might be affected by decomposition at the centre rather than at the margins †.

The hardness of the glass of Ardtun is 6, and its fusibility equals 2·5 of von Kobell's scale, the product of fusion being a brown glass full of bubbles, which is blown out almost to a pumice when treated in the blast of a Herapath blowpipe. The powder of the rock is not attracted even by a powerful bar-magnet.

Under the microscope this tachylyte is found to repeat in the basic series the transition from glassy to completely spherulitic forms which is so familiar among acid lavas. Near the surfaces of junction the glass, rich orange-brown when thinly ground, is full of crystal-dust and shadowy aggregations. A few minute amygdaloidal vesicles, elliptical in section, are scattered here and there, the glass being lightest round them, this zone of different hue being very likely due to alteration spreading inwards. During the infilling of such cavities, the surrounding glass may often undergo a change, this being notably the case in the tuff of Aci Reale, Sicily, where every vesicle in the fragments of basalt-glass is bordered by a ring of brown palagonite. By gradual extension these rings unite, and effect the alteration of whole areas.

The Ardtun glass contains spherulites in all stages of development; and the brown globulitic matter of which they are composed is more and more condensed towards their centres, where they become practically opaque. A layer of spherules has formed in places on the very surface of the intrusive sheet, and the condensation of material towards the flattened side of these has given rise to a dark band along the plane of contact. A similar instance of the separating-out of materials on the plane of junction is described by Mr. Rutley ‡, who has kindly allowed me the use of his original slides. In both of these cases, the artificial and the natural, I take it that no very sudden chilling has occurred, and in the subsequent gradual cooling the crystallites have utilized the surface presented to them as a basis of aggregation, just as they cluster round a porphyritic crystal or any similar inclusion (Pl. XI. fig. 1).

Further from and parallel to the edge of the intrusive sheet, bands of brown spherulites traverse the darker glass, which is here more opaque through accumulation of minutely separated matter; and finally the glass is practically eliminated, the spherulites assuming polygonal outlines as they come in contact with one another

* Métamorphisme des Roches, pp. 403–407.

† *Ibid.* p. 406.

‡ Proc. Roy. Soc. vol. xl. (1886), p. 438.

(Pl. XI. fig. 2). At the same time the material of the spherulites, settling into a crystallized condition, becomes greyish in certain sectors and richly brown in others. A minute vesicle, filled with secondary minerals, occurs frequently at the centre of the spherulite, and may perhaps be a feature of alteration, extending inwards from the point of weakness; but, on the other hand, the regular outline of these vesicles gives support to the view of several writers, that such gas-bubbles may, like included bodies, serve as centres of devitrification *.

The radial structure in the Ardtun spherulites is seldom regular, though clearly seen; and the black cross, its arms parallel to the vibration-planes of the crossed nicols, is frequently much disturbed. With a single nicol the spherulites, when well developed, show remarkable phenomena of absorption. The browner fibres become of a darker hue when their longer axes are placed parallel to the shorter diagonal of the nicol; while the greyer groups, in the same spherulite, are at their darkest in the reverse position. Since this change of hue is very striking, a dark bar like one half of the cross, and due to brown or greyer fibres, is frequently seen traversing the spherulite when only one nicol is employed: and, if grey and brown sectors are suitably grouped in the same example, a complete dark cross may be shadowed out in one position, rotation of the slide through 90° reversing the conditions, and showing both vertically and horizontally placed fibres at their lightest †.

While I am not prepared to explain the pleochroism of the greyer sectors, it seems probable that, among the fibres of these basic spherulites, a separation into distinct mineral substances has occurred ‡. The greater tendency to crystallization in basaltic rocks may, indeed, cause a granophyric structure to arise under conditions that would, in acid lavas, produce spherulites practically isotropic. The surface of a section of the Ardtun rock, when etched with hydrofluoric acid, gives no very definite evidence; but somewhat greater resistance to the acid is offered by the browner rays. It must be borne in mind that the minerals composing such a granophyric spherule—a "pseudospherulite" of Rosenbusch—may be far different from those that separate during a less hurried process of crystallization, and that combinations may indeed be formed unknown to the cabinets of collectors. In augites rich in alkalies, however, such as are developed in many glassy rocks, the axis of maximum elasticity approximates to the vertical crystallographic axis, and a prismatic section exhibits its darkest tint when the

* The possible liberation of gas during the formation of a spherulite is discussed by Iddings (Amer. Journ. of Sci. vol. xxxiii. (1887), p. 43).

† Such phenomena of absorption seem to be by no means rare. They occur, for example, in a spherulitic tachylyte from Tasmania, and in the spherulites developed in artificial basalt-glass, as in the fused product of the "Rowley Rag." Even some acid lavas, as the perlitic rocks of Hlinik and of Puszti Hrad in Hungary, contain spherulites with pleochroic rays.

‡ I am glad to find that Dr. Wenjukoff holds the same opinion with regard to the spherulitic tachylyte of Sichota Alin (Bull. Soc. Belge de Géologie, tome i. (1887), p. 174).

light entering it vibrates parallel to this same direction. It will be seen that the extinctions and pleochroism of the browner rays, as described above, are not opposed to the suggestion that they are of pyroxenic character.

Two and a half inches from its outer surface, the Ardtun basalt has given rise to a multitude of interlacing rods, with here and there traces of a radial arrangement. These rods, like those in the tachylyte of Lamlash *, are themselves composed of individualized granules grouped along definite lines. In this instance the constituent crystallites are of prismatic outline, and may be measured with a high magnifying-power, being about ·004 of a millimetre long. As we trace this structure towards the interior of the mass, long skeletons of colourless felspar are evolved, and round these are clustered numberless little prisms and granules, the embryos of the pyroxenes that abound at the centre of the sheet.

A glassy selvage of even an inch in thickness would seem in itself to indicate a basalt rich in silica and the alkalies, a rock, in fact, on the threshold of the andesitic series †. A determination of the chief chemical constituents of the Ardtun tachylyte has yielded me the following result, the specimen selected being from the lower selvage of the intrusive sheet:—

Silica	53·03
Alumina	20·09
Ferric oxide	9·43
Lime	6·05
Magnesia	2·63
Soda	4·52
Potash	1·27
Loss on ignition	2·64
	99·66

The rock thus corresponds closely in composition with the basalt-glass of the Beal in Skye ‡, and is another addition to the more highly silicated and more aluminous examples, as distinct from the lavas of Hawaiï, which are far richer in magnesia and lime.

The next occurrence of tachylyte to be described is at Kilmelfort, on the Argyll coast, where, in 1883, in a quarry just north of the Cuilfail Hotel and opposite a tiny lake, I noticed a dyke, fringed with glass, giving off a vein into the surrounding greyer rock. This dyke was only from one to two feet across, and had merely a film of glass upon its surfaces; the vein connected with it, about two inches in width, showed also a thin tachylytic selvage. In another part of

* Quart. Journ. Geol. Soc. vol. xxxix. pl. xiv. fig. 2.

† I am aware of the objection raised by Stecher to this inference (Tschermak's Mittheilungen, 1887, p. 198); but almost all the tachylytic dykes described from Scotland traverse basaltic masses, and the similarity of conditions at the immediate edge has prompted the comparisons that have been made.

‡ Quart. Journ. Geol. Soc. vol. xxxix. p. 455.

the quarry a sharply-defined little dyke or vein, perhaps connected with the other below the surface, and $2\frac{1}{4}$ inches wide at the most, was similarly bounded by black glass.

In section this last-named tachylyte appears brown, but its narrowness diminishes its interest. The development of felspars in the adjacent basalt is, however, well displayed, the colourless prisms being often incomplete or bifurcated at the ends. This basalt is of normal character, with porphyritic olivines, a fact that may in itself explain, when ordinary temperatures are concerned, the small development of the glass. The surrounding rock is a rudely columnar hornblende-mica-porphyrite, with inclusions of mica-slate, and shows in section a very thin film, as if of partial fusion, at its junction with the invading basalt *.

I am indebted, as already mentioned, to Mr. A. W. Dymond, of the Royal School of Mines, for a specimen of tachylyte from the Quiraing in Skye. Although this fragment was found upon the talus, it probably formed part of the layer described and analyzed by Prof. Heddle †, and this fact must be my excuse for dealing with a rock with which I have no acquaintance in the field.

The glass in its present condition is easily scratched with a knife, and is, in fact, as its analysis sufficiently indicates, verging on palagonite. It retains, however, when viewed in microscopic section, all the delicate structure produced by devitrification during cooling. The matrix is of a yellow-brown tint, and includes numerous small spherulitic aggregations, about 1 millimetre in diameter. The first-formed fibres of these are frequently arranged in sheaves, recalling the "chiasmolites" of Krukenberg ‡, which are in this case converted by subsequent additions from without into double or single spherulites and axiolites. In comparison with their rich brown colour, the surrounding glass looks almost grey. The steam-vesicles in this rock seem to have had no influence whatever on the development of the spherulites.

The residual glass abounds in transparent globulites, and in spherical groups of these minute bodies, forming the cumulites of Vogelsang. There are also little bunches of dark crystallite-fibres, grouped so as to form right-angled figures with hollow sides. These, together with more defined crystals, probably represent the

* Through the kindness of Mr. F. H. Butler, M.A., I am able to record here the following occurrences of tachylyte, which were noticed by himself and Mr. P. F. Kendall, during a visit to the Isle of Mull. A columnar dyke below a waterfall in the Tobermory Burn, about three feet across, and a fine-grained columnar dyke at Rudha nan Gall, are bordered by basalt-glass. Another basalt, near the Erray Burn, west-north-west of this last point, and containing porphyritic felspars, has also vitreous selvages.

† Min. Mag. vol. v. p. 8. In the errata of the same volume, Prof. Heddle directs attention to the old term "Gallinase." It is of interest to find that in Buffon's 'Histoire Naturelle' (edition of 1801 &c., vol. ix. p. 349), *Gallinace* is carefully described as a black semi-transparent glass occurring in Iceland, Etna, Peru, &c., amid volcanic matter, in a manner that suggests its identity with the sideromelane and palagonite of von Waltershausen. The name is derived from the *Gallinazo*, a black carrion-bird of the Andes.

‡ Mikrographie der Glasbasalte von Hawaii (Tübingen, 1877), p. 8.

magnetite of the rock, the glass being, for a tachylyte, unusually clear.

The sections also show the passage of the rock into a stony condition by the dense accumulation of spherulites, though alteration has here gone considerably farther than in the vitreous portions. Altogether, this Quiraing fragment presents, in its wealth of detail, the most beautiful example of basalt-glass with which I am acquainted (Pl. XI. fig. 3).

If we find, however, that this instance exhibits certain phases of alteration, the next example has advanced several stages on the downward path. At an elevated point of the highroad from Newcastle, County Down, west of Bryansford and near the park of Tollymore, a columnar basalt-dyke traverses the Ordovician strata of the district, and is bounded on both surfaces by decomposing tachylyte. This selvage, however, must have at one time resembled closely the rock of the Quiraing, although the glassy interspaces are now green in section, and the spherulites a ruddy brown. Cumulites are observable in the thinnest portion of the slide, the magnetite is aggregated into little cubes, and the fibrous structure of the spherulites still remains, the characteristic black crosses with polarized light being easily apparent. A rude perlitic structure and traces of banding traverse the rock; and a few corroded porphyritic felspars have been seized on as centres of devitrification. The numerous vesicles, on the other hand, seem to have had a very partial connexion with the arrangement of the crystallizing particles (Pl. XI. fig. 4).

The basalt at the centre of the dyke contains some biotite and a fair residuum of glassy matter; like the rock of Ardtun headland, it has closer relations with the augite-andesites than with the basalts rich in olivine.

The extent to which alteration has proceeded in this last case, without the fundamental characters of the rock becoming obscured, and the corresponding retention of original structure among the most ancient and devitrified of acid glasses, leads one to inquire whether tachylytes may not be identified among the relics of our older volcanic areas. Already Mr. Rutley * has given detailed evidence that the rocks of St. Minver, Cornwall, include vesicular andesite-glass in a state of considerable alteration. As has been often pointed out †, the surface-products and other glassy portions of ancient and denuded lavas are frequently to be recovered among the ashes and detrital deposits formed during the eruptive period. Thus at Snead, near Bishop's Castle, on the outskirts of the Corndon volcano, a tuff of Ordovician age occurs, containing numerous black and blue-black fragments which at once recall the glass-particles of more recent areas. The palagonite-tuffs of Sicily, the Kaiserstuhl, and Iceland, or the glassy tuff of Hilzingen in the Hegau, may be cited as examples of such deposits of later age. The black

* Quart. Journ. Geol. Soc. vol. xlii. (1886), p. 392.

† *E. g.* Jukes, Journ. Geol. Soc. Dublin, vol. viii. p. 32.

fragments at Snead are soft, and devoid of vitreous lustre; but sections go far to prove that they were formerly more distinctly glassy than the tachylytes of Mull or Skye. They are, indeed, from their associations, referable rather to andesite-glass, like the matrix of the well-known rock of Eskdale, than to the rarer and more basic group of tachylytes.

Their colour under the microscope varies from a warm brown to yellow, and the relation of this material to the included porphyritic crystals affords very satisfactory evidence. The plagioclase felspars, of the broad type common in andesitic lavas, are corroded and perforated by the yellow matrix; this matrix, moreover, though it now polarizes in streaky irregular areas, has given rise only to minute brown aggregations resembling the magnetite- and pyroxene-microlites formed during the consolidation of basic glass. Some particles of the yellow substance are pumiceous; and similar material occupies the interstices between the other ejected fragments in the ash (Pl. XI. fig. 5).

A comparison with the tuff of Aci Reale, Sicily, in which "sideromelane" and palagonite fragments abound, greatly aids one in assigning a vitreous origin to the soft dark particles of Snead. If, further, we examine the andesites associated with this Ordovician tuff, we find an anisotropic substance, clear yellow in thin section, taking the place that in modern examples is occupied by the glassy matrix. Thus in the Corndon area, and, to take another example, in the andesites of the Carneddau Hills near Builth, the cavities of the corroded felspars, and the interstices of the crystalline meshwork of the ground-mass, are filled with this yellow alteration-product. The interesting augite-andesites of Iceland and the Faroe Islands, with their areas of yellow-brown residual glass, form an admirable series for comparison.

It may be claimed, then, that the tachylytes thus brought together add in some measure to our knowledge of the spherulitic forms; while we have evidence of the persistence of similar types from early Palæozoic up to Tertiary days—evidence, indeed, of the detailed similarity of causes operating at various periods, however far apart in time. I would, in conclusion, call attention to a rock as yet, I believe, unrecognized in Britain, the Variolite of continental authors. Little need be added to the full and excellent discussion of its characters given by Prof. Rosenbusch *. The well-known pebbles of the Durance, which are to be found in most old collections, are referred by M. Lory † to the selvages of the euphotides of Mont Genèvre, the age of their intrusion being later than the Infra-lias. Delesse ‡ has analyzed the included spherules, and regarded them as a form of triclinic felspar; while M. Lévy § has determined that the fibres of which they are composed are elongated crystals of oligoclase. He points out, moreover, that the

* Mikro. Physiog. der massigen Gesteine, 2te Auflage, p. 227, &c.
† Descript. géol. du Dauphiné, p. 577.
‡ Comptes Rendus, tome xxx. (1850), p. 741.
§ Bull. de la Soc. géol. de France, 1876–77, p. 238.

surrounding matrix possesses a perlitic structure *. The discussion that has arisen as to the amorphous or crystalline condition of the matrix of variolite may be explained if we admit the efficacy of secondary devitrification, and if we regard the rock as having been originally a massive tachylyte. The perlitic cracks, filled with minerals of alteration, are admirably shown in one of the specimens that I have to hand (Pl. XI. fig. 6); and the works published on the selvages of various "diabase" dykes, such as the recent paper on Sordawalite by F. Lœwinson-Lessing †, convince one that developments of basic glass, and even coarsely spherulitic tachylytes, have occurred on the margin of such intrusive masses in the past. In Britain the search for variolite may not be vain; and its discovery will give us an indubitably basic rock to set beside the "pyromerides" that are so well represented in our Isles.

I am much indebted to Profs. Judd and Bonney for kind assistance in correlating the foregoing observations. Almost all the sections have been prepared, and the chemical work has been carried out, in the Geological Laboratory of the Normal School of Science and Royal School of Mines.

EXPLANATION OF PLATE XI.

[The numerator of the fraction expressing the degree of enlargement of an object represents the magnifying-power of the objective with which it was viewed.]

Fig. 1. Junction of the intrusive sheet of Ardtun with the basalt above it. Section showing bands of spherulites formed in the tachylyte on and parallel to the plane of contact. $\times \frac{25}{3}$.

2. Section of spherulites with polygonal outlines in the tachylyte of Ardtun. The rays showing the more fibrous structure are of various tints of brown, the intervening areas being greyish. $\times \frac{100}{3}$.

3. Section showing small spherulites, cumulites, &c., in the tachylyte of the Quiraing. $\times \frac{300}{3}$.

4. Section of red-brown spherulites and green-mottled matrix in the altered tachylyte of Tollymore, County Down. $\times \frac{400}{3}$.

5. Section of the Ordovician Ash of Snead, near Bishop's Castle, showing fragments of altered basic glass, which contain porphyritic and corroded crystals of felspar. $\times \frac{25}{3}$.

6. Section of pebble of variolite, from an old collection, showing perlitic structure; the cracks being marked by alteration-products, and the former glassy character of the rock being obscured by secondary devitrification. $\times \frac{35}{3}$.

Discussion.

Dr. Sorby referred to the changes which had occurred since he first took up the subject of rocks, and congratulated the Society on the reading of papers like this one.

Prof. Bonney also expressed his approval of the paper. He had not been fortunate in finding tachylytes. He could corroborate the Author's views as to the existence of these basic glasses in the

* *Ibid.* p. 255; also Minéralogie micrographique, planche xxiv.

† Tschermak's Mittheilungen, 1887, p. 61.

older tuffs, but the latter were generally of a more acid character. The specimen of variolite was unusual. This rock occurs *in situ* on the east side of the Durance, near Briançon, in thin dykes.

Col. McMahon also expressed his gratification at hearing the paper.

Prof. Judd was pleased to think that he had suggested the study of this class of rocks to Mr. Cole. There were, in the paper, many interesting points of comparison between the basic and the better-known acid glasses.

Mr. Teall observed that there was very little to criticize in the paper. He spoke of the interesting generalization to which the Author made his facts point.

Mr. Rutley said that the remarkable opacity of this group of rocks, due to disseminated magnetite, often rendered microscopic observations very difficult. He contrasted the structure of the Ardtun rock with that of certain artificially devitrified glasses. It would be interesting to ascertain the relative specific gravity of the spherulitic and non-spherulitic portions. He had seen structure somewhat similar to that of the Ardtun specimen in rocks of the same class from one or two other localities.

The Author thanked the speakers for their kind reception of his paper. He believed that the occurrence of tachylyte-fragments in the old rocks was no new point. The observation of perlitic structure in variolite was due to MM. Fouqué and Lévy. To Mr. Rutley he replied that spherulites, apparently similar, occur in tachylytes of different compositions. The question of the specific gravity of these bodies presents considerable difficulties.

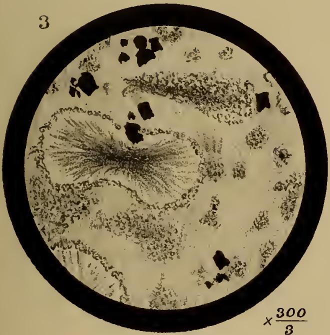
1

$\times \frac{25}{3}$

2

$\times \frac{100}{3}$

3



$\times \frac{300}{3}$

4

$\times \frac{400}{3}$

5

$\times \frac{25}{3}$

6

$\times \frac{35}{3}$

G. A. J. Cole del.
Parker & Coward lith.

West, Newman & Co. imp.

TERTIARY AND OLDER TACHYLYTES.

24. *On the* Gneissic Rocks *off the* Lizard. By Howard Fox, Esq., F.G.S. *With* Notes *on the* Specimens, by J. J. H. Teall, Esq., M.A., F.G.S. (Read March 14, 1888.)

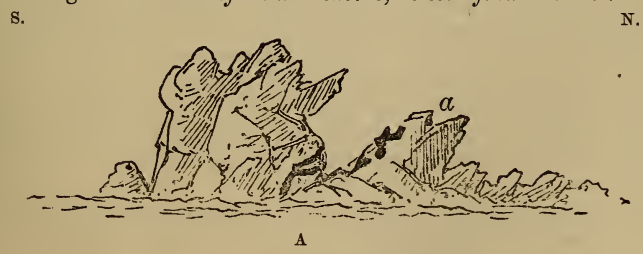
At Mr. Teall's suggestion, I made, during the past autumn, a methodical examination of the outlying rocks at the Lizard, and forwarded to him series of specimens from the various rocks. They may be classed under three heads:—the coarse gneisses or "Mên Hyr" type, the light banded granulitic gneisses or "Wiltshire" type, and the transition micaceous rocks of "Labham-Reefs" type. The annexed map (fig. 7, facing p. 316) shows how these rocks lie with respect to each other and the mainland. The coarse gneisses compose the outer rocks, and the fine gneisses the inner rocks. The transition rocks associate the gneisses with the typical schists of the mainland.

Beginning at the extreme west, we find the "Mulvin" composed of a dark granulitic gneiss with a strike and dip both clearly conformable with the rocks of the Lizard Head, the strike being about N.N.W. and S.S.E., the dip E.N.E.

The "Taylor" rocks are a group of three coarse gneissic rocks. The outer of these has a basic porphyritic dyke running across it from the S.W. to the N.E. with a S.E. dip. This dyke varies in width from one to four feet, and branches at the western end. The middle or main "Taylor" rock has a small gully on its southern extremity. At low-water spring-tide a basic porphyritic dyke, 18 inches wide, is seen to traverse this gully in an E.N.E. and W.S.W. direction, dipping S.S.E. The inner "Taylor" rock is mostly composed of a coarse gneiss with some basic bands.

The most conspicuous of the outlying rocks are the "Man-of-War" series, the western end of which towers high above the sea-level and is separated from the next highest, locally known as the "Spire," by a cleft or gully. The annexed rough diagram, fig. 1,

Fig. 1.—"*Man-of-War*" *Rocks, as seen from the east.*

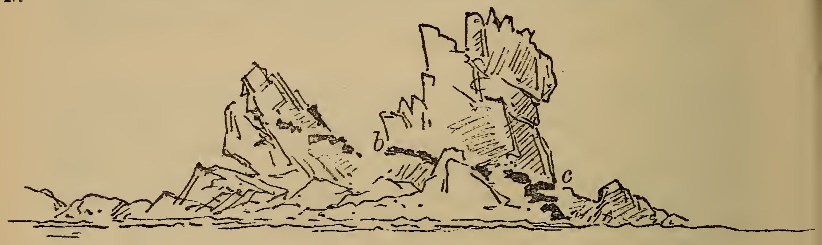


The black marks represent dykes.

A. The cleft in which landing is most easily effected.
a is known as the "Spire."

gives the general outline of the rock and dykes as seen from the east at extreme low water, and fig. 2 as seen from the west. The

Fig. 2.—"*Man-of-War*" *Rocks, as seen from the west.*



b, c. Basic dykes.

cleft A is the best place on which to land. A basic porphyritic dyke, from four to five feet wide, is seen to cut the high rock on the left hand. This dyke can be traced round the back of the rock (*b*, fig. 2), and appears again after a great fault on the south near the water's edge (*c*, fig. 2). It has a S.S.E. dip of about 50°. On the north and western side it is thickly studded with crystals of felspar which occasionally weather outside the ground-mass. On the right hand of the cleft A (fig. 1) stands the "Spire" (*a*, fig. 1). A basic porphyritic dyke, originally several feet thick, cuts the southern end of this rock. At the top of the "Spire" the strike of the gneiss and dyke appear to be conformable, viz., about N.N.W. and S.S.E. Below this the dyke cuts the gneiss. The dyke weathers out in huge blocks near the top, and in other places forks and branches into veins thinning away to mere threads. Veins of gneiss occasionally appear to traverse the dyke (see fig. 3), whilst both the gneiss and the dyke are in some places much weathered and altered. Quartz-veins run through both the gneiss and the dykes at right angles. Patches of the dyke are seen adhering to the gneiss on the western summit of this rock, the remainder of the dyke having in that spot jointed out. The gneiss composing the "Man-of-War" rocks is mostly coarse. After repeated and careful observations I believe both strike and dip to be conformable with the Lizard Head schists. When the "Man-of-War" rocks are viewed from the east or west the strike appears to be about east and west, and this is especially the case with the low ledges to the north of the "Spire." When, however, they are viewed from the south in a line with the Lizard Head the conformability of the two is seen pretty clearly.

The three rocks marked on the 25-inch Parish Map as the "Stags" are composed of coarse gneiss.

An isolated rock, immediately south of the "Quadrant," is locally known as "Sanspareil." It is composed of somewhat coarse gneiss with a basic porphyritic dyke running about N.W. and S.E.

with a S.W. dip. This dyke is thickly studded with crystals of felspar, and it branches and cuts the gneiss in an intricate manner. The original dyke appears to have been about 18 inches wide, and by jointing out to have caused a cleft on the east side of the rock.

Fig. 3.—*Portion of Basic Dyke in the "Man-of-War" Rocks, traversed by veins of gneiss.*

The shaded part is the dyke.

The high isolated mass of rock immediately south-west of the mainland is the "Quadrant." When the sea is calm this island is easily climbed, and the relations of the two basic porphyritic dykes which traverse it can be well studied, free from the barnacles which completely cover most of the other dykes. Approaching it from the south-east the "Quadrant" appears, as roughly sketched in fig. 4, with a dyke cutting the middle, faulted and almost perpendicular. When seen from the north-north-west the rock appears somewhat as in fig. 5. Both dykes are seen here, each about two feet wide, running E.N.E. and W.S.W. with an average S.S.E. dip of 50°. The northern dyke is a dark basic rock studded thickly with small crystals of felspar. In some places it weathers a glossy black; in other places the crystals project outside the weathered surface as if peppered on the rock. On the north-east it is abruptly cut off by an open fault or cleft (*a*, fig. 5). The southern dyke is seen to traverse the highest point in the centre of the island. At the extreme top it appears to be conformable with its gneissic surroundings and to dip at a very high angle towards the east-north-east. It weathers dark grey at this point with crowded projecting crystals, and is itself traversed by a gneissic band $1\frac{1}{4}$ inch wide at *b*, fig. 5. This dyke

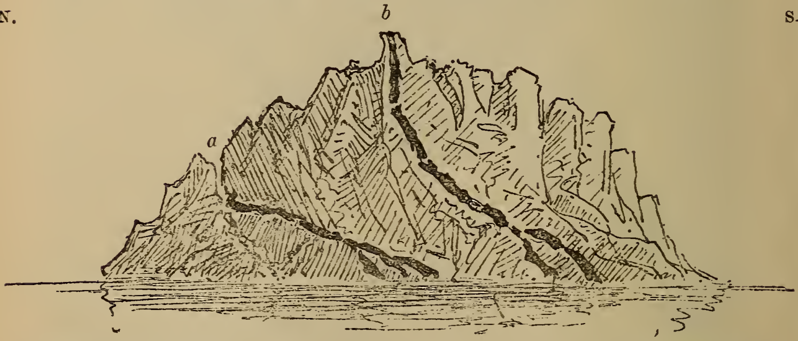
Fig. 4.—*The "Quadrant" Island, as seen from the south-east.*

S.

The black bands represent porphyritic basic dykes cutting the gneiss.

Fig. 5.—*The "Quadrant" Island, as seen from the north-north-west.*

N. S.



The black bands represent porphyritic basic dykes. *a*, northern dyke cut off by cleft; *b*, southern dyke traversed by thin gneissic vein.

is faulted below as seen in fig. 6, and resumes its normal dip. The "Quadrant" is composed mostly of somewhat coarse gneiss, but also of granulitic gneisses and of apparently transition-rocks intermediate between granulitic and actinolitic schists. From the top it appears to be conformable with the Lizard Head schists.

The rocks exposed at low water north-east of the narrow channel called Quadrant Drang are known as the "Quadrant Shoals." They are accessible from the mainland at extreme low spring-tides and are conformable with the Lizard Head rocks. Their composition is more basic than that of the "Quadrant." A dyke two feet wide similar to those on the "Quadrant" cuts the south-west rocks of these shoals.

North-east of the "Quadrant Shoals" we have "Canker Drang," which is covered with boulders and is dry at spring-tides, and on the north-east of the Drang we have the "Canker ledges." The south-west extremity of these ledges shows a fine granulitic rock approaching the "Wiltshire" type.

Fig. 6.—*Southern Dyke in "Quadrant" Island, faulted on north-west side of extreme summit.*

The "Wiltshire" Rock is accessible from the mainland at dead low water. This and the surrounding rocks are composed of a light-banded granulitic gneiss with sundry exposures of basic porphyritic rocks in their immediate vicinity. The strike of these "Wiltshire rocks" appears to be north of east and south of west with a southerly dip.

"Shag Rock" is partially gneissic. "Mên Par" is an isolated rock of coarse gneiss 450 yards south of Pistil Ogo.

The "Clidgas" are a group of three rocks from 650 to 800 yards south of Pistil Ogo. The inner of these, marked No. 1 on the map, is traversed by two almost parallel basic dykes with crystals of felspar scattered sparingly through their ground-mass. These dykes are from 18 inches to 24 inches wide, running N.N.E. and S.S.W. with an E.S.E. dip of about 50°. These three rocks are all comprised of coarse gneiss.

"Mên Hyr" and "Vasiler" are about 900 yards due south of Polpeor Cove, and are both composed of typically coarse gneiss.

"Pen Ervan" is a boss of somewhat coarse gneiss, with a band of softer micaceous rock at its extreme base on the west.

"Enoch Rock," or "St. Enoch," as the fishermen call it, and the ledges to the north of it, are more basic than the other rocks, and appear to dip S.W. by W.

"Labham Rock" is distinctly gneissic. "Labham Reefs," which can be reached at extreme low water without a boat, are apparently transition rocks, and present in close association rocks in various stages of transition from the brown micaceous schists of Polpeor to the distinctly gneissic rocks. The "Labham Reefs" appear to be conformable with the Lizard-Head schists.

All the foregoing rocks are covered at high water excepting Mulvin, Man of War, Quadrant, Wiltshire, Shag rock, and Labham. Some are uncovered only at extremely low spring-tides.

Notes *on* Rock-specimens collected *by* Mr. Fox *from the* Islands *off the* Lizard Head. By J. J. H. Teall, Esq., M.A., F.G.S.

The two small islands of Mên Hyr and Vasiler lie half a mile due south of Polpeor. A line drawn between these islands in a N.W. by W. direction passes through the Clidgas Rocks, the Man-of-War Rocks, and the Stags. These islands, together with Taylor's Rocks and Mulvin, which lie slightly to the south-west of the above line, constitute what may be termed the Outer Group. Inside these we have Enoch Rock, Pen Ervan, Labham Reefs, Labham Rocks, Mên Par, the Shag Rock, Wiltshire, the Quadrant, and Sanspareil. We will now describe the rocks from the different islands, taking the latter in the order mentioned.

Outer Group.

Mên Hyr.—A coarse gneissose rock showing a marked foliation. Dark lenticular patches, rich in ferro-magnesian minerals, alternate with light-coloured patches of similar form composed of quartz and felspar or pseudomorphous substances after felspar. Under the microscope the rock is seen to be composed essentially of felspar, quartz, dark mica, and hornblende. The felspar is so altered in places as to have lost all individual action on polarized light; it is then represented either by aggregates of a vividly polarizing scaly mineral (mica) or by patches which appear opaque by transmitted, and snow-white by reflected light. The unaltered felspar is abundant in certain portions of the slide; the larger grains are mostly striated. Quartz occurs in grains and granular aggregates. The quartz and felspar in certain portions of the slide exhibit the relations characteristic of igneous rocks; in others they form a fine-grained granulitic aggregate.

Brown mica occurs in scales which are often arranged with their flat surfaces lying roughly parallel to each other.

Hornblende occurs in grains, often elongated in the direction of the vertical axis, but without definite crystalline outline:—α, pale brown; β, green; γ, bluish-green. Iron-ores and a few small garnets occur as accessory constituents.

The rock possesses the mineralogical composition of quartz-diorite or tonalite, and may be described as a tonalite-gneiss. The granulation of the quartz and the felspar in certain portions of the rock is probably a consequence of the dynamic metamorphism which has affected the district.

Vasiler.—The specimens are similar to those from Mên Hyr.

Clidgas Rocks.—(1) Coarse tonalite-gneiss of the Mên Hyr type.

(2) A greenish-black rock (greenstone) with occasional crystals of porphyritic felspar. Under the microscope the porphyritic felspars are turbid and without individual action on polarized light; they lie in a ground-mass of hornblende and granulitic water-clear felspar. Grains of iron-ore and a few yellow prisms and twins of rutile are also present. The hornblende forms the greater portion of the mass; it occurs in extremely ragged patches and only here and there shows traces of crystalline form. The terminations of the longer patches sometimes run out into actinolitic needles. The granulitic felspar plays the *rôle* of matrix to the hornblende. The individual grains are as a rule untwinned, but the larger of them occasionally show striation. The hornblende is probably secondary after augite, and the rock may be termed a porphyritic epidiorite.

Man of War.—(1) Coarse tonalite-gneiss. A specimen from the east end of the Post differs from the one described from Mên Hyr only in containing more hornblende and garnet. The latter mineral occurs in well-formed crystals.

(2) Porphyritic greenstone (epidiorite) and actinolite-schist. Mr. Fox's sketches show that the rock-masses have been deformed since the dykes were intruded. We find evidence of this in the dykes themselves. In one specimen the greenstone, near its junction with the gneiss, has become a felspathic actinolite-schist. The actinolite-schist differs from the epidiorite of the Clidgas in possessing very perfect schistosity and foliation, and in having the whole of its hornblende in the condition of actinolite. The porphyritic felspars form "eyes" in the actinolitic schist.

Taylor's Rock.—(1) Gneiss. A section of one of the coarser gneisses from this island shows an irregular granulitic aggregate of quartz and felspar, the latter often striated, and actinolitic hornblende, which may be either brown, green, or nearly colourless. Iron-ores, garnets, and zircons occur as accessories. This rock differs from the tonalite-gneiss of the Mên-Hyr type in the extent to which the granulation of the quartz and felspar has been carried on. It might on this account be designated a granulitic gneiss, reserving the term granulite for a rock in which the quartz and felspar are present wholly in the form of a micro-crystalline mosaic of fairly uniform grain.

(2) Porphyritic greenstone (epidiorite).

The Stags.—(1) Moderately coarse-grained tonalite-gneiss containing garnet and sphene as accessories, and having the foliation imperfectly developed.

(2) Light-coloured, fine-grained granulite or granulitic gneiss, with well-marked foliation.

(3) Dark-coloured, fine-grained granulite or granulitic gneiss.

The last-mentioned rock is largely composed of a fine-grained micro-crystalline mosaic of quartz and felspar, in which needles of actinolite lie imbedded. Iron-ores are fairly abundant. Certain bands are rich in turbid felspar-pseudomorphs and larger grains of hornblende, so that the rock is not a typical granulite.

Mulvin.—Dark-coloured, fine-grained granulite or granulitic gneiss similar to the rock just described from the Stags.

Inner Group.

Enoch Rock.—Coarse hornblendic schist and gneiss (without quartz), quite distinct from the tonalite-gneiss and having close affinities with the hornblende-schist of the mainland.

Pen Ervan.—(1) A somewhat fine-grained, evenly foliated tonalite-gneiss.

(2) Brown micaceous rock, similar to the transition rocks of Labham Reefs.

Labham Reefs.—(1) Light-coloured or brownish granulite or granulitic gneiss.

(2) Brown micaceous schistose rocks intermediate in character between the granulitic rocks of the islands and the mica-schists of the mainland.

Labham Rock.—(1) A finely crystalline pinkish granulitic rock without well-marked foliation. Under the microscope this rock is seen to consist principally of quartz and turbid felspar. It contains also a very little hornblende and a few grains of epidote. The granulitic structure is well developed in places. A narrow vein containing much epidote traverses the slide.

(2) A rock similar to the above, but somewhat richer in the darker constituents. Under the microscope turbid felspars (original ?) are seen to lie in a granulitic aggregate of colourless quartz and felspar (secondary ?). Long needles of actinolite lie in the granulitic material. This rock possesses, in a certain sense, the "mortar-structure" of Törnebohm. It is, however, the "mortar" and not the "stones" that constitutes the greater portion of the mass.

(3) A banded and corrugated granulite or granulitic gneiss.

Mên Par.—Tonalite-gneiss of the Mên-Hyr type.

The Shag Rocks.—Rocks similar to those from Labham.

Wiltshire.—(1) Light-coloured, banded granulite, showing a finer foliation than that of Labham, but belonging to the same type.

(2) Granulite of the same colour, but without conspicuous banding. Under the microscope this rock is seen to consist principally of quartz and felspar, the latter mostly unstriated. Ferro-magnesian constituents are sparingly represented by a little green mica. The micro-structure of the rock is thoroughly granulitic.

The Quadrant.—(1) Granulite of the Wiltshire type. One specimen contains garnets and a little hornblende.

(2) Porphyritic greenstone (epidiorite).

Sanspareil.—(1) Granulite without well-marked banding, com-

d Reefs..

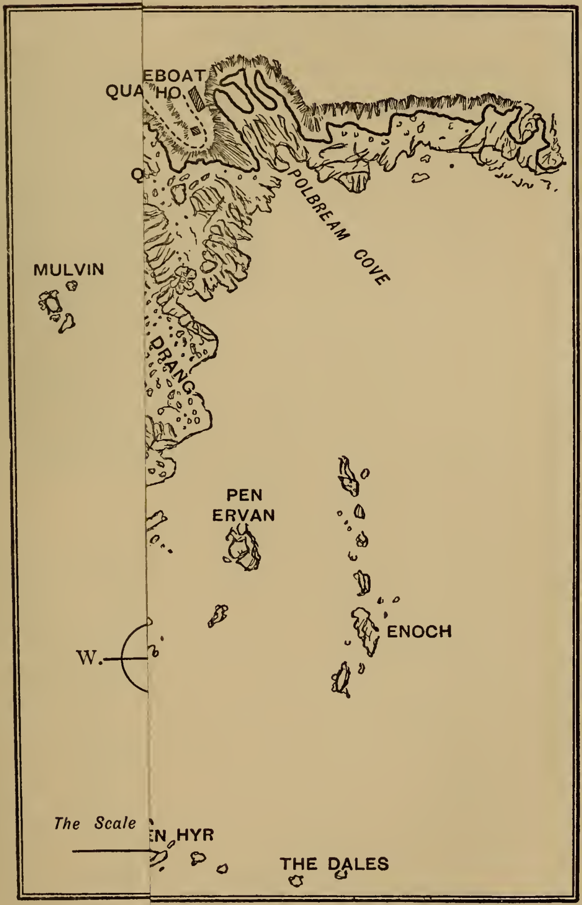

EBOAT
QUA HO
Q
POLBREAM COVE
MULVIN
DRANG
PEN ERVAN
ENOCH
W.
The Scale
EN HYR
THE DALES

Fig. 7.—*Sketch Map of the Lizard and adjacent Rocks and Reefs..*

posed of a granulitic aggregate of quartz and felspar, actinolite, and garnet.

(2) Porphyritic greenstone (epidiorite) precisely similar to that described from the Clidgas.

General Conclusions.

(1) The outer islands consist largely of coarse gneisses.

(2) The parent rock of these gneisses may have been an eruptive quartz-diorite or tonalite.

(3) The inner islands consist largely of granulites and granulitic gneiss.

(4) Associated with the gneisses and granulites are metamorphosed basic eruptive rocks in which porphyritic crystals of felspar are frequently present.

(5) The relations of these basic eruptives to the surrounding rocks have been much disturbed by the forces which have deformed the rock-masses in this district.

(6) The petrographical characters of the rocks themselves have been affected by these deforming forces, and actinolite-schist has been locally developed out of the intrusive greenstone.

(7) Some of the rocks of the Labham Reefs are intermediate in character between the granulitic rocks of the inner group of islands and the mica-schists of Polpeor.

(8) The period of dynamic metamorphism, of which the most striking results are seen in the schists of the south-western portion of the Lizard peninsula, was posterior to the formation of the basic dykes. There is no evidence of igneous action in this district since the period of metamorphism.

Discussion.

Prof. Bonney spoke in high terms of the value of the work, done, as it was, in a region accessible with difficulty, which time did not permit him to explore when working at the rocks of the mainland. The gneissose rocks are such as he would on *à priori* grounds have expected to find there, and somewhat resemble the gneiss of the Eddystone Rock. He considered that two structures occurred in the Lizard rocks—an older one, to which some would refer the apparent stratification of the rocks of the country, of a date long anterior to Ordovician times; and a later one, whose exact age is unknown, which seems to have acted with much energy nearly parallel with the coast-line, which very possibly is near a fault.

The Rev. E. Hill added his testimony to the extreme diligence required to elucidate an area such as that described.

25. *On some* VERTEBRATE REMAINS *in the* TRIASSIC STRATA *of the* SOUTH COAST *of* DEVONSHIRE *between* BUDLEIGH SALTERTON *and* SIDMOUTH. By H. J. CARTER, Esq., F.R.S. (Read February 29, 1888.)

(Communicated by A. T. METCALFE, Esq., F.G.S.*)

[Abridged.]

IN August last my attention was particularly called by the late Dr. John Millar, F.G.S., to the microscopic structure of the remains noticed by Mr. Metcalfe under No. 11 in his paper "On further discoveries of Vertebrate Remains in the Triassic Strata of the South Coast of Devonshire" †. These are small pellet-like amorphous bodies, averaging from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, composed of white calcareous matter, traversed in all directions by semitransparent crystalline plates showing bone-structure. These pellets occur plentifully in the fallen blocks of Triassic rock on the beach, which contain the remains of Labyrinthodonts &c. Dr. Millar remarked that they very much resembled coprolites and were identical in appearance with some in his possession from the Lias, which he would send me for comparison.

I had previously observed that the contained plates, when examined in water under the microscope, presented the same bone-structure as the scales of the Bony Pike of North America (*Lepidosteus osseus*), as shown by Prof. Quekett in his 'Lectures on Histology' ‡; and on grinding down a fossilized Lepidostean scale from Hordwell, Hants, I found its structure to be exactly like that of the recent species. On breaking up some of the pellets (which are formed of concentric layers), I found a fragment representing the angular part of a scale, on which the same agatoid lines of growth were visible as on the ganoid scales from Hordwell.

The slides of Ichthyosaurian coprolites sent to me by Dr. Millar showed sections of the same kind of plates with the same characteristic bone-structure, so that it became evident that the Ichthyosaurians of the Lias and the Amphibians of the Triassic age fed upon the same kind of Ganoid fish, whose scales, being too hard for digestion, have remained in the coprolites.

The plates of the Sturgeon present the same kind of bone-structure, viz. large lacunæ, which, when compared with those of Reptiles, Amphibia, &c., are seen to be provided with longer and less numerous canaliculi, elegantly waved and dendritically branched.

As regards the bone-structure of the so-called "Spine," No. 1 (*loc. cit.* p. 260, fig. 2), and that of the middle part of the jaw-bone

* This paper is supplementary to one on the same subject read by Mr. A. T. Metcalfe before the Society on January 9, 1884, and published in the Quarterly Journal of the Society, vol. xl. p. 257.

† *Loc. cit.* p. 261.

‡ Vol. i. p. 174, fig. 136.

of a Labyrinthodont, No. 2, there appears to me to be no difference between this and Reptilian bone-structure generally. It is totally different from that of the Lepidostean scale.

Lastly, as regards the above-mentioned spine, having examined generally and microscopically the spines of two species of *Hybodus*, I have to state that not only are the latter hollow and the former solid, but the bone-structure is quite different in the two cases; thus I can see no lacunæ at all in the spines of *Hybodus*, although there are canaliculi. Hence, whatever this fossil may be, we have no grounds for regarding it as a "spine."

Discussion.

The President observed that perhaps the most interesting remark in the paper was that relating to the so-called spine of Mr. Metcalfe's paper.

Mr. Smith Woodward said that on a former occasion he had suggested that the spine was the premaxilla of *Hyperodapedon* (see p. 163). He still adhered to that view.

Mr. Whitaker commented upon the complete destruction of the fish by the reptiles of the Triassic age.

26. *On the* Lower Beds *of the* Upper Cretaceous Series *in* Lincolnshire *and* Yorkshire. By William Hill, Esq., F.G.S. *With the* Description *of a* New Species *of* Holaster, by A. J. Jukes-Browne, Esq., F.G.S. (Read April 11, 1888.)

[Plate XII.]

Until recently no attempt had been made to describe the zonal divisions of the lower beds of the upper part of the Cretaceous series in Lincolnshire. Indeed, Prof. Judd remarked in 1869, "The time has not yet come for separating the great mass of the Chalk formation in this county into zones, ... such a task not having been accomplished in the best-explored districts of the Chalk" *.

In 1876 Dr. Charles Barrois †, having been unable to visit this county, follows, in his well-known work, the description given by Prof. Judd. It was not until the publication, in the spring of 1887, of the "Geology of part of East Lincolnshire," a memoir of the Geological Survey, that a systematic attempt was made to correlate any part of the Chalk of Lincolnshire with that of the more southern counties of Cambridgeshire, Hertfordshire, &c.

But the author of this memoir laboured under a disadvantage; for, as he remarks (p. 28), "The zones of the latter county [Cambridge] have not yet been traced northward into Norfolk, where the Chalk begins to put on what may be termed the northern or Lincolnshire facies; the data requisite for the proper correlation of the two areas are therefore incomplete." And again (p. 31), "As yet we know nothing of the changes which the Chalk zones undergo in their passage from Cambridge to Norfolk; and in the absence of this connecting stratigraphical evidence, the correlations now suggested are not to be received as a decided expression of opinion."

But while this memoir was in the press, Mr. Jukes-Browne and myself undertook the investigation of the lower part of the Chalk in Suffolk and Norfolk, the results of which have already been published ‡.

We therefore now possess that connecting-link of stratigraphical evidence which was wanting when my friend and colleague in the Norfolk paper completed the Memoir for the Geological Survey on East Lincolnshire; and it seemed to me almost as much a duty as a pleasure to carry forward the knowledge obtained by the study of the Chalk in Suffolk and Norfolk, and apply it to the same series of the Cretaceous system in Lincolnshire and Yorkshire.

The Chalk of Yorkshire has been the subject of several papers.

The Rev. Prof. Wiltshire § has given a brief description of the Speeton cliffs, written before the main divisions of the Chalk were

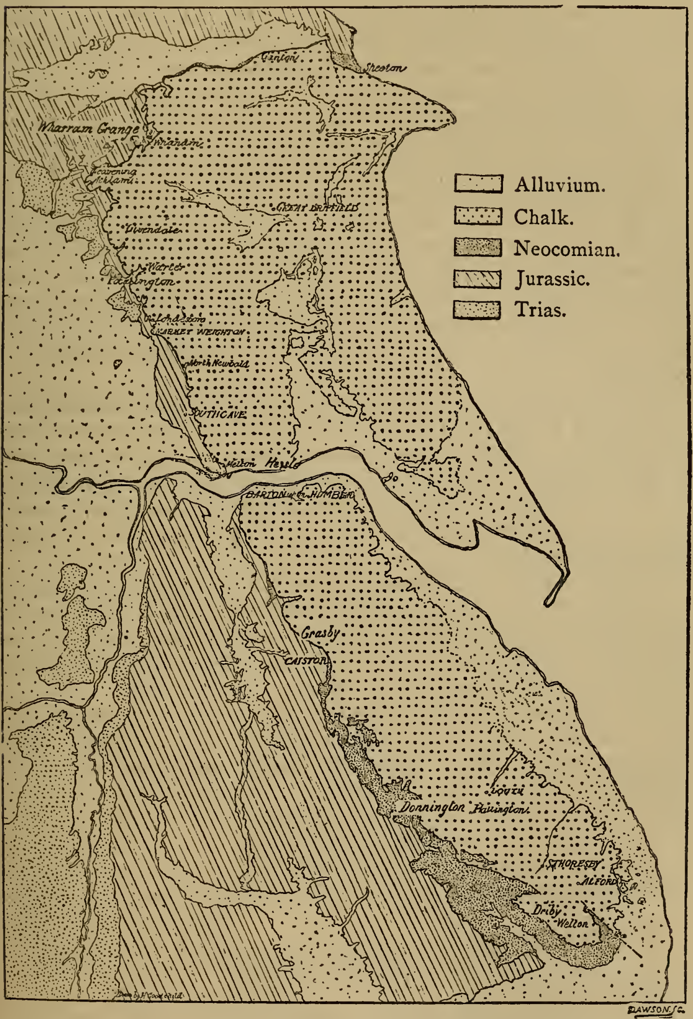
* Prof. J. W. Judd on "The Lincolnshire Wolds," Q. J. G. S. vol. xxiii. p. 235.

† C. Barrois, "Recherches," &c. Mém. Soc. Géol. du Nord, vol. i. p. 189.

‡ "On the Lower Beds of the Upper Cretaceous Series in Suffolk and Norfolk," by A. J. Jukes-Browne and W. Hill, Q. J. G. S. vol. xliii. p. 544.

§ Wright's 'Mon. Brit. Fossil Cretaceous Echinodermata,' p. 8.

Fig. 1.—*Sketch-Map of the Outcrop of Cretaceous Rocks in Lincolnshire and Yorkshire.* (Scale 15 miles to 1 inch.)



understood. It contains, however, valuable information. Mr. Meyer* has also contributed a short paper on the Red Chalk of Speeton.

Dr. C. Barrois † visited Yorkshire in 1875, but he states that his time was limited. He describes very briefly the interior of the county, but speaks at greater length of the section at Speeton. He correlates the lower beds of the Upper Cretaceous series with those of the South of England; but the absence of information concerning the changes which these beds undergo as they are followed north from Cambridge, and the misconception (since corrected) which he formed as to the position of the Totternhoe Stone, appear to have affected his judgment as to the thickness and sequence of these beds both at Hunstanton and in Lincolnshire and Yorkshire. He appears, however, to acquiesce in the greater extension of the zone of *Holaster subglobosus* at Speeton in his criticisms ‡ on the paper by Prof. J. F. Blake.

Prof. J. F. Blake § has contributed a valuable paper in which he describes the whole of the Chalk of Yorkshire. He correlates it with the divisions of the South of England in a general way and discusses the classification of it as adopted by Dr. Barrois, for whose criticisms thereon see note ‡. Much information on the Lower Chalk of Yorkshire is given in three small Memoirs of the Geological Survey ‖, but the correlation of it with that of Lincolnshire is not attempted.

A detailed description of the lower part of the Speeton cliffs may be found in Phillips's 'Geology of Yorkshire.' The measurements given differ but slightly from my own, but no two observers seem to agree exactly in the amount of coloured and uncoloured Chalk seen here. This may be the result of taking colour-lines as the basis of measurement; they will be shown in the sequel to be untrustworthy guides.

I must thank Mr. Jukes-Browne for his cooperation in the correlation of the Norfolk and Lincolnshire series, and for giving me the benefit of his knowledge of the latter county, thereby saving me much time and labour in the field, and also for the description appended of a new species of *Holaster*.

And I am also much indebted to Mr. C. Fox-Strangways, who gave me every assistance in the investigation of the Lower Chalk of Yorkshire, and to Mr. Goodchild for the accompanying sketch map (fig. 1).

§ I. LINCOLNSHIRE.

Stratigraphy.

From the results of recent work in Suffolk and Norfolk ¶ it

* Geol. Mag. vol. vi. p 169.

† C. Barrois, "Recherches sur le terrain Cretacé Supérieur de l'Angleterre et de l'Irlande," Mém. Soc. Géol. du Nord, vol. i. p. 191.

‡ Proc. Geol. Assoc. vol. vi. p. 165.

§ Prof. J. F. Blake, "On the Chalk of Yorkshire," Proc. Geol. Assoc. vol. v. p. 232.

‖ Geol. of York and Hull, Geol. of Driffield, Geol. of 'Scarboro': Mems. Geol. Survey.

¶ Q. J. G. S. vol. xliii. p. 544.

appears that, in spite of greatly reduced thickness and considerable lithological change, the zonal divisions of the lower beds of the Upper Cretaceous series in these counties agree with those established in the Midlands and South of England.

It is shown, in the paper referred to, that the Melbourn Rock is continuous from Newmarket to Hunstanton, thus defining the upper limit of the Lower Chalk, although the Belemnite-marls were found to die out; that the Grey Chalk became thinner and harder as it was followed northwards; that the Chalk Marl passed laterally into a pure and very hard chalk, its summit, however, still marked by the Totternhoe Stone, which, like the whole series, shared in a general attenuation. The Cambridge Greensand was found to die out gradually, and the Gault, also thinning and becoming more calcareous, appears to be represented in the extreme north-west corner of Norfolk by the Red Chalk or Hunstanton Limestone, the so-called "Sponge-bed" overlying it being included in the Chalk Marl (see Section I. p. 366).

The very full and minute details concerning the Chalk, published in the "Geology of part of East Lincolnshire" *, render it scarcely necessary to do more than review the Lower Chalk of this county, adding only the results of my own work which confirm and strengthen the opinions of Mr. Jukes-Browne, and noting such facts as may be of service in the correlation of the series in Yorkshire.

The Lower Chalk of Lincolnshire is divided in the Memoir into two portions, which are considered separately, viz. a lower, which includes, besides the basement-bed of Red Chalk or Hunstanton Limestone, some 36 feet of rough greyish-white chalk, and an upper portion, about 40 feet, which contains locally some pink bands, the line being drawn about 7 feet below the lowest of these †.

The summit of the Lower Chalk is fixed at certain marly bands which are considered to be the representatives of the Belemnite-marls of Cambridge, Hertfordshire, &c.

This division so nearly corresponds with my own reading of the strata, that it will be convenient to follow the Memoir in discussing the Lower Chalk of this county, separating only the basement-bed of Red Chalk, which has been shown to be the probable equivalent of the Gault.

It is fortunate that in South Lincolnshire, near Welton, at a point nearest to the Hunstanton cliff, there are pits which give almost a complete section of the lower beds of the Upper Cretaceous series. It will be seen from the accompanying diagrams (facing p. 366), and by reference to the text, that there is a remarkable similarity in the sequence of the beds at both places; certain points of difference will be noted in the sequel.

The sequence and general character of the various beds seen in

* Mem. Geol. Survey, Sheet 84.

† This division was only adopted for the sake of convenience in describing the exposures. In the fossil lists the Lower Chalk is divided into three portions, a lower, central, and upper, the division-line between the central and upper parts being taken at the base of the pink band.

the chalk here extends throughout Lincolnshire and Yorkshire. I propose, in this county, to deal with each separately, and note any important difference which may occur further to the north, or help in the correlation of the Yorkshire series.

The diagram No. II. is drawn up from sections exposed in the following pits:—that worked by Mr. Rutter ¼ mile S.S.W. of Welton Mill, at the cross roads on the west side of the road to Candlesby (page 44 of the Memoir); the pit on the opposite side of the road to the Cross Keys Inn, close by the first and forming with it a continuous section; lastly, a pit ½ mile west of Welton and ¼ mile N.N.E. of the Mill (page 51 of the Memoir).

(A.) *Red Chalk or Hunstanton Limestone.*

This bed, continuous throughout Lincolnshire, is about 11 feet thick at the southern extremity of the Wolds. It retains this thickness to the north of Louth, but diminishes to 4 feet in the northern part of the county. It is the "amplified counterpart" of the Hunstanton Limestone. Its base seems invariably to partake of the nature of the underlying material, and it is frequently difficult to say exactly where the Red Chalk begins. It passes up into rough and rather nodular chalk with marly partings, and its summit is frequently, though not always, marked by a thin band of red clay, which separates it from the pinkish or yellowish-grey chalk, the equivalent of the so-called Sponge-bed of Hunstanton, which overlies it.

The list of fossils given in the Memoir from this bed is a short one, and I can, with one important exception, add little to it. *Belemnites minimus*, which occurs commonly in the Gault and Hunstanton Limestone of Norfolk, is also abundant in the Red Chalk of this county, occurring throughout it, though individuals are more abundant near the base. I am fortunate, however, in being able to add to the list *Ammonites interruptus* from Withcall, a fact which considerably strengthens our expressed opinion that *this bed is the equivalent of the Gault.*

(B.) *Lower Chalk.—Chalk Marl.*

The Chalk Marl, as before noted, alters its lithological characters and becomes thinner as it is followed northward. At Hunstanton its base is recognized in the so-called Sponge-bed, which is followed by the grey and gritty *Inoceramus*-bed, with a layer of green-coated nodules at its base. This, passing up into hard whitish chalk, is finally overlain by a marked course of grey-coloured chalk, also with green-coated nodules at its base. This bed, the representative of the Totternhoe Stone, marks the summit of the Chalk Marl, and the fauna obtained from this division will compare with that from the upper part of it in Cambridgeshire, Hertfordshire, &c.

"*Sponge-bed.*"—The pinkish or yellowish-white chalk which immediately overlies the Hunstanton Limestone in Lincolnshire, and is the equivalent of the "Sponge-bed," retains its character as a thin band of compact limestone, differing somewhat in appearance and fracture from the overlying beds, not only through this county but far into Yorkshire. It is generally thicker in Lincolnshire than at Hunstanton, and the line of separation from the underlying bed is not always so well marked as in the Hunstanton cliffs.

Inoceramus-*beds.*—Grey in colour and gritty to the touch, the next 5 or 6 feet of the Chalk are usually compared with the *Inoceramus*-beds of Hunstanton. Here the bed appears to me rather more nodular in its character than its Norfolk equivalent, the nodules being of a less gritty material than the surrounding matrix. A marked layer of green-coated nodules occurs about 6 inches above the top of the Sponge-bed in the various pits near Welton. The base of the Chalk appears to retain this gritty character throughout the county. The greater part of the Chalk, for some 30 feet above the basement-bed in this county, may be described as rough and nodular; this division, however, contains courses of smoother chalk, for example, the "blue course" (Mem. page 43), near the base, and others near the summit, where the chalk is divided into courses by more or less marked bands of greenish-grey marl.

The section recorded in the Survey Memoir at Mr. Rutter's pit near Welton (see Section II. p. 366) is that of the face of the quarry which is still worked; but a little to the north of this, in the older part of the workings further up the slope of the hill, the section can be carried higher. The platy chalk with marked marly bands, the uppermost bed in the section given, can be followed round the pit and seen to continue for about 4 feet more upwards.

(C.) *The Grey Bed.—The equivalent of the Totternhoe Stone.*

Overlying the Chalk just described a bed with strongly marked characters occurs. This is about 3 feet thick, sometimes in more than one course, and of rough rather nodular massively bedded chalk, its darker grey colour showing plainly by contrast with the whiter material above and below.

Its base, in which there are many pale yellowish green-coated nodules, is here not well defined, the greyer material being let down in pipes and mottlings into the whiter chalk below; in Central Lincolnshire the lower 6 inches will frequently weather and split into thin flaky pieces, and a band of grey marl forms a line of division from the underlying chalk, which for about a foot down is often hard and "knobbly." It passes up into a course of hard, nodular, and whiter chalk, the top of the bed not being well marked.

It is very fossiliferous, and the fauna which I have collected from it is characteristic of the Totternhoe Stone (see page 349), and its structure, when seen in thin sections under the microscope, will compare with that of this stone.

The "Grey Bed" I believe to be without doubt the continuation of that which marks the summit of the Chalk Marl at Hunstanton, and therefore it is the representative in Lincolnshire of the Totternhoe Stone. This bed, which is formed by the basal courses of "nodular grey chalk underlying the lower pink course" *, is always well marked throughout the county by the characters noted above, as well as by the chalk which lies beneath and above it.

In the following details I indicate its position in the sections described in the Memoir, and give other sections to the north of the area included in it.

Besides Mr. Rutter's pit at Welton, the "Grey Bed" is seen in a pit just on the other side of the road, opposite the Cross Keys Inn, at the north corner of which the following succession was measured (page 44 in the Memoir):—

		ft.
	Thin-bedded rubbly chalk with persistent layers of shaly buff-coloured marl, containing *Terebratulina gracilis*	10
The "Grey Bed."	Very hard nodular grey chalk, irregularly bedded (*Rhynch. Mantelliana* and *O. vesicularis*)	3
	Hard *greyish-white* † chalk in thin beds with partings of laminated marl	6
	Hard *greyish-white* † chalk in beds about a foot thick	5

The bed is seen again at South Thoresby. The following is the section (slightly abridged) given in the Memoir (page 52):—

		ft.
	Broken rubbly chalk	1
	Pale pinkish-white chalk	2
	Hard brittle yellowish-pink chalk	7
	Layer of dark grey clay	—
	Greyish-white chalk	6
	Compact grey chalk	4
	Layer of grey shale	—
	Hard cream-coloured chalk	4
	Thin layer of soft yellowish marl	—
	Reddish marly chalk indistinctly bedded, pink and brick-red above, pink with grey lumps below	6
	Hard grey(*ish*) † gritty chalk in thick beds, the top being nodular and broken	4
	(A large Ammonite seen here.)	
The "Grey Bed."	Hard grey chalk with nodular crystalline lumps	3

The next important exposure of this bed is at Tetford Wood. The section was originally taken by Prof. Judd. It is slightly altered in the Memoir and given as follows (page 54):—

		ft.
	Soil and chalk-rubble	2–3
	Greyish-white chalk in thin beds rather broken	10
	Pale pink chalk, with soft marly layers, and a whitish band at base	5½
	Hard nodular grey chalk	2
The "Grey Bed."	Grey sandy [? gritty] chalk ("drab bed")	1½
	Greyish nodular chalk ("knobbly white bed")	2
	Greyish-white chalk, evenly bedded, &c.	12
	Nodular grey chalk in regular beds	3

* Geol. E. Linc. p. 34. See also diagram.

† The alteration here is mine.

I have not seen this section. Mr. Jukes-Browne agrees with me as to the position of the Grey Bed.

In Mr. Clapham's pit, on the north side of Louth, and just west of the Union, it is seen again. The section is a long one and the description (page 57) is here abridged :—

		ft.	in.
	Soil and Hessle clay	6	
	Chalk-rubble	1	
	Yellowish-pink chalk	8	
	Greyish-white chalk, thin-bedded	11	
	Hard nodular massive chalk	4	
	Nodular *greyish-white* * chalk	3	
	Seam of grey marly clay	—	
	Pink and grey chalk passing down into reddish, lumps of grey and seams of red marl in the middle	7	
	Hard *greyish-white* * nodular chalk	2	9
The "Grey Bed."	Compact grey chalk, gritty or sandy, very hard and dark grey when wet (resembles the *Inoceramus*-bed)	1	7
	Hard grey nodular chalk, becoming platy below ...	2	6
	Hard *greyish-white* * chalk in thick beds with partings of shale	20 †	

The "Grey Bed" is included in the "hard grey chalk in massive blocks (fossils)" 8 feet thick, given in the section which occurs in the valley north of Hubbards Hill and opposite to Louth Waterworks.

At Hallington it is seen again and seemed to me to approach the colour-band more closely than in any other section. It is described as "hard grey nodular chalk (*Ammonites rotomagensis* and *Pecten orbicularis*), 2 feet," and "Hard Grey Chalk, open-jointed and breaking into blocks, 1¾ feet." At Withcall Station it is well shown, and is included in the basement-bed of the section given. It can be followed for some distance along the railway, being constantly thrown up by a succession of small faults.

In a pit on the hill about 5 furlongs east-north-east of Donnington Station it is again exposed, its position in relation to the lower pink band being the same as at Louth. The most northerly point at which I saw this bed was at Grasby, north of Caistor. In a pit in the village, close to the main road, the section is as follows :—

		ft.
	Soil and rubble	1
	Whitish, soft and rather marly chalk, with buff-coloured marly bands, faulted down to the north-east	12
The "Grey Bed."	Hard, grey, gritty chalk, with grey-coated nodules (fossils)	3½
	Hard, greyish-white chalk in massive beds	8

The section is now somewhat obscured by talus. The Grey Bed weathers into large flaggy pieces.

Without the knowledge of the lateral change which takes place in the lower beds of the Chalk between Cambridge and West Norfolk, it is not surprising that so comparatively insignificant a bed should

* The alteration here is mine.

† I saw 20 feet of greyish-white Chalk below the Grey Bed in November, 1887.

have been overlooked. But the recognition of its true horizon is of the greatest importance in considering the correlation of the Chalk of this northern area with that of the south.

(D.) *The Grey Chalk.*

The section of the Chalk of South Lincolnshire is continued upwards for 12 feet more above the "Grey Bed" in the pit opposite to the Cross Keys Inn (for section see page 326). Above the "Grey Bed" is a rather nodular course of greyish-white chalk, and over this the chalk becomes indefinitely bedded, weathers into rubbly or nodular fragments, and is divided into courses by bands of buff-coloured shaly marl. The sequence of "Grey Bed," and hard, compact, nodular course, followed by 10 or 12 feet of indefinitely bedded chalk with marked marl bands, seems always to occur throughout the county, although in pits which have been freshly quarried, the peculiarities of the marly chalk are not so evident. To the north, at Thoresby, Louth, Withcall, and Donnington, it is this vaguely bedded chalk with marl bands which is partly coloured pink—the lower pink band—the colour of which at once takes the eye; but this chalk is always described as, "marly," or "shaly," or "with marly layers," &c.

Between the top of this pit, opposite the Cross Keys Inn, and the base of the exposure showing the summit of the "Grey Chalk" there is a gap.

In the pit half a mile west of Welton church (Memoir, page 51) the chalk is capped by two bands of laminated marl enclosing a band of hard whitish chalk. From evidence obtained further to the north these bands are without doubt the representatives of the Belemnite-marls (zone of *Belemnitella plena*) of Hertfordshire and Cambridge, and the rock below them is therefore the summit of the Grey Chalk.

In this pit it is seen to be fairly massive and evenly bedded; it appeared to pass down into rough and more nodular Chalk with marly bands, and I should judge that 20 feet of Chalk below the Marls is exposed here. From its appearance and from the knowledge obtained of this horizon further to the north, I believe the floor of this pit is not very far above the top of that at the Cross Keys.

Many exposures fill the gap which occurs at this point, and by reference to the Memoir it will be seen that on the whole the upper part of the Grey Chalk is evenly bedded, and divided into courses of uncertain thickness by bands of grey marl. From South Thoresby to Louth it is seen to be coloured pink immediately beneath the Belemnite-marls, but this coloration is lost in the northern part of the county. It will be seen in the sequel that the recognition of the sequence of the beds described above is of hardly less importance than that of the "Grey Bed."

The incoming of the marly chalk at the base of this division is foreshadowed in Norfolk. It will be seen in the diagram of the Hunstanton cliff * that indefinite marly bands are mentioned; these

* Quart. Journ. Geol. Soc. vol. xliii. p. 562.

occur also at Snettisham and Dersingham, but they seemed at the time hardly worth recording; their significance is now evident.

A remarkable feature throughout Lincolnshire and Yorkshire is the number of large Ammonites which occur in the basal part of the Grey Chalk.

(E.) *Zone of* Belemnitella plena.

It only remains to note the bands of marl which are taken in the Memoir as the upper limit of the Lower Chalk. That they are the true representatives of the zone of *B. plena* of Hertfordshire and Cambridge* is, I think, beyond doubt, for I am able to record from them the typical fossil *Belemnitella plena*, and moreover the fossils which occur in the under- and overlying chalk are such as occur at the same horizon in the Midlands and the South of England, and there are indications of a break at this horizon, which has been discussed elsewhere †. The Belemnite-marls are seen in the Welton pit as two layers of rather dark grey laminated clay separated by a course of hard whitish chalk, that beneath the lower band being broken and rubbly. These bands fringe the top of the pit on the north side, and nothing is seen above them.

The presence of the Marls in this pit is not noted in the Memoir, the face having probably been cut back since the district was surveyed. To their constant presence throughout the area described in the Memoir I need not further allude, ample information concerning them being given.

To the north of this area I have seen them at Caistor, where, in a pit about 3 furlongs south-east of the church, they are just seen at the base; the section is:—

		ft.
	Soil and rubble	3
	Hard white chalk with 2 lines of flints	6
	Jointed chalk and shale	¾
	Hard buff and greyish chalk in even courses about 1 ft. thick, with partings of grey shale	11
Zone of *Bel. plena*	Variegated, buff and bluish-grey laminated clayey marl seen for	1½

They are again well shown in the three large quarries west of Barton on Humber. Here I had no difficulty in finding for myself specimens of *Belemnitella plena* ‡, and they were evidently well known by the quarrymen.

As there is, so far as I know, no published account of the section seen here, I give it as follows:—

* Quart. Journ. Geol. Soc. vol. xlii. p. 216.

† "Geol. of Cambridge," Mem. Geol. Survey, p. 137.

‡ Mr. E. Hall of Louth showed me the lower half of a specimen of *B. plena* from one of the pits in which the marls occur, on the London road just south of Louth. I am also indebted to Mr. Hall for specimens obtained from the Grey Bed.

Section shown in the first of the three large quarries nearly two miles west of the railway station, Barton-on-Humber.

			ft.
Middle Chalk.	? Zone of *Terebratulina gracilis.*	Hard white chalk with lines of flints in courses of unequal thickness, divided into massive blocks by irregular joints, which pass through many feet of material, passing down gradually but decidedly into	+ 35
	Zone of *Rhynch. Cuvieri* and Melbourn Rock.	Hard rough yellowish-white rocky chalk, weathering into thin flakes with uneven nodular surfaces, divided into beds of uncertain thickness, by persistent but thin bands of greyish marl, no flints	10
Lower Chalk.	Zone of *Belemnitella plena.*	Thin greenish-grey marly veins enclosing whiter marly chalk	$\frac{1}{4}$
		Smooth grey marly chalk, weathering into thin laminæ	2
		Dark bluish-grey marly chalk, weathering into thin laminæ, centre darkest, the colour variegated with buff or lighter grey	1
	Zone of *Holaster subglobosus.*	Very rough nodular chalk, graduating to	$\frac{3}{4}$
		Less rough, irregularly jointed whitish chalk	2
		A remarkably massive course of whitish hard chalk	$2\frac{1}{2}$
		Bedded whitish chalk, separating by weathering into thin platy pieces along green-grey marly veins	10

The fossils which I found in these pits are those which occur most commonly at this horizon in the South of England. In the base of the Chalk with flints, I found *Rhynchonella Cuvieri*, *Echinoconus subrotundus*, and *E. globulus* (?). *Inoceramus mytiloides* was very abundant at the top of the yellowish chalk, and *Rhynchonella Cuvieri* occurred. *Belemnitella plena* was found in the blue-grey marl, and *Rhynchonella plicatilis*, *Terebratula biplicata*, and *Ostrea vesicularis* in the rubbly band below. *Holaster subglobosus* and *Discoidea cylindrica* were not uncommon in the lowest bed.

With regard to the thickness of the Lower Chalk of Lincolnshire, I should estimate it generally at about 75 feet, and I am hardly prepared, with the author of the Memoir, to consider it thicker at the southern end of the Wolds than at Louth.

I have now sketched, as briefly as the matter will allow, the characters and sequence of the lower beds of the Upper Cretaceous series in Lincolnshire; and, viewed by the light of recent investigations in Norfolk, the correlation of the series is by no means difficult. The general likeness of the Red Chalk and lower part of the Chalk Marl has long been recognized.

The persistence of the Totternhoe Stone through Norfolk and Suffolk, in spite of the general attenuation, is a fact which, of itself, would lead one to infer the possible existence of a like bed in Lincolnshire, where the similarity of the chalk below is so great. That it is represented by the band of gritty grey-coloured chalk, which in its position, general character, and fauna, bears the closest relation to the Totternhoe Stone, is, I think, a natural inference.

General Succession of the Lower Beds of the Upper Cretaceous series in Lincolnshire.

				ft.
	Middle Chalk.		Hard, creamy, yellow chalk without flints, containing a marked layer of whitish chalk—the columnar bed .... about	15
Lower Chalk.	Zone of *Belemnitella plena.*		Buff or dark grey shaly marl, sometimes stained reddish or purple; in some localities including a layer of harder whitish chalk	2
Lower Chalk.	Grey Chalk.		Bedded whitish chalk in courses, sometimes separated by thin marly bands .... The upper part of this division is coloured pink in central Lincolnshire.	21
Lower Chalk.	Grey Chalk.		Indefinitely bedded and rather marly chalk, with marked marl bands .... This bed is also partly coloured pink in central Lincolnshire.	16
Lower Chalk.	"Grey Bed."		A marked course of grey-coloured chalk, with green-coated nodules at its base	2 to 4
Lower Chalk.	Chalk Marl.		Rough chalk, with marked marl bands, smoother courses at intervals, base grey and gritty	30
Lower Chalk.	Chalk Marl.	Sponge bed.	Hard compact bed of chalk, sometimes stained yellowish red, the colour graduating into the bed below	2
	Gault.		Red Chalk or Hunstanton Limestone............... Thins in the northern part of the county to 4 ft.	12

§ II. Yorkshire.

The evidence concerning the sequence of the Lower Beds of the Upper Cretaceous series in Yorkshire is of the scantiest, and far different from that of Lincolnshire, where quarries are of frequent occurrence at all horizons. There are, in fact, so far as I know, only three exposures along the whole escarpment of the Wolds where a reliable section of the sequence can be obtained. Small pits or patches of bare chalk afford just sufficient evidence of the continuation of beds of marked lithological characters, but, as will be explained, little reliance can be placed on their relations to beds above or below.

There is a gradual rise in the base of the Chalk in Yorkshire as we proceed to the N.W. along its outcrop, from 150 feet at Welton, near the Humber, to about 600 feet between Leavening and Acklam. It will be seen in the sequel that this point nearly coincides with that at which the Red Chalk is thinnest and the overlying beds show a slight attenuation.

With the gradual change in the direction of its outcrop from N.W. to E.N.E. the base begins to descend, and it ultimately nearly approaches sea-level at Speeton. But in neither case does its line of outcrop coincide with the true strike of the beds, which must be taken along a line joining the points where its outcrop is intersected by the plane of the sea, *i. e.* N.N.E. from North Ferriby to Speeton Cliff. The centre of the Yorkshire basin therefore is somewhere to the east of Driffield. The northern escarpment of the Yorkshire

Wolds seems to me the southern edge of a transverse valley, the northern side of which has been entirely removed, so that the strata exposed may be regarded as a nearly transverse section of the Cretaceous basin.

To the well-known unconformity between the Chalk and the underlying strata I need not further allude.

As in Lincolnshire, I separate the Hunstanton Limestone, dealing with it alone; but it will be more convenient, to save repetition, if the whole of the Lower Chalk to the Belemnite-marls is dealt with at each of the principal exposures, taking the minor evidence of the continuance of the beds as we proceed from south to north.

The Condition of the Chalk on the brow of the Wolds.

In the consideration of the thickness and sequence of the Lower Beds of the Upper Cretaceous series in Yorkshire, a formidable difficulty presents itself in the broken and disturbed condition of the Chalk along the brow of the Wolds. For the greater part of their length the stratum underlying the Chalk is a clay, and as the base of the Chalk becomes elevated, this occupies a proportionally larger part of the slope at the base of the Wolds.

Everywhere the effect of the weather on this clay is apparent; for the rain, helped probably by frost, destroys its cohesion for a short distance from the surface, and a mass, usually not very extensive or deep, begins to move down the hillside. In the central and northern part of the Wolds, where the base of the Chalk reaches its highest elevation and the clay-slopes are mostly grass land, this general downward motion is evidently now going on, and its action is seen in the fact that the roots of herbage and grass are parted more or less perfectly along the outer edges of the slip and also in the wave-like roll which the mass assumes at its lower boundary.

Such slipping masses can be seen in any railway-cutting through clay near London, and are evidently a constant trouble to the district engineer.

But the effect of this constant removal of clay from a higher to a lower level has, I think, been somewhat underestimated. It appears to me that the gradual removal of the supporting material from the base of the Chalk would first cause the outer edge of the solid chalk to incline towards the valley, and ultimately the higher beds would slip over the lower ones in their descent on the yielding surface of the clay, or a large part of the hillside would slip down bodily, the more solid beds retaining their normal relations to each other. That considerable masses of chalk have slipped over the lower beds must be evident to anyone who will examine the Chalk along the brow of the Wolds.

This overslipping of the beds may be the reason why for so long a distance no Red Chalk can be seen, the actual outcrop being buried under the débris of higher beds. Slips of considerable importance have taken place in comparatively recent times; for instance, a large part of the hillside near Wharram Grange has slipped down, I think, within this century, and the débris entirely obscures for some distance all traces of the lower beds. The site of this slip is now planted with trees, but it still bears the name of "Earthquake" plantation. A slip of minor importance took place at Leavening within living memory (see p. 341). It is without the province of this paper to discuss at greater length the question of the weathering of the Chalk-escarpment of Yorkshire, my object being to show that little dependence should be placed on the position of small exposures (mere patches frequently) as indicating the original outcrop of the beds.

It is, indeed, quite possible that the surface on which the Cretaceous rocks rest is not a perfectly level one, and that features developed during the period of time represented by the unconformity may interfere with the regularity of the base-line of the Chalk; but I cannot help thinking that the irregularity of this base-line has been exaggerated, and is due in a large degree to the displacement of the Chalk itself; nor can much dependence be placed on estimates of the thickness of the Lower Chalk which are based on the position of the outcrop of certain beds in relation to the contour-lines.

Part of the Chalk escarpment of Wiltshire south and east of Swindon seems to present similar features, according to the diagram and description given in the Survey Memoir (Expl. of Sheet 34, pp. 33 and 34). In that district large masses of Chalk and Upper Greensand seem to have slipped and foundered down the steep slope, so that "the boundary of the Chalk and the Upper Greensand is generally completely obscured."

The undercliff of the Isle of Wight may be also quoted as an analogous case on a more extended scale.

(A.) *The Red Chalk or Hunstanton Limestone.*

Entering Yorkshire from the south, the Red Chalk is first seen at Welton Springs; to the north of this, though giving ample evidence of its presence near the base or higher on the brow of the Wold, there is no exposure where a satisfactory section can be seen between the Humber and the well-known cuttings on the Hull, Barnsley, and West Riding Junction Railway, more than a mile east of the station at South Cave.

The best section of the Red Chalk is to be found in the cuttings between the two short tunnels, the one at Weedly Springs and the other under Sugar Loaf Hill. Here it is seen to be about 7 feet thick, and is of a grey colour in the centre. *Belemnites minimus* occurs commonly. It may be said to rest on Kimmeridge (?) Clay; but between it and this formation can be seen at intervals a thin layer of yellowish, very fine sandy material, containing roundish concretionary nodules of ironstone, which show, when broken, a slightly oolitic structure; but there seems to be hardly any coarse quartz or other mineral fragments in it, and in the Red Chalk itself, whose base partakes of the character of this yellowish material, there is an absence of the mineral grains which characterize it at Hunstanton and through Lincolnshire.

The section is now somewhat obscured by weathering and by the facing of the embankment. Messrs. Middlemiss and Keeping * give the following as the section, taken probably at this point:—

	ft.	in.
Nodular red chalk	1	6
Pale nodular chalk	1	3
Clayey red chalk	0	6
Grey nodular chalk	1	0
Red chalk	0	3
Yellowish-green clay	0	9
Unctuous red clay	1	6

On the brow of the Wolds, to the south of the railway, the same yellowish sandy-looking material can be seen beneath the Red Chalk.

Proceeding northwards, a small section in the Red Chalk can be seen at Rudstone Walk, and the bed can be followed through Newbald and Sancton to the north of Market Weighton, where, just south of the railway, the Red Chalk, very conglomeratic, can be seen resting on the ironstone and clays of the Lias †.

In the valleys near Goodmanham are many small exposures, and again at Londesboro' village, and in the valley running back into the Wolds at Park Farm.

The Red Chalk continues to be seen "in the valley leading up to Warter ‡, . . . more particularly in the brickyard on the north side of the Park, where, although the beds are much slipped, the following sequence may be made out" §:—

	ft.	in.
Grey chalk		
Red chalk	2	6 to 3 ft.
Yellow marl	1	0
Lias		

At Millington Springs and in Deep Dale, just opposite the field-path leading to Millington Grange, at Grimsthorpe and Great Givendale, the ruddy colour of the chalk catches the eye in many a small exposure, or as fragments scattered over the brow of the Wolds, but none of them afford a clue to the thickness or to the succession of the beds above. Along the brow of the Wolds, between Great Givendale and Garrowby Park, several small exposures occur, and the bed seems to continue very conglomeratic, large fragments of ironstone of oolitic structure occurring in it.

In the Park, about half a mile east of Garrowby Hall, the follow-

* Geol. Mag. dec. 2, vol. x. p. 218.

† Mem. Geol. Survey, Sheet 93 S.E., and 94 S.W., p. 28.

‡ This is, I believe, the only exposure of the Red Chalk in Yorkshire that I have not seen.

§ Mem. Geol. Survey, Sheet 93 S.E., and 94 S.W., p. 27.

ing section is seen in the side of a prominent knoll, covered by a clump of trees:—

		ft.	in.
	Soil	0	8
Inoceramus-bed.	Rough gritty, greyish-white chalk, weathering into uneven lumps	3	6
Sponge-bed.	Yellowish-red, very hard chalk, with smooth, clean fracture	1	0
Hunstanton Limestone.	Red chalk, smooth at top, nodular below, the base hidden by talus	4	0

From its appearance, I think the Red Chalk is not 5 feet thick. It is full of quartz- and other mineral-grains, and at the lowest point I could reach it was mottled by inclusions of a brownish material. Débris of Red Chalk is scattered abundantly around, especially near two springs and along the banks of the streamlets to which they give rise.

In Painsthorpe Dale, east of Kirby Underdale, there is a bed of dark brown ferruginous grit, about 12 feet thick, generally considered to be of Neocomian age, lying beneath the Red Chalk, but beyond the relations of these two beds nothing can be made out satisfactorily.

Along the Wolds by Uncleby Dale, by Hanging Grimston, to Greet's Hill, just above Acklam, the continuation of the Red Chalk is marked by fragments strewed over the surface of cultivated land, or by small outcrops in the hillside.

At the last-mentioned place, Prof. J. F. Blake * gives the following section as occurring in a small quarry which is now filled up and the land cultivated, though fragments of the Red Chalk and an uneven surface still mark the spot.

Section at Greet's Hill quarry:—

	ft.
Grey spongy chalk without flints	16
Red rubbly chalk containing masses of dark brown Oolitic ironstone imbedded in it—*B. minimus*	2–3
Dark, hard Kimmeridge? clay.	

The next section is the most important one north of the railway-cutting at South Cave; it is, so far as I know, the only other inland one in which the whole of the Red Chalk with any considerable amount of the overlying White Chalk can be seen at a glance along the western escarpment. It derives additional importance from the fact that it happens to be at the most westerly point of the Yorkshire Chalk; almost immediately north of it commences that alteration in the direction of the outcrop, which finally changes from a northerly to an easterly direction.

The exposure occurs in a mass of chalk which has slipped down from its original position, and now lies along the brow of the Wold. It is within the recollection of a farmer, now occupying adjacent

* Prof. J. F. Blake, "On the Chalk of Yorkshire," Proc. Geol. Assoc. vol. v. p. 247.

land, that the chalk here has given way considerably by reason of the gradual undermining of a spring which issues from the hill just below, and now the section, of which full particulars are given on page 339, is exposed to view.

Except that the Red Chalk has thinned from 7 feet to 2 feet, there is a resemblance in the details of the lower part of this section to that in the railway-cutting.

Oxford Clay is here the formation on which the Red Chalk may be said to rest; but between the two is a well-defined layer, not more than 6 inches thick, of a yellowish material, full of dark-coloured oolitic grains, coarse quartz-sand, and small lumps or nodules of ironstone having an oolitic structure. This bed passes up rapidly into Red Chalk, there being no definite boundary-line. The Red Chalk itself is well marked, 2 feet thick, capped by a paler band, full of quartz and mineral grains &c., and contains the characteristic Belemnite.

Except as fragments scattered along the hillside, the Red Chalk is not seen again for some distance.

On the south-west side of an outlier on which Wharram Grange Farm is situated, and just beyond the west end of Earthquake plantation, the basal beds of the Chalk are exposed in rather a confused manner by a large slip in the hillside; but evidence is given here of a somewhat peculiar state of things. The deep red colour, so striking a feature in the Red Chalk, is gone, and the beds assume a dirty yellow colour, which is here and there streaked, veined, or mottled by brown rust-like stainings.

The foot or eighteen inches which appears to occupy the position of, and to represent, stratigraphically and palæontologically, the Red Chalk is intensely hard, and in its lithological characters seemed to me to resemble the Sponge-bed rather than the true Red Chalk. It is full of large fragments of oolitic ironstone, quartz, and oolitic grains. It is also very fossiliferous. *Belemnites minimus*, *Terebratula biplicata* and *T. capillata*, and *Cardiaster suborbicularis* are common. Fragments of Ammonites also occurred, which, although in too poor a state of preservation to admit of positive identification, appear to belong to *Ammonites auritus* or its varieties. About a quarter of a mile to the south fragments of the Red Chalk lying on the hillside showed a reddish tint. Prof. J. F. Blake records the following section near Wharram Station; its position with regard to the last would be little more than a mile to the E.S.E.

The details are as follows:—

	ft.	in.
1. Flintless chalk, with *Holaster subglobosus* and *Terebratula semiglobosa*	20	0
2. Yellow, reddish Chalk with rounded quartz-grains, most calcareous towards the top, becoming argillaceous below, with *Belemnites minimus* and *Terebratula biplicata*	2	0
3. Dark ferruginous Grit, becoming yellow and argillaceous above, passing into No. 2	1	6
4. Black Kimmeridge Clay with doggers, with a marked junction with the overlying beds.		

My search for this exposure was, unfortunately, in vain.

North of Leavening the line of the outcrop of the Chalk begins to alter from the north-westerly direction which it has taken from South Lincolnshire to this point. Trending gradually to the north, it finally changes its direction, about four miles beyond the exposure near Wharram Grange, to E.N.E.

The next exposure of importance is that on Scragglesthorpe Brow; at the base of a pit on the hillside the Hunstanton Limestone is seen. The position of this exposure is about five miles N.N.E. of Wharram Grange, and about a mile west of Thorpe Basset church. Unfortunately the broken-up condition of the bed allows little more than a mere record of its presence; judging, however, from the amount and extent of the débris, it must be of some thickness, possibly 6 feet*. *Avicula gryphæoides* is here a common fossil, with *Belemnites minimus*. It appeared to me that the character of the bed had altered considerably; it is smoother, contains no mineral fragments, and resembles the Red Chalk of Speeton rather than that along the western edge of the Wolds.

Rather more than five miles more to the eastward, at East Heslerton, the following section was obtained in the boring of a well †:—

	ft.
Chalk	50
Red clay (*chalk*)	25
Black clay	92

Mr. C. Fox Strangways has no doubt that the "Red Clay" is the Hunstanton Limestone, and similar to the 30 feet of "Deep Red Chalk" at Speeton.

At Potter's Brompton, Prof. Blake‡ estimates that at least 10 feet of Red Chalk were exposed. When I visited this pit the sides were either levelled or much weathered down, but there was clearly a very considerable thickness.

Near the head of the Coombe, west of Ganton Hall, the Red Chalk is again seen, and this, with a small exposure at a spring near Bennington, is the last inland exposure that I need mention.

The final section of the Red Chalk occurs at Speeton. It will be needless to recapitulate the opinions of many writers as to the stratigraphical position of the basement-bed of the Upper Cretaceous series in this famous locality. All consider it to be, without question, the representative of the Hunstanton Limestone; and Dr. C. Barrois and Prof. Judd agree in considering it the probable representative of the "Flammen-mergel" of North Germany. In its thickness and general lithological characters it differs somewhat from that at Hunstanton.

In the cliff about 500 yards east of the mouth of Speeton Beck, exactly 20 feet of it are now to be seen in a vertical face, and more

* Mr. C. Fox Strangways tells me he saw 10 feet of Red Chalk there.

† "Geol. of the Oolitic and Cretaceous Rocks south of Scarboro'," Mem. Geol. Surv. $\frac{1}{4}$ Sheets 94 S.W. and 95 S.E., p. 26.

‡ Geol. Mag. vol. v. p. 244.

than 10 feet are shown below this, having slipped out on the yielding surface of the underlying clay in such a way as to leave no doubt as to the continuity of the bed.

I was unable to find the actual junction of the Red Chalk with the Speeton Clay, but, judging from the fragments which I saw on the shore, it would seem that the base of the Red Chalk is somewhat nodular, the colour rendered dull by a tinge of bluish grey, due apparently to the working-up of the underlying clay. This apparent passage from Red Chalk to blue clay is noticed by Prof. Wiltshire, who says *, "This red band gradually becomes nodular and of a bluish cast, and finally merges into Speeton Clay."

The Red Chalk passes up and into firm deep red material, and is, where clearly exposed, nodular. The nodules are potato-like, calcareous lumps, separated by a well-defined matrix of a marly nature. The nodular character passes gradually away upwards, and the upper 4 feet are a smooth and moderately hard material of rather a lighter colour. The bed is altogether free from fragments of ironstone, quartz, and other mineral fragments which are so conspicuous in it at Hunstanton, in Lincolnshire, and along the western escarpment of the Yorkshire Wolds; but, as before, its base contains small portions of the underlying strata worked up in it (see p. 355).

As at Hunstanton and throughout the country already described, *Belemnites minimus* is the most common fossil occurring throughout the bed.

Thus it seems there is a remarkable thickening of the Red Chalk as it is followed along the northern escarpment of the Wolds from 18 inches at Wharram to 30 feet at Speeton.

(B.) *The Lower Chalk.*

The first exposure of any part of the Lower Chalk worthy of note north of the Humber occurs in the Greystones pit, about three quarters of a mile north of the village of Melton, near Welton. Only a few feet of the Grey Chalk are exposed above the talus slope, which now greatly obscures the face; but the Belemnite-marls are well shown in the upper part of the pit, consequently that shown beneath them must be the Grey Chalk.

Grey Chalk is seen in a cutting on the Beverley Road, near Brantingham, and again in a small pit on the hillside nearly a mile north of South Cave, and in a cutting of a road leading up to the Wolds near by. But no exposure of importance occurs until the cuttings of the railway to the east of South Cave Station are reached. As before noted, the sides of the cuttings are obscured by débris &c., which renders a detailed description somewhat difficult; nor can the whole series be seen in a continuous section. The following details are, I believe, fairly accurate.

Section of the Lower Chalk in the cutting of the Hull, Barnsley, and West Riding Junction Railway †. The first part is taken 85 yards

* Wright's 'Mon. British Cretaceous Foss. Echinodermata,' p. 8.

† See Section IV. p. 366.

west of the bridge over the line near the entrance to a short tunnel under Sugar Loaf Hill, north side of line:—

		ft.	in.
Middle Chalk.	Chalk with flints—(section is measured from the lowest flint line)	+100	0
	Hard, rough, cream-coloured chalk, weathering in platy pieces with rough surfaces, divided into courses not less than a foot thick by bands of yellowish-grey marl	13	0
The zone of *Belemnitella plena.*	Yellowish-grey marly chalk, soft, but enclosing lenticular beds of harder material	1	9
	A variegated marl, upper part usually bluish or yellowish grey, centre dark grey, in places almost black, its base almost invariably greyish buff, passing down or graduating to	1	4
Grey Chalk.	Rough nodular layer, nodules parted by green-grey marl; this bed also graduates into the chalk beneath... 8 in. to 1 ft.		

Section continued 65 yards west of a milestone and between 300 and 400 yards west of last position, on south side of line:—

The Grey Chalk.	Whitish chalk, weathering in platy pieces, apparently in courses divided by marl bands; all rather hard...	23	0
	A course of hard whitish chalk, but passing down rapidly into greyish, with a marked grey marly band at base (fossils)	1	3
	Hard whitish chalk, weathering into rough platy fragments, divided into courses by marked marl bands...	6	0
	Softer marly chalk, rather nodular, bedding indefinite, stained a bright pink	4	0
	Whitish, rough, hard chalk in courses	3	0
The "Grey Bed."	Hard, grey, nodular chalk, becoming platy below, green-coated nodules at base; fossils	1	6

Section continued at the east end of the short tunnel at Weedly Springs, north side of line:—

Hard whitish chalk seen underlying the "Grey Bed" for 8 ft.

Continued north side of line, 200 yards east of the signal-box at Weedly Springs:—

Chalk Marl.	Hard whitish chalk, rather rough; the continuation of that at the east end of the tunnel. Total thickness below the "Grey Bed" (which is not seen here) estimated at	20	0
	Hard grey chalk, more gritty at its base, divided into courses by marl bands	10	0
	Bed of compact limestone, yellowish white, rather obscure and broken, appeared to graduate into the Red Chalk	1	0
Gault	Red Chalk (for details see page 333)	6	9

The similarity in the relations and sequence of the beds shown in this cutting to those of the Lower Chalk of Lincolnshire must be obvious to anyone who compares them. The section shows a complete continuation of the Lincolnshire facies thus far north of the Humber. The "Sponge-bed" seemed to me to be present, but with no distinct parting between it and the Red Chalk. Above it grey and gritty chalk, the equivalent of the *Inoceramus*-bed, passed up gradually into the hard and whiter Chalk Marl. There is a difference of about 2 feet in my estimation of the thickness of the Lower Chalk here and in South Lincolnshire. Large Ammonites are common, as usual, at or just above the horizon of the "Grey Bed," and I left one in the cutting 1 foot 8 inches in diameter.

Following the outcrop of these beds to the northward, in a road from South Newbald to the Wolds, Grey Chalk is well exposed; dark grey shaly bands (the Belemnite-marls) are seen at the angle of the roads *.

The next important exposure of the Lower Chalk occurs about 300 yards E.S.E. of Park Farm, Londesboro.' The face is much obscured by the slipping down of rubble from the upper part of the pit. Beneath two or three feet of loose material there are clear indications of the Belemnite-marls. Lower down a pink band and the "Grey Bed" occur, the latter fossiliferous as usual, but not enough exposed for a large collection.

I hardly think the Chalk seen here is in its natural order; most of the higher beds seem to me to be slipping over the lower ones. The Belemnite-marls are 23 feet above the "Grey Bed." The central part seemed fairly solid and continuous. I give the following section for what it may be worth:—

		ft.	in.
	Rubbly chalk and soil with marked indications of the Belemnite-marls at base	2–3	
Grey Chalk.	Face obscured by talus, chalk appeared broken up	10–12	
	Hard roughish chalk weathering into platy pieces, thin marl bands	3	
	Rather soft marly pink chalk	3	6
	Hard rough chalk with green-grey marl bands	5	
The "Grey Bed."	Hard grey chalk, rather nodular, green-coated nodules at base (fossils)	1	6
	Greyish-white chalk underlying, covered by talus.		

The top of the Grey Chalk can be seen near Towthorpe corner and again at Warter, a locality which time and circumstances prevented me from visiting †. Between Millington and Bishop Wilton I saw nothing worth recording, but on the brow of the Wolds, about half a mile E.S.E. of the latter village, 4 or 5 feet of rough nodular chalk was exposed in a shallow pit. *Holaster subglobosus* and *Terebratulina gracilis* occurred, the former testifying to Lower Chalk, but the horizon is uncertain. A similar exposure in a similar chalk occurs about a mile to the north of the last.

Garrowby Park is the next place where Lower Chalk is seen. Above a foot of compact yellowish-red chalk, which I regard as the "Sponge-bed," $3\frac{1}{2}$ feet of rough grey gritty chalk occurs, reminding one of the *Inoceramus*-bed of South Cave. The section here is given on page 335.

Grey chalk is seen again in Painsthorpe Dale, east of Kirby Underdale, and in Uncleby Dale I saw a pink band in rather marly soft chalk. In the rubble above, exposed by burrowing rabbits &c., *Echinoconus subrotundus* and *Rhynchonella Cuvieri* occurred, but nothing could be seen of the succession of the beds.

* "Geol. of the country between York and Hull," Mem. Geol. Survey, p. 29.
† Geol. Surv. Mem. York and Hull, p. 29.

On Greet's Hill, above Acklam, a section showing 16 feet of "Grey Spongy Chalk" has been given on page 335.

The next exposure of the Lower Chalk is at Leavening; the circumstances connected with the exposure are to be found on page 333. The section is as follows:—

		Descending. ft.	in.
	Chalk rubble, showing no pink colour, much broken up	6	0
Grey Chalk.	Whitish chalk, not hard, much broken but apparently in place, irregularly bedded, with strongly marked buff-coloured bands of marl	9	0
	Whiter chalk less marly than hard	2	6
The "Grey Bed."	Hard nodular chalk, grey in colour, clearly distinguishable from that above or below	2	0
Chalk Marl.	Hard whitish chalk, more massively bedded than the underlying, and less rough	9	6
	Thin-bedded chalk, rather rough and nodular, weathering into thin platy pieces—a marked marly band divides this from the course above	8	0
	Hard, very gritty, massively bedded, greyish-white chalk	6	0
	Hard, crystalline, reddish-yellow limestone, seemed sharply marked from the chalk above	1	0
Gault	Red chalk, passing down into next	2	0
Neocomian.	Yellowish-brown sandy material, with quartz and dark-coloured oolitic grains and nodules of ironstone showing oolitic structure ... about		6

A yard or two beyond the point where the section ends, rubble of pink chalk is seen, but its relative position with regard to the remainder of the section is not determinable, nor, as will be seen presently, is the position of a colour-band an important point.

It seems to me impossible to consider the sequence of the beds here and not see that there is a repetition of the succession in the cutting east of South Cave and also of the Lower Chalk of Lincolnshire *. Red Chalk, Sponge-, and *Inoceramus*-bed, followed, after an interval of smoother and whiter chalk, by a marked grey-coloured bed, overlain by marly chalk with marked buff-coloured bands, is a recurrence of the succession seen from south to north.

Between the cuttings east of South Cave and this place there is a diminution in the thickness of the equivalent of the Chalk Marl of 6½ feet, an attenuation shared in a greater degree by the Red Chalk. There are grounds for considering this decrease in the thickness of the Red Chalk gradual, and the cause of it was probably not without its effect on the beds above; but judging from the uniformity of thickness of the Grey Chalk and its apparent freedom from influences which we shall shortly see affect the equivalent of the Chalk Marl, I consider the chalk above the "Grey Bed" to be but little thinner, and estimate the entire thickness of the Lower Division of the Chalk to be at this point not less than 60 feet.

Following the outcrop northwards, yellowish marly chalk is seen along Birdsall Wold, about ¾ of a mile west of Swinham, probably that above the "Grey Bed." About ¼ mile east of this place, pink chalk occurs above a bed of grey-coloured chalk very like that

* See Section V. page 366.

at Leavening. A small spring, which may be taken as indicating the outcrop of the underlying clay, is about 30 feet below this bed, a measurement which corresponds fairly with its position with regard to the Red Chalk at Leavening; but I believe this exposure to be in a large slip, and much reliance cannot be placed upon it.

The coloured band was proved by digging to be 4 feet thick, and its position is singular if the beds are in place. At the exposure about ½ mile south-west of Wharram Grange and at the west end of Earthquake plantation, the dirty yellow-coloured chalk, representing the Hunstanton Limestone, seems to be overlain by very rough and gritty chalk like that exposed above the Red Chalk at Leavening. *Holaster subglobosus* and *Discoidea cylindrica* occurred in this material; but from the broken condition of the chalk nothing certain was made out.

On Scragglethorpe Brow are two or three exposures of the basal part of the Lower Chalk. In a pit on Mr. Richardson's farm where the Hunstanton Limestone is exposed, no very clear evidence of the sequence of the beds above it can be obtained, the chalk being much broken. Very rough nodular chalk, the nodules separated by greenish-grey marl, seemed to be overlain by smoother and whiter material. There was no indication of a second red band above the Hunstanton Limestone.

At the base of the hill in the corner of the Knapton Wood is an old pit; talus and rubbish hide much of the face; the chalk shown near the top is hard, whitish, and rough. There was no indication of the Hunstanton Limestone at its base, which appears to rest on clay; but at the top of the pit and on the talus slope I found fragments of pink chalk which I do not think belonged to the basement-bed. I saw no sign of the "Grey Bed," although at least 30 feet of chalk must have been exposed.

At the Glebe Farm, east-south-east of West Heslerton, a pit shows hard, greyish, nodular chalk. *Ostrea vesicularis* and *Terebratula semiglobosa* were common in a marked marly band, separating one of the lower courses of the chalk; the upper part was rubbly and broken up. No exposure of the Lower Chalk occurs between this last and Ganton.

In the fine coombe which extends back into the hills west of Ganton Hall the Grey Chalk can be fairly seen. I made out the following section:—

	ft.
Chalk with flints	—
Hard, rough, creamy-yellow chalk with *Inoceramus mytiloides* about	8–10
Thin-bedded, platy chalk, much covered by débris, seen only at intervals to the base of the above .... about	38
Pinkish-red chalk, rather soft and marly	4
Rough chalk with marly bands, weathering into thin laminæ...	6–8
Hard lumpy chalk, darker grey in colour than the above; this and the preceding appeared to have slipped, and the section was somewhat obscure	2
Rough greyish-white chalk, weathering into platy pieces, no trustworthy guide to its thickness	+20

When I saw this exposure I had not recognized the constant succession of the beds of the Lower Chalk to which I have drawn attention, and I have been unable to visit the locality again. A large Ammonite occurred above the grey-coloured bed, and *Holaster rotundus* (sp. nov.), which will be described in the sequel, occurred just above the pink band.

Between Ganton and Speeton I have seen no exposure in the Lower Chalk, and my final section in this division is in the grand cliffs east of Speeton Gap, where the whole can be seen. The section of these cliffs about to be described commences 800 yards east of the mouth of Speeton Beck, near a spot marked on the map of the Ordnance Survey as "Nanny Goat's House." For the convenience of reference *only* I have divided the chalk into beds, which are numbered from the base upwards, the Red Chalk or Hunstanton Limestone already described being bed 1.*

Bed 2. Thickness 10 feet. At the base of the cliff, at the point indicated, is a bed of bluish-grey nodular chalk. Only about 5 feet of it forms part of the cliff face, but under favourable conditions of the shingle on the beach it may be seen to be about 10 feet thick.

During the past summer (1887) I saw beneath this bed a strip of smooth Red Chalk containing Belemnites, and agreeing in appearance with the Hunstanton Limestone. I was unable to clear away the shingle and boulders sufficiently to see the junction of the two beds, but I feel sure that the bluish-grey chalk is the actual upward continuation of the section above bed 1. In several subsequent visits, this part of bed 2 was covered by shingle and seaweed to a considerable depth.

The chalk of Bed 2 seemed to me rather smoother near its base, but it passed up into the rough and very lumpy chalk of the bed above. The lowest part near Bed 1 contained *Belemnites minimus.*

Bed 3. Thickness 28 feet. Like the central part of bed 1, the base of this bed consists of calcareous potato-like lumps in a marly matrix, the marly element being, however, less evident. The nodular character is less pronounced near the top, and above the lower third of the bed discontinuous layers of smoother chalk occur, a foot or more in thickness.

The first 8 feet above the base is of a brick-red colour, perhaps a shade pinker than bed 1; in the succeeding 5½ feet it appears to be only the marl separating the lumps or nodules which is coloured pinkish purple; about 4 feet higher the colour dies away entirely. After an interval of 7½ feet the colour reappears, and this forms the middle pink band noted by Prof. Wiltshire and Prof. J. F. Blake (see also "Coloured Bands," p. 353).

The whole of this bed is divided into courses by bands of marl, some of which are two or three inches thick, greenish-grey or red in colour, according to position. No *Belemnites* occur; *Avicula gryphœoides* is the common fossil, very abundant in the base, gradually disappearing in the higher part, above which I have not met with it.

Bed 4. Thickness estimated at 39 feet. Its base is somewhat

* See Section VI. page 366.

rough and nodular, but the nodules do not weather out so prominently as in the beds below, and the marl which separates them is gritty and full of coarse shelly fragments. There seems to be no abrupt change in the material from the base of this to the underlying chalk, the grittiness coming on gradually, and the division is marked rather by the accidental circumstance of the colour-band than by any real lithological or palæontological distinction. Upward, however, the chalk becomes decidedly smoother and is parted into courses some 2 feet thick by thin marl bands. Two or three feet from its summit the nodular character of the chalk is again more evident.

Bed 5. Thickness 22 feet. The first course, about 2 feet thick, of bed 5 is of rather nodular chalk, markedly greyer in colour than that over- and underlying it. A marl band 3 inches thick separates it from the last division.

This course, which is the continuation of the "Grey Bed," can be followed from "Nanny Goat's House" to where it finally disappears with the dip of the beds to the S.E. It retains its massive and solid appearance throughout, and does not break up under the influence of weather or waves. The lower 6 inches splits readily into thin flakes, graduates into the underlying marl band, and is fossiliferous; but unfortunately, at Speeton, where it can be most easily examined, the shells it contains appear to have suffered much from weathering or sea-water, and I found it difficult to obtain many identifiable specimens of fossils common in this bed.

Pecten orbicularis, which is everywhere the most abundant form in the "Grey Bed," occurred commonly here; except at this horizon, I have not met with it in either the Chalk Marl or the Grey Chalk of Lincolnshire or Yorkshire, though it is not confined to this bed in the Chalk of the south of England.

The chalk above this bed is very hard and nodular or lumpy; the lumps are separated by marly material, and the whole divided into beds by strongly marked marl bands; between these the bedding is indefinite; in some places, especially in the upper part, the marl seems to be in excess, and its colour, which is bluish, greenish, or buff-grey, predominates, but neither marl nor colour is persistent at the same horizon; the effect of this is to give a curiously indefinite appearance to the bedding and colour.

Five or six feet of this bed immediately above the lower course are, at Nanny Goat's House, coloured pink and form the upper pink band noted by other observers (see also "Coloured Bands," p. 354).

Bed 6. Thickness 21 feet. At the base of this is another course, 3 feet thick, the massive and solid appearance of which takes the eye at once along the face of the cliff; its colour, buff grey, is intensified by veins with which it is streaked; a marked marl band, in which *Ostrea vesicularis*, *Terebratula biplicata*, and *T. semiglobosa* are very abundant, divides it from the chalk below. Throughout the remainder of this bed the chalk is white, hard, fairly smooth, and divided into courses by thin marl bands.

It will be seen that at Speeton the hard compact "Sponge-bed," which from South Lincolnshire to Leavening in Yorkshire has formed a fairly marked basal bed of the Chalk Marl, is gone, and its place taken by rough, nodular, and coloured chalk, unlike any which occurs at this horizon elsewhere in England. The thickness of this bears a close relation to the accession in the thickness of the Chalk Marl. *Avicula gryphæoides*, a characteristic fossil of the beds separating the Gault and Chalk Marl both in Bedfordshire and West Norfolk, is abundant.

There is no marked line of division in the lower beds excepting colour, the material of the Red Chalk graduating into the Chalk Marl, and this into gritty chalk at the top of bed 3 and base of bed 4, and this, again, passing away upwards.

The "Grey Bed" forms a well-defined line at the summit of the Chalk Marl, and above it the Chalk, differing slightly in minor points, presents much the same characters and sequence which become familiar to anyone following the outcrop of these beds along the Wolds of Lincolnshire and Yorkshire, while its thickness throughout is remarkably uniform.

The three Echinoderms, *Holaster subglobosus*, *Holaster rotundus*, (sp. nov.), and *Discoidea cylindrica* occur throughout the Lower Chalk in the Speeton Cliffs.

The entire section of the Speeton Cliffs is as follows:—

		ft.	in.
Middle Chalk.	Hard white chalk, with flints		
	Bedded whitish chalk, very hard and crystalline (*Inoc. mytiloides*)	5	0
	Courses of creamy white chalk, about 6 inches thick, divided by buff marl bands	2	6
Zone of *Bel. plena*.	Band of shaly marl, variegated, bluish grey or buff		4–6
	Hard, smooth, white chalk	1	0
	Shaly marl, almost a clay, paler bluish grey at the edges, almost black in the centre		9
Grey Chalk.	Rubbly chalk passing down into smoother and more compact material	1	0
	Compact whitish chalk, smooth on the whole, in courses, a marked massively bedded layer at the base	21	0
	Rough, nodular, or lumpy chalk, with well-marked marl bands, the marl separating the lumps sometimes in excess; colour varied, the base is, in some places, stained pink	20	0
"Grey Bed" = Totternhoe Stone.	A marked course of grey-coloured chalk, rather nodular, graduating at its base into a marked marly band	2	0
Chalk Marl.	Rather rough chalk, with smoother courses inclining to become nodular at its base, where the marl bands and chalk become more gritty. The top of this bed is sometimes stained pink	39	0
	Rather nodular or lumpy chalk, this character becoming more pronounced downwards. Material coloured pink and white in alternate bands	28	0
	Bluish-grey nodular chalk, with marl bands	10	0
Gault	Red Chalk or Hunstanton Limestone	30	0

(C.) *Zone of* Belemnitella plena.

It remains to indicate briefly the evidence of the continuation of the Belemnite-marls.

Besides the fact that there is a band of laminated marl, almost black in the centre, greyer at the top and bottom, and in all respects similar to the band in which the fossil *Belemnitella plena* occurs just on the other side of the Humber, no other information can be obtained from the Greystones pit.

Full details of this horizon of the Chalk, as seen in the cutting of the railway to the east of South Cave, have been given on p. 339, the section being an almost exact repetition of that at Barton-on-Humber.

The "dark shaly band" at the top of the Grey Chalk is seen just "at the angle of the road" leading from South Newbald to the Wolds *.

A pit a mile and a half south-east of Londesboro', near a road leading from Towthorpe corner to Easthorpe, shows a fair section of the chalk at this horizon as follows:—

			ft.	in.
	Middle Chalk.	Soil and rubble	1	6
		Rather thin-bedded platy chalk, hard and whitish, flints	3	0
		Massively bedded chalk, creamy white, divided into courses by thin marly bands	6	6
		Hardish, smooth, white chalk	10 in. to 1 ft.	
		A marked marl band	3 inches.	
		Hard, smooth, creamy chalk	2	0
Lower Chalk.	Zone of *Bel. plena.*	Softer, marly, creamy yellow chalk	1	6
		Grey shaly marl, darkest in the centre, graduating into the bed below	1	6
	Grey Chalk.	Rubbly nodular chalk, nodules separated by marl	1	0

The presence of the Belemnite-marls has been noted at Park Farm (p. 340), but between this point and Speeton I know only of two exposures where they can be seen. The first is in Earthquake plantation, ½ mile south-west of Wharram Grange, and the second by the Glebe Farm near Heslerton. In neither place do they occupy the original position of their outcrop, and no idea can be formed as to the sequence of the beds above and below. The marls have been seen by Mr. Mortimer very near Wharram Station †.

In the Speeton Cliffs they are seen again occupying the same relative position to the beds above and below them. The section from the first line of flints to the top of bed 6 is given on page 345. The marls here enclose a lenticular band of hard white chalk, as frequently the case in Hertfordshire and Cambridgeshire.

* "Geol. York and Hull," Mem. Geol. Survey, p. 29.
† "Geol. of Driffield," Mem. Geol. Survey, p. 9.

§ III. Palæontology.

Table I.—*Fossils from the Red Chalk or Hunstanton Limestone.*

	Lincolnshire.	Yorkshire.			
		Speeton.	Whanam Grange.	Railway-cutting East of South Cave.	Other localities.
Vermicularia	§ †				
Serpula, sp.	...	B ‡	*	*	*
Cidaris gaultina, *Forbes*	...	B			
Cardiaster suborbicularis, *Defr.*	...	...	*		
Terebratula biplicata, *Sby.*	*	*	*	*	*
—— var. Dutempleana	?	*	...	...	*
—— capillata, *D'Arch.*	*	B	*	...	*
—— semiglobosa, *Sby.*	*	*	*	*	*
Terebratulina gracilis, *Schloth.*	...	*	*		
Rhynchonella lineolata, *Phil.*	§	B			
—— sulcata, *Park.*	...	...	*		
Kingena lima, *Defr.*	§	B	*	...	*
Ostrea vesicularis, *Lam.*	§				
Avicula gryphæoides, *Sby.*	*	*	...	*	*
Pecten quinquecostatus, *Sby.*	§				
—— Beaveri, *Sby.*	...	...	...	...	*
Spondylus truncatus ?, *D'Orb.*	§				
—— striatus, *Goldf.*	...	B			
Inoceramus tenuis, *Mant.*	§	? B			
—— Crispii, *Mant.*	...	*			
—— sulcatus, *Park.*	...	...	*	*	
Ammonites interruptus, *Brug.*	*				
—— rostratus, *Sby.* (? var. inflatus)	...	...	...	*	
——, sp. (? auritus)	...	...	*		
Nautilus, sp.	*	...	*		
Belemnites minimus, *List.*	*	*	*	*	*

† Forms marked § are those recorded in the Geol. of Lincolnshire.
‡ The letter B in the above list indicates that the species is quoted from Dr. Barrois, 'Recherches sur le terrain Crétacé Supérieur.'

It will be seen from the above that I am able to add to the list from the Red Rock of Lincolnshire and Yorkshire *Ammonites interruptus* and *Ammonites rostratus*, two most important additions to the fauna of this bed north of Hunstanton: these with *Inoceramus sulcatus* considerably strengthen an opinion previously expressed * that this bed is the equivalent of the Gault. The remainder of the list calls for no special remark.

* Quart. Journ. Geol. Soc. vol. xliii. p. 593.

TABLE II.—*Fossils of the Lower Chalk of Lincolnshire.*

	Chalk Marl.	The Grey Bed = Totternhoe Stone.				Grey Chalk.
		South Thoresby.	Louth.	Hallington.	Withcall.	
Brachiolites	...	...	...	...	...	§
Vermicularia umbonata, *Sby.*	...	...	...	§		
—— sp., or Serpula	§					
Serpula antiquata, *Sby.*	...	...	*	...	*	§
Cidaris dissimilis, *Sby*	...	...	*			
—— sceptrifera, *Mant*	...	...	...	...	...	§
Discoidea cylindrica, *Lam.*	*	...	*	...	*	*
Goniaster, sp	...	...	...	...	...	§
Holaster lævis, *De Luc*	*					
—— subglobosus, *Leske*	*	...	*	...	*	*
—— trecensis, *Leym.*	*	...	...	...	...	§
—— rotundus (sp. nov.)	*	...	...	...	...	*
Pseudodiadema variolare, *Brongn.*	§					
Terebratula semiglobosa, *Sby*	*	*	*	*	*	*
—— biplicata, *Sby.*	*	*	*	*	*	*
—— sulcifera, *Morr*	...	...	*			
—— capillata, *D'Arch.*	...	*	*			
Terebratulina gracilis, *Schloth.*	*	*	*	*	*	§
Kingena lima, *Defr.*	...	...	*	...	*	
Magas pumilus, *Sby*	...	...	...	...	...	§
Rhynchonella Mantelliana, *Sby*	*	*	*			
—— Martini, *Mant*	...	§				
—— Cuvieri, *d'Orb*	*					
—— plicatilis, *Sby.*	...	...	...	...	...	*
Ostrea vesicularis, *Lam.*	*	...	*	...	*	*
—— curvirostris, *Nilss.*	...	...	*			
Exogyra conica, *Sby.*	§					
—— haliotoidea, *Lam*	...	...	*	...	*	*
Anomia, sp.	§					
Pecten orbicularis, *Sby.*	...	*	*	*	*	
—— Beaveri, *Sby*	...	*	*	...	*	
—— fissicosta, *Ether.*	...	...	§	...	*	
Plicatula inflata, *Sby.*	*	...	*	...	*	
Avicula gryphæoides, *Sby.*	*	...	...	...	...	*
Lima echinata, *Ether.*	*	...	?*			
—— globosa, *Sby*	*	...	*			
Inoceramus mytiloides ?, *Mant.*	...	...	...	...	...	?
—— Cuvieri	*	...	...	...	...	?
—— latus, *Mant.*	*	...	*			
—— striatus, *Mant*	§					
Teredo amphisbæna, *Goldf*	...	...	§			
Pollicipes, sp	...	...	*	...	*	
Ammonites navicularis, *Mant.*	§	...	*			
—— varians, *Sby.*	*	...				
—— Austeni, *Sharpe*	...	...	*			
—— rotomagensis, *d'Orb.*	...	...	*	*		
—— sp. (large)	*	...	*	*	*	
Turrilites Scheuchzerianus, *Bosc*	§					
—— tuberculatus, ? *Bosc*	§					
Belemnitella, sp.	...	...	*	...	*	
Fish teeth	*	...	*	...	*	*

Species recorded in the geology of East Lincolnshire and not found by myself are marked thus §.

The occurrence of *Teretrabula capillata* in the "Grey Bed" in two localities is worthy of special notice, as up to the present time this fossil has been considered peculiar to the "Red Chalk," with the exception of two specimens found in the Lower Greensand of Upware †.

The assemblage of fossils from the "Grey Chalk" of Lincolnshire calls for no special remark, with the exception of an Echinoderm recorded in the East Lincolnshire memoir as *Ananchytes ovatus*. This Urchin appears to have been named from an examination of much crushed and distorted specimens, and its occurrence is remarked on as an anomaly (p. 147). I have, however, been fortunately successful in obtaining specimens in a more perfect condition, and the form in question proves to be a *Holaster*. A description of it by Mr. Jukes-Browne is appended to this paper.

To the list of fossils of my own collecting from the Lower Chalk of Lincolnshire I have added those given in the Survey Memoir on Lincolnshire. On referring to that memoir, it will be seen that Tables VI. & VII. contain the fauna which occurs below the lower pink band. My own experience of collecting was that this fauna did not pass up above the "Grey Bed" about 3 or 4 feet above the coloured chalk. Indeed Mr. Jukes-Browne remarks, on p. 58, "from the grey beds at the base [of the pit] Mr. Rhodes obtained many fossils (see Appendix, p. 144)."

As I recognize in the "Grey Bed" the equivalent of the Totternhoe Stone, the underlying chalk must be the equivalent of the Chalk Marl, to which division only the fossils given in Table VI. of the memoir should be referred.

Table III.—*Fossils from the Chalk Marl and Totternhoe Stone in Norfolk, Suffolk, and Lincolnshire.*

[Vertebrata and varieties are not included.]

	Chalk Marl.		Totternhoe Stone.	
	Norfolk and Suffolk.	Lincolnshire.	Norfolk and Suffolk.	Lincolnshire.
Vermicularia umbonata, *Sby.*	*	...	*	*
Serpula antiquata, *Sby.*	*	...	...	*
Cidaris dissimilis, *Sby.*	*	...	...	*
—— vesiculosa, *Goldf.*	*	...	*	
Discoidea cylindrica, *Lam.*	*	*	*	*
Holaster lævis, *De Luc.*	*	*		
—— subglobosus, *Leske*	*	*	*	*
—— trecensis, *Leym.*	...	*		
—— rotundus, sp. nov.	...	*		
Epiaster crassissimus, *d'Orb.*	*			
Pseudodiadema ornatum, *Goldf.*	*			

† T. Davidson, 'Cret. Brachiopoda,' Supplement, p. 33.

TABLE III. (*continued*).

	Chalk Marl.		Totternhoe Stone.	
	Norfolk and Suffolk.	Lincolnshire.	Norfolk and Suffolk.	Lincolnshire.
Pseudodiadema variolare, *Brongn.*	*	*		
Terebratula biplicata, *Sby.*	*	*	*	*
—— semiglobosa, *Sby.*	*	*	*	*
—— sulcifera, *Morr.*	*	...	*	*
—— squamosa, *Mant.*	...	...	*	
—— capillata, *D'Arch.*	...	...	...	*
Terebratulina gracilis, *Schloth.*	*	*	*	*
—— striata, *Wahl.*	*			
Kingena lima, *Defr.*	*	...	*	*
Rhynchonella Cuvieri, *d'Orb.*	*	*		
—— Grasiana, *d'Orb.*	*			
—— Martini, *Mant.*	*	...	...	*
—— Mantelliana, *Sby.*	*	*	*	*
Ostrea vesicularis, *Lam.*	*	*	*	*
—— curvirostris, *Nils.*	...	*		
—— frons, *Park.*	*			
Avicula filata, *Ether.*	...	...	*	
—— sp. nov.	...	...	*	
—— gryphæoides, *Sby.*	*	*		
Pecten orbicularis, *Sby.*	*	...	*	*
—— Beaveri, *Sby.*	*	...	*	*
—— elongatus, *Lam.*	...	...	*	
—— fissicosta, *Ether.*	*	...	...	*
Neithea quinquecostata, *Sby.*	...	...	*	
Plicatula inflata, *Sby.*	*	*	*	*
Teredo amphisbæna, *Goldf.*	...	...	*	*
Lima globosa, *Sby.*	...	*	*	?*
—— echinata, *Ether.*	*	*	...	?*
Inoceramus latus, *Mant.*	*	*	*	*
—— striatus, *Mant.*	*	*		
—— Cuvieri, *Sby.*	...	*		
Pleurotomaria, sp.	*	...	*	
Fusus, sp.	...	...	*	
Turbo, sp.	...	...	*	
Pollicipes, sp.	*	...	*	*
Ammonites varians, *Sby.*	*	*	?	
—— navicularis, *Mant.*	...	*	...	*
—— Austeni, *Sharpe*	?	...	...	*
—— rotomagensis, *Brongn.*	*	...	*	*
—— Mantelli, *Sby.*	*			
Turrilites Scheuchzerianus, *Bosc*	...	*		
—— ? tuberculatus, *Bosc*	...	*		
—— costatus, *Lam.*	...	...	*	
Nautilus elegans, *Sby.*	...	...	*	
—— Deslongchampsianus, *d'Orb.*	...	...	*	

On comparing the list of fossils obtained from the Chalk Marl and Totternhoe Stone of Norfolk and Suffolk with that from the "Grey Bed" and underlying chalk of Lincolnshire, it will be seen that they possess a remarkable similarity, while those from the "Grey Bed" alone are especially characteristic of the Totternhoe Stone.

Table IV.—*List of Fossils from the Lower Chalk of Yorkshire.*

	Chalk Marl.			The Grey Bed = Totternhoe Stone.			Grey Chalk.		
	Railway-cutting East of South Cave.	Speeton.	Other localities.	Railway-cutting East of South Cave.	Speeton.	Other localities.	Railway-cutting East of South Cave.	Speeton.	Other localities.
Serpula antiquata, *Sby.*	*	*	...	*	*				
—— umbonata, *Sby.*	...	...	...	...	*				
Cidaris vesiculosa, *Goldf.*	...	*	...	...	*				
—— dissimilis, *Forbes*	...	*							
Discoidea cylindrica, *Lam.*	*	*	*	*	...	...	*	*	*
Holaster subglobosus, *Leske*	*	*	*	...	*	...	*	*	*
—— lævis, *De Luc.*	...	*							
—— ? trecensis, *Leym*	...	? *							
—— rotundus (sp. nov.)	...	*	...	...	...	...	...	*	*
Peltastes stellulatus, *Ag.*	...	*							
—— ——, var.	...	*							
Cyphosoma, sp. (fragment)	...	*							
Pseudodiadema ?, sp.	...	B							
Terebratulina gracilis (*Schloth.*)	*	*	*	*	*	*	...	*	
—— var. nodulosa, *Eth.*	...	*	...	...	*				
Terebratula semiglobosa, *Sby.*	*	*	*	*	*	*	*	*	*
—— subundata, *Sby.*	...	*							
—— biplicata, *Sby.*	*	*	*	*	*	*	...	*	*
—— var. faba, *Sby.*	...	*							
—— sulcifera, *Morr.*	...	*							
Kingena lima, *Defr.*	*	*	*	...	*				
Rhynchonella Grasiana, *d'Orb.*	...	...	...	...	*				
—— lineolata, *Phil.*	...	*	*						
—— Mantelliana, *Sby.*	...	? *	...	...	*				
Ostrea vesicularis, *Lam.*	*	*	*	*	*	*	...	*	
Avicula, sp. nov.	...	...	...	...	...	*			
—— gryphæoides, *Sby.*	...	*	*						
Plicatula inflata, *Sby.*	...	*	*	*	*				
Pecten orbicularis, *Sby.*	...	...	...	*	*	*			
Lima echinata, *Eth.*	...	*	...	? *	*				
—— globosa, *Sby*	...	...	...	*					
Spondylus striatus	...	*	...	...	...	...	*		
Inoceramus latus, *Mant.*	*	*	...	*	*				
—— Cuvieri, *Sby.*	...	*	...	...	...	...	*	*	*
—— striatus, *Mant.*	...	B							
Belemnitella, sp.	...	...	...	*					
Turrilites ? tuberculatus, *Bosc*	? *	...	*						
Ammonites laticlavius, *Sharpe*	...	...	...	...	...	...	...	*	
—— varians, *Sby.*	...	B							
—— rotomagensis, *d'Orb.*	? *	...	...	*					
—— sp. (large)	...	*	...	...	...	...	*	*	*
Glyphea (? cretacea)	*								
Fish-teeth	...	*	...	*	*				

The letter B in the list signifies that the species are quoted from Dr. Barrois's 'Recherches.' I am indebted to Mr. S. Chadwick of Malton for some welcome additions to my Yorkshire list.

It will be seen from the list that the fauna which characterizes the Lower Chalk of Lincolnshire continues through Yorkshire, and though the beds which form the base of the Chalk Marl at Speeton differ somewhat from those occupying an equivalent position in the western escarpment of the Wolds, the assemblage of forms contained in them leaves but little doubt as to their general relations.

The sharp lithological divisions of Red Chalk, Sponge-bed, and *Inoceramus*-bed are lost at Speeton, but *Avicula gryphæoides*, whose appearance in abundance is a special characteristic of the basement-bed of the Chalk Marl in West Norfolk, is here also a prominent fossil in a like position. Common in bed 2, it becomes abundant in the base of bed 3, from which point it seems to die away gradually, becoming at last associated with *Lima echinata*, *Plicatula inflata*, and *Rhynchonella lineolata*, which last form appears to replace *Rhynchonella Martini* as the Chalk Marl puts on its northern facies.

Holaster subglobosus occurs from the base of bed 3 to the Belemnite-marls, with *Holaster rotundus* (sp. nov.) and *Discoidea cylindrica*, the last being by no means common at Speeton.

A species of *Peltastes* resembling *Peltastes stellulatus* appears to be not uncommon in the Chalk Marl of Speeton. Prof. Wiltshire records it, apparently from bed 2; I found a perfect specimen at the top of bed 3 and another a few inches only under the "Grey Bed." This last specimen, however, differs from *P. stellulatus* and resembles *P. Wrightii* in its large size and more inflated test; and, again, it differs from *P. Wrightii* and resembles *P. stellulatus* in the ruggedness and punctation of the apical disk and in having less numerous and more prominent tubercles, and also in the size of the mouth. Finally it differs from both the Lower Greensand forms in the thickness and strength of the apical disk, by its greater height, and by the much greater number of granules between the tubercles of the ambulacral areas.

Viewed as a whole, the assemblage of forms found in and below the "Grey Bed" in Lincolnshire and Yorkshire agrees with that from the same division in West Norfolk. This northern facies, which differs from that of the Chalk Marl of Cambridge and Bedford, &c., has been shown * to come on gradually as the Marl is followed northward to Hunstanton.

The similarity of the fossils of the "Grey Bed" to those of the Totternhoe Stone has been already noticed.

The assemblage in the "Grey Chalk" is such as would be met with in the South of England. The abundance of Ammonites at its base just above the "Grey Bed" in both counties is remarkable; at Speeton I counted 7 large ones in about 25 yards.

Besides *Belemnitella plena* I found nothing in the Belemnite-marls but fish-scales.

In the overlying Middle Chalk a very short search usually disclosed the commoner species met with at this horizon, viz.: *Inoceramus mytiloides*, *Rhynchonella Cuvieri*, and *Echinoconus subrotundus*. The first is abundant everywhere about 6 feet above the

* Quart. Journ. Geol. Soc. vol. xliii. p. 576.

Belemnite-marls; the two latter, although not so common as in the South, I found in either county in most of the larger exposures.

The Coloured Bands.

Bands of bright red or pinkish colour forming so marked a contrast to the white Chalk have long attracted the attention of geologists in Lincolnshire and Yorkshire. In the former county, besides the Hunstanton Limestone, too well known to call for further remark, two bands occur, both of which are in the Grey Chalk. The lower of these, about 7 feet thick, occurs about 3 or 4 feet above the "Grey Bed," and is darker and perhaps on the whole more uniform in its tint of bright reddish pink than the upper, which is of the same thickness and occurs in the extreme upper part of the Grey Chalk, the colour extending to the Belemnite-marls. Neither band is continuous, and they are seen only in central Lincolnshire for a distance of about 16 miles.

In Yorkshire the colour of the Hunstanton Limestone varies. In the cuttings east of South Cave Station a greyish-white band about 18 inches thick occupies its central part, and at Wharram Grange exposure the colour, as before noted, is yellowish with darker stainings. At Speeton, lines of greyish-white nodules occur in the Red Chalk.

Throughout the county traces of a pale pink-coloured band, seen in two or three places to be about 4 feet thick, are constantly found in the Grey Chalk, occupying a horizon analogous to the position of the lower band in Lincolnshire; but no trace of coloration is seen at the horizon of the Belemnite-marls.

The Lower Chalk of the Speeton Cliffs is strongly marked by bands of colour, the lowest of which occurs about 10 feet above the Hunstanton Limestone. The base of this bed, which is of a dull brick-red, forms an undulating line which does not coincide with the plane of stratification, a fact already noted by Prof. J. F. Blake*. The deep red colour which pervades the chalk for about 8 feet appears to die away above this, and it is the marl only, separating the potato-like lumps of which the chalk is composed at this horizon, that is coloured red or rather pinkish purple. The nodules themselves, faintly coloured pink throughout, weather greyish white at those portions most remote from the marl, the tint deepening gradually to the point of contact with it. The colour of the upper part of the lowest red band does not retain the same depth of tint for a great distance laterally, and it fades away upward in an uncertain manner, rather difficult to describe, until the blue or grey colour of the marl predominates. The thickness of the whole of this colour-band is about 18 feet. About 7 feet above it, the marl separating the nodules again becomes tinted a pinkish purple, and the nodules faintly so for a thickness of 3 ft.; this forms the middle pink band noticed by Prof. T. Wiltshire, Prof. J. F. Blake, and others. These beds, which form the base of the cliff near "Nanny Goat's House," pass beneath the shingle of the beach and are not seen again.

* Proc. Geol. Assoc. vol. v. p. 240.

The uppermost pink band, 6 ft. thick, noticed by all observers of the Speeton cliffs, is, near Nanny Goat's House, about 40 feet above the preceding, and immediately *overlies* the "Grey Bed." As before, it is the marl which is of the deeper colour, the nodules being only faintly pink. The base of the colour-line is seen here to vary as much as 2 feet in a few yards. Passing now to the eastward, this colour-band can be followed at intervals in the face of the cliff, and it appears to vary in its intensity; but from its inaccessible position it cannot be easily examined.

Nearly a mile to the east it reaches the beach, and it is then seen that the band of bright pink, now about 8 ft. thick, *underlies* the "Grey Bed," there being no coloration above it. The chalk below the Grey Bed is fairly smooth and the colour pervades the whole of the material equally. Some 100 yards only further to the east the whole of the colour is abruptly lost.

An instance of the sudden alteration of the colour is seen between two extensive falls of the cliff a little nearer "Nanny Goat's House." Here the colour-band, 8 ft. thick, dies away near the centre, leaving a kind of gap; above the thick bed and separated from it by an interval of about 2 ft. are two tongue-like strips of bright red, in the centre of which are patches of orange-brown (see fig. 2).

Fig. 2.—*Section in Speeton Cliff, near Nanny Goat's House.*

a. Very rough nodular chalk, with marl bands.
b. Bright pink chalk.
c. Grey, rather rough chalk.
d. Pink chalk.

From these facts it is evident that the colour-bands are liable to sudden alteration of their stratigraphical position, and cannot be relied on as indicating a particular horizon.

Minute Structure.

The specimens from the examination of which the following details are drawn up number about 70. The points from which the series was obtained are sometimes widely separated, but the results of their investigation are of some interest.

Hunstanton Limestone.—Specimens of this formation obtained in Lincolnshire and along the western escarpment of the Yorkshire Wolds, from various localities mentioned in this paper, show that it is a deposit laid down in quiet water, beyond the action of mud-bearing currents, and is throughout this line of outcrop as purely a calcareous deposit as that at Hunstanton. Between Welton at the southern end of the Lincolnshire Wolds and Leavening at the most north-western point of the Wolds of Yorkshire there is practically no difference in its structure. Disunited or primordial cells of Foraminifera form a very large part of its mass ; shell fragments are few, and the finer amorphous material appears to be made up entirely of calcareous atoms.

In Lincolnshire mineral fragments, probably derived from the underlying Neocomian sands, are found in the lower part of it. In Yorkshire these fragments are much coarser, and their character frequently suggests derivation from Neocomian rocks even in localities where the Red Rock now appears to rest on still older formations. Gritty Red Chalk sometimes rests on Kimmeridge Clay, having probably overlapped the Neocomian sands.

In some localities large pieces of oolitic ironstone and phosphatic nodules, besides fragments of quartz and other minerals, are in such abundance as to give a conglomeratic appearance to the rock.

As the Red Chalk thins, a proportionally larger part of it is affected by the working up of finer material of the strata over which it passes, but its upper part everywhere shows the calcareous nature of the deposit.

It has been stated (p. 336) that the Red Chalk thins to the N.W. in Yorkshire, and at the exposure near the Wharram Grange, almost its most north-westerly point, the material which is the representative of the Red Bock presents to the eye a different appearance in colour and character. Its examination by means of thin sections shows that here coarse shelly fragments, large Foraminifera, detached sponge-spicules, and glauconitic grains of large size (these latter not occurring in any other specimen from Lincolnshire or Yorkshire) are conspicuouly abundant, and there is a corresponding diminution in the amount of the single Foraminiferal cells which usually form so large a part of it. It would appear that at Wharram the bed which contains *Belemnites minimus*, *Inoceramus sulcatus*, and other undoubted Gault forms presents at this point peculiarities which are associated in Yorkshire rather with the *Inoceramus*-bed than with the Hunstanton Limestone.

With the thickening of the Red Chalk along the northern escarpment of the Wolds a change comes over the character of the deposit.

At Speeton, in the lower third, shelly fragments of small size are abundant, and Foraminiferal cells common; but the amorphous matrix is largely composed of fine inorganic material, with larger particles, probably quartz, sparsely distributed throughout it, calcareous atoms forming quite a subordinate part in its composition.

In the middle third, where the nodular character is most pronounced, single Foraminiferal cells again form the greater portion of it, these becoming less abundant in the smoother part at the top. The matrix becomes gradually more calcareous upward, but the fine inorganic material and larger quartz particles are not entirely lost, even in bed 2, and not until bed 3 is reached does the deposit appear purely calcareous.

It has already been noted that the material of the beds over which the Red Chalk was deposited is invariably worked up, and fragments incorporated at its base. The Red Chalk at Speeton rests on blue clay, and in the specimen which I obtained, as near its base as possible, fragments of a bluish-grey colour are included. These appear to be made up entirely of very fine inorganic material, are free from calcareous atoms, and are doubtless derived from the underlying clay.

Chalk Marl.—The material of the Sponge-bed, which has been taken as the true base of the Chalk Marl, is, in Lincolnshire, very similar to that of the Red Chalk. In Yorkshire, though, as a rule, defined by its lighter colour, as the Red Chalk thins to the northward it becomes practically inseparable from it.

As in North-west Norfolk, the Sponge-bed is overlain in Lincolnshire and along the western escarpment of the Yorkshire Wolds by the grey-coloured and gritty *Inoceramus*-bed. The grittiness is produced for the most part by the abundance of prisms of *Inoceramus*-shells, and gradually passes away upwards. Large glauconitic grains are abundant at the base of this bed, but I have detected no other mineral particles.

Above this the deposit, as a whole, is purely calcareous, consisting for the most part of amorphous material in which Foraminiferal cells and entire tests, with shelly fragments, are present in varying proportions.

In the section at Speeton, except for the small proportion of inorganic matter in bed 2, the deposit which immediately follows the Red Chalk appears purely calcareous, and differs in no important particular from the general structure of the Chalk Marl of Yorkshire. The single Foraminiferal cells form a considerable part of the material in bed 3, and I would note that in the coloured part of this bed I see nothing exceptional in their appearance and preservation as compared with those in the uncoloured part of the chalk. In the upper part of bed 3, and at the base of bed 4, thin bands and veins of coarse shelly material occur, which, besides a grittiness of the chalk at this horizon, remind one of the *Inoceramus*-bed. Although the general character of the chalk here will hardly compare with specimens from the *Inoceramus*-bed obtained along the western escarpment of the Wolds, yet the presence of glauconite-grains, which I have seen only at this horizon at Speeton, leads me to think that the base of my bed 4 is really the horizon of the *Inoceramus*-bed.

The Grey Bed.—The Grey Bed which has been followed through Lincolnshire and Yorkshire, forms, like its amplified equivalent in Bedfordshire and Cambridge, a break in the steady deposition of the chalky mud. It would appear that a slight current carried away the finer material at this horizon, leaving the coarser shell-fragments, thus probably retarding deposition and affording conditions favourable to the growth of the fauna which always occurs so abundantly at this horizon.

Besides the shell-fragments which form the major part of the material of the Grey Bed, there are many Foraminifera and an abundance of glauconite-grains, so that in its composition it will compare with the Totternhoe Stone.

The Grey Chalk.—Little need be said concerning this division. Like that below, the "Grey Bed," it consists in great part of fine amorphous material of a purely calcareous nature in which shelly fragments and Foraminifera occur in varying proportions.

The Belemnite-Marls.—The material of which these marls consist is probably derived from the erosion of the chalk below; but inorganic matter, in the form of fine amorphous material and measurable particles (? of quartz), again makes its appearance, although the proportion to the whole does not seem large. Microscopic examination affords no clue to the reason of the dark colour of the marls in North Lincolnshire and Yorkshire.

Middle Chalk.—Specimens which I have examined from the base of the Middle Chalk show the same marbled or nodular structure which characterizes the Melbourn Rock, and also the remarkable increase in the amount of single Foraminiferal cells, which though quite as abundant for a space at other horizons, notably in the Hunstanton Limestone of Lincolnshire and Yorkshire, do not persistently and regularly form so large a proportion of the material of the Chalk as they do here.

Chemical Composition of the Chalk in Lincolnshire and Yorkshire.

Mr. J. W. Knights of Cambridge has made for me general analyses of several specimens of the Chalk of Lincolnshire and Yorkshire; the results are as follows:—

An analysis of the Red Chalk of Lincolnshire is given in the "Geology of East Lincolnshire"*. The comparison of this with the analysis by Dr. Johnson † of the Hunstanton Limestome shows that the Red Chalk of Lincolnshire contains a higher percentage of calcareous matter than that of Hunstanton. But different conditions of deposition are manifest on the comparison of these two with two of the upper and lower parts of the Hunstanton Limestone at Speeton. For convenience of reference I give below a general tabular view of the proportions of the principal elements of the Gault and its equivalent, the Hunstanton Limestone, from various localities.

It will be seen on referring to this that the amount of insoluble siliceous matter has risen from 7·50 per cent. at Hunstanton to 42·40 per cent. in the lower, and 24·60 per cent. in the highest part of

* Mem. Geol. Survey, p. 33.
† Quart. Journ. Geol. Soc. vol. xliii. p. 588.

the Red Rock at Speeton; while the proportion of carbonate of lime is at Hunstanton 83·81 per cent., it is at Speeton only 45·00 and 59·60 per cent. in the lower and upper parts respectively.

It appears also that the lower part of the Red Chalk at Speeton is even less calcareous than the Upper Gault of West Norfolk at Roydon and Dersingham or that of Fancourt, Bedfordshire, while the upper part at Speeton will compare with the pink Gault of Grimston and Dersingham.

General tabular view of analyses of the Gault of Norfolk and the Hunstanton Limestone of Norfolk, Lincolnshire, and Yorkshire.

	Pink Gault. Dersingham, Norfolk.	Red Chalk. Hunstanton, Norfolk.	Red Chalk. Donnington, Lincolnshire.	Red Chalk. Speeton, Yorkshire.	
				Upper.	Lower.
Insoluble siliceous matter	25·70	7·50	4·49	24·60	42·40
Carbonate of lime	64·49	83·81	90·56	59·60	45·00
Oxide of iron and alumina	4·96	7·39	3·52	4·80	10·20
Carbonate of magnesia	1·32	·62	1·10	8·46	1·51
Other matter	3·53	1·20	1·08	2·54	·89

The admixture of siliceous material with the chalky deposit does not end with the Hunstanton Limestone at Speeton, as the analysis of a piece of the bluish-grey chalk of bed 2, taken about 4 ft. from the top of it, will show *.

	Speeton.	Cambridge. Chalk Marl.
Insoluble siliceous matter	12·40	11·98
Oxide of iron and alumina	1·40	1·49
Carbonate of lime	82·40	84·41
Carbonate of magnesia	1·80	1·11
Undetermined matter	2·00	1·01

As will be seen, this analysis will compare with that of the upper part of the Chalk Marl at Cambridge.

That the deposit becomes purely calcareous is shown by the analyses of a specimen taken from near the top of bed 3, where the chalk is faintly tinted pink, and of the white chalk about the middle of bed 7.

Analysis of Bed 3.—Speeton, Yorkshire.

Insoluble siliceous matter	5·40
Oxide of iron and alumina	·80
Carbonate of lime	92·80
Carbonate of magnesia	·75
Undetermined matter	·25

* I am indebted to Mr. J. W. Knights for this analysis.

The very small amount of iron in this specimen of slightly coloured chalk is noteworthy and confirms some remarks of Mr. Staniland *, who considers ·35 per cent. of Fe_2O_3 sufficient to give colour to the rock.

Analysis of middle part of Bed 7.—Specton, Yorkshire.

Insoluble matter, silica	6·00
Oxide of iron and alumina	1·00
Carbonate of lime	89·80
Carbonate of magnesia	1·66
Undetermined matter	1·54

The following is an analysis of the dark bluish-grey Belemnite-marls of the railway-cutting east of South Cave.

Insoluble siliceous matter	17·80
Oxide of iron and alumina	1·20
Carbonate of lime	66·20
Carbonate of magnesia	6·20
Undetermined, chiefly carbonaceous matter	8·60

Analysis of the Grey Bed: the specimen came from Mr. Chapman's pit, Louth :—

Insoluble siliceous matter	7·40
Oxide of iron and alumina	1·20
Carbonate of lime	86·40
Carbonate of magnesia	2·15
Undetermined matter	2·85

Summary and Inferences.

There is no doubt that the Red Chalk which forms the basement-bed of the Upper Cretaceous series in Lincolnshire and Yorkshire is the continuation of that bed which forms so striking a feature in the Hunstanton cliffs, the relations of which to the Gault have been already discussed †. This bed has been followed throughout Lincolnshire, and its outcrop in Yorkshire has been described at some length in this paper.

The evidence thus obtained shows that it has developed considerably to the north of Hunstanton and is, in South Lincolnshire, 10 or 11 feet thick. Through the major part of this county this thickness is maintained, but as it is followed northward it becomes thinner and is, in North Lincolnshire, only 4 feet thick ‡. Immediately north of the Humber it is not less than 7 feet in thickness; but north of Pocklington there is evidence of continued thinning to about 4½ feet at Garrowby Park and 2 feet at Leavening, at which point the base of the Chalk reaches its highest altitude (about 600 feet) along the brow of the Wolds. Although at the last two exposures the position of the Sponge-bed is indicated by the paler colour of the upper part of the Red Chalk, there appears to be practically no difference in the nature of the deposit.

* "Geol. East Linc.," Geol. Surv. Mem. p. 35.
† Q. J. G. S. vol. xliii. p. 590.
‡ Q. J. G. S. vol. xlii. p. 488, Strahan on the Lincolnshire Carstone.

At the exposure near Wharram Grange, about $3\frac{1}{2}$ miles N.E. of Leavening, the colour of the Red Chalk is lost, and fossils (*Inoceramus sulcatus*, *Belemnites minimus*) which occur in the Gault or Hunstanton Limestone are found in a dirty yellow-coloured material, the gritty character of which is similar to that of the *Inoceramus*-bed at the base of the Chalk Marl.

It is unfortunate that from the broken-up condition of the Chalk at this exposure the evidence to be obtained as to the sequence of the beds is not very reliable, yet the gradual attenuation which has just been noted from south to north, and the change in the character of the rock at this point, might lead one to infer that the Red Chalk did not extend originally much further to the north-west in Yorkshire, but was overlapped by the beds representing the Chalk Marl; but the evidence on this point is insufficient. Its characters, however, are persistent to the eastward if it does not actually thicken, for Prof. Blake * records 2 feet of Red Chalk near Wharram Station, about a mile to the east of the exposure near Wharram Grange, and Mr. Mortimer † records its thickness as 2 feet in Fairy Dale, just north of Burdale tunnel, and $2\frac{1}{2}$ miles east of the Grange exposure.

Chemical analysis and microscopical examination show that the deposit from South Lincolnshire to its most westerly point in Yorkshire is almost a purely calcareous one, made up chiefly of Foraminifera and amorphous calcareous material.

In the early part of Upper Cretaceous time, land doubtless existed over the central parts of northern England and formed the western shore of the Cretaceous sea. It is remarkable, considering the contiguity of this coast-line, that the effects of its waste should not have been more evident in the Chalk of the area we are now discussing. The calcareous nature of the deposit, however, shows that it was probably laid down in quiet water of considerable depth, out of the reach, or away from the path, of detritus-carrying currents.

Mr. Jukes-Browne has suggested to me that the Pennine Chain may have extended southward as a promontory from the continental land which probably limited the Cretaceous basin in the north and north-west, and that its area was not sufficient to give rise to any large rivers; possibly, too, its drainage was mainly directed to the area of the Irish Sea. These conditions would probably much resemble those which now exist in the Gulf of Genoa, the Maritime Alps taking the place of the Pennine Chain.

Although the Red Chalk in the area now under discussion is unlike its more southern equivalent, the Gault, the occurrence in Lincolnshire and Yorkshire of such forms as *Ammonites interruptus*, *Ammonites rostratus*, and *Inoceramus sulcatus* in this bed is a further proof of the stratigraphical relations of the one to the other.

In the roughly defined curve caused by the gradual alteration in the direction of the outcrop of the chalk from N.W. to E.N.E., Leavening is at the most westerly and Wharram at the most north-westerly point of the outcrop.

* Proc. Geol. Assoc. vol. v. p. 245.
† Proc. Yorksh. Geol. and Polyt. Soc. vol. ix. p. 32.

Proceeding round this curve to the east-north-east, we find a rapid change in the thickness and character of the Red Chalk; but how this change comes on, or whether the thickening of the bed is regular or irregular, there exists no evidence to show, owing to the broken-up condition of the base of the Chalk.

That it thickens rapidly is certain; for on Seragglethorpe Brow, about 5 miles north-east of Wharram Grange exposure, the Red Chalk, though much broken up, was seen by Mr. Strangways to be 10 feet thick. About 5 miles more to the east it is proved to be 25 feet thick in the well-boring at East Heslerton, and the deposit is roughly described as a "clay," and therefore more like the Speeton material than that along the western escarpment. A little more than 3 miles further, at Potters Brompton, Prof. Blake considered that 10 feet was shown; but its full thickness is certainly not seen here. The remaining inland exposures are minor ones and tell only of the extension of the Red Chalk to Speeton, where there is at least 30 feet of it.

My own opinion, based on a general knowledge of the "behaviour" of the chalk, is, that in all probability the thickening is fairly regular and increases gradually to the east.

Chemical analysis and examination by the microscope show at once that we have reached here another area of deposition, and that the augmentation in the thickness of the Red Chalk is due to fine mud deposited contemporaneously with the calcareous matter.

The incoming of so much inorganic material testifies to the existence of a current bringing detritus from continental land and therefore an approach to another limit of the Cretaceous sea.

The gradual lateral passage of the Gault mud of Bedfordshire and Cambridgeshire into the calcareous deposit which is its equivalent in north-west Norfolk shows that there was a deep sea to the south of Lincolnshire, and that the mud is not likely to have come from that direction in early upper Cretaceous time.

It would appear therefore more probable, considering the nature of the deposit along the western escarpment of the Wolds, that land lay to the N. and N.E., and that the current carrying detritus came from this direction.

We have in Yorkshire a close analogy to that which occurs in the Gault of West Norfolk; there a gradual lateral passage can be followed from the inorganic sediment of the Gault to a clear and probably deep-water deposit, in which Foraminifera and calcareous particles form the chief part of the material; here the reverse is the case, and the passage is from a deep- to a shallow-water deposit, within the range of mud-bearing currents.

Chalk Marl.—The base of the Chalk Marl through Lincolnshire continues to be marked by the bed of compact limestone, the representative of the "Sponge-bed" of Hunstanton; and although this can be followed along the western escarpment of the Yorkshire Wolds at their most north-westerly point it can scarcely be separated from the Red Chalk.

Above this 4 or 5 feet of grey gritty chalk retain the character of the *Inoceramus*-bed of Hunstanton throughout the area above mentioned.

The remainder of the Chalk Marl, though seamed by well-marked marly bands and of a somewhat rough and nodular character, continues without much variation as a hard, whitish, and purely calcareous deposit, similar to that of North-west Norfolk. As in the case of the Red Chalk, there is an increase in its thickness from 18 feet at Hunstanton to 32 feet at the southern end of the Lincolnshire Wolds; this it probably maintains through the county. At the north-west extremity of the Yorkshire Wolds it becomes some 8 feet less in thickness, probably from the same cause to which the attenuation of the Red Chalk may be referred. From Wharram along the northern escarpment of the Yorkshire Wolds so little evidence of the sequence of the beds above the Red Chalk can be obtained that it is somewhat puzzling to find that the thickness of the Chalk Marl has increased from 25 feet at Leavening to 77 feet at Speeton, that the well-marked divisions above the Red Chalk of Sponge- and *Inoceramus*-beds are gone, and that lithologically, as microscopical and chemical evidence prove, there is a complete passage from the Gault to the Chalk Marl. Sympathy of the mind with the eye must be the reason that the division-line is taken at the top of the coloured material; except for this peculiarity, the change from Red Chalk to bed 2 would appear to be gradual. The Belemnite so characteristic of the Red Chalk continues to occur at least halfway through the bluish-grey material of bed 2, which I take as the basement-bed of the Chalk Marl, though this fact has its parallel in the occurrence of the same Belemnite in the base of the "Sponge-bed" in Norfolk.

The colour, nodular character, and marked marly bands of beds 2 and 3 are, except at Speeton above the "Grey Bed," without a parallel in the English Chalk. The chemical analysis of bed 2 shows that it contains siliceous matter in proportions comparable with parts of the Chalk Marl near Cambridge; but it passes up to a purely calcareous deposit in bed 3. Although in its 28 feet of thickness this bed shows some variation of structure, it may be compared generally with the Chalk Marl of the north, and with the base of it at Roydon or Shouldham in Norfolk.

In Bedfordshire and Norfolk the bed overlying the Gault is invariably marked by the abundance of *Avicula gryphæoides*. At Speeton this fossil occurs commonly in bed 2 and is abundant in the base of bed 3, towards the upper part of which it gradually disappears.

Near the top of bed 3 there is an increase in the quantity of shelly fragments in the Chalk, and this is especially noticeable in the marly bands and veins. In a specimen from these, I found the only glauconite-grains I have seen in the Speeton Chalk. This grittiness passes away upward, and the material assumes the normal aspect of northern Chalk Marl.

The above evidence leads me to conclude that bed 2 and the lower two thirds of bed 3 are the equivalent of the "Sponge-bed," although, from some cause or other during or after deposition, the base of this division assumes characters differing entirely from its usual appearance, and that the gritty chalk above is at the horizon of the *Inoceramus*-bed.

But, again, we have an analogy in Norfolk, and, as before, reversed; there the base of the Chalk Marl becomes harder, more calcareous, and its central part more gritty as it thins to the northward, and the Sponge- and *Inoceramus*-beds are found as the condensed equivalents of these portions of it ; in Yorkshire both these beds appear to be losing much of their distinguishing characters, and are being absorbed, as it were, in the thickening Chalk Marl.

Notwithstanding the fact of invasion by mud-bearing currents, the deposition of the Red Chalk and Chalk Marl must have continued at Speeton without interruption; there is no break, no evidence of variation in the direction or strength of current-action, and therefore no bed such as the Cambridge Greensand or the Chloritic Marl which can be taken as the line of separation between these divisions.

The Grey Beds.—The courses of grey-coloured chalk which I recognize in Lincolnshire as the equivalent of the Totternhoe Stone determine the upper limit of the Chalk Marl. I use the term "Grey Bed" in preference to Totternhoe Stone, because I found the courses referred to known and recognized by that name in Lincolnshire. Although well marked by its fauna and lithological characters, it is by no means so important a bed, except for stratigraphical purposes, as the Totternhoe Stone, and the name would lead to a higher estimation of it than is due. The persistence of so thin a bed and its fauna so far north is remarkable, and, though it seems to be dying out, it is quite recognizable at Speeton.

The Grey Chalk.—With such marked variations in thickness as occur in the Red Chalk and Chalk Marl, it is remarkable to find that the variation in the thickness of this division over the whole area included in this paper is only a few feet.

It has been shown that, as we proceed northward, certain lithological characters, which first begin to manifest themselves in the marly bands just above the Totternhoe Stone in Norfolk, become greatly developed in South Lincolnshire; and throughout this county and Yorkshire the base of the Grey Chalk is usually of a marly nature. This fact serves to confirm the correctness of my reading of the sequence of the Lower Beds of the Upper Cretaceous series in Lincolnshire and Yorkshire.

At Speeton the circumstances of its weathering bring the nature of this part of the Grey Chalk into strong relief. There, however, it seems to be nodular and much like bed 3.

The Belemnite-Marls.—The occurrence of *Belemnitella plena* in the band of variegated marl some 14 feet or 15 feet below the flints in Lincolnshire confirms the correlation suggested by Mr. Jukes-Browne *, viz. that these marls are the representatives of the Belemnite-marls of Hertfordshire, Cambridge, &c. The band of bluish-black clayey material in which I found the Belemnite at Barton-on-

* "Geol. of part of East Lincolnshire," Mem. Geol. Survey, p. 29.

Humber continues throughout Yorkshire to Speeton, though rarely seen in place. Its occurrence has long been noticed, and Mr. C. Fox Strangways * has taken it to mark the upper limit of the Lower Chalk. The true position of this bed in Yorkshire as the zone of *Belemnitella plena* is now for the first time recognized.

The base of the Middle Chalk.—I also agree with Mr. Jukes-Browne † in recognizing the rough creamy yellow chalk which occurs between the *zone of Belemnitella plena* and the chalk with flints as the condensed equivalent of the Melbourn Rock and Zone of *Rhynchonella Cuvieri.*

The occurrence of *Inoceramus mytiloides, Rhynchonella Cuvieri,* and *Echinoconus subrotundus,* the structure and rough character of the chalk, suggestive of rearranged chalky material, always seen at this horizon, and which is continued through Lincolnshire and Yorkshire, identify it with the base of the Middle Chalk of the South of England. The gradual approach of the Chalk with flints to the Lower Chalk should be noted, and the value of the flints for stratigraphical purposes may be estimated from the following:—at Dover they are about 120 feet above the zone of *Belemnitella plena*; at Hitchin the first line of flints, followed by others at distant intervals, occurs about 45 feet above the base of the Middle Chalk. In Lincolnshire flints occur in regular lines and as close together as in the Upper Chalk in the South of England, only 15 feet above the Belemnite-marls, and this is reduced by nearly one half at Speeton, where flints come on 8 feet above the Marls. Moreover, at Speeton beds of flints some yards in extent occur as low as bed 4 in the Chalk Marl.

It will be seen from the foregoing that the divisions of the Lower Beds of the Upper Cretaceous series of Lincolnshire and Yorkshire are in harmony with those of the more southern counties, and that the differences which exist between my own reading of these strata and that of those who have gone before me are matters of detail rather than of fact. It was not possible to compare the Chalk-area north of Hunstanton with that of southern England until the remarkable changes which occur between Cambridge and North-west Norfolk were understood. But with the help of the recent work of Mr. Jukes-Browne and myself, the correlation of the two areas can now be made, and is, I think, satisfactorily established in the present paper.

Description *of a* new Species *of* Holaster.

By A. J. Jukes-Browne, Esq., F.G.S.

Holaster rotundus, sp. nov. (Plate XII.)

Description.—Test large, rather thick, tumid, circular, or broadly ovate, but generally as broad as long. Upper surface elevated and sloping evenly all round towards the ambitus. Under surface

* "Geol. of the country between York and Hull," Mem. Geol. Survey, p. 29.
† "Geol. East Linc.," Mem. Geol. Survey, p. 29.

flattened, but rounded at the border. Mouth opening in a slight depression near the anterior border; anal opening above the base on the posterior border, with a small depression or hollow below it. The dimensions of full-grown specimens are two and a half inches in breadth or transverse diameter and the same in length; height about two inches. The ambulacral summit is central; the ambulacra, which are straight, lanceolate, and apetaloid, radiate from it.

The anteal sulcus is feebly developed, the depression in front of the mouth being continued for a short distance along the ambulacral area, but hardly far enough to break the circular outline when the test is viewed from the summit.

Both the antero- and postero-lateral ambulacra are straight and nearly equal; the poriferous zones are similar and narrow; the pores are clearly visible from summit to base, about 50 being visible in each avenue of the anterior pair, but not quite so many on the posterior pair. The apices of the three anterior pairs converge at a little distance from the posterior pair, just as in *Holaster subglobosus.*

The composition of the apical disk appears to be as usual in the genus *Holaster*, and the madreporiform body is distinct in the specimens examined.

The interambulacral areas are formed of large wide plates, those between the lateral ambulacra being more than three times the width of the ambulacral plates. Their surface appears to have been minutely granulated and ornamented with primary tubercles rather sparsely and irregularly scattered.

Affinities and differences.—The characters of this well-marked species are distinctly those of *Holaster*, but some of them serve to connect this genus very closely with *Echinocorys* (*Ananchytes*). Its general shape is, indeed, so similar to the more globular forms of *Echinocorys vulgaris* that the imperfect specimens obtained by the fossil-collector of the Geological Survey were mistaken for that species, and catalogued under that name in the Survey Memoir (Explanation of Sheet 84). The peculiarity of the supposed occurrence of that species in the Lower Chalk was remarked upon at p. 147 of that memoir.

It is the largest of our British *Holasters*, though it seems to be occasionally rivalled by *Holaster subglobosus*; in many respects it resembles this species, but differs in several important particulars. In *H. subglobosus* the test is sometimes nearly circular, but is generally more or less cordiform, narrowing towards the posterior border, which is truncated somewhat abruptly, and there is generally a dorsal carina; the under surface is always convex, and in many specimens the sectional curve of the sides is nearly equal upwards and downwards; the anal aperture is situated on the horizon of greatest width, which is about midway between apex and base; lastly the anteal sulcus is always visible when the test is viewed from the top. As compared with this, the test of *H. rotundus* is generally circular, though in one specimen before me it is slightly produced posteriorly so as to have a suboval outline and an obtusely subcordate base (see Pl. XII. fig. 2); the posterior border is not truncated, but only flattened or hollowed below the vent; there is no dorsal carina. The under surface is always flattened, and the test is so elevated that the horizon of greatest width is always nearer the base than the apex, and the sectional outline often resembles that of *Echinoconus subrotundus*. The vent is always below the horizon of greatest width, and its height above the base is generally one fourth of the elevation of the test. The anteal sulcus is hardly visible from the top. It may also be noticed that typical specimens of *Holaster subglobosus* are abundant in Lincolnshire and Yorkshire, but that specimens of large size are rare, while a small and presumably young specimen of *H. rotundus* from Speeton presents the same characters as the adult individuals from Louth (Pl. XII.).

From the larger varieties of *H. lævis* this species can easily be distinguished by its circular outline, its size, height, and great tumidity, as well as by the feebler development of the anteal sulcus.

Locality and Position.—Lincolnshire and Yorkshire; ranging from the base of the Chalk Marl just above the Red Chalk to the highest part of the Lower Chalk. It is not at all uncommon in the chalk with pink bands of Louth, and occurs also in equivalent beds at many other localities in Lincolnshire; Mr. Hill has obtained it from Speeton and Ganton in Yorkshire, and I saw a specimen of this species in Mr. Mortimer's Museum at Driffield in 1880.

EXPLANATION OF PLATE XII.

Figs. 1 & 2. Full-grown specimen of *Holaster rotundus*, from Louth: (1) posterior aspect, (2) upper surface, outline slightly subcordate.
3. Under surface of a nearly circular specimen, from Louth.
4 & 5. Posterior and anterior views of a small specimen from the Lower Chalk of Speeton Cliff.
6. Under surface of the same specimen, showing the continuous poriferous zones, which are made conspicuous by the infiltration of oxide of iron.

All the figures are of the natural size, and the originals are in the Museum of Practical Geology, Jermyn Street.

Discussion.

The President commented on the singular fact that English geologists, who were among the first to recognize the main divisions of the Cretaceous system, should have been the last to define the zones in the Chalk. Mr. Hill, with others, had contributed to remove this defect.

Mr. Etheridge observed that the detailed correlation of the beds of the south with those of Lincolnshire and Yorkshire had never been attempted before. He felt sure that in investigating the relations of the Hunstanton Limestone at Speeton we could not go wrong in placing it with the Gault. He referred to the work of Phillips, Wiltshire, and Barrois. He also spoke of the value of the

[To face p. 366.

Series in Yorkshire.

VI.

Section of the Cliffs near "Nanny Goat's House," Speeton.

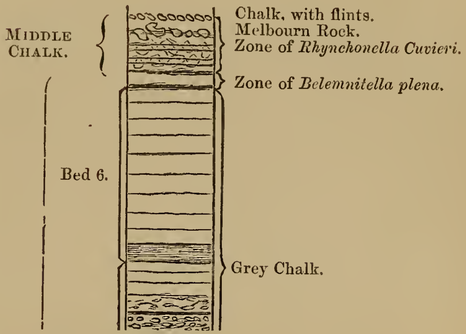
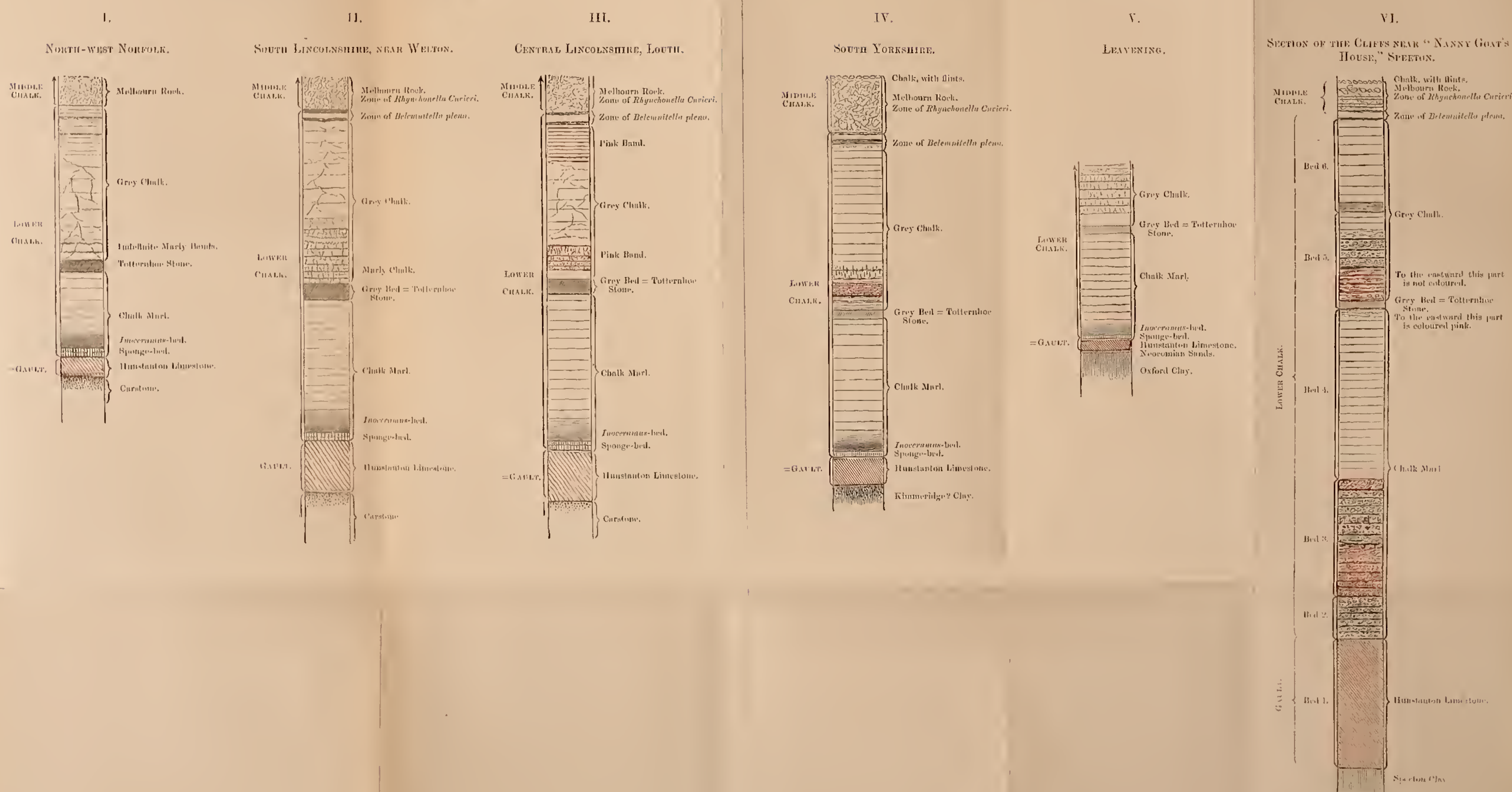
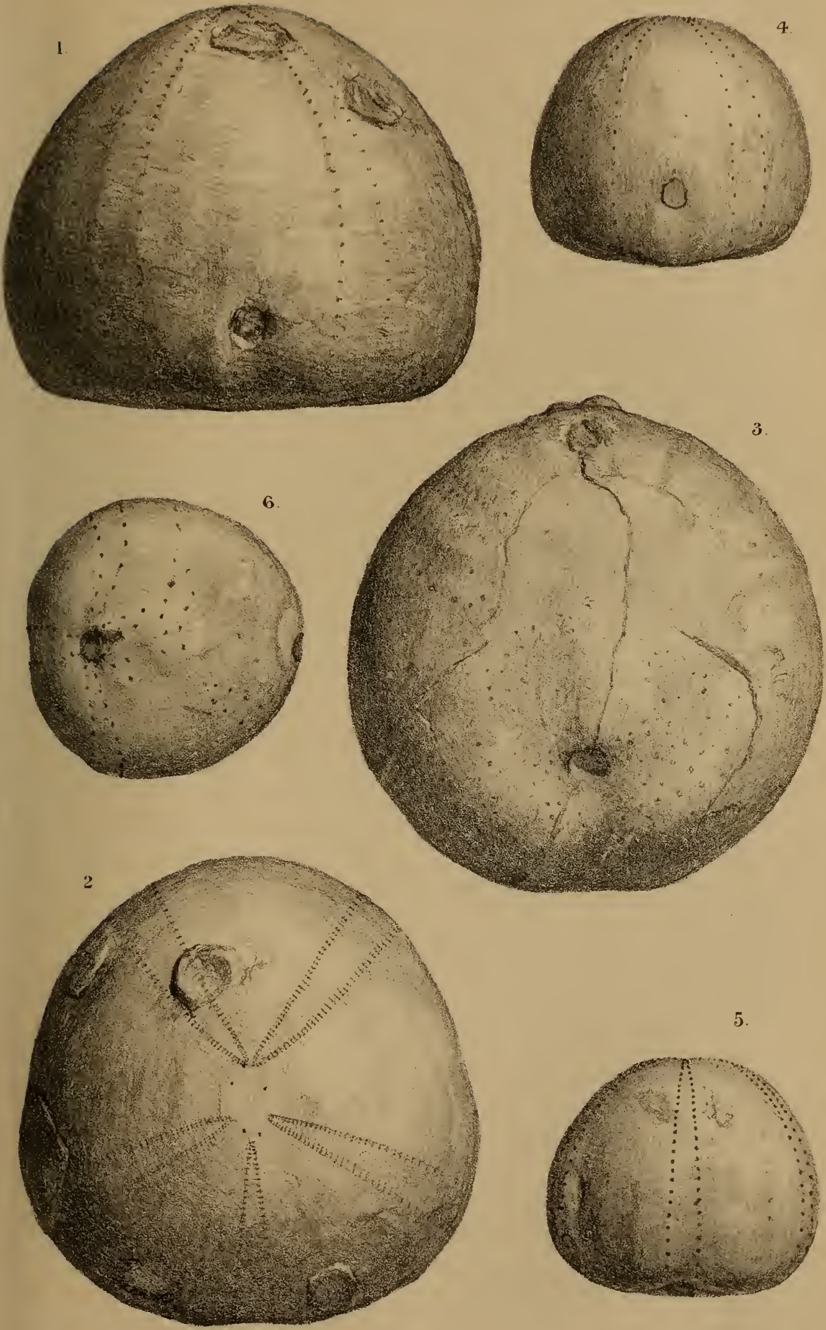


Diagram-Sections of the Lower Beds of the Upper Cretaceous Series in North-west Norfolk and South and Central Lincolnshire. (Scale, $\frac{1}{24}$ inch to 1 foot.)

Diagram-Sections of the Lower Beds of the Upper Cretaceous Series in Yorkshire. (Scale, $\frac{1}{24}$ inch to 1 foot.)





F. H. Michael del. et lith.

Mintern Bros. imp.

HOLASTER ROTUNDUS.

Melbourn rock and Totternhoe Stone as zones for defining the position of the intermediate Chalk.

Mr. Strahan admitted the persistence of the Chalk-zones, and said that when he worked in Lincolnshire it had not been possible to go into these details. The only difference recognized was between Chalk with and Chalk without flints. The Red Chalk contains derived fossils as it is traced northwards. He inquired whether *Ammonites interruptus* and *Am. rostratus* were indigenous or derived.

Mr. Hudleston said that the Author had earned the right to do the work of correlation for the northern region from the share he had taken in defining the very difficult beds in Norfolk and Suffolk, which constituted the key to the whole series of changes. As we go further north, especially in Yorkshire, the fauna of these beds is scanty; yet Professor Blake had made the general correlation clear, though, now we have the details. It was interesting to note with regard to the Gault that its Cephalopoda sustained the proof of a definite palæontological horizon, whether a blue marl in Bedfordshire, a red chalk at Hunstanton, or a yellow conglomeratic bed, as at Wharram. If Ammonites are scarce, *Belemnites minimus* never fails us. On the other hand, the rest of the fossils at Speeton and elsewhere in Yorkshire are mostly Cenomanian, like those of the beds above. The red coloration must have been effected after the decomposition of all the organic matter in the bed so coloured, and this seems to point to subsequent infiltration.

Mr. Herries inquired if there was any representative of the Upper Greensand at Speeton. How did the Author account for the colour-bands extending for such a long distance?

Mr. Newton corroborated the identification of *Amm. interruptus* and *Amm. rostratus* as occurring in the Red Chalk.

Mr. De Rance suggested that *Amm. interruptus*, a Lower-Gault form, might have been derived.

The Author, in reply, thanked the meeting for the reception accorded to his paper. The specimen of *Amm. interruptus* had been found in the lower third, and that of *Amm. rostratus* about the top of the Red Chalk. There was no sign of Greensand at Speeton; the beds there became more calcareous above the Hunstanton Limestone. He allowed that the key of the whole position had been found in the study of these beds between Cambridge and Hunstanton, and he also acknowledged the value of the work done by others. He had endeavoured to simplify matters by bringing the facts together.

27. *On some* Eroded Agate Pebbles *from the* Soudan. By V. Ball, Esq., M.A., F.R.S., F.G.S., Director of the Science and Art Museum, Dublin. (Read March 28, 1888.)

Among a large number of pebbles and rock specimens collected by Surgeon-Major Greene in the Soudan, and recently presented by him to the Science and Art Museum in Dublin, I found that the majority of the former were of very similar character to the Agate and Jasper pebbles derived from the basalts of India. Upon closer examination I observed that a certain proportion of them are eroded in a manner unlike anything I have ever noticed in India, though, if the cause of erosion is what I believe it to have been, it is most probable that similarly eroded pebbles would be found in certain localities there also. Inferentially we may conclude, from the nature of these pebbles, that they originally came from a region in which basaltic rocks occur to a considerable extent. That this conclusion is of no little importance will presently be seen.

Throughout India, wherever there is deficient subsoil drainage on the one hand, or excessive evaporation and limited rainfall on the other, saline matters make themselves apparent, either in saturated subsoil solutions, or by crystallizing out in the soil itself, in the latter case, during wet seasons, being sometimes the cause of saline lakes and pools.

The nature of these salts varies with that of the minerals constituting the rocks from which they have been derived; and in reference to the distribution of the various salts of sodium, potassium, and magnesium, extensive observations have been made, both in India and America, in connexion with the injurious effects upon cultivation of these salts, which in India are commonly spoken of collectively by the native term *reh.* Considerable light, too, has been thrown upon the question in connexion with the economic utilization of these salts. A *résumé* of this information will be found in my ‘Economic Geology of India,’ and it need not be further discussed here, save as regards the character of the salt, which is most abundantly found in basaltic regions. In the Lonar lake in Berar, which occupies a large hollow in the basalt, carbonate of soda is deposited in such abundance from the water, which becomes supersaturated during the heats of summer, that it has some considerable economic importance. Incrustations of carbonate of soda are also met with even on the banks of streams traversing basaltic regions, and though other salts are not altogether absent, it is this one which is most abundant.

Now whatever may be the potency of other alkaline salts,—including borax—in reference to the solution of silica, there can, I believe, be no doubt as to the great effect which a supersaturated solution of carbonate of soda would have on silica, especially when, as we may suppose was the case with these pebbles, they were alternately stewed and roasted in the hollows which served to collect the scanty rainfall in the region in which they were obtained.

It is interesting to observe the selective action of the solvent agent in these specimens ; some layers and particular spots in the pebbles have been scarcely touched, other portions have been deeply eaten into. While to some extent this may be due to slight differences in composition, it seems on the whole to be more likely to be in consequence of differences in the consolidation of the originally colloid silica—differences in the arrangement of the constituent atoms, which have caused some parts to yield more readily than others to the solvent action of the alkaline solution.

I omit here all discussion of the possible agency of humic acids, because the salt to which the solvent action is attributed is capable of doing the work, and because it is probably abundant in the arid region referred to, while *primâ facie* we might expect the contrary to be the case with regard to humic acids.

Discussion.

The President remarked that the question whether solutions of sodium carbonate are likely to be found in the Soudan required further research. He corroborated the statement as to the quantity of this salt among the basalts of India, and had seen similar eroded agates in that country. It should be considered whether any other agent could produce similar effects.

Mr. Whitaker referred to the banded flints of south-east England as presenting somewhat similar phenomena, although not acted upon by sodium carbonate; but the erosion was less marked than in the Soudan pebbles. The differences in the bands of the flints are molecular.

Rev. A. Irving bore out Mr. Whitaker's remarks on banded flints, and referred to Rammelsberg's researches on the action of solvents on different portions of the same mineral with variations of molecular structure. The humus-acids furnished by the desert-scrub he regarded as the more likely solvent.

Mr. De Rance had seen agates in this country eroded by the action of blowing sand. He also alluded to the ridges produced by wind-action in the laminated rocks of the Lake-district volcanic beds, and alluded to the possibility of the Soudan pebbles being acted upon in this manner.

Sir Warington Smyth instanced the existence of groovings in the rocks of the parish of St. Just, and in St. Agnes, Scilly, which had been formed by sand driven by wind, in the latter case to the depth of 6 feet. He referred to the advantage taken by the Romans of their knowledge of the physical differences of banded pebbles to heighten artificially the colour of onyxes. Whilst supposing that some erosion might be produced by sand, he considered that in Nubia, where the soil was impregnated with salts, these would heighten the effect. Amygdaloidal rocks remained to be discovered *in situ* in the Soudan.

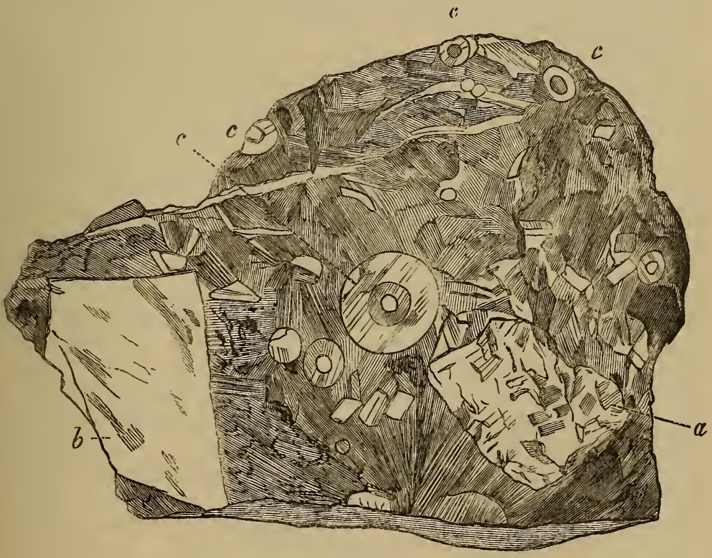
The PRESIDENT said that his first impression had been that the erosion might have been produced by wind and sand, but such action produced more rounded contours than those of these pebbles.

The AUTHOR, in reply, said that he had not lost sight of the possibility of wind-action. It was quite possible that some effect might have been produced in this way, but the pebbles had the appearance of a banded material which had been acted upon by a solvent.

28. *On the* PROBABLE MODE *of* TRANSPORT *of the* FRAGMENTS *of* GRANITE *and other* ROCKS *which are found imbedded in the* CARBONIFEROUS LIMESTONE *of the* NEIGHBOURHOOD *of* DUBLIN. By V. BALL, Esq., M.A., F.R.S., F.G.S., Director of the Science and Art Museum, Dublin. (Read March 28, 1888.)

FOR some time I have been endeavouring to obtain specimens of the limestone containing fragments of granite which were first found nearly forty years ago in the neighbourhood of Dublin. The quarries being now filled up and inaccessible, I followed on the track suggested by having observed a specimen built into a garden wall, and through the aid of Mr. H. B. White, M.E., I was enabled to discover a wall in which such specimens occurred in considerable abundance. The permission of the owner, Dr. E. P. Wright, having been obtained, a fine series of blocks, in which the granite was visible, was delivered at the Museum; these, after they had been trimmed and split by a stone-mason, afforded such a variety of beautiful specimens that I have thought it would interest the Society

Fragment of Carboniferous Limestone, with Fossils and Fragments of Granite &c., from the neighbourhood of Dublin. (Natural size.)



a. Granite. *b.* Quartzite. *c, c.* Portions of Encrinite-stems.

to exhibit a selection of them, as I believe comparatively few geologists have had an opportunity of examining anything of the kind.

The examination of these specimens has revealed the presence not only of angular fragments of granite but also of schist, quartzite, and vein-quartz, such as might have been derived from the metamorphosed Silurian rocks which rest on the granite near Dublin, and are in one locality exposed in a sea-cliff at the base of Killiney hill. As a rule, these fragments, though in some cases permeated with calcareous matter, show little if any signs of decomposition; the surfaces of contact with the enveloping limestone are sharp and clean, and the adhesion is very firm. As will be observed, fragments of fossils, especially of Encrinites, some being of very large size, occur abundantly in the limestone, together with the pieces of crystalline rocks.

Before proceeding to discuss what appears to have been the most probable means of transport, I shall give a brief account of what has been recorded by previous writers on the subject.

Previous Notices.

In the year 1851 *, the Rev. Professor Haughton published an account of the occurrence of fragments of granite in the limestone exposed in a quarry at Crumlin, near Dublin. They occurred, as then observed, in one thin bed only, and were pretty uniformly distributed. They varied from pieces about 8 inches in diameter, down to the size of small grains of gravel; they were quite angular, and showed no signs of having been rolled. The nearest granite, *in situ,* is four miles off.

Reference is made in this paper to another specimen from Monkstown, co. Dublin, consisting of a rolled boulder of dolomitic limestone, which contained fragments of slate as well as granite. Dr. Haughton subsequently wrote:—"In 1851 I brought forward at the Geological Society of Dublin a case of angular fragments of granite, occurring in the Carboniferous Limestone of the Co. Dublin, and explained the phenomenon by the supposition of the transporting power of ice" †.

In 1864 Mr. Henry B. S. Montgomery ‡ described a quarry on the banks of the Dodder, at Rathgar, near Dublin, in which two strata of limestone were met with, each containing imbedded masses of granite clustered together; these two strata were parted by two others, in which no granite was found. It is stated in this paper, that a second bed had been met at the Crumlin locality, separated from the one mentioned above by twenty separate beds. It was remarked by Mr. Montgomery that the fragments always had the heavier ends downwards, as though they had fallen through water and subsided in mud.

In 1862 Prof. Jukes § refers to the subject thus: "The probable

* Journ. Geol. Soc. of Dublin, vol. v. p. 113.
† Appendix to the Voyage of the 'Fox' in the Arctic Seas. By Capt. M'Clintock, R.N., LL.D., p. 395.
‡ Journ. Roy. Geol. Soc. Ireland, vol. xi. (N. S. vol. i.) p. 15.
§ Manual of Geology, new edition, 1886, p. 298.

existence of dry land is often confirmed (during the Carboniferous period) independently, as in the case of the granite-sand and fragments scattered in the carboniferous limestone of Dublin; the most probable cause for their occurrence being their transport in the roots of plants, which grew somewhere on the granite land, and were washed down into the Carboniferous sea."

Mr. Croll, in his 'Climate and Time' (p. 296), quotes the statements by the first of the above authors in support of his argument as to the existence of glacial conditions during the Carboniferous Period.

We have therefore two suggested theories as to the means by which these fragments were transported and dropped in the sea at depths sufficient for the growth of the organisms, such as Encrinites, of which the limestone is composed.

With regard to the former, I believe that all who carefully examine the specimens now exhibited will agree that they exhibit none of the indications of the existence of glacial conditions such as we might reasonably expect to find. The fragments, so far as I know, are invariably angular, and show no marks of having been acted upon by ice, or even of having been rolled by water; they look as if they had been freshly broken or torn off the rocks from which they were derived. Although some of them rest upon a thin earthy parting in the limestone, their environment is strictly calcareous, consisting largely of Encrinite-stems, and there is an absence of the argillaceous silt which is so conspicuously present, for instance, in the now well-known boulder-bed of the Talchir formation in India. I am therefore unwilling to accept any iceberg or ice-raft theory of transport, and would consequently reject the conclusions which have been based upon that hypothesis.

That the fragments of granite and other rocks now found in the limestone were transported from their original sites by the agency of plants, appears to be, upon the evidence, the only safe conclusion; but that these were terrestrial plants may I think be questioned, though I cannot see that it can be actually disproved. To any one who has examined the manner of growth of shrubs and trees on poor rocks and soils, and has, moreover, noticed that, when overturned by storms or landslips, their roots often hold fragments of rock firmly in their grasp, it may appear that the carrying out to sea of such shrubs and trees by floods would afford a sufficient means of explaining the phenomenon, especially as we have evidence of the great distances to which fragments of stone have been borne by this very agency. Still there is another possible means, and, as I venture to believe, a more probable means, to account for the transport; and that is, that the fragments were conveyed into the deep sea, possibly from no great distance, by means of seaweed, which during storms had been torn from a submarine reef consisting of the rocks whose fragments we now find imbedded.

It is only necessary to traverse any sea-coast near to which there are reefs, after a storm, to be assured of the carrying power of certain seaweeds and the tenacity with which they adhere to rocks at their points of attachment, in order to accept the possibility of the agency in the case under investigation having been some such seaweed as the 'wrack' or oar-weed of our coasts. In the case of the larger fragments the transporting weeds may have been of a more buoyant character than those of the present day; while as regards the very minute fragments of granite which we find, they are more likely to have been carried to sea in the grasp of the sucker-like roots of the seaweed than entangled in the roots of a terrestrial plant, which, in the wash, would soon give up the finer particles and only retain the firmly entangled larger fragments. I have recently been informed by the Rev. Wm. S. Green that a sandy beach in the neighbourhood of Youghal, co. Cork, is strewn with fragments of limestone which have been conveyed by seaweeds thrown up after storms from a submarine reef. In this case the rock is much bored by mollusks and other animals, and when the waves beat with violence on the attached seaweed, fragments are broken off which, buoyed by the weed, are driven on shore.

Natural fissures in the rocks and cracks produced by concussions from large masses hurled about by the waves would, I think, sufficiently explain how the fragments might have become freed from the main mass of the reefs, under the stress of the waves.

I have recently received from Mr. G. H. Kinahan a specimen of a schistose rock from Donegal, containing a sharply angular fragment of red granite, and I cannot but think that it may have owed its anomalous position to having been transported by a somewhat similar means to that which is described above.

Discussion.

Mr. De Rance confirmed the Author's observations, angular fragments of limestone being found attached to the roots of *Laminaria* at the Ormes Head, North Wales.

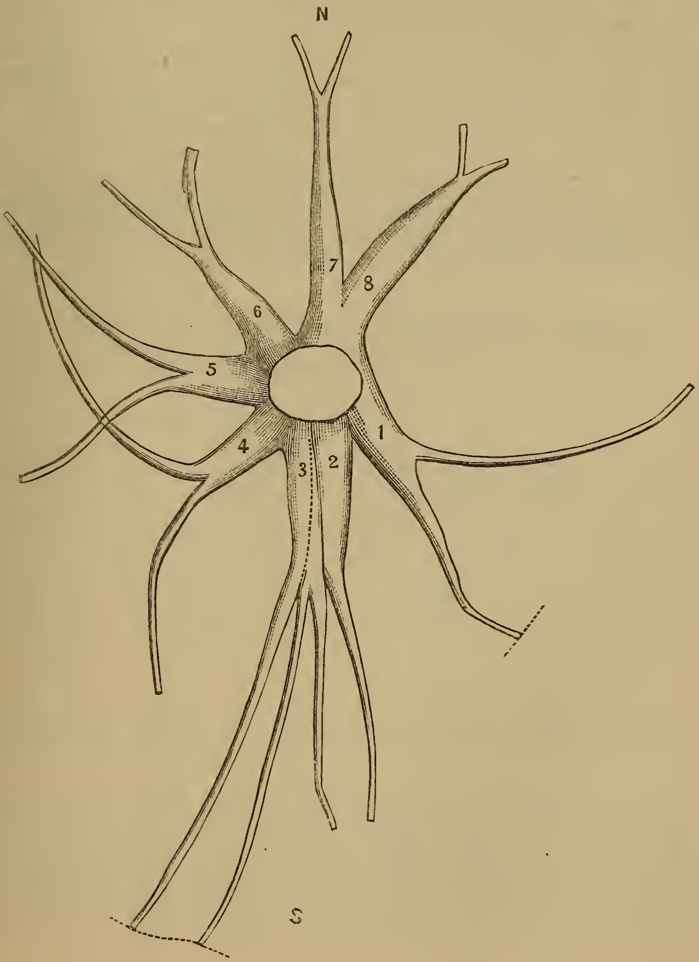
Dr. E. Perceval Wright pointed out that the enormous fucoid seaweeds do not live in tropical, but in the cold and temperate seas. He referred to Anson's mention of the occurrence of seaweeds out at sea with stones attached to them.

Mr. Ball replied that Dr. Wright's remarks testified strongly to the truth of his theory. There was no evidence of the wide distribution of the fragments in the limestone, they having been observed in only one or two adjacent localities.

29. NOTES *on a* RECENT DISCOVERY *of* STIGMARIA FICOIDES *at* CLAYTON, YORKSHIRE. By SAMUEL A. ADAMSON, F.G.S. (Read April 25, 1888.)

THE extensive quarries of Messrs. Murgatroyd and Sons, at Fall Top, Clayton, near Bradford, Yorkshire, are now justly celebrated, not only for the excellence of the stone worked there, but also for the discovery of the finest and most fully developed examples of *Stigmaria ficoides* yet seen. The bed of stone, which is so famous throughout the

Ground-plan of roots of Stigmaria ficoides *discovered at Clayton, near Bradford, in November* 1887. (Scale about $\frac{1}{100}$.)



country, owing to its durability when used for landings, flags, &c., and known as the Elland Flagstone of the Lower Coal-measures, is here extensively quarried. In this neighbourhood the sequence of the beds in descending order is as follows: first, the Better-Bed Coal, then some 30 feet of irregularly bedded and raggy sandstone, followed by about 40 feet of sandy shale, and finally the lower flagstone, which is of great thickness. It was in the measures above the lower flagstone, and about 5 feet below the surface, that the stump of this large fossil tree was found. The raggy stone and shale is of little commercial value, and Messrs. Murgatroyd have to resort to blasting operations to remove it. In November 1887, during this work, the ramifications of the roots of a large tree were partially exposed, and the firm at once gave orders that they should be carefully bared. These praiseworthy instructions were skilfully followed by their workmen, with the result that this splendid example could be perfectly seen (see plan, p. 375). The stump rose a little above the surface on which the roots were almost horizontally extended. When first exposed, there was a film of carbonaceous matter covering the stump and roots. The roots presented the usual markings of *Stigmaria ficoides*. As in other adjacent examples, the roots were much longer to the south than those which branched in other directions. This fossil has been since removed, and Messrs. Murgatroyd have presented it to the Bradford Corporation, by whom it will be placed in the Bowling Public Park. The following measurements were carefully made whilst it was *in situ*:—

	ft.	in.
Height of stump above surface of roots	3	8
Diameter of stump (longest axis)	4	4
„ „ (at right angles to longest axis)...	3	6

Root No.	Diameter close to stump.	Distance from stump to bifurcation of roots.	Distance from point of bifurcation to present termination of root. Right fork.	Distance from point of bifurcation to present termination of root. Left fork.	Greatest length of root exposed.
	in.	ft. in.	ft. in.	ft. in.	ft. in.
1.	17	2 3	9 6	7 0	11 9
2.	12	3 6	8 0	13 0	16 6
3.	12	3 6	7 9	12 6	16 0
4.	13	2 9	7 9	9 6	12 3
5.	17	2 0	6 0	8 0	10 0
6.	14	3 9	3 6	3 0	7 3
7.	13	7 3	2 0	2 0	9 3
8.	15	6 0	2 0	1 9	8 0

It may be well also, for comparison and reference, to give the dimensions of the fine example of *Stigmaria ficoides* discovered in the same quarry in July 1886, which the writer had the honour to describe in the Geological Section of the British Association at the Birmingham meeting in the same year. This specimen was obtained by Professor Williamson and removed to the Owens College, at Manchester, to be mounted in a style worthy of its grandeur *.

	ft. in.
Height of stump	3 9
Diameter of stump (longest axis)	4 6
" " (at right angles to longest axis)...	3 10

Root No.	Diameter close to stump.	Distance from stump to bifurcation of roots.	Distance from point of bifurcation to present termination of root.		Greatest length of root.
			Right fork.	Left fork.	
	in.	ft. in.	ft. in.	ft. in.	ft. in.
1.	21	4 0	9 6	13 0	17 0
2.	17½	4 0	8 0	6 6	12 0
3.	16	5 0	7 0	4 0	12 0
4.	16	4 0	2 0	4 6	8 6
5.	17½	7 0	1 6	3 0	10 0
6.	18	5 6	3 0	4 6	10 0
7.	17	7 6	3 0	2 0	10 6
8.	17	7 0	9 6	7 0	16 6

In the adjoining quarry, about a hundred yards distant from the second example, but upon the same geological horizon, was exposed last autumn a third fine specimen, details of which are here given :—

Root No.	Diameter close to stump.	Distance from stump to bifurcation of roots.	Distance from point of bifurcation to present termination of root.		Greatest length of root.
			Right fork.	Left fork.	
	in.	ft. in.	ft. in.	ft. in.	ft. in.
1.	20	6 0	2 3	2 6	8 6
2.	20½	7 6	1 9	2 6	10 0
3.	19	7 6	6 0	8 6	16 0
4.	17½	8 0	7 6	7 6	15 6
5.	20	7 0	3 0	0 3	10 0
6.	18	7 0	4 0	1 9	11 0
7.	20	7 0	not b	ared.	7 0
8.	20½	part bared.	dit	to.	5 6

* A photograph of this specimen was reproduced by Prof. Williamson in his Monograph on *Stigmaria ficoides* (Palæont. Soc. vol. for the year 1886).

30. Report on the Recent Work of the Geological Survey in the North-west Highlands of Scotland, based on the Field-notes and Maps of Messrs. B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. Hinxman, and H. M. Cadell. (Read April 25, 1888.)

(Communicated by A. Geikie, LL.D., F.R.S., Director-General.)

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4'. Igneous rocks in "pipe-rock."
5. Fucoid beds.
6. Serpulite-grit.
7. Limestone.

8. } Sheared gneiss
9. } ("Green Schist").

10. Eastern schists above Moine Thrust.

Black lines=Thrusts. t t t, Minor Thrusts. T T, Major and maximum Thrusts. T^1, Glencoul Thrust. T^2, Ben-More Thrust. T^3, Moine Thrust.

INTRODUCTION.

IN November 1884 a brief notice or report was published of the results of the work of the Geological Survey in Sutherland*. The object of that report was mainly to announce that the detailed mapping of the region had convinced us that the views entertained by our former chief, Sir Roderick Murchison, were no longer tenable. It was then intended that an official Report should soon be published, embodying the details of the survey work and containing a full digest of all that had previously been done by other observers. But the complicated structure of the region and the necessity of continuing the mapping southward along the great line of disturbance have hitherto delayed the publication of this Report. It is felt, however, that instead of further postponement until the conditions of official publication are fulfilled, it will be of advantage to publish a *résumé* of the chief results which the Survey has up to the present time obtained, and hence the present communication is laid before the Society.

PREVIOUS LITERATURE.

In fulfilment of the promise made in the preliminary notice above referred to, we now offer an outline of the work of previous observers, chiefly with the view of showing how far our own labours have been forestalled by theirs.

In 1819 Macculloch described a remarkable development of red sandstone, quartz-rocks, and limestones among the gneiss and schists of the North-west Highlands and Islands. He maintained

* 'Nature,' vol. xxxi. p. 29, Nov. 1884.

that the red sandstones and conglomerates rest unconformably on the western gneiss, and that, in Sutherland, they are overlain by quartz-rocks and limestones, which alternate with and are succeeded by gneiss and schists forming the chief portion of the Highlands of Scotland. He chronicled the important discovery of worm-tubes (named by Salter *Serpulites Maccullochii*) and *Orthoceratites* in the quartz-rock of Loch Eriboll*.

In 1841 Hay Cunningham confirmed Macculloch's observations regarding the unconformability between the red sandstones and the underlying gneiss, and the occurrence of an upper gneiss resting on the quartz-rocks and limestones. He further corroborated the discovery of organic remains in the quartz-rock, and stated that "there are gneisses and mica-slates that have been elaborated after these were called into being"†.

In 1852 a suggestive memoir was published by Mr. Daniel Sharpe on the foliation of the rocks of the Northern Highlands, in which he endeavoured to show that foliation is the ultimate stage of cleavage. He distinguished between the gneiss lying east and west of a line drawn from Loch Eriboll to the head of Loch Maree, the foliation and cleavage of the western area and of Lewis striking N.W. to S.E., and that of the eastern area striking S.W.‡

The discovery of fossils in the Durness Limestone, in 1854, by Mr. C. W. Peach §, imparted fresh interest to these rocks, and led Sir Roderick Murchison to revisit the north-west Highlands, which he had seen with Sedgwick as far back as 1827. He invited Professor Nicol to accompany him, and the two observers went over some of the northern sections together in the autumn of 1855. At the British Association meeting of that year Murchison spoke guardedly of the age of the limestones of Sutherland, but was evidently inclined to regard them as Lower Silurian, the fossil evidence not having yet proved decisive on that question. Next year Nicol returned to the ground and extended his observations. He detected a marked unconformability between the red sandstones and quartz-rocks, which he traced for upwards of a hundred miles. At the same time he was led to the conclusion that the red sandstones of the west of Sutherland and Ross-shire were probably of Devonian age, and the quartzite and limestone Lower Carboniferous. When, in the following year, Peach found better-preserved fossils, which put the Lower Silurian horizon of the limestones beyond doubt, Nicol, abandoning the suggestion he had put forward as to the geological age of the rocks, applied himself with renewed energy

* 'A Description of the Western Islands of Scotland,' vol. i. pp. 1–234, 243, 295 *et seq.*, vol. ii. pp. 89, 104, 508, 515, &c. 'A Geological Classification of Rocks,' London: p. 333. "Supplementary Remarks on Quartz-Rocks," Trans. Geol. Soc. ser. 2, vol. i. pp. 53–60. 'A System of Geology,' vol. ii. chap. 29.

† "Geognostic Account of the County of Sutherland," Trans. Highl. Soc. vol. xiii. p. 73.

‡ "On the Arrangement of the Foliation and Cleavage of the Rocks of the North of Scotland," Phil. Trans. vol. cxlii. p. 445.

§ "Notice of the Discovery of Fossils in the Limestone of Durness," Proc. Roy. Phys. Soc. Edinb. (1885), vol. i. p. 23.

to the investigation of the problem of the "newer gneiss." He had at an early period recognized the possibility that this gneiss might have been "forced over the quartzite;" and this view he endeavoured to establish by the evidence of many natural sections. He was ultimately led to maintain that the limestone is the highest member of the Silurian series in that region, and that the so-called "Upper Quartzite" and "Upper Limestone" of Murchison's sections are merely the repetitions of the lower quartzite and limestone, due to faults or folds. While admitting that in places the quartzite and limestones are overlain by gneiss, he contended that there is no conformable upward succession from the fossiliferous limestone to the overlying schists and gneiss, but "that the line of junction where this conformable succession is said to occur is clearly a line of fault, everywhere indicated by proofs of fracture, contortion of the strata, and powerful igneous action." The igneous rocks, which he erroneously regarded as having been erupted simultaneously with the displacement of the strata, were termed "granulite." Along the line of fault, where the disturbance has been most violent, Nicol further observed that the quartzite is "often much hardened and semifused," though its fragmentary character is still recognizable. From the foregoing data he inferred that the sections in the North-west Highlands are but the counterpart of those in the Alps, where crystalline rocks are seen resting on unaltered strata due to enormous inversion and overthrow, and that a comparatively small amount of inversion and extrusion of older crystalline masses will suffice to explain any of the Scottish sections.

With reference to the strike of the crystalline rocks, Nicol admitted that in the western region the general trend is N.W., and in the central areas N.E.; but this distinction is not universal. He ventured the suggestion that the gneiss of Scotland may belong to distinct geological periods. Regarding the divergence in mineralogical character between the western and eastern gneiss, he conceded that hornblendic varieties of gneiss are very characteristic of this formation in the west of Sutherland, but the more usual kinds also occur; while, in the eastern district, he contended that rocks quite as hornblendic and as thoroughly granitic in character are to be found. In his opinion the peculiar character of the rock has no relation to its age or locality, but to its proximity to the great foci of igneous action. Near the granitic and syenitic eruptions the gneiss appears in the more coarsely crystalline and hornblendic forms *.

* "On the Red Sandstone and Conglomerate, and the superposed Quartz-rocks, Limestones, and Gneiss of the North-west coast of Scotland," Quart. Journ. Geol. Soc. vol xiii. p. 17.

"On the Age and Relations of the Gneiss Rocks in the North of Scotland," Rep. B. Assoc. for 1858, see p. 96.

"On the Relations of the Gneiss, Red Sandstone, and Quartzite in the North-west Highlands," Rep. B. Assoc. for 1859, see p. 119.

"On the Structure of the North-west Highlands, and the Relations of the Gneiss, Red Sandstone, and Quartzite of Sutherland and Ross-shire," Quart. Journ. Geol. Soc. vol. xvii. p. 85.

'The Geology and Scenery of the North of Scotland.' Edinb. 1866.

The marked unconformability between the red sandstones and quartzites detected by Professor Nicol was observed independently by Sir Henry James, and described by him in a letter to Sir Roderick Murchison, dated 26th July 1856*.

The fossils obtained from the Durness Limestone by Mr. Charles Peach were considered by Salter to have strong affinities with certain Lower Silurian forms of North America, ranging from the Calciferous Sand-rock to the Trenton Limestone†. This determination, confirming, as it did, Sir Roderick Murchison's reference of the limestones and quartzites of Sutherland to the Lower Silurian system, gave that geologist a new impetus in his investigation of the structure of the North-west Highlands. After devoting parts of the summer of several successive years to the task, he arrived at what he believed to be the true order of geological succession in that region. The western gneiss, forming the ancient foundation-stone of Britain, he correlated with the Laurentian gneiss of Canada, and the red sandstones and grits with the Cambrian formation of Wales. The great succession of Silurian strata, resting unconformably on the Cambrian sandstones and Laurentian gneiss, were grouped by him in ascending order, (1) Lower Quartz-rock, (2) "Fucoid-beds" with *Serpulites Maccullochii* at the top, (3) Limestone with fossils, (4) Upper Quartz-rock followed in places by (5) an Upper Limestone passing upwards into micaceous flagstones, chloritic schists, and gneissose beds, covered unconformably by the Old Red Sandstone. From this unbroken sequence he inferred that the Highlands are mainly composed of metamorphosed Silurian strata.

In his various papers Murchison maintained that the prevalent strike of the western gneiss is N.W. and S.E., while that of the eastern schists is N.E. and S.W., and further, that this difference is made still more apparent by distinct lithological characters. He called special attention to the contrast between the hornblendic gneiss in the west of Sutherland and the micaceous flaggy strata overlying the limestones and quartzites to the east of Assynt, Loch More, and Loch Eriboll. He naturally held that such a difference in strike and lithological character implied a different geological horizon. It is due to his memory to recognize how clearly he saw the impossibility of accounting for the superposition of the eastern or upper gneiss on the limestone by supposing it to be the western or fundamental gneiss brought up again by mere ordinary faulting or inversion. He was mistaken, as we now know, in regarding this superposition as a normal stratigraphical sequence. But the mistake was hardly avoidable at the time, and was shared in at first by Nicol also. Indeed it could not be completely cleared up until laborious and detailed mapping had been undertaken. To Murchison's mind the fact of prime importance in the geological structure of the North-west Highlands was the position

* Memoirs of Sir R. I. Murchison, by A. Geikie (1875), vol. ii. p. 213.

† Rep. Brit. Assoc. for 1857, p. 83; Quart. Journ. Geol. Soc. vol. xv. p. 374 *et seq.*

of fossiliferous Lower Silurian rocks under enormous masses of gneisses and schists, and the proof thereby afforded of a vast regional metamorphism which could not be other than of Silurian age. He was entirely in error when he believed his younger gneiss to be merely metamorphosed Lower Silurian strata; but that the crystalline rocks of the Eastern Highlands contain the records of a gigantic Post-Lower-Silurian metamorphism is now established beyond dispute on evidence of which he never dreamed *.

The order of succession advocated by Murchison, and supported by Professors Ramsay, Harkness, A. Geikie, and others, seemed to furnish a simple solution of the geological phenomena of the Highlands, and hence met with general acceptance.

In 1878 the controversy was reopened by Dr. Hicks, in a paper "On the Metamorphic and Overlying Rocks in the neighbourhood of Loch Maree"†. While agreeing with Murchison that there is a perfect passage from the quartzites, "Fucoid-beds," and limestones into the overlying flaggy strata of Glen Logan and Glen Docherty, resembling the Lower Silurian flags of Wales, he maintained that the flaggy strata rest unconformably on the Pre-Cambrian Archæan rocks of Ben Fyn. Subsequently Dr. Hicks disputed that the eastern schists rest conformably on the Lower Silurian strata. He arranged the Pre-Cambrian rocks in three groups—(*a*) lower, consisting of massive gneisses (Loch Maree); (*b*) middle, comprising more banded gneisses (Loch Shiel); (*c*) upper, composed of crystalline schists (Ben Fyn); and contended that, between Glen Shiel and the Highland border, there are representatives of various Archæan rocks with patches of Silurian strata resting on them unconformably.

In 1880 an important contribution towards the solution of the

* "On the Relations of the Crystalline Rocks of the North Highlands to the Old Red Sandstone of that region, and on the recent Discoveries of Fossils in the former by Mr. Charles Peach," Brit. Assoc. Rep. 1855.

"The Quartz-rocks, Crystalline Limestones, and Micaceous Schists of the N.W. Highlands of Scotland proved to be of Lower Silurian age through the recent fossil discoveries of Mr. C. W. Peach, with a Note on the Fossils by J. W. Salter," Brit. Assoc. Rep. for 1857.

"On the Succession of the Older Rocks in the north-west counties of Scotland, with some observations on the Orkney and Shetland Islands," Quart. Journ. Geol. Soc. vol. xv. p. 353.

"Some Results of Recent Researches among the Older Rocks of the Highlands of Scotland," Brit. Assoc. Rep. for 1858, p. 94.

"Supplemental Observations on the Order of the Ancient Rocks of the North of Scotland and their associated Eruptive Rocks," Quart. Journ. Geol. Soc. vol. xvi. p. 215.

"On the Altered Rocks of the Western Islands of Scotland and the North-western and Central Highlands." By R. I. Murchison and A. Geikie. Quart. Journ. Geol. Soc. vol. xvii. p. 171.

† Quart. Journ. Geol. Soc. vol. xxxiv. p. 811.

On the Pre-Cambrian Rocks of West and Central Ross-shire," with Petrological Notes by T. Davies. Geol. Mag. dec. 2, vol. vii. pp. 103, 155, 222, 266.

"On some Recent Researches among the Pre-Cambrian Rocks of the British Isles," Proc. Geol. Assoc. vol. vii. p. 59.

"On the Metamorphic and Overlying Rocks in parts of Ross- and Inverness-shires," Quart. Journ. Geol. Soc. vol. xxxix. p. 141.

problem was made by Professor Bonney, who described the so-called "intrusive syenite" of Glen Logan, pointing out the occurrence of foliation in the rock and the N.W. strike; from which he inferred that all the "syenite," with the exception of a few dykes, is simply a rather granitoid variety of the Hebridean gneiss. He showed that its junction with the calcareous series is a faulted one and indicated the direction of the fault. He called attention to a marked fragmental structure in a green schist occurring in the mass, which he attributed to crushing *in situ* *.

Similar views to those of Professor Bonney regarding the "Logan Rock" were advanced by Mr. Hudleston, in 1882, who described it as the local representative in the Ben-More-Assynt range of the fundamental gneiss, and "as the framework or core round which the newer rocks are folded." He disputed the existence of the "Upper Quartzite," but considered that the section at Craig-a-Knockan shows a regular ascending series from the Silurian rocks to the upper gneiss †.

The various papers contributed by Dr. Callaway, embracing his researches in the districts of Loch Broom, Assynt, and Loch Eriboll, still further weakened the belief in Murchison's order of succession. Regarding those areas he maintained that there is no conformable sequence from the quartzites and limestones to the eastern gneiss, that the "Upper Quartzite" is merely a repetition of the lower quartzite, and that the "Upper Limestone" is either a repetition of the dolomite of the "Assynt Series" ‡ or an integral part of the Archæan series, as at Loch Ailsh. Recognizing the lithological distinction between the western and eastern gneisses, he grouped them in two great formations of Pre-Cambrian age—(*a*) the Hebridean, (*b*) the Caledonian, the latter resting unconformably on the former. Though the eastern gneiss (Caledonian) overlies the Silurian strata at certain localities, he contended that it had been brought into this position by overfolding and faulting without materially altering its original structures. In the district round Loch Broom, and in Assynt, the "Logan Rock" (Heddle) is regarded as part of the Hebridean gneiss brought up by faults, showing signs of crushing at the points of junction with other strata; at Loch Eriboll it is regarded as the base of the Caledonian gneiss. At Loch Broom the Hebridean gneiss, by means of faulting, is brought into contact with almost every member of the Silurian series in turn, and slightly overlies them; while in Assynt, where it is sometimes accompanied by the Torridon Sandstone, this gneiss is thrown over on to the Silurian series, "the overthrow increasing in breadth northwards, so that in Glencoul it is more than a mile wide."

In the appendix to Dr. Callaway's paper (Quart. Journ. Geol. Soc. vol. xxxix. p. 416) Professor Bonney describes the microscopic

* "Petrological Notes on the Vicinity of the Upper Part of Loch Maree," Quart. Journ. Geol. Soc. vol. xxxvi. p. 93.

† "First Impressions of Assynt," Geol. Mag. dec. 2, vol. ix. p. 390.

‡ Dr. Callaway applied the term "Assynt Series" to the Quartzites, Fucoid beds, Salterella-grit, and Limestone of Murchison's Silurian succession.

characters of some of the thrust Hebridean gneisses in Assynt and at Ullapool which show indications of crushing and recementation. In some instances these features have so obscured the original structure that it is difficult to determine the true characters of the rocks.

Subsequently Dr. Callaway referred to certain localities where the members of the Silurian series become more highly altered towards the junction with the Archæan gneiss, when the latter, by folding or thrust, has been made to overlie the former. He maintained that there is no material alteration in the Silurian series underlying the Hebridean gneiss in Glencoul, because there is no evidence of extraordinary pressure; but near the base of the Stack of Glencoul, at the junction with the eastern gneiss (Caledonian), the quartzite loses all traces of clastic structure and passes into quartz-schist. He accounts for this progressive alteration by enormous pressure due to the quartzite being "reflexed again and again in closely adpressed folds"*.

The investigations of Professor Lapworth demand special notice, because they involve a departure from Professor Nicol's views regarding the nature and origin of the eastern schists of Sutherland. Selecting the region of Durness and Eriboll, he mapped a large portion of it in great detail during the summers of 1882 and 1883. In the pages of the 'Geological Magazine' he published a series of papers on "The Secret of the Highlands"†, in which he described the geological structure of that region, completely confirming Nicol's conclusions (*a*) that the Durness Limestone is the highest member of the "Ordovician" series (Lower Silurian, Murchison), (*b*) that the "Upper Quartzite" and "Upper Limestone" are non-existent, (*c*) that there is no conformable sequence from the quartzites and limestones into the eastern gneissic series, (*d*) that the line of junction of the unaltered Palæozoic rocks is a line of fault and overthrust. But the results of his work, in so far as they affect the age, composition, and mode of formation of the eastern schists, were read at a meeting of the Geologists' Association, July 4th, 1884‡. As these results are practically identical with those obtained independently by the Geological Survey, and published in the official Report ('Nature,' vol. xxxi. p. 39), it is desirable to give a brief summary of them:—

1. The lithological distinctions between the Hebridean gneiss and the Logan and Arnaboll rocks are primarily due to the mechanical disturbances to which the latter have been subjected.

* "The Limestones of Durness and Assynt," Quart. Journ. Geol. Soc. vol. xxxvii. p. 239.

"The Torridon Sandstone in Relation to the Ordovician Rocks in the Northern Highlands," Quart. Journ. Geol. Soc. vol. xxxviii. p. 114.

"The Age of the Newer Gneissic Rocks of the Northern Highlands," Quart. Journ. Geol. Soc. vol. xxxix. p. 355.

"Notes on Progressive Metamorphism," Geol. Mag. dec. 3, vol. i. no. 5, p. 218.

† Geol. Mag. dec. 2, vol. x. pp. 120, 193, 337.

‡ Proc. Geol. Assoc. vol. viii. p. 438; see also Geol. Mag. dec. 3, vol. ii. p. 97 (1885).

2. The planes of schistosity in the eastern metamorphic schists are not planes of bedding, but planes of shearing and cleavage, along which the rocks have yielded to the lateral crust-pressure.

3. By the action of this lateral earth-thrust, the Archæan, the Plutonic, and included patches of sedimentary rocks have been locally sheared and flattened out into rocks resembling hälleflintas, rhyolites, and finely laminated shales.

4. The eastern metamorphic series of Sutherland and Ross not only contains Archæan rocks, but also local patches of metamorphosed Palæozoic, intrusive, and segregatory rocks, together with local patches of material, probably compounded of all these in different degrees.

5. The eastern metamorphic series has received its present strike, pseudo-bedding, and its present foliated and mineralogical characteristics through the agency of the crust-movements which have operated within the district since Lower Silurian times.

The stratigraphy of the West Highlands, he maintained, is of the same character as that described by Heim, in his work on the Alps of Central Switzerland; while the metamorphic phenomena are identical with those detailed by Lehmann, in his publications on the metamorphic rocks of the Saxon Erzgebirge.

In 1885 * a valuable paper was published by Mr. Teall "On the Metamorphosis of Dolerite into Hornblende-schist," as displayed by two more or less parallel dykes in the Archæan gneiss, near the village of Scourie, in Sutherlandshire. From a careful examination of the phenomena presented by the dykes in the field and by microscopic sections of the rocks, he concluded (1) that the hornblende-schist has been developed from a dolerite by causes operating after the consolidation of the dolerite, and that the metamorphosis has been accompanied by a molecular rearrangement of the augite and felspar; (2) that the molecular rearrangement has in certain cases taken place without the development of foliation; (3) that the plasticity which has led to the development of foliation is that due to high pressures at ordinary temperatures. These deductions are of far-reaching importance in interpreting many of the phenomena of the Archæan rocks.

The Geological Survey began the detailed mapping of the North-west Highlands in 1883, by tracing out the structure of the limestone district of Durness and Eriboll in the north of Sutherland. Since that time the work has made considerable progress, chiefly along the belt of extraordinarily complicated ground from Eriboll southwards through Assynt to Dundonald—a distance of fifty-five miles. To the west of that belt the tract between Cape Wrath and Lochinver, mainly occupied by Archæan rocks, has been surveyed. To the east, large districts of the eastern or newer schists between Tongue and Loch Broom have also been examined in detail. A large mass of evidence bearing on the nature and extent of the ancient terrestrial movements in the North-west Highlands, and throwing much light on the origin of the schistose structure in

* Quart. Journ. Geol. Soc. vol. xli. p. 133.

Archæan rocks and regional metamorphism in general, has been gathered together. The chief parts of this evidence are now laid before the Society.

The field-work of the Geological Survey in the region has been executed by Messrs. Peach, Horne, Gunn, Clough, Hinxman, and Cadell, under the immediate supervision of Mr. Peach. Mr. Cadell mapped that portion of the line of complicated structure extending from the head of Loch Eriboll to Loch More; Mr. Clough, from Loch More to the northern base of Glasven; Messrs. Peach and Horne, from Glasven to Elphin and the Cromalt Hills; Mr. Hinxman, from Elphin to Strath Kanaird; and Mr. Gunn, from the latter point to Little Loch Broom.

I. Archæan Rocks.

The detailed examination of the Archæan rocks lying between Loch Laxford and Lochinver has led to the conclusion that they have been subjected to enormous mechanical movements in Pre-Cambrian time. In attempting to unravel the history of these ancient rocks, it is best to follow the chronological order of the movements, as it enables us to interpret the successive modifications which the crystalline rocks have undergone.

1. *Original Types of Gneiss.*

1. Throughout the region referred to there are certain tracts where foliated rocks occur, evidently representing the original types of Archæan gneiss. From Lochinver south to the river Kirkaig and northwards along the coast to Loch Rooe, and again near Kylesku by the shores of Loch A'Chairn Bhain, these typical gneisses are admirably displayed. They are arranged in gentle anticlines and synclines, the axes of which usually run N.N.E. and S.S.W. or N.E. and S.W. Occasionally the angle of dip of the foliation is so low that the outcrop of the bands forms a series of parallel escarpments along the hill-slopes (Kylesku). Structurally they occur either as massive, rudely foliated crystalline rocks, with few divisional planes, or as well-banded gneisses in which the constituents have a distinct parallel arrangement. Both varieties are traversed by segregation-veins and pegmatites. The prominent minerals are plagioclase felspar, pyroxene (augite, diallage), hornblende, quartz (frequently opalescent), and magnetite. It is worthy of note that mica is a rare constituent of these original types of gneiss. On close examination it is apparent that the bands present certain lithological varieties of variable thickness; some consisting mainly of pyroxene or hornblende and a small quantity of plagioclase felspar; some of plagioclase, pyroxene, or hornblende and opalescent quartz; others of opalescent quartz and felspar. These varieties frequently cross the lines of schistosity and are evidently due to differences in the nature of the materials prior to the development of the foliation *.

* The term gneiss, as applied to these rocks, may be regarded as a misnomer, but for the sake of convenience we in the meanwhile use the generally accepted name.

2. *Unfoliated Igneous Rocks in original Gneisses.*

A remarkable feature of these original gneisses is the occurrence among them of numerous masses of highly basic igneous rocks (gabbros, peridotites, palæo-picrites, pyroxene-granulites, and diorites), either possessing no foliation, or foliation of such an imperfect type that it is impossible to tell its angle of inclination. They occur as lenticular zones or belts running for several hundred yards more or less parallel with the foliation, or as irregular patches covering about a quarter of a square mile of ground. Many of the dark bands of gabbro or diorite are highly garnetiferous (pyroxene-granulite), the garnets having no special arrangement except in those cases where they have been affected by later Pre-Cambrian movements.

These patches of non-foliated igneous rock are intersected by veins of grey pegmatite varying in thickness from a few inches to several yards, consisting mainly of felspar and quartz usually opalescent. Occasionally a small quantity of pyroxene or hornblende is associated with the quartz and felspar. In some instances the pegmatites are so prominently developed that they form a large proportion of the mass, and in such cases it frequently happens that "eyes" or bosses of the basic rock have been isolated from the parent sheet. Where the basic rocks are non-foliated, the pegmatites have no regular arrangement; where, on the other hand, incipient foliation is displayed in the former, the latter are drawn out parallel with the direction of movement.

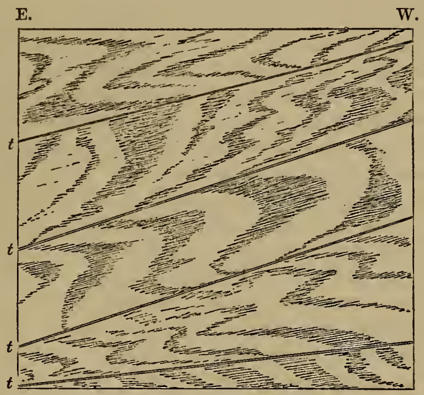
In tracing the boundaries of many of these non-foliated masses and their pegmatites, it is observable that the dark eruptive rocks pass gradually into the rudely foliated basic gneisses; while the pegmatites merge into the grey highly quartzose bands, consisting mainly of opalescent quartz and felspar. The conclusion is, therefore, obvious *that the original types of gneiss in the west of Sutherland have been formed out of eruptive basic rocks and the pegmatites developed in them prior to the foliation.* It is equally apparent also that the relative proportion of pegmatite and other segregation-veins to basic rock in the non-foliated areas should generally correspond with the proportion of grey highly quartzose gneiss to the more basic varieties.

3. *Evidence of mechanical Movements in the Formation of the original Gneisses.*

A careful study of the coast-sections at Lochinver and Kylesku reveals the fact that these original gneisses possess certain structures analogous to those met with in the quartz-schists overlying the fossiliferous limestones and quartzites produced by the Post-Lower-Silurian movements. The planes of schistosity traverse the various basic rocks and pegmatites, irrespective of the boundaries of the original materials. Such a result could not have been produced if the foliation had been due to the deformation of a mass of half consolidated Plutonic rock at the time of the intrusion. The foliation must have been developed after the consolidation of the igneous rocks and after the segregation of the pegmatites and other veins.

Of equal moment is the evidence supplied by the existence of thrust-planes, oblique foliation, and overfolding in these original gneisses. When the thrust-planes are traced along the face of a cliff, it is observable that they truncate folia lying at an oblique angle to them, thus producing a phenomenon resembling current-bedding. On the surfaces of these movement-planes there is no trace of brecciation, the line being sharply defined after the manner of the Post-Lower-Silurian thrusts in the Moine schists. The oblique foliation viewed in connexion with the prevalent overfolding indicates a gradual movement and piling up of the materials as the Plutonic rocks underwent enormous pressure. Further, it is possible to detect on the foliation-surfaces subparallel lines in-

Fig. 1.—*Section of original Archæan Gneiss, showing Thrust-planes, oblique Foliation, and Overfolding.*



t, t. Thrusts.

The figure represents an area of several hundred square yards, the plane being vertical, and the observer facing the south.

dicating the direction of the movement of the particles over each other. The latter, however, are by no means so common in the original gneisses as in those which have been affected by the later Pre-Cambrian movements to be described presently. From these data it would appear that even the first or original foliation of the Plutonic rocks was produced by mechanical movement.

4. *Igneous Rocks injected into the Archæan Gneiss after the first Foliation and prior to the later Pre-Cambrian Movements.*

After the development of the first foliation, the original gneisses were pierced by a remarkable series of igneous intrusions, mainly in the form of dykes, which may be grouped in the following order:—

a. Basalt-rocks, comprising dolerites, basalts.
b. Peridotites and palæo-picrites.
c. Microcline-mica rocks.
d. Granites.

(*a*) One of the most striking features of the Archæan rocks in the west of Sutherland is the extraordinary series of basic dykes, composed mainly of members of the first group (Basalt-rocks), throughout the tract extending from Lochinver to Loch Laxford. Between Lochinver and Kylesku their general travel is W.N.W. and E.S.E; between Kylesku and Loch Laxford the direction is more northerly, and in some instances it is nearly E. and W. Frequently they occur in groups, upwards of fifteen dykes being met with in the course of a mile. So persistent are they, that many of them have been traced for a distance of ten or twelve miles from the west coast of Sutherland, across the Archæan area, till they are buried underneath the Cambrian sandstones and Silurian quartzites. Sometimes they send forth branches or veins, which maintain separate courses for a considerable distance, and ultimately reunite with the parent dykes. Sometimes basalt-veins traverse dykes of dolerite, the peculiar lithological characters of each being preserved at the points of intersection. In all cases they possess the various zones characteristic of these igneous intrusions: the outer parts are more fine-grained than the centre and along the edges patches of tachylyte are occasionally met with. Only a very few of the dykes preserve the original prisms running at right angles to the walls; but their absence is satisfactorily accounted for by the extraordinary amount of deformation which they have undergone owing to the later Pre-Cambrian movements. Attention will be directed presently to the evidence in proof of the metamorphosis of many of these dolerites into diorites and hornblende-schists resulting from these later movements. But notwithstanding these facts, it must be admitted that many of the phenomena presented by this grand series of Archæan dolerite-dykes are but the counterpart of what may be seen in the splendid development of basalt-dykes of Tertiary age connected with the volcanic plateaux of the Inner Hebrides.

(*b*) The trend of the peridotite- and palæopicrite-dykes, which are best displayed in the Canisp deer-forest and westwards by Brackloch, Torbreck, and Riecairn near Lochinver, is more nearly E. and W. than that of the dolerites. As they traverse the various dolerite-dykes in their path, there can be no doubt that they were erupted after the basalt-rocks; and the evidence is also conclusive that their date of intrusion was prior to the later Pre-Cambrian movements. Weathering into a dark brown earth, they usually form long narrow clefts or hollows, thus giving rise to conspicuous features in the scenery of the Archæan area.

(*c*) On the south side of Loch Glendhu, a dyke consisting mainly of felspar and mica appears in the coast-section trending N.E. and

S.W. Under the microscope it is found to contain microcline, black mica, calcite, and garnet. It deserves special notice because it is believed to represent the unfoliated form of certain thin veins of mica-schist in the Archæan gneiss, to be afterwards referred to.

(*d*) Equally interesting are the intrusive dykes and sheets of granite (or syenite), containing quartz, felspar, mica, and frequently hornblende, traceable from Loch Stack westwards to Loch Laxford. Their general trend is W.N.W. and E.S.E., and they often coalesce, occasionally forming belts upwards of 500 yards across. Along their lines of outcrop they give rise to conspicuous "slacks" or hollows. From the evidence already obtained in the field, there can be little doubt that they were intruded into the older gneisses after the eruption of the dolerite-dykes; but whether the injection was prior to the foliation of the dolerite-dykes is not quite so certain.

5. *Later Pre-Cambrian Movements and their Direction.*

We have now reached an important stage in the history of the Archæan rocks in the west of Sutherland; for after the eruption of these various igneous materials the whole area was subjected to enormous mechanical movements, which exercised a powerful influence both on the dykes and on the crystalline rocks which the dykes traverse.

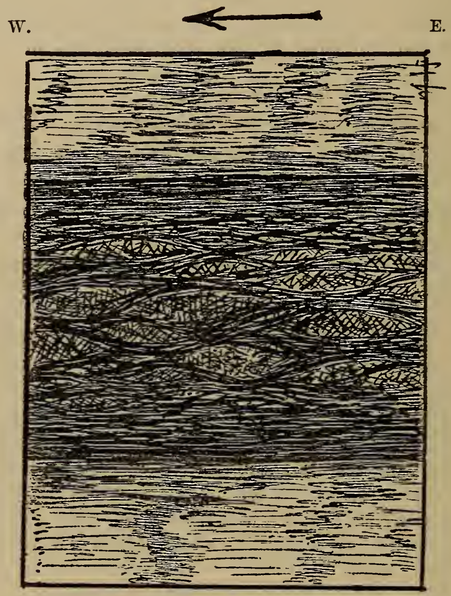
These lines of movement run in certain definite directions and may be described as thrust-planes, crush-lines, or lines of shearing, resulting in a newer foliation. They may be grouped in three systems:—(1) those running more or less parallel with the dykes of basalt-rock, viz. W.N.W. and E.S.E. or N.W. and S.E.; (2) those trending nearly E. and W. at an oblique angle to the basic dykes; and (3) those running N.E. and S.W. or N. and S. Of these systems the first and second are by far the most important. For the sake of convenience of description it will be desirable to indicate the effects of these movements first on the dykes, and secondly on the gneiss.

6. *Effects of these Movements on the intrusive Dykes.*

When the lines of movement are more or less parallel with the direction of the basic dykes, the dolerites gradually merge into diorites without the development of foliation. Under the influence of enormous pressure the dolerites have undergone complete molecular reconstruction; the felspars become opaque white and the augite is replaced by hornblende, recognizable in the field by its cleavage-angle. Indeed, this molecular change has been so extensively developed in these basic dykes that much of the existing rock deserves the name of diorite. But this type of metamorphosis is only a stage in the conversion of the rock into hornblende-schist.

When lines of movement coincide with the margins of one of the dolerite-dykes, it usually happens that portions of the outer parts—it may be a few inches or a few feet—are converted into hornblende-schist. So characteristic is this feature that few of the dykes do not display the marginal strips of schist. A further stage of change is met with when a broad dyke is traversed by several lines of shearing, in which case lenticular or eye-shaped masses of diorite are formed, round which curve in wavy lines beautiful bands of hornblende-schist (Canisp deer-forest).

Fig. 2.—*Diagram Sketch, showing Formation of 'Eyes' of Diorite in Hornblende-schist, from shearing of Dolerite-dyke intrusive in Gneiss.*



The gneiss has been modified by a secondary foliation parallel to the walls of the dyke.

The arrow indicates the direction of movement.

Area represented, about 600 square yards.

Finally the 'eyes' of diorite disappear, and the whole of the original dyke is converted into a zone of hornblende-schist. This extreme alteration is almost invariably accompanied by a complete reconstruction of the surrounding gneiss to be described presently. The bands of hornblende-schist consist mainly of secondary felspar and hornblende with a small quantity of mica, and can be split into thin laminæ from a quarter to half an inch thick, the direction of foliation being parallel with the lines of movement, viz. W.N.W. or N.W. An examination of the foliation-surfaces shows that the parallel lines or "striping" indicating the direction of movement are usually inclined at angles varying from 15° to 25° to the horizon. It is also observable that the north wall of the dyke has in most cases advanced further to the west than the south wall.

An important feature connected with the metamorphosis of the diorite into hornblende-schist is the occurrence of segregations of vitreous quartz, varying in width from a few inches to several yards. When best developed the direction of the segregation-veins usually coincides with that of the foliation of the schist.

In the neighbourhood of Loch Glencoul thin veins of mica-schist traverse the gneiss, which are believed to represent in a foliated form the dykes of microcline-mica rock near Loch Glendhu.

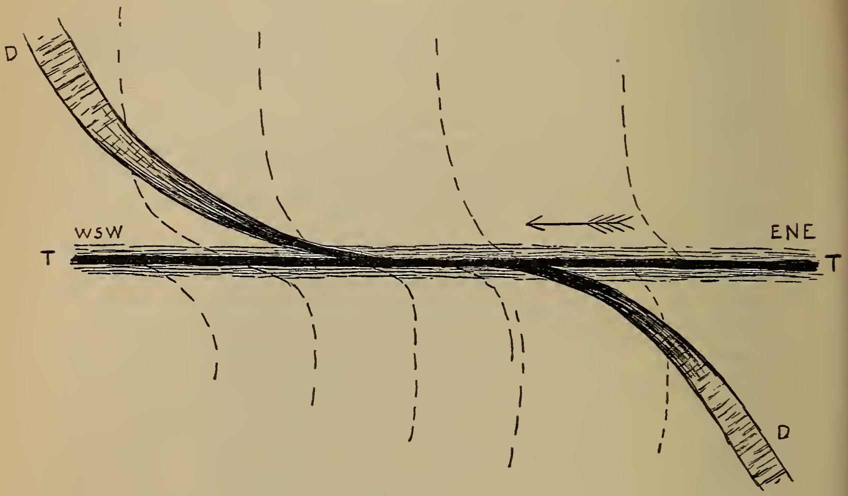
The result of these movements trending N.W. on the dykes of peridotite and palæopicrite has been to convert them, either wholly or in part, into soft talcose schists which can be easily cut with a penknife, the direction of the foliation being determined by the lines of shearing.

The veins and belts of granite have been changed by the same series of movements into granitoid gneiss, the general trend of the foliation running W.N.W. Of special interest is the appearance of massive pegmatites in connexion with these intrusions. From their mineralogical character there can be no doubt that the constituents have been mainly, if not wholly, derived from the granite. They may occur in the heart of the bands of granitoid gneiss, or the former may run parallel with the latter for long distances, and in some cases portions of the dykes have been completely isolated by the pegmatites. Occasionally the latter have been sheared with the granitic dykes in which they occur, but in such instances the shearing of the pegmatites was subsequent to the first foliation of the granitic intrusions; for there is clear evidence to show that the latter were subjected to a second series of movements, resulting in a modification of the first foliation. Some of the quartz-veins in the hornblende-schists have been similarly affected by this later series of movements.

The lines of movement trending E. and W. are either vertical or nearly so. When one of these typical thrusts crosses the path of a dolerite-dyke running W.N.W. or N.W., the dyke is gradually deflected from its normal course till it coincides with the line of thrust. On leaving it, the dyke resumes its natural trend. In some of the more striking examples the dykes are wrenched out of their normal course for nearly a mile (N. of E. of Ben Strome).

Where the gradual deflection takes place, the diorite begins to lose its granular character and eventually passes into a black, compact, flinty rock in the line of crush; or the dyke is completely recrystallized and converted into a fine hornblende-schist. These changes are accompanied by a remarkable attenuation of the basic intrusions, for in some cases dykes measuring 50 or 60 yards across shrink into bands 4 feet wide in the crush-lines. They are not reduced to the same uniform width, however, as they frequently form eye-shaped masses, completely isolated from each other and enveloped in crushed or reconstructed gneiss. In most cases the northern portion of the dyke has been moved further towards the west than the southern portion.

Fig. 3.—*Ground-plan, showing Deflection and Disruption of Dykes by vertical Thrust-planes.*



T. Thrust-plane.

D. Dyke, becoming attenuated and deflected and increasingly schistose as it approaches the plane, and being reduced to a "crush-rock" in immediate vicinity of the thrust. Displacement about $\frac{1}{4}$ mile.

Dotted lines indicate the strike of the gneiss, the planes being deflected as they approach the thrust.

The arrow shows direction of movement.

The parallel lines indicate the newer schistosity produced in the gneiss within the influence of the thrust.

When the hornblende-schist is extremely fine-grained there is a considerable development of black mica along the divisional planes, the direction of the foliation being more or less parallel with that of the thrust-planes; but variations commonly occur as the folia curve round the patches of diorite or granular igneous rock. When the orientation of the minerals in the hornblende-schist is examined, it is found to point towards the west; and when this fact is viewed in connexion with the deflection of the dykes, it is clear that, with one or two exceptions, there must have been a powerful movement towards the west, on the *north* side of these thrust-planes.

Similar schistosity is produced by the third system of disruption-lines, running N.E. and S.W., the direction of the foliation in this case also being determined by the trend of the lines of shearing.

An interesting example occurs on the hills to the east of Stoer, where a dolerite-dyke trending N.W. is traversed by a thrust-plane nearly at right angles to its course. Wrenched out of its path for some distance in accordance with the line of shearing, the dyke has been completely recrystallized and converted into hornblende-schist, which is not continuous. Along the path of the newer shearing the dyke is represented by lenticular strips of schist, the dip of the foliation being the same as that of the adjacent gneiss, which at this point has also undergone reconstruction owing to the same movement.

In all the cases above described belonging to these three systems of disruption-lines, the divisional planes developed in the hornblende-schist are either vertical or highly inclined. But we have yet to call attention to the presence of nearly horizontal foliation in these basic dykes.

In the neighbourhood of Stoer various dolerite-dykes, trending N.W. and occurring in the heart of gently inclined gneiss, are traversed by divisional planes crossing them at low angles and curving downwards towards the edges. The adjacent gneiss, though nearly flat or lying at low angles, has also been reconstructed. In such cases the dykes lose many of their characteristic features; they no longer present their wall-like form, but weather with much the same contour as the gneiss.

These horizontal movements, resulting in gently inclined thrust-planes and the development of horizontal schistosity, are not uncommon throughout the Archæan area. But there can be no doubt that they have an intimate relation with the vertical disruption-lines, for it sometimes happens that the one merges into the other. A remarkable example of this phenomenon is met with about a mile to the N.N.W. of Kylestrome. The general direction of the thrust-plane is W. 47° S., the hade being sometimes nearly flat, sometimes forming an angle of 30° with the horizon; while on the north side of the dolerite-dyke which it traverses the thrust-plane is inclined at a high angle. This instance is of special importance, because it illustrates those sharp curves so common in the far later disruption-lines which traverse the Silurian limestones and quartzites; nay, further, it shows how the same phenomena were repeated after long cycles of time in the production of the eastern schists.

7. *Effects of these Movements on the Gneiss.*

We now come to consider the effects of these various systems of movement on the original Archæan gneiss.

a. On approaching one of these vertical lines of movement the original gneiss suddenly loses its low angle, becomes highly inclined, and dips either towards or away from the disruption-line. Still more frequently the gneiss is thrown into a series of sharp folds forming a belt of contorted strata close to the lines of shearing. No matter what may have been the strike of the original gneisses, the axes of the folds are always more or less parallel with the powerful disruption-lines. In the case of the first system of movements, the strike of the gneiss in these contorted belts is W.N.W. or N.W.; in the second system the strike is nearly E. and W.

b. Coincident with this folding and high inclination of the gneiss there is a modification of the constituent bands; the folia are attenuated, and there is a partial reconstruction of the rock. In some cases this reconstruction has been so complete that the orientation of the minerals in the gneiss coincides with that of the minerals in the hornblende-schist in the basic dykes. Where this happens, the movements have given rise to a second foliation of the original types of gneiss.

c. The constituents of the different laminæ have undergone a mineralogical change, the original opalescent quartz-granules, besides being elongated, lose much of their opalescent character and become clear and vitreous; black mica has been abundantly developed out of the original hornblende, and a white hydrous mica out of the original felspar; the hornblende has recrystallized in the form of needle-shaped crystals of hornblende or actinolite; and, lastly, there is a plentiful development of secondary felspar.

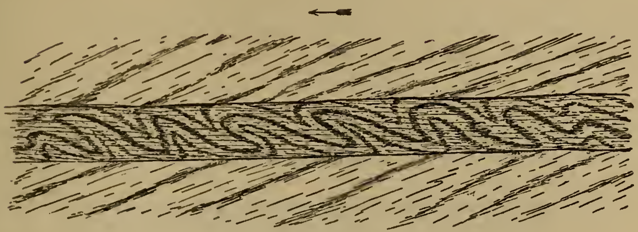
d. The high inclination and folding of the gneiss is usually accompanied by crush-lines, forming sometimes coarse breccias full of irregular fragments, sometimes very thin schistose bands several inches in breadth or even less, the foliation being parallel with the sides. Indeed, along the crests of many of these sharp folds new shear-planes occur, indicating complete disruption.

One of the best examples of the second foliation developed in the original gneisses by these vertical lines of movement occurs in the neighbourhood of Lochinver. It forms a belt from a quarter to half a mile in width, running W.N.W. through the Canisp deer-forest by Torbreck to Loch Rooe and Achmelvich. The strata consist of fine-grained gneiss and schist striking W.N.W., and inclined at high angles to the S.S.E. Indeed, as a general rule, this second foliation, wherever it occurs throughout the area *in connexion with the N.W. vertical movements*, dips at high angles in a south-easterly direction. Excellent examples of narrow zones of newer foliation trending E. and W. are displayed to the north of Kylesku.

In the case of the flat thrust-planes near Kylestrome, the disruptions in the gneiss are prominently marked, being sometimes filled with a layer of soft, rusty micaceous matter, on either side of which the folia of gneiss are inclined at different angles to the thrust. Occasionally there are repeated overfolds of a thin band in the micaceous layer, though the adjacent gneiss shows no trace of similar contortions.

In all the cases observed near Kylestrome the crests of the overfolds point S.W. or S.S.W., so that it would appear that the upper layers had moved over the lower ones in this direction. These layers of micaceous material may reach a few feet in thickness, and the plates of mica may be repeatedly folded by renewed movement along the line. The micaceous matter found in these flat thrust-

Fig. 4.—*Overfolding of Micaceous Layers along Thrust-planes in Archæan Gneiss.*



The arrow indicates direction of movement.

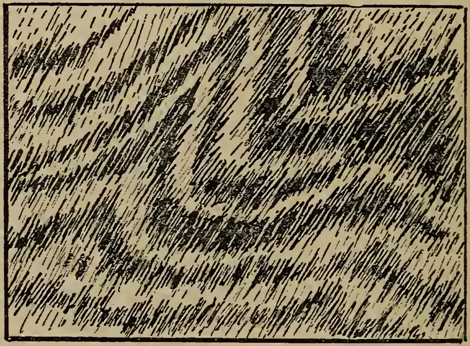
planes is usually of a yellow colour, probably from the weathering of specks of iron-pyrites. The bands of partially reconstructed gneiss sometimes possess the same tint, in particular those trending from Loch na Seilge to the sea-coast near Tarbat (Loch Laxford), which contain a large quantity of mica. The folia of the more micaceous layers in these bands are most frequently arranged at an oblique angle to the planes of schistosity, which seems to indicate that the higher bands of gneiss had moved over the lower ones in a westerly direction. A similar arrangement is met with near Loch na Claise Fearn, where the more quartzose layers of gneiss have been piled over each other; but in this case the laminæ are further apart. These phenomena closely resemble the heaping up of the bands of the eastern schists (Moine), to be referred to on a subsequent page.

Another important structure resulting from these mechanical movements is the development of incipient newer foliation at an oblique angle to the older one, and rudely parallel with the adjacent lines of movement. This newer schistosity occurs in various stages of development, sometimes so indistinct that it is hardly observable except when the rock-surface is carefully examined, sometimes so well marked that it is quite as conspicuous as the older one; while, again, it may be carried a stage further, when the old foliation is wholly destroyed. The effect of the attempt to establish a newer foliation is to rearrange the constituents of the bands along new planes more or less inclined to the old ones.

Black mica invariably accompanies this structure, and it occurs in greater or less quantity according to the stage of development of the second foliation. When the original folia form an alternation of light- and dark-coloured layers, it is observable that the oblique schistosity is most conspicuous in the dark bands; indeed, in some cases the lighter quartzose parts seem hardly affected at all, even where the adjoining layers, both above and below, show a marked second foliation.

This double foliation is frequently accompanied by intense crumpling and rapid contortions of the bands of gneiss, representing the effects of mechanical movements, which, along the same line of strike, merge into a disruption-line. Hence it follows that a zone or belt of gneiss with newer foliation trending W.N.W. may cease or disappear, and be replaced along the same line of strike by contorted gneiss with both the first and second lines of schistosity. (Canisp deer-forest, hills east of Scourie.)

Fig. 5.—*Diagram showing Double Foliation in Archæan Gneiss.* (About nat. size.)



This contortion and double foliation of the gneiss are characteristic of the area between Ben Auskaird and Loch Laxford, the general strike of the imperfect second foliation being from 8° to 20° S. of E. and N. of W.

A careful examination of the region near Claisfearn, north of Scourie, points to the conclusion that *the folding and contortion of the original gneiss were subsequent* to the injection of the basic dykes already described. It seems also pretty clear that the reconstruction of the gneiss in that region has taken place more or less along the old foliation-planes. Where this reconstruction has been carried so far as to involve the complete recrystallization of the original ingredients, then the gneiss may be regarded as practically a new rock. Just as the Silurian quartzites have been crystallized and converted into quartz-schists, frequently along the old bedding-planes, by movements later than Lower Silurian time, even so has the original Archæan gneiss undergone reconstruction along the old planes of schistosity.

From the evidence now adduced it is apparent that, owing to the effects of the various systems of movements here described, the Archæan gneiss possessing the first foliation has undergone considerable modification over extensive areas in the west of Sutherland. Its gentle arches and troughs, striking N.E. and S.W., have given place to sharp folds trending N.W., W.N.W., or E. and W., in harmony with the two great systems of disruption-lines. In places the old foliation has been completely destroyed and we find belts of newer foliation trending W. or N.W., or, it may be, a combination of the old and the new schistosities, accompanied by violent contortion. Or, again, the original gneiss has undergone partial or complete reconstruction along the old foliation-planes, whether they happen to be inclined at high or low angles. Hence it is only within limited areas that we can study the characters of the original gneisses. We believe, and the evidence in the field warrants the belief, that the highly basic, pyroxenic, and hornblendic gneisses at one time extended over the whole area, and that the lithological varieties now met with, so different from the older set, have been produced by the deformation of the original gneisses *.

8. *Evidence proving the Pre-Cambrian Age of these Movements.*

There is an overwhelming amount of evidence to prove that these various mechanical movements, which have so powerfully affected the basic dykes and the Archæan gneiss, took place prior to the deposition of the Cambrian (Torridon) sandstones. The various disruption-planes and the belts of secondary foliation can be traced from the sea-coast, across the Archæan area, till they are buried underneath the pile of Cambrian sandstones and Silurian quartzites. Neither the red sandstones nor the quartzites along the western escarpment show the slightest trace of having been affected by these movements. The disruption-lines, like the basic dykes, disappear at the base of the great cliff of Palæozoic sedimentary deposits. We are therefore forced to conclude that these movements have no connexion with the gigantic Post-Lower-Silurian displacements, and that the rocks had assumed their present characters in Pre-Cambrian time.

The Archæan area is still further complicated by a double system of normal faults, one set trending N.W. and S.E., and the other set N.E. and S.W. Most of these are probably later than the Post-Lower-Silurian movements.

Among the Archæan rocks certain dykes are met with which are all probably later than the deposition of the Cambrian and Silurian strata of Sutherland. These include some of mica-diabase occurring in the Archæan gneiss and Cambrian strata, and the porphyritic quartz-felsites of the same age as the Canisp "porphyry" to be referred to presently, and probably certain dykes of olivine-diabase.

9. *Summary of the foregoing Researches in the Archæan Rocks.*

The series of phenomena revealed by these researches in the Archæan rocks in the north-west of Sutherland may be tabulated as follows:—

(1) The eruption of a great series of igneous rocks of a more or

* From the evidence adduced in the foregoing pages regarding the effects of the *later* Pre-Cambrian movements, it is obvious that they are merely the differential results of an enormous thrust of these Archæan rocks, generally from the E.N.E. towards the W.S.W.

less basic type (gabbros, peridotites, palæopicrites, quartz-diorites, &c.), in which pegmatites and segregation-veins were formed.

(2) The development of foliation in these eruptive rocks and pegmatites by mechanical movement, and their conversion into "gneisses," the axes of the folds running generally N.E. and S.W.

(3) The intrusion of a great series of igneous rocks, mainly in the form of dykes, in the gneisses, consisting of (*a*) basalt-rocks, (*b*) peridotites and palæopicrites, (*c*) microcline-mica rocks, (*d*) granites, &c.

(4) The subjection of the original gneisses to enormous mechanical movements, giving rise to disruption-lines or thrust-planes trending, (*a*) N.W. and S.E., or W.N.W. and E.S.E., (*b*) E. and W., (*c*) N.E. and S.W.

(5) The alteration of the dykes consequent upon these movements :—(*a*) the dolerites being changed into diorites and hornblende-schists, (*b*) the peridotites into talcose schists, (*c*) the microcline-mica rocks into mica-schists, (*d*) the granites into granitoid gneiss. Pegmatites were also formed in the hornblende-schists and granitoid gneiss.

The plication of the gneiss in sharp folds trending E. and W. or N.W. and S.E., the development of secondary foliation running generally N.W. and S.E., or W.N.W. and E.S.E., or E. and W., and the partial or complete reconstruction of the gneiss along the old planes of schistosity.

6. The foliation of the granitoid gneiss and associated pegmatites by a still later series of movements.

II. Cambrian Formation. (Torridon Sandstone.)

1. *Denudation of the Pre-Cambrian Land-surface.*

Between the formation of the Archæan rocks in the west of Sutherland and the deposition of the overlying Cambrian conglomerates and sandstones an enormous interval of time must have elapsed, during which the primeval land-surface was subjected to extensive denudation. In order to form an accurate idea of the outline of this ancient land, the observations must be confined to the area bordering the line of junction between the gneiss and the sedimentary deposits. It would obviously be unsafe to accept the present contour as any indication of the primeval one, in tracts where the Archæan rocks have been stripped of the red sandstones and quartzites, and exposed for long ages to denudation. Indeed, there is clear evidence for maintaining that where such has been the case the agents of waste have been to a large extent guided in their operations by the trend of the basic dykes, the various Pre-Cambrian disruption-lines, and the great series of normal faults that followed the terrestrial displacements of Post-Lower-Silurian date. From the evidence obtained in the district of the Parph, west of the Kyle of Durness, it is apparent that the old land-surface must have been worn down to a comparatively level plane ; while in Assynt it must have been carved into a series of dome-shaped eminences, sometimes reaching a considerable elevation. In one case, a Pre-Cambrian hill, *about* 700 *feet high*, projects through the lower, and is overlapped by the higher members of the Red-Sandstone series on the north-west slope of Quinaig. Similar evidence, though not so remarkable, is obtained round the margin of the outlier at Stoer north of Lochinver, on the shores of Cama Loch near Elphin, and to the south of Loch Broom.

2. *Order of Succession in the Parph District.*

The general ascending order of succession in the Parph district is as follows:—

Total maximum thickness 1800 feet.	4. Fine-grained, friable, yellow and mottled sandstones and marls.
	3. Alternations of coarse sandstones, grits, and beds of conglomerate.
	2. Conglomerate, containing well-rounded pebbles of slaggy diabase-porphyrite, quartzite, greywacke, hardened shales, cherty limestone, jasper, &c.
	1. Angular basal breccia, occurring at any horizon where the domes of gneiss project through the Cambrian deposits.

Of the foregoing subdivisions, zone 2 presents features of special interest, as the component pebbles have not been derived from the underlying gneiss. They point to the existence of an older series of sedimentary deposits and volcanic rocks, no trace of which has yet been met with throughout the Archæan area*.

3. *Succession in Assynt.*

In Assynt the foregoing subdivisions cannot be traced, as the vast thickness of strata mainly consists of coarse sandstones, grits, and occasional bands of conglomerate corresponding with zone 3 of the above section. Towards the base, however, the beds become flaggy and fine-grained and contain several bands of purple and greenish-grey shales and sandstones. In places there is an important local development of conglomerate named "the Button Stone," which seems to have filled hollows in the old land surface. This horizon has been of great service in the identification of the masses of Cambrian strata thrust forward by the Post-Lower-Silurian displacements.

At Stoer north of Lochinver there is a small patch of Cambrian strata, covering about six square miles of ground, which possesses special interest owing to the discovery of organic remains in grey, green, and black mudstones and cornstones near the base of the series. The fossils consist of calcareous rods, which have as yet defied determination. The total thickness of the members of this formation in Assynt varies from 3800 to 4000 feet.

* The occurrence of rocks foreign to the North-west Highlands, in the Cambrian conglomerates of Ross-shire, has been chronicled by Dr. Hicks (Q. J. G. S. vol. xxxiv. p. 813).

4. *Succession in Loch-Broom district.*

Advancing southwards to the shores of Little Loch Broom, this formation undergoes a still further development by the occurrence of dark and grey flags and shales, occupying a higher position than any of the beds lying to the north. These dark shales have also yielded certain doubtful impressions which may prove to be organic, together with worm-casts. In this region the total thickness of strata is about 8000 feet.

Considering the coarse materials which compose the greater portion of the Cambrian strata and the indications of rapid accumulation, it may be plausibly inferred that they represent a great lacustrine formation.

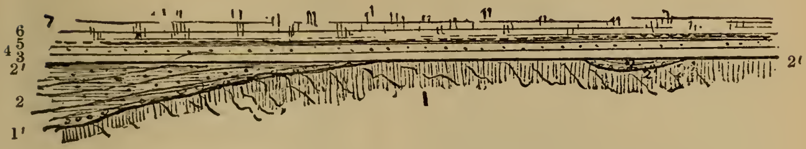
5. *Formation of Outliers of Cambrian Strata in Post-Cambrian and Pre-Silurian time by Folding and Denudation.*

After the accumulation of the Cambrian strata there is clear evidence to prove that they must have been subjected to extensive denudation prior to the deposition of the fossiliferous quartzites and limestones. That there is a marked discordance between the two formations, as originally established by Professor Nicol and Sir Henry James, cannot for a moment be doubted. As the red sandstones are either horizontal or inclined to the E.S.E. at lower angles than the quartzites, it is observable that the former are transgressed, bed after bed, by the basal quartzites, till the latter rest directly on the Archæan gneiss. This double unconformability is admirably displayed on the slopes of Ben Garbh, forming the southern shore of Loch Assynt.

That this was not the original eastern limit of the formation is evident from the fact that several masses of Cambrian strata have been carried from areas lying far to the east by the Post-Lower-Silurian displacements to be referred to presently. The Cambrian age of these thrust-masses is placed beyond doubt (1) by the occurrence of the local conglomerate ("Button Stone"), (2) by the double unconformability of the basal quartzites on the red sandstones and the Archæan gneiss; and (3) by the sheets of intrusive felsite occupying their proper horizon.

It is obvious therefore that during the interval which elapsed between the deposition of the Cambrian sandstones and Silurian quartzites, the former must have been thrown into a series of gentle folds, a vast thickness of strata was then removed, the Archæan rocks were exposed over wide areas, and the surface was reduced to a great plane of marine denudation. By these means various outliers of Cambrian strata were formed, far to the east of the present apparent limit of this formation, which tell an interesting story in connexion with the metamorphism induced by the Post-Lower-Silurian movements (see fig. 6).

Fig. 6.—*Diagram showing the Formation of Outliers of Cambrian Strata by folding and denudation in Post-Cambrian and Pre-Silurian time.*



1. Archæan.
2. Cambrian.
3–7. Silurian.

1′. Pre-Cambrian Plane of Marine Denudation.
2′. Pre-Silurian Plane of Marine Denudation.

III. The Silurian Formation.

1. *Uniformity in the Order of Successsion.*

The results of our researches along the line of complicated structure from Eriboll to Ullapool demonstrate the remarkable uniformity of the order of succession of the Silurian formation. All the various zones and even the minor subdivisions, from the basal quartzites up to the horizon of the Eilean Dubh limestones (Group II. of vertical section of Durness limestones), have been traced for a distance of nearly 60 miles with very small variations in their respective thicknesses.

2. *Subdivision of the "Pipe-Rock" Zone.*

The detailed mapping of the Assynt region and the tract north to Ben Arkle has enabled us still further to subdivide the "Pipe-Rock" zone of the quartzites into five horizons. At the top of the fourth subzone (see vertical Section II. p. 406) an interesting discovery was made of a thin band containing Serpulites (like those in the Serpulite-grit) on Ben Arkle. This band, however, seems to be local; for though it has been carefully searched for to the south, it has not yet been met with.

The lowest group of Limestones (Group I., vertical section of Durness Limestone) has been also subdivided into eight zones, which have been of the greatest service in unravelling the complicated structure of the limestone plateau at Inchnadamff. A recent examination of the representatives of this group in Eriboll has proved their occurrence in that region also.

In order to compare the vertical section of strata at Durness and Eriboll with that along the line of complicated structure from Loch More to Ullapool, we have drawn out a vertical table of the strata in the latter region (vertical Section II. p. 406), showing the various subdivisions and the horizons of the numerous sheets and dykes of intrusive rocks in Assynt.

Vertical Section I. of Silurian Strata at Durness and Eriboll.

C. Calcareous Series.	VII. Durine Group.	Fine-grained, light-grey limestones, with an occasional dark fossiliferous band.
	VI. Croisaphuill Group.	*c.* Fine-grained, cleaved, lilac-coloured limestones, full of flattened worm-casts; fossils distorted by cleavage. *b.* Alternations of black, dark-grey, and white limestone, with an occasional fossiliferous band, like zone (*a*) of this group. *a.* Massive, dark-grey limestone, chiefly composed of worm-casts which project above the matrix on weathered surfaces. Near the base are several lines of small chert nodules. This is one of the most highly fossiliferous zones in the Durness basin.
	V. Balnakeil Group.	Alternations of dark- and light-grey limestone, highly fossiliferous, with occasional impure, argillaceous, unfossiliferous bands. Most of the beds are distinctly cleaved, and contain few worm-casts.
	IV. Sangomore Group.	Fine granular dolomites, alternating near the top with cream-coloured or pink limestone. Near the base are two or more bands of white chert, one of which is about 5 feet thick.
	III. Sailmhor Group.	Massive, crystalline-granular, dolomitic limestones, occasionally fossiliferous, charged with dark worm-castings set in a grey matrix; large spheroidal masses of chert near the base. This limestone is locally known as "the Leopard Stone."
	II. Eilean Dubh Group.	Fine-grained, white, flaggy, argillaceous limestones and calcareous shales. As yet no fossils have been found in this division.
	I. Ghrudaidh Group.	Dark leaden-coloured limestones, occasionally mottled, alternating near the top with white limestone. About 30 feet from the base there is a thin band of limestone charged with *Serpulites Maccullochii*, and a similar band occurs at the base.
B. Middle Series (partly calcareous and partly arenaceous).	Upper Zone.	At the base lies a massive band of quartzite and grit, passing upwards into carious dolomitic grit, crowded in patches with *Serpulites Maccullochii*, more especially in the decomposed portions (Serpulite-grit).
	Middle Zone.	Alternations of brown, flaggy, calcareous, false-bedded grits and quartzites with cleaved shales.
	Lower Zone.	Calcareous mudstones and dolomitic bands, weathering with a rusty brown colour, traversed by numerous worm-casts, usually flattened, and resembling fucoidal impressions. These beds are often highly cleaved. This and the overlying zone form the "Fucoid-beds" of previous authors.

Vertical Section I. (continued).

A. Arenaceous Series.	Upper Zone.	Fine-grained quartzites, perforated by vertical worm-casts and burrows, becoming more numerous towards the top of the zone ("pipe-rock" of previous authors).
	Lower Zone.	False-bedded flaggy grits and quartzites, composed of grains of quartz and felspar. At the base there is a thin brecciated conglomerate, varying from a few inches to a few feet in thickness, containing pebbles of the underlying rocks, chiefly of quartz and orthoclase, the largest measuring about 1 inch across.

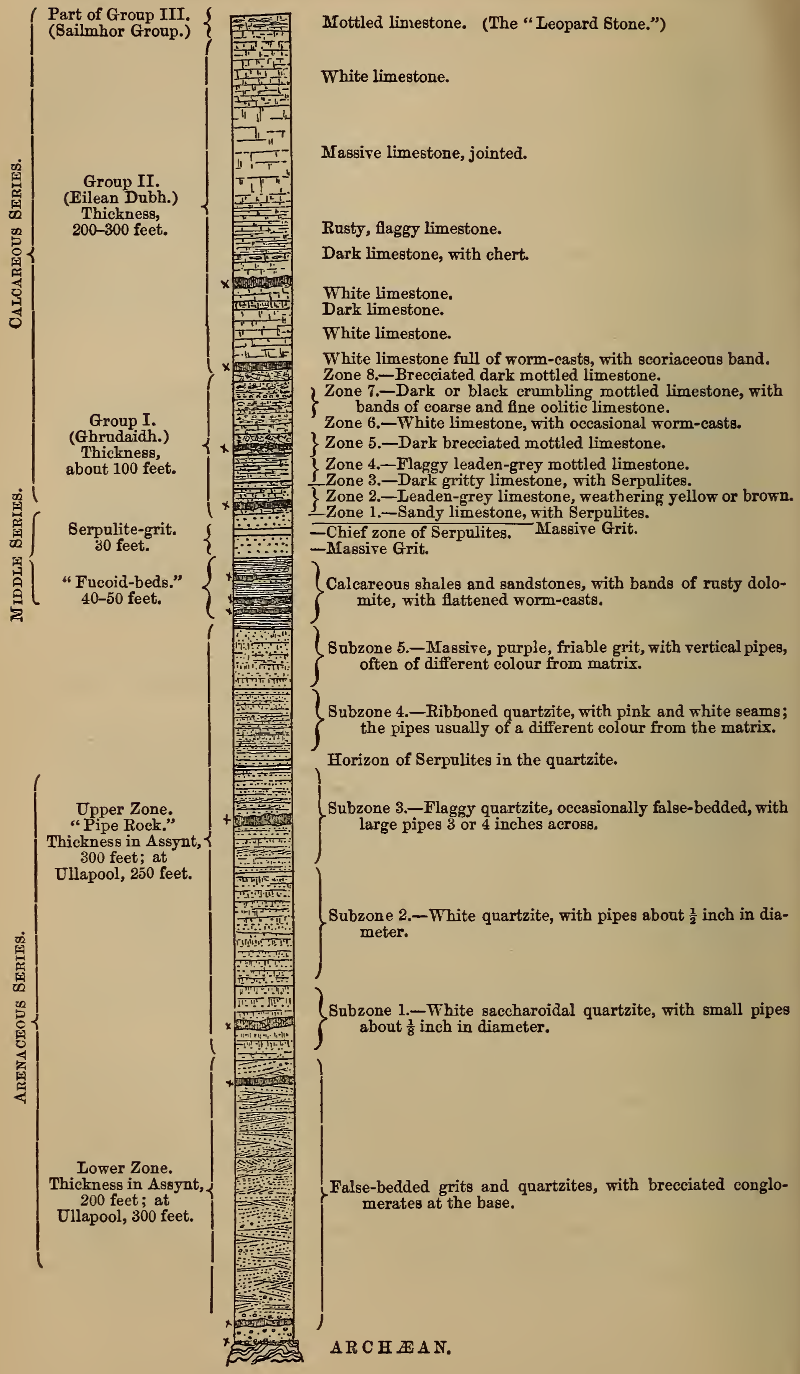
The highest beds which occur along the line of complicated structur belong to the Sailmhor Limestones (Group III. vert. Section I.). These dark mottled limestones, representing only the basal beds of this group, occur on the limestone-plateau of Inchnadamff, and nowhere else along the line. None of the rich, fossiliferous zones of Durness is met with anywhere between Eriboll and Ullapool, because they all occupy higher horizons. The *Orthoceras* found by Mr. Charles Peach in Assynt must have been obtained from one or other of the bands of Serpulite-limestone at the base of the Ghrudaidh Group.

3. *Physical Conditions during Deposition of Silurian Strata, and Horizon of the latter.*

Mr. B. N. Peach thus summarizes the physical conditions indicated by the Silurian strata in Sutherland. In the case of the basal quartzites, where there is a passage from a land-surface to a sea-bottom, there is little or no organic matter mixed with the coarse siliceous sand, which, from its texture and the false-bedding of the layers, bears evidence of rapid accumulation. There would therefore be no food for the support of Annelides under these conditions. But with the slower accumulation indicated by the "pipe-rock" there was evidently time for the fertilization of the sand by the shower of minute pelagic organisms which is ever falling on the sea-floor, so that it could afford food for the burrowing Annelides whose casts now form the stony pipes.

Different species of errant Annelides make their appearance in the "Fucoid-beds" along with the survivors of those that formed the vertical burrows in the quartzite, the surfaces of the beds presenting a matted network of their flattened excrements, thus misleading the older observers, who regarded them as the remains of seaweeds. The zone of Serpulite-grit indicates a shallowing of the area of deposit and the introduction of coarser sediment; but after its deposition hardly any sediment derived from the land entered into the composition of the overlying limestones. Eventually nothing seems to have fallen on the sea-floor but the remains of minute organisms,

Fig. 7.—*Vertical Section II. of Silurian Strata from Eriboll to Ullapool, showing horizons of Intrusive Rocks (marked ×) in Assynt.*



whose calcareous and siliceous skeletons have slowly built up the great mass of limestone and chert so conspicuously developed at Durness. That small pelagic animals played the chief part in the formation of this accumulation of limestone, is rendered almost certain by the fact that most of the beds are traversed by worm-casts in such a manner that nearly every particle must have passed through the intestines of worms. It is evident from the prevalence of these Annelid traces that the limestones cannot be due to coral-reefs, but must be of detrital origin. Only one undoubted specimen of coral, resembling a *Michelinia*, imbedded in a fine calcareous sediment, has been obtained from the series. That shell-banks had little to do with the accumulation of the limestone, is apparent from the mode of occurrence of the shells which are found in it. The most abundant forms are chambered shells, such as *Orthoceratites*, *Lituites*, and *Nautilus*; next in order are the Gasteropods, chiefly *Maclurea* and *Pleurotomaria*, while the Lamellibranchs and Brachiopods rank last in point of number. The two latter are found with their valves attached, and the Lamellibranchs occur in the position in which they lived and died. All the specimens show that every open space into which the mud could gain access and the worms could crawl is traversed by worm-casts. In the case of the *Orthoceratites*, they seem to have lain long enough uncovered by sediment to allow the septa to be dissolved away from the siphuncles which they held in place. Many of those siphuncles are now found isolated; indeed Salter established his genus *Piloceras* on such large examples as those found in *Endoceras*. Sponges of the genera *Archæocyathus* and *Calathium* occur at intervals in the muddy matrix. One example is preserved in chert; but the larger masses of chert in the limestone do not seem to be derived from sponges, but more probably from the siliceous skeletons of Diatoms, which, in all likelihood, were as abundant in that ancient ocean as they are now. No undoubted remains of Foraminifera have been discovered, though on several horizons there are zones of limestone made up of small rounded bodies, probably oolites; but owing to the fact that the limestones are crystalline, and that many of them have been more or less dolomitized, it is now almost impossible to decide definitely as to the nature of these spherules. For the same reasons it is almost hopeless to find minute organisms in this formation. The shell-substance of the larger fossils has in almost every case been dissolved out, and the spaces have been filled with calcite and, in some cases, with beekite, so that all the finer markings on their surfaces are obliterated.

The fossils, as Salter long ago pointed out, are distinctly of an American type, and do not resemble those found in the contemporaneous deposits of Wales and England. So far as the order of succession of the beds and their fossil contents are concerned, we have almost an exact counterpart of the strata exposed along the axis of older Palæozoic rocks, stretching from Canada through the eastern States of North America. In the latter region the Silurian strata of Sutherlandshire are represented by:—(1) the Potsdam Sandstone, always described as being vertically piped by *Scolithus* like the "pipe-rock," and (2) the Calciferous Group; in other words, the highest beds of the Cambrian and the lowest members of the Silurian formations. There can be little doubt that some old shore-line or shallow sea must have stretched across the North Atlantic or Arctic ocean, along which the forms migrated from one province to the other, and that some barrier must have cut off this area from that of Wales and Central Europe.

IV. Igneous Rocks in Cambrian and Silurian Formations.

1. *Evidence of their Intrusive Character.*

The Lower Palæozoic strata of Assynt furnish evidence of an outburst of volcanic activity after the deposition of the Limestone series. The crystalline rocks which contain the records of this episode in the geological history of the North-west Highlands are all intrusive and occur in the form of sheets extending for miles along the bedding-planes.

That these igneous rocks are intrusive and not contemporaneous will readily be admitted for the following reasons:—first, when the sheets are followed along the line of outcrop they pass transgressively from lower to higher members of the same group; second, where they reach a considerable thickness, both the overlying and underlying strata are altered by contact-metamorphism; and third, they frequently contain patches of the sedimentary beds which they have traversed, as, for example, fragments of altered quartzite in the diorites associated with the limestone.

2. *Horizons.*

The phenomena presented by these intrusive sheets are admirably displayed on the slopes of Ben Garbh and Canisp, south of Loch Assynt, where they have been injected along the bedding-planes of the Cambrian sandstones and Silurian quartzites, and again in the great limestone cliff at Stronechrubie (Inchnadamff) on the horizon of the Ghrudaidh Group. For long distances the foregoing masses keep to the same horizon, even where the strata are dipping at low angles, but eventually they leave it and pierce the beds above or below. On the western face of Canisp, a large mass of porphyritic felsite rises from the old platform of Archæan rocks, passing upwards into the Cambrian sandstones and ultimately spreading along the bedding-planes of the strata. Several important sheets are also found on higher horizons both on Canisp and Ben Garbh.

The foregoing vertical Section II. (fig. 7) shows the prevalent horizons of these intrusive masses in the Silurian rocks of Assynt, from which it will be seen that they occur in both zones of the quartzites, the "Fucoid-beds," and in the two lowest limestone groups. It ought to be remembered, however, that though they generally occupy the particular horizons indicated in the table, they not unfrequently appear either in higher or lower subdivisions of the same group.

The thickness of these dykes and sheets varies from 10 to 50 feet. But towards the southern limits of Assynt there is quite an exceptional development of one of these intrusive masses extending continuously for a distance of five miles from Ledbeg to a point near the road leading to Loch Ailsh. Occurring within the area affected by the Post-Lower-Silurian movements, it is traversed by numerous thrusts which have had the effect of repeating portions of the mass. It is highly probable that it resembles the others in its mode of occurrence, and was originally injected along the bedding-planes, forming a sheet not less than 600 feet thick. As might naturally be expected, such a great thickness of igneous material has developed important changes in the lithological characters of the strata by contact-metamorphism.

3. *Area of Distribution.*

The area of *undisturbed* Lower Palæozoic strata penetrated by these sheets is limited, extending from Loch Assynt to near Elphin, a distance of about nine miles; but their development in the territory affected by the Post-Lower-Silurian movements is somewhat remarkable. Indeed from the evidence obtained by the detailed mapping of the displaced masses, it is clear that originally the igneous rocks must have spread over a large area, stretching from Glencoul to Ullapool—a distance of twenty-four miles. In the latter district they occur near the base of the limestone or between the limestone and the Serpulite-grit; while in Strath Kanaird (north of Ullapool) they are met with apparently about the junction of the "pipe-rock" with the basal quartzites. It is further evident that they must have extended far to the east (though how far it is impossible to say), because they occur in the Cambrian sandstones and Silurian strata carried westward along the higher thrust-planes.

4. *Macroscopic Characters.*

A detailed description of the petrographical characters of these igneous rocks is not contemplated in this paper. It will be sufficient if we indicate their general macroscopic characters and the types to which they belong. In his papers published in the 'Mineralogical Magazine'*, Dr. Heddle has called attention to some of their lithological features, and has figured some of the beautiful crystals of felspar and hornblende; Professor Bonney† has described the microscopic characters of certain specimens from the Traligill burn, Inchnadamff, and near Alltnacallagach, naming the former a hornblendic porphyrite; while Mr. Teall‡ has contributed notes on the macroscopic and microscopic characters of several dykes taken from different horizons in the Silurian series, giving the chemical analyses of three varieties, which show a considerable variation in chemical composition, the most basic being obtained from the series

* Mineralog. Mag. vol. iv. p. 233, vol. v. pp. 137–145.
† Quart. Journ. Geol. Soc. vol. xxxix. p. 419.
‡ Geol. Mag. dec. 3, vol. iii. p. 346.

in the limestones. He has called attention to the presence of augite in addition to the hornblende, and suggests that the pyroxene may be due to the absorption by the igneous magma of a certain amount of the dolomite-limestone into which the rock has been intruded.

These interesting observations of Mr. Teall are confirmed by the results of the detailed examination of the Assynt region. Indeed, during the season of 1885, when the limestone-plateau of Inchnadamff was mapped, it became sufficiently obvious that, with few exceptions, the intrusive rocks in the limestones are more basic than those in the quartzites. It was also noted that the development of pyroxenes is a characteristic, not only of the thinner bands in the calcareous series, but of those portions of the great sheet of igneous material east of Ledbeg which are in immediate contact with the marble.

The following varieties are met with in the lower and upper zones of quartzite :—(*a*) compact, fine-grained, pink or grey felsite, with or without porphyritic quartz; (*b*) porphyritic felsite, with crystals of felspar and hornblende set in a felsitic ground-mass; (*c*) the former shades into a highly crystalline rock in which large crystals of orthoclase and albite, with beautiful zonal banding, occur in a micro-crystalline ground-mass consisting of felspar and hornblende; (*d*) porphyritic diorite in which hornblende-crystals are porphyritically developed in a crystalline matrix of plagioclase felspar with some hornblende.

The igneous sheets and dykes in the Ghrudaidh limestones (Group I.) consist mainly of diorite, some of them being fine- and others coarse-grained. With the hornblende and plagioclase felspar augite is occasionally associated. The dyke occurring in the Eilean-Dubh limestone is usually a grey felsite or hornblendic felsite.

The macroscopic characters of the great intrusive mass, extending from Ledbeg eastwards by Loch Borrolan to a point near the Loch-Ailsh road, are somewhat different from the foregoing types. The greater portion is highly granitoid, consisting mainly of crystals of felspar (albite, microcline, orthoclase) with secondary quartz. In those localities where hornblende is present, the rock resembles a hornblendic granite. Where the intrusive mass has come in contact with the limestone, pyroxene has been developed; indeed the molten material must have absorbed a large quantity of calcareous matter, for in many places it effervesces freely.

5. *Contact-Metamorphism.*

Where the bands are comparatively thin, not much alteration is observable in either the quartzites or the limestones, except a slight induration of the strata along the edges of the intrusive masses. But where they reach a considerable thickness, some remarkable changes occur. For example, on the slopes of Ben Garbh, south of Loch Assynt, the quartzites, traversed by a massive sheet of porphyritic felsite, have been so altered that the two rocks are welded together. In the case of the great granitoid mass at Ledbeg and

Loch Borrolan the limestone, as is well known, has been converted into a beautiful white marble, which is found over a considerable area. At Ledbeg the marbles underlie the intrusive sheet, and to the east of Alltnacallagoch they are found resting on it in small isolated patches. The marble is again traceable across the moor southwards to Loch Urigill, while far to the north it is met with on the southern slope of Sgonnan More, immediately below the outcrop of the Ben-More Thrust-plane to be afterwards referred to. Along the eastern margin of the Loch-Borrolan sheet, it appears close by the road leading to Loch Ailsh. The lithological characters of the marble have been well described by Professor Heddle, who calls attention to the presence of malacolite, serpentine, Wollastonite, magnetite, and margarodite in the calcite-matrix. That the marble is merely a portion of the limestone-series altered by contact with the intrusive igneous rocks, as pointed out by Professor Heddle, can be proved by most conclusive evidence. Passing outwards from the margin of the intrusive mass, the observer can trace all the stages of change from the crystalline to the unaltered bands of the calcareous series. Nay, further, it is possible to identify some of the zones of the limestone even in the midst of the marble. In places, however, the alteration has been so extreme that all traces of bedding have been destroyed. Finally, sheets and dykes of granitoid rocks occur in the marble, apart from the great Loch-Borrolan sheet.

6. *Sheets injected prior to Post-Lower-Silurian Movements.*

While these igneous rocks have been intruded after the deposition of the limestone, there is satisfactory evidence to prove that the injections took place prior to the Post-Lower-Silurian movements. Throughout the whole of the area affected by the displacements the dykes and sheets are truncated by numerous reversed faults, like the strata in which they occur. Further, they have in many cases been made schistose by these displacements, and there can be no doubt, therefore, that this phase of volcanic activity had ceased before the great terrestrial movements began.

V. Physical Relations of the Strata between Eriboll and Ullapool.

The conclusions to which the Geological Survey was led in the district of Eriboll, regarding the nature and extent of the terrestrial movements of Post-Lower-Silurian date, have been confirmed by the examination of the line of complicated structure southwards to Ullapool.

1. *Modification of two Inferences announced in former Official Report.*

There are two points, however, in the former official Report which, in the light of recent evidence, require modification. First, it was stated that during the incipient stages of the movements the strata were thrown into folds, which became steeper along the western fronts, till they were disrupted and the eastern limbs pushed westwards. The folds were believed to have culminated in reversed faults; but it is now apparent that the latter need not necessarily be preceded by folding. Secondly, in the horizontal section illustrating the previous report, the reversed faults in advance of the great thrust on Ben Arnaboll are represented as extending downwards, till each pierced the buried platform of Archæan rocks. But from the evidence obtained between Foinne Bheinn and Ullapool, it is clear that such may not be the case. Numerous sections demonstrate the fact that the strata, piled up by minor thrusts, have been driven along a major thrust-plane, separating the underlying undisturbed masses from the overlying displaced materials.

2. *Classification of Terrestrial Movements.*

With the view of simplifying the description of the extreme complications of this region, the following classification of the various terrestrial movements is proposed. They may be arranged in three groups, according to the magnitude and importance of the displacements:—

a. Minor thrusts or reversed faults.
b. Major thrusts.
c. Maximum thrusts.

a. The reversed faults included in group (*a*) repeat the strata by bringing lower to rest on higher beds, and lie at oblique angles to the major thrust-planes. By means of them, the Silurian strata are piled up to an enormous thickness.

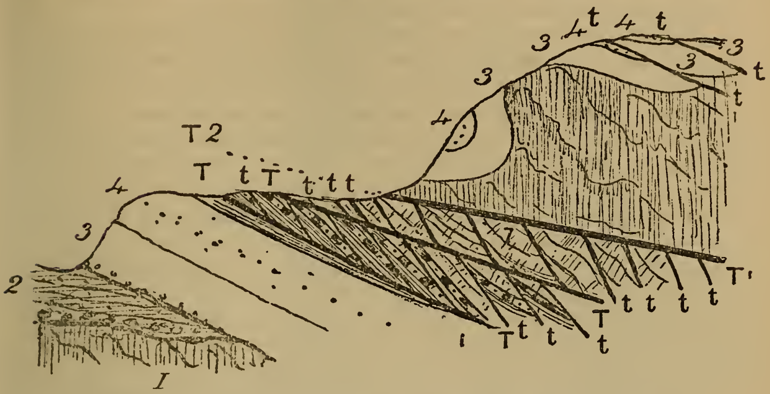
b. The major thrusts have driven the piled-up strata westwards, along planes separating the displaced materials from the underlying undisturbed strata. They always truncate the overlying minor thrusts and may nearly coincide with the lines of bedding of the strata over considerable distances.

c. The maximum thrusts are by far the most powerful, because they bring up and drive westwards portions of the old Archæan platform with the Cambrian and Silurian strata resting on it, and likewise usher in the eastern schists. The accompanying horizontal section (fig. 8) shows the characteristic features of these various displacements.

3. *Chief Maximum Thrusts.*

There are several maximum thrusts throughout the area affected by the movements, but three of them are of special importance because they enter into the geological structure of the complicated tract between Loch More and Ullapool. Stated in order, passing from west to east, they are—1, *the Glencoul Thrust*; 2, *the Ben-More Thrust*; 3, *the Moine Thrust.* The first is magnificently displayed in dip section on Loch Glencoul and Loch Glendhu, near Kylesku; the second, on the great cliff of Ben More in the Bealloch of Coinne-mheall; the third, at Knockan near Elphin and on the coast-section of the Moine between Loch Eriboll and the Kyle of Tongue.

Fig. 8.—*Diagrammatic Section in West Face of Glasven, near Loch Gamnheach, to show Minor Thrusts or reversed Faults, Major and Maximum Thrusts.* (Horizontal distance 1½ mile.)



t, Minor, T, major, T′, maximum thrusts. T². Glencoul Thrust.

4. *Features characteristic of the Maximum Thrusts.*

There are certain features characteristic of these maximum thrusts which ought to be enumerated before proceeding to describe the geological structure of the line of complication.

a. The outcrops of these maximum thrust-planes resemble the boundary lines between unconformable formations, because (1) there is always a complete discordance between the strata lying above and below the planes of disruption, and (2) each successive thrust may be overlapped in turn by the higher one. In other words, *the Glencoul Thrust-plane may be overlapped by the Ben-More Thrust-plane, and the Moine Thrust-plane may overlap both these and all major and minor thrusts, till the materials lying above it rest directly on the undisturbed Silurian strata.* A remarkable example of the latter phenomenon will be described in the sequel as occurring at Craig-a-Knockan, south of Elphin.

b. By means of denudation, outliers of the materials lying above these planes are formed. Perhaps the most extraordinary instances are the two prominent outliers, resting on the limestone-plateau at Inchnadamff, of Archæan rocks with Cambrian and Silurian strata, separated by two circular faults from the underlying limestones!

c. The planes of these powerful thrusts along which the materials have been driven are not always inclined at low angles, indeed they are frequently very irregular. In some cases the thrusts may be inclined at a gentle angle to the horizon and may suddenly become vertical.

d. Owing to the movements of the strata from east to west and also to the friction along the unyielding lower plane or "sole" of the thrust, there was a tendency in the materials to fold over and curve under, thus producing inversion of the beds. As a result of this tendency, the Cambrian and Silurian strata resting on the Archæan rocks brought forward by one of these powerful thrusts, fold over the western face of the displaced gneiss and actually underlie the Archæan rocks in inverted order.

e. From the foregoing phenomenon (*d*) it follows that along the line of outcrop of a maximum thrust the materials above the plane, in contact with the underlying strata, may consist of either Archæan rocks, Cambrian sandstones, or some zone of the Silurian series. For example, along the outcrop of the Glencoul Thrust, in Loch Glencoul and Loch Glendhu, the Archæan gneiss rests directly on the piled-up Silurian strata; but when it is traced southwards towards Inchnadamff, the thrust brings the quartzites to overlie the limestones along the base of the western slope of Glasven. In like manner, along the outcrop of the Ben-More Thrust, at one point the Archæan gneiss is made to overlie the piled-up Silurian strata, at another point the Cambrian sandstones are brought in contact with the heaped-up beds, while at a third point different members of the Silurian series are thrown against each other.

All these various features are beautifully illustrated along the line of complicated structure between Eriboll and Ullapool.

5. *Horizontal Sections illustrating the Physical Relations of the Strata between Eriboll and Ullapool.*

In order to show the remarkable variations in the geological relations of the strata and the extraordinary complexity of the structure, we propose to describe a series of horizontal sections drawn across the general strike of the sedimentary deposits and the eastern schists, leaving out minute details.

Section from Ben Arkle to the Moine Thrust-plane (fig. 9).—Beginning with the tract lying to the north of Loch More, there is a magnificent example of the abnormal thickness of the quartzites, due to the piling-up of the beds by minor thrusts or reversed faults. Indeed there is no finer instance along the line to Ullapool. So deceptive is the structure that, were it not for the subdivisions of the "pipe-rock" recently established, the task of unravelling the complications would be hopeless. Along the western base of the mountain, the basal quartzites rest unconformably on the old Archæan platform; but a short distance up the slope a great major thrust-plane occurs, separating the underlying undisturbed quartzites from the overlying displaced beds. Along the "sole" of this major thrust the zones of the quartzite, chiefly of the "pipe-rock," have been driven, piled on each other by minor thrusts or reversed faults, the latter being truncated by the former. In tracing these reversed faults, the band of Serpulite-quartzite in the "pipe-rock" has been of the utmost service. Advancing eastwards to Loch-an-na-Faoilege, the same phenomenon is met with, viz. the constant repetition of various zones of the quartzites by minor thrusts. Eventually the "pipe-rock," "Fucoid-beds," and Serpulite-grit are repeated by similar displacements, till they are overlapped by a maximum thrust, bringing forward a slice of Archæan rocks with the basal quartzites. By means of another maximum thrust a belt of green schist and sheared gneiss, with recognizable bands of

Fig. 9.—*Horizontal Section across Ben Arkle to the outcrop of the Moine Thrust-plane.*
(About 5 miles in length.)

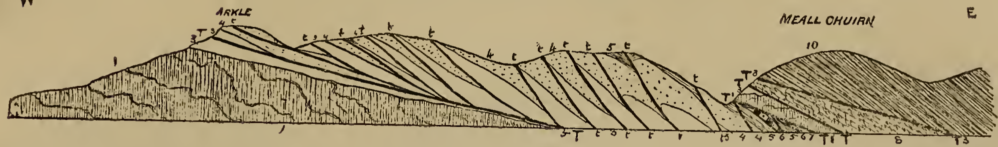


Fig. 10.—*Horizontal Section showing Structure of Ground between Loch More and Strath nan Carran.*
(About 6 miles in length.)

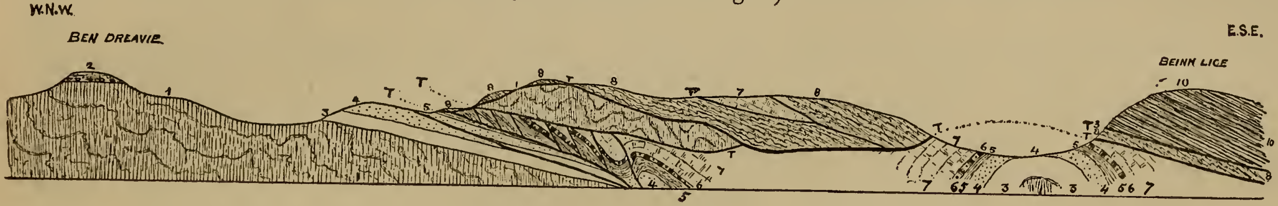
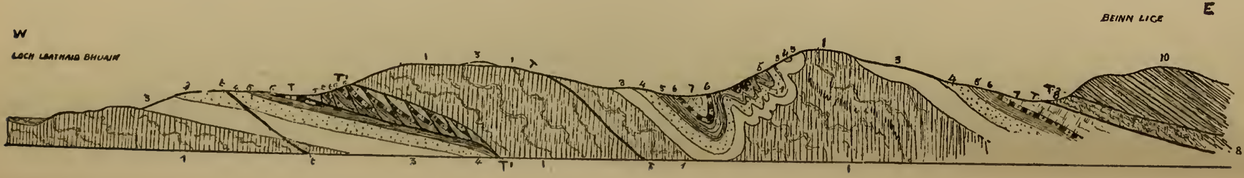


Fig. 11.—*Horizontal Section showing the Structure of the Ground between Strath nan Carran and Loch Glendhu.*
(About 5 miles in length.)



Archæan gneiss at the base and in the heart of the mass, is made to overlie these displaced materials. Within a short distance this belt of green schist and sheared gneiss is succeeded by the Moine Thrust, ushering in the micaceous and quartzose flagstones belonging to that horizon.

Section south of Loch More (fig. 10).—On the ridge south of Loch More Lodge the Archæan gneiss *with the basic dykes* is covered by the basal quartzites and the "pipe-rock" in natural order, the latter being traversed by a powerful thrust. The "pipe-rock" and "Fucoid-beds" are eventually truncated by a major thrust-plane, along which the Fucoid-beds, Serpulite-grit and limestones, piled on each other by reversed faults, have been driven, till they are overlapped by a maximum thrust bringing up the Archæan gneiss of a red, massive, granitoid type. These recognizable Archæan rocks are abruptly truncated by a second maximum thrust ushering in reconstructed gneiss and schists, the prominent planes, dipping E.S.E., having been determined by the Post-Lower-Silurian movements. The general colour of the rock is light or dark grey, forming a marked contrast to the underlying red, granitoid gneiss. As the inclination of the thrust-plane is variable, numerous outliers of the reconstructed gneiss and schist have been formed. In the heart of the main mass, however, there is a patch of Silurian limestone belonging to the Eilean Dubh and Ghrudaidh groups. The occurrence of this large mass of Silurian limestone is of special importance, as it shows how calcareous bands are formed among the eastern schists, their geological relations being determined by mechanical movement. Advancing still further eastwards, this belt of crushed and reconstructed gneiss and schist is buried underneath the dark micaceous flagstones lying above the Moine Thrust-plane.

Along this line of section, the geological relations of the strata are somewhat different from the foregoing. Towards the southern margin of Loch an Leathaid Bhuain, the basal quartzites rest unconformably on the Archæan gneiss, followed by the "pipe-rock," "Fucoid-beds," and Serpulite-grit. These are traversed by a major thrust-plane, along which the "Fucoid-beds," Serpulite-grit, and basal limestones have been piled up by minor thrusts. To these succeed the Glencoul Thrust-plane, above which there is a great slice of Archæan rocks with no basic dykes. This mass has been laid bare for a distance of nearly two miles, from Ben a Ghrianain to Ben a Bhutha; but to the east of the latter hill there is a splendid development of Silurian rocks resting naturally on the slice of the old Archæan platform. All the Silurian zones, from the basal quartzites up to the horizon of the Eilean Dubh limestones, are met with, thrown into a series of inverted synclinal folds. On the hill to the west of Lochan nan Ealachan, a small patch of the old Archæan gneiss has been exposed on the crest of the arch by the denudation of the basal quartzites. Advancing eastwards, the Silurian zones are met with up to the horizon of the limestone, the latter being truncated by the maximum thrust bringing in the sheared gneiss and green schist; and within a short distance the micaceous flagstones above the Moine Thrust-plane appear on the slopes of Ben Lice.

As the observer passes southwards to Glendhu and Glencoul (fig. 11), the outcrop of the Glencoul Thrust-plane is magnificently displayed in dip-section in these sea lochs. To the west lies the natural escarpment of the basal quartzites and "pipe-rock," resting unconformably on the undisturbed Archæan platform; and within a distance of half a mile to the east occurs an enormous slice of the old crystalline rocks, which has travelled for miles along the "sole" of the Glencoul Thrust. Underneath this maximum thrust, however, there is a powerful major thrust driving forward the "Fucoid-beds," Serpulite-grit, and basal limestone piled up by numerous reversed faults, the latter being admirably seen in dip-section in Loch Glencoul.

The great mass of Archæan rocks brought forward by this maximum thrust rises from the sea-level like a wall round the head of Loch Beag, to a height of over 1750 feet, presenting the typical features of the Archæan gneiss to the west with the basic dykes. Ascending the ridge of Archæan rocks on the south side of the Glen to the Stack of Glencoul, various Silurian zones dip towards the E.S.E., piled on each other by minor thrusts. A careful examination of the sections shows that these zones are separated from the Archæan rocks by a powerful thrust-plane which descends the slope at a high angle. There can be no doubt whatever that these Silurian zones have been driven westwards along the "sole" of this thrust.

At the base of the Stack of Glencoul the Silurian quartzites have undergone important changes, due to the movements which will be refered to presently. They are overlain by a thin belt of green schist, the latter being rapidly succeeded by the micaceous flagstones above the Moine Thrust-plane.

Advancing south-eastwards towards Cnoc an Fhuarain Bhain (fig. 12), across an area of intense complication, all the

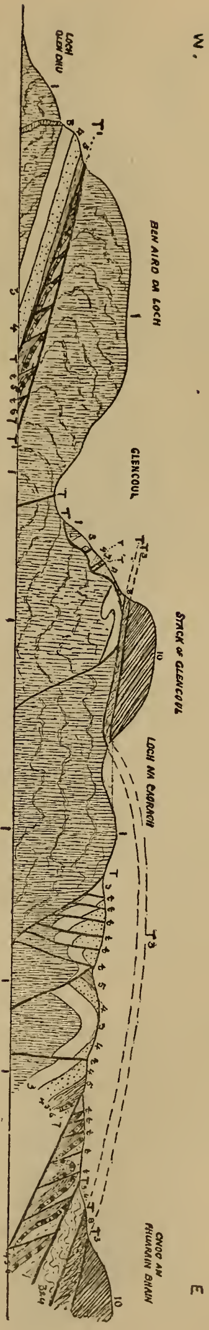


Fig. 12.—*Horizontal Section from Glendhu, across the Stack of Glencoul to Cnoc an Fhuarain Bhain.* (About 6 miles in length.)

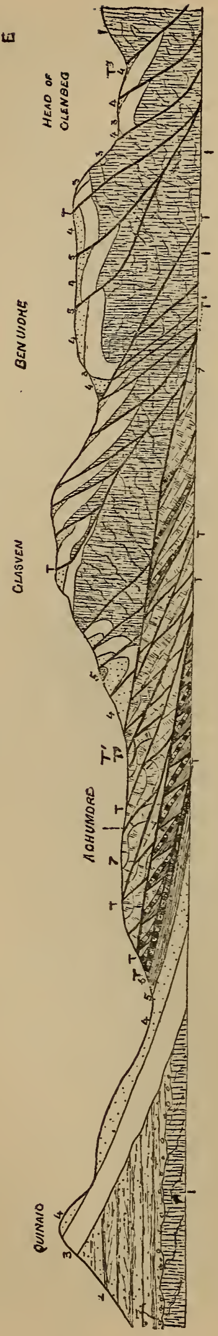


Fig. 13.—*Section from Quinaig east by Achumore, Glasven, and Ben Uidhe, to the Ben-More Thrust-plane.* (Distance about 7 miles.)

Silurian zones from the basal quartzites up to the limestone are repeated by thrusts of more or less magnitude, till we reach the maximum thrust which brings in the green schists and sheared gneiss with strips of highly altered quartzites. These are overridden in turn by the micaceous flagstones above the Moine Thrust-plane.

On the southern slope of Quinaig (fig. 13) the unconformability between the quartzites and the Cambrian sandstones is well exposed in the great escarpment skirting Loch Assynt, the sandstones being nearly flat, while the quartzites are inclined to the E.S.E. at angles varying from 15°–20°. Both zones are succeeded by the "Fucoid-beds" and Serpulite-grit in natural order; but close to the highroad leading to Kylesku the strata are truncated by a major thrust-plane, along which the "Fucoid-beds," Serpulite-grit, and basal limestones have been driven, repeated by numerous minor thrusts. Generally the piled-up strata belonging to these horizons are tilted at high angles to the plane of the major thrust. Owing to the extraordinary number of these minor thrusts, there are no fewer than thirteen outcrops of the Serpulite-grit in the course of one third of a mile. Close to Achumore another powerful major thrust ushers in the basal limestones, lying at gentle angles and resting on the highly inclined thrust-strata just described. They are repeated by numerous minor and major thrusts, and thrown into a series of arches and troughs, as shown in section, till they are overridden by the materials brought forward by the Glencoul Thrust-plane. The outcrop of this thrust-plane has been traced continuously from the shore of Loch Glencoul, southwards by Loch na Gainmhich along the base of the western slope of Glasven, to the Poll an Droighinn burn, thence by the base of Ben Fhuarain and Coinne-mheall of Ben More, till it is eventually overlapped by the Ben-More

Thrust-plane. For several miles of its course, from a point near Loch na Gainmhich to Cnoc an Droighinn, this maximum thrust brings various members of the quartzites to overlie different subdivisions of the Ghrudaidh and Eilean Dubh limestones. These quartzites have been driven westwards with the great slice of Archæan rocks above this thrust-plane, the latter rocks being exposed, with their characteristic basic dykes, to the north of the Chalda Lochs. But it ought to be borne in mind that the quartzites along the western face of the disrupted gneiss do not lie in regular inverted order: they are traversed by numerous thrusts, bringing different subdivisions of the quartzites with their intrusive sheets against each other. The extreme complications resulting from these minor thrusts and subsequent folding in the quartzites and their associated igneous rocks are splendidly displayed in Cnoc an Droighinn near Inchnadamff.

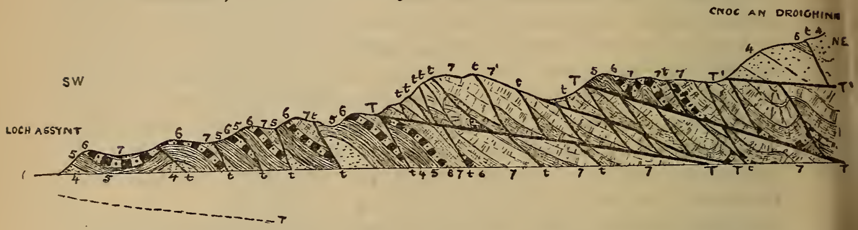
Between Glasven and Ben Uidhe there is a powerful maximum thrust driving westwards the Archæan gneiss with the basal quartzites and the "pipe-rock," while on the crest of the latter mountain both zones of the quartzites are repeated by various thrusts. On the northern shoulder of Mullach an Leathaid Riabhaich several powerful thrusts and extraordinary flexures of the strata are met with, until we reach the horizon of the Ben-More Thrust-plane, at the head of Glenbeg.

The Limestone Plateau at Inchnadamff.—The great development of Silurian limestone at Inchnadamff occurs almost wholly within the area affected by the Post-Lower-Silurian movements. Indeed it is rather remarkable that only one small patch, belonging to the lower subdivision of the Ghrudaidh group, lies in the undisturbed area, viz. on the north shore of Loch Assynt near the mouth of the Skiag burn. Between Achumore and Inchnadamff the belt of limestone is nearly a mile wide, but to the east of the great Stronechrubie cliff it forms a broad plateau about two and a half miles in width. As indicated in the foregoing vertical Section II. (p. 406), the beds belong mainly to the two lowest groups of the Durness limestones, only a small portion of the Sailmhor group being represented. Owing to the extraordinary complications of the strata, due to the number of minor and major thrusts, it is difficult to estimate accurately the thickness of the limestones, but it cannot exceed 450 ft. or 500 ft.

That the calcareous beds are not arranged in an inverted synclinal fold can be demonstrated in the most conclusive manner. Taking first that portion of the plateau between Inchnadamff and Achumore, the following horizontal section (fig. 14) shows the general relations of the strata. Starting from the shore of Loch Assynt, about half a mile north of the mouth of the Traligill, the "Fucoid-beds," Serpulite-grit, and a portion of the basal limestones are repeated by numerous minor thrusts, till we reach a powerful major thrust-plane, along which the Eilean Dubh limestones have been driven westwards, over the underlying Ghrudaidh Group. Within a distance of half a mile of the shores of the Loch, the piled up limestones are truncated by another major thrust, bringing up the "Fucoid-beds," Serpulite-grit, and basal limestones to overlie the Eilean Dubh beds.

This powerful thrust can be traced northwards to the Chalda burn and southwards across the Poll an Droighinn and Traligill burns to the great plateau east of Stronechrubie. Following the line of

Fig. 14.—*Horizontal Section from Loch Assynt, across the Silurian Limestones, to Cnoc an Droighinn.* (About ¾ mile in length.)



section east to Cnoc an Droighinn, various subdivisions of both the lowest limestone groups with their dykes are repeated by reversed faults, till they are overlapped by the "pipe-rock" above the Glencoul Thrust-plane.

Between Ardvreck Castle and Achumore the relations of the strata are still more complicated. Briefly stated, the principles involved in the structure are as follows:—(1) the occurrence of a series of major thrusts running roughly parallel with each other, producing great horizontal displacement; (2) the piling up of the limestones along the planes of these thrusts by minor reversed faults; (3) the subsequent arrangement of the strata in a series of gentle arches and troughs, *the axes of the folds being quite independent of the trend of the major thrust-planes.*

Precisely the same principles are illustrated in the broad plateau east of Stronechrubie. The first great major thrust in the limestone is well seen in dip-section in the great cliff about half a mile south of the Inchnadamff Hotel, where it drives forward the Eilean Dubh limestones, the latter dipping at a high angle to the plane. Again, on the slope south of the Traligill burn at Glenbain about six major thrusts are admirably seen in dip-section, the beds between these planes being piled up by minor reversed faults. Occasionally outliers of the "Fucoid-beds" and Serpulite-grit are found, capping the Eilean Dubh limestones in the north-east part of the plateau, separated from each other by major thrusts. But subsequent to these various displacements driving the strata together, the area along the north-eastern and eastern margins of the limestone-plateau was elevated in the form of a great dome; and hence we find, at intervals, various sections showing the natural passage from the "pipe-rock" to the "Fucoid-beds," Serpulite-grit, and basal limestones, the strata being inclined towards the west. This feature has given rise to the belief, advocated by several observers, that the limestones were arranged in a great synclinal fold. But the examination of the great quartzite range of Braebag, to the east of the limestone plateau, points to the conclusion that the quartzites were piled on each other by numerous thrusts prior to the formation of the great anticline. Along the western side of the arch, where the quartzites and limestones dip to the west, the thrust-planes are inverted, so that the observer has, metaphorically, to stand on his head to realize the effect of the displacements.

Geological Structure of Ben More.—Along the line of complicated structure between Eriboll and Ullapool, Ben More stands unrivalled for the extreme intricacy of the geological relations of the strata, for the striking evidence in proof of the existence of two maximum thrust-planes, and finally for the brilliant light which it throws on the metamorphism induced by these mechanical movements.

This mountain has two peaks, one, Ben More (3273 ft.), the other, about a mile to the west, named Coinne-mheall (Coniveall) (3234 feet). Between the latter peak and Braebag there is a col or narrow pass termed the Bealloch, separating the head-waters of the Oykel from the sources of the Traligill. In order to illustrate the structure of the mountain, we propose to describe three horizontal sections traversing it in various directions (figs. 15, 16, 17).

Fig. 15.—*Section across Coinne-mheall from one of the sources of the Traligill east to Corrie Mhadaidh.* (About $1\frac{1}{2}$ mile in length.)

S.W. Coinne-mheall. N.E.

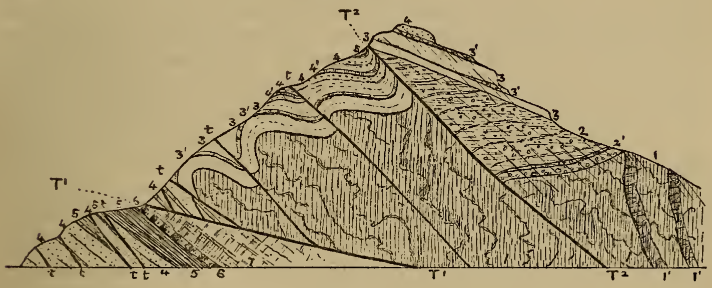
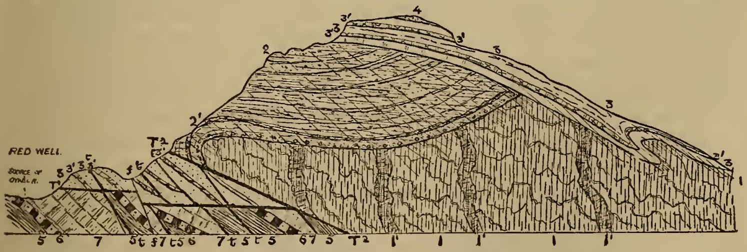


Fig. 16.—*Horizontal Section from the Bealloch across Coinne-mheall to Corrie Mhadaidh.* (About $1\frac{1}{2}$ mile in length.)

S.S.W. Coinne-mheall. N.N.E.



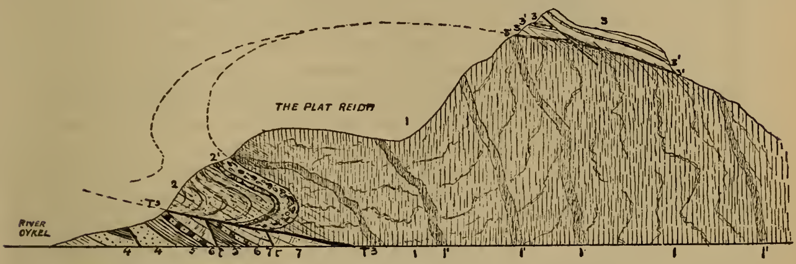
Beginning at the base of the western slope (fig. 15), both the zones of the quartzite, the false-bedded grits, and "pipe-rock" are driven on to the Silurian limestone by the Glencoul Thrust. Ascending the slope, the false-bedded grits are made to overlie the "pipe-rock" by means of a reversed fault, and for some distance upwards, to near the 2500 feet contour-line, the strata exposed in the stream-section consist wholly of the lower zone of quartzites with their dykes, repeated by inverted folds and minor thrusts. Indeed, from the various arches exposed, it is clear that the basal quartzites only form a thin veneer over the concealed Archæan rocks. Were the slope denuded further back, there can be no doubt that the latter would be revealed. About the 2500 feet contour-line the basal quartzites are followed in regular order by the various subdivisions of the "pipe-rock," with their intrusive sheets, and the "Fucoid-beds," until they are abruptly truncated by the great Ben-More Thrust-plane. At the point where this line of section is drawn the effect of this maximum thrust is to bring the basal quartzites to overlie the highest zone of the "pipe-rock" and "Fucoid-beds." When the false-bedded quartzites (Zone 1) are traced along the crest of the mountain they are found to overlie unconformably both the Cambrian sandstones and the Archæan rocks. The false-bedded quartzites are succeeded by the lowest subdivision of the "pipe-rock," exposed on the mountain top. Descending the north-eastern slope of Coinne-mheall (fig. 15), the observer crosses (1) the unconformable junction of the basal quartzites and the Cambrian sandstones, and (2) the boundary line between the latter and the Archæan gneiss.

Owing to the high inclination of the Ben-More Thrust-plane at this point, the outcrop descends from the crest of the mountain to the Bealloch, where it is well seen on the great cliff in dip-section. As a result of the friction along the unyielding "sole" of the thrust, causing the upper layers to move more rapidly than the lower, we find that the Cambrian sandstones fold over the western face of the disrupted gneiss, as shown in the foregoing section (fig. 15). By means of the local conglomerate ("the Button-stone") at the base, the line of junction with the old Archæan platform is easily traced, and the proof of inversion is beyond all doubt. The basal conglomerate and the overlying grits, sandstones, and shales can be followed continuously from the Bealloch, round the south-eastern spur of Coinne-mheall, to the southern shoulder of Ben More, where they are unconformably overlain by a cake of the basal quartzites. That these grits and sandstones are really a portion of the Cambrian sandstones to the west, as originally maintained by Prof. Nicol, is apparent from the fact that the double unconformability is admirably seen along the ridge between Coinne-mheall and Ben More, and further from the presence of the various intrusive dykes on their proper horizons. The area occupied by the Cambrian strata is about half a square mile, about half of which is buried under the basal quartzites. In the corrie on the north-east side of the mountain they reappear with the conglomerate at the base, resting on the old platform. The general inclination of the Cambrian strata is towards the W.N.W., at an average angle of 20°; the greatest thickness is about 1500 feet.

In the Bealloch of Coinne-mheall (fig. 16), the hade of the Ben-More thrust-plane becomes almost flat, and hence the outcrop can be followed for two and a half miles down the river Oykel. Along the line of outcrop, the Cambrian sandstones reappear above the thrust-plane, dipping underneath the Archæan gneiss in inverted order (see section), as previously described by Mr. Callaway. There can be no doubt, however, that this strip of Cambrian strata, extending nearly two miles down the valley, is merely a continuation of the mass on Coinne-mheall, as shown in section.

Fig. 17.—*Horizontal Section from the Oykel Valley across Ben More.* (About 2 miles in length.)

S. Ben More. N.



The slice of Archæan rocks bearing these Cambrian sandstones and Silurian strata, driven westwards by the Ben-More Thrust, is of large dimensions. The Archæan gneiss and basic dykes form a grand cliff about 1500 feet high overlooking Dubh Loch More, and they sweep across the lofty peaks separating the Oykel from the Gorm Lochs. Though still recognizable as a part of the old Archæan platform, the rocks have undergone important changes due to the movements, as will be shown further on.

The outcrop of this great thrust-plane can be followed southwards from the Oykel valley, round the western slope of Sgonnan More, by Strathsheaskich, thence to Allt an Loin Dubh, curving round Cnoc na Glas Choille to the base of the Cromalt Hills, where it is overlapped by the Moine Thrust-plane.

Of special interest, however, are the numerous outliers of the materials lying above this thrust-plane, left by denudation in the most extraordinary situations. The most important occur on Cnoc an Leathaid Bhuidhe west of Loch Awe, on the moor south of Loch Urigill, and on the limestone plateau south-east of Stronechrubie. The two isolated masses, resting on the limestones to the north and south of Allt nan Uamh, are of great importance, as they show the original folding of the Ben-More Thrust-plane over the quartzite range of Braebag, and the overlap of the Glencoul Thrust-plane by the former (see fig. 18).

Descending the slopes of Canisp the double unconformability of the quartzites on the Cambrian sandstones and Archæan rocks is well exposed, the lower zone being overlain by the "pipe-rock" in natural sequence. Crossing the Loanan, the "pipe-rock" is followed by the "Fucoid-beds," Serpulite-grit, and basal limestone, the latter three zones being repeated by reversed faults. Ascending the west declivity of Beinn an Fhuarain, the two lowest groups of limestone are repeated by minor thrusts till we reach the outcrop of the Ben-More Thrust-plane. Just above the plane, on the north-west face

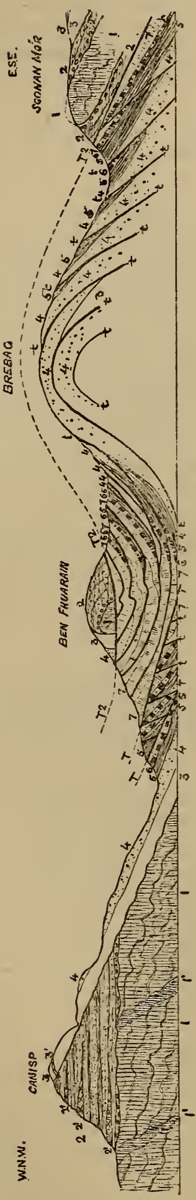


Fig. 18.—*Horizontal Section from Canisp east by the River Loanan, Ben Fhuarain, Braebag to Sgonnan More.* (About 8 miles in length.)

of the hill, the "pipe-rock" appears with an inverted dip, plunging underneath the basal quartzites, the beds being inclined to the E.S.E. at tolerably high angles. Near the hill-top the unconformable junction of the basal quartzites on the Cambrian sandstones is exposed, and when followed southwards *the false-bedded quartzites pass transgressively across the Cambrian strata and rest directly on the Archæan gneiss.* Only a small exposure of the gneiss is met with, but it presents the normal characteristics and contains one of the basic dykes.

This remarkable outlier is about a mile in length, from north to south, the outcrop of the thrust-plane forming a striking feature round the hill. The limestones are exposed in the various swallow-holes adjoining the plane, and the actual disruption-line is seen in dip-section on the north-west shoulder of the ridge. The Allt nan Uamh has carved a deep channel through the underlying limestones and has isolated the outlier on Beinn Fhuarain from that on Beinn nan Cnaimhseag on the north side of the stream. In the case of the latter, the Archæan rocks are not exposed, but the basal quartzites rest unconformably on the Cambrian sandstones. By means of these and other outliers, originally continuous with the strata lying above the main outcrop on Sgonnan More, we can form a clear conception of the enormous extent of these terrestrial displacements and also of the vast amount of denudation which has since taken place.

Only a brief reference can be made to the large number of thrust-planes repeating the Silurian strata, with occasional wedges of Archæan rocks, to the east of the Ben-More Thrust-plane. The alteration produced by these movements in advance of the Moine Thrust-plane is remarkable. So striking is the change, as will be shown presently, that Mr. Callaway grouped the Loch-Ailsh limestones with the Caledonian series, thus regarding them as of Pre-Cambrian age. But in the course of the survey of that region we found that the false-bedded quartzites, the "pipe-rock," the "Fucoid-beds," the Serpulite-grit (with the Serpulites) are associated with the crystalline limestones and the intrusive sheets, the whole series being intersected by numerous thrusts which develop new structures of an important kind.

Advancing southwards to the confines of Assynt, we find evidence of an extraordinary overlap of the Moine Thrust-plane, along the base of the Cromalt Hills to the south of Elphin and Loch Urigill. From the base of the Stack of Glencoul the outcrop of this thrust-plane can be traced continuously, southwards by Loch Ailsh, thence crossing the Oykel and Allt Ealag in a S.S.W. direction. From the latter point *it runs west for a distance of six miles, along the base of the north slope of the Cromalt Hills to the famous Knockan cliff south of Elphin, passing transgressively across the Ben-More Thrust-plane and all underlying thrusts, till the micaceous flagstones rest at various localities on the undisturbed Silurian strata.*

Between Loch More and Glencoul the belt of complicated ground extending from the outcrop of the Moine Thrust westward to the edge of the undisturbed Silurian strata varies from two to four miles ; while from Glencoul to the base of the Cromalt Hills, the belt averages about six miles in width. When we reach the Knockan cliff, the southern prolongation of this complicated ground is buried underneath the materials borne along the plane of the Moine Thrust. Indeed, had it not been for the extensive denudation of the strata above the latter thrust-plane, we should never have been able to study the sequence of these terrestrial movements, or the various stages in the production of the Moine schists.

With the view of showing the belt of complicated ground, comprising displaced Archæan, Cambrian, and Silurian strata, along the northern margin of this great overlap, the accompanying horizontal section (fig. 19) has been drawn from Elphin eastwards by Am Pollan and Cnoc na Glas Choille, to the outcrop of the Moine Thrust-plane in Allt Ealag.

At Elphin, close to the road leading to Ullapool, the "Fucoid-beds" and Serpulite-grit are truncated by a powerful major thrust, bringing forward the piled-up "Fucoid-beds," Serpulite-grit, and basal limestone. The latter are abruptly cut off by another major thrust-plane, along which the Eilean Dubh limestones have been driven, repeated by innumerable minor thrusts, for a distance of two miles. At Am Pollan, these displaced limestones are capped by an outlier of the materials lying above the Ben-More Thrust-plane, consisting of Archæan rocks covered unconformably by the Cambrian sandstones and the basal quartzites, the latter resting unconformably on both. Advancing eastwards, the strata are mainly composed of piled-up limestones, which, at the base of the west slope of Cnoc na Glas Choille, are overlapped by the Silurian strata lying above the main outcrop of the Ben-More Thrust-plane. In the

Fig. 19.—*Horizontal Section from Elphin to Allt Ealag.* (About 6 miles in length.)

heart of the latter displaced materials a small patch of Archæan rocks has been exposed by the denudation of the basal quartzites. In addition to the latter, all the Silurian zones, up to the horizon of the Eilean Dubh limestones, have been borne westwards along this disruption-plane, comparatively unaltered in places, till we approach the micaceous flagstones above the Moine Thrust-plane, where the quartzites have been converted into quartz-schists, and the dykes have also been rendered schistose.

Advancing southwards to the Knockan cliff, about two miles to the south of the foregoing line of section, there is a remarkable difference in the order of succession of the strata.

On the eastern slope of Coul More the basal quartzites rest unconformably on the Cambrian sandstones, followed in natural order by the "pipe-rock," "Fucoid-beds," and Serpulite-grit, the latter being exposed on the Knockan cliff east of Lochan Fasaig. Overlying the Serpulite-grit in natural sequence, there is a small portion of the basal limestone of the Ghrudaidh group, which is abruptly truncated by a major thrust-plane, bringing forward the white limestones and marble of the Eilean Dubh group. The latter are succeeded by the finely laminated micaceous flagstones above the Moine Thrust-plane.

Following the outcrop of this thrust-plane southwards to Strath Kanaird, a distance of nearly six miles, the Moine micaceous flagstones rest, now on the basal limestones, now on the Serpulite-grit, and again on the "Fucoid-beds," passing transgressively from one horizon to the other, thus showing the complete discordance between the materials above and below the thrust-plane (fig. 20). As the flagstones lie on the undisturbed beds, there seems at first sight to be a natural passage from the Silurian strata into the eastern schists; but the apparent conformity is entirely deceptive.

That such is the true explanation of the relations of the strata along this line of section is still further confirmed by the remarkable evidence in Strath Kanaird, near Langwell. *About a mile to the east of the normal outcrop of the Moine Thrust, the river has cut down through the thin cake of micaceous flagstones, and exposed on the south side of the valley a large mass of Archæan gneiss, covered unconformably by the* *basal quartzites* (fig. 21). There can be little doubt, from the evidence obtained at Am Pollan (Loch Urigill), in the valley of the Achall, and at Ullapool, that this mass of Archæan rocks and basal quartzite has been borne along by the Ben More Thrust, and that the materials rest on the piled-up Silurian strata underneath.

Passing southwards to the Achall valley, there is a regular ascending series from the basal quartzites, resting unconformably on the Cambrian sandstones, up to the Serpulite-grit and a portion of the basal limestone. The latter zones are abruptly truncated by a powerful major thrust driving forward nearly all the zones of the Ghrudaidh and Eilean Dubh limestone-groups, repeated by numerous reversed faults. The limestones are overlapped in turn by the materials lying above the Ben-More Thrust-plane, consisting of a great development of Archæan gneiss with the basic dykes covered unconformably by the Cambrian conglomerate and sandstones, with the basal quartzites resting unconformably on the latter. The serpentine referred to by Prof. Nicol as occurring in the Achall valley is one of the ultrabasic dykes in the thrust Archæan gneiss. The Ben-More Thrust-plane in the Achall valley is inclined to

Fig. 20.—*Horizontal Section from the Knockan Cliff to the Cromalt Hills.* (About 6 miles in length.)

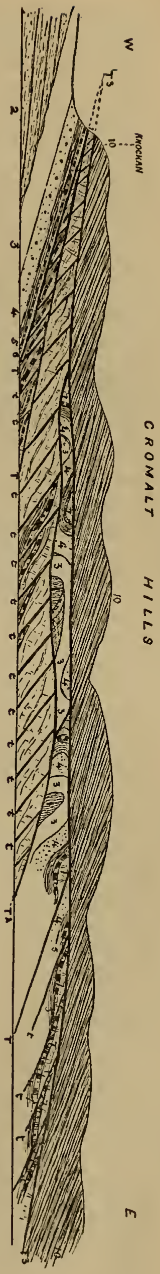
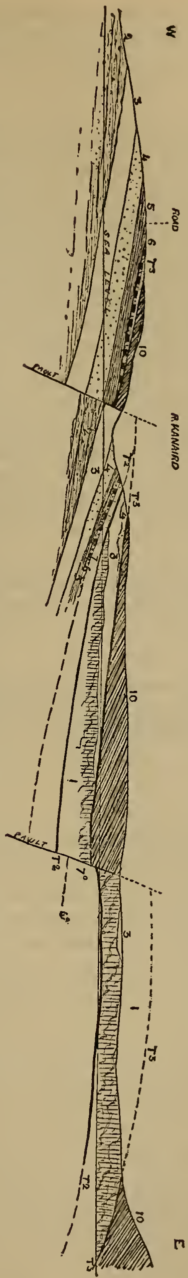


Fig. 21.—*Horizontal Section along Strath Kanaird at Langwell with the Archæan Gneiss and basal Quartzites exposed by denudation in the midst of the Moine Flagstones.* (About 3 miles in length.)

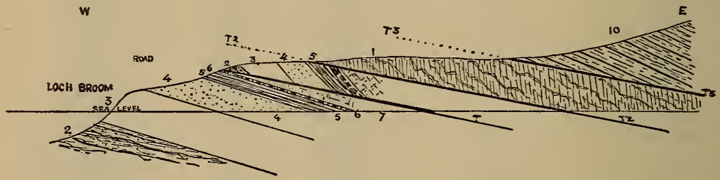


the east at an angle of 35°; but in places it has been folded, and the materials lying above it have been denuded away. Hence we find, to the west of Glastullich, that it is overlapped by the Moine flagstones, which there rest directly on the thrust Silurian limestones.

From the Achall valley southwards to Ullapool the outcrop of the Ben-More Thrust-plane can be traced almost continuously by means of the Archæan rocks. In two places, however, it is overlapped by the Moine Thrust, which ushers in the micaceous flagstones.

To the east of Ullapool there is an undisturbed order of succession from the basal quartzites to the Serpulite-grit. Along this latter horizon there is a powerful major thrust, bringing in a portion of the Cambrian sandstones overlain unconformably by the basal quartzites and succeeded by the various members of the Silurian series up to the limestone. Following the line of outcrop of this major thrust, southwards by the Braes of Ullapool to the shore of Loch Broom, a large mass of Cambrian sandstone appears above the plane, resting on the Serpulite-grit and spreading over a considerable area to the north of Corry Point. Near the latter locality the basal quartzites, in several places, rest unconformably on the Cambrian sandstones (fig. 22).

Fig. 22.—*Horizontal Section south of Ullapool.*
(About 1 mile in length.)



Passing eastwards, the Cambrian and Silurian strata borne along by this major thrust are abruptly truncated by the Ben-More Thrust-plane, well exposed at various localities. Along the western face of the disrupted gneiss, small patches of Cambrian strata rest unconformably on the latter with an inverted dip towards the plane of disruption. Eventually within a short distance the Archæan gneiss is overlapped by the micaceous flagstones above the Moine Thrust-plane.

To the south of Loch Broom the major thrust, which forms such an important feature in the geological structure of the Ullapool and Achall districts, is entirely overlapped by the Ben-More Thrust-plane, bringing forward a large slice of the old Archæan platform, consisting of gneiss with numerous basic dykes, covered unconformably by patches of Cambrian conglomerate and sandstone. Advancing southwards towards Little Loch Broom, the materials lying above the Ben More Thrust-plane consist almost wholly of Cambrian strata, which, at Dundonald, have been converted into schists. Indeed, so striking is the metamorphism developed by these movements in the Cambrian strata near Dundonald that it is difficult to trace the line between the schistose sandstones and the eastern schists.

VI. Metamorphism resulting from the Post-Lower-Silurian Movements.

Having described the evidence in proof of enormous terrestrial movements along the chain of mountains between Eriboll and Ullapool, we now proceed to consider the relation of these displacements to regional metamorphism *. In reviewing the effects of these movements, we will describe the evidence furnished by (1) the Archæan, (2) the Cambrian, (3) the Silurian, and (4) the igneous rocks intrusive in the Cambrian and Silurian strata. From these various lines of evidence it will be seen that with each successive maximum thrust there is a progressive alteration in the displaced materials as we pass eastwards to the horizon of the micaceous flagstones overlying the Moine Thrust-plane.

1. *Metamorphism of Archæan Rocks.*

The great slice of Archæan rocks brought forward by the Glencoul Thrust does not present any striking evidence of deformation except close to the lines of disruption. To the north of Glencoul the original banding of the gneiss is as distinct as that in the Archæan area to the west of the Post-Lower-Silurian displacements, the general strike being W.N.W., and the dip of the foliation being S.W., at high angles. It is a significant fact that although the north-west dolerite-dykes are numerous in the undisturbed Archæan area between Ben Stack and Glencoul, none is met with in the thrust-gneiss, above this thrust-plane, till we pass southwards to Glencoul. Indeed the absence of these basic dykes and the presence of broad veins of red pegmatite point to the conclusion that the displaced gneiss between Strathcarran and Glencoul resembles that in the Archæan area to the north of Ben Stack. By protracting the angle which the basic dykes in the undisturbed gneiss on Ben Stack make with the direction of movement in the displaced masses, it is clear that the disrupted rocks must have travelled for several miles from the east.

Overlying the thrust-plane, a thin band of slaty schist or highly sheared gneiss is frequently met with, the strike of the foliation being more or less parallel with that of the thrust-plane. Advancing eastwards towards the limit of the displaced mass, these new divisional planes are more strikingly developed, owing to the number of more or less powerful thrusts. In the latter case, the new planes of schistosity may be either parallel with those of the

* It ought to be borne in mind that, though the movements affecting the Cambrian sandstones and the fossiliferous quartzites and limestones are now regarded as of Post-Lower-Silurian date, it may ultimately be possible to fix their age with greater precision, when the fossils from the Durness Limestone have been correlated with those of other countries.

thrust-planes or inclined at a higher angle. The basic dykes on the northern slope of Glasven show no perceptible alteration except where they have been traversed by some of the powerful Post-Lower-Silurian disruption-lines; but they show in a marked degree the foliation produced by the Pre-Cambrian movements.

The alteration of the Archæan rocks is more pronounced above the horizon of the Ben-More Thrust in Assynt. Along the unconformable junction of the gneiss with the Cambrian and Silurian strata, the former has entirely lost its original structure, and has been converted into greenish epidotic schist, the dip of the foliation being E.S.E. In one remarkable case, to be immediately described, where the gneiss is overlain by the Cambrian conglomerate, the schistosity developed in the latter passes downwards into the former, irrespective of the original bedding of the Cambrian beds or the original foliation of the gneiss. The new structures in the gneiss, along the junction-line, have been produced by the more rapid movemeut of the upper layers of displaced materials, without destroying the geological relation between the two. In other words, there has been a differential movement of the several layers of the thrust-masses as well as of the constituent particles over each other. Along the eastern slope of the Ben-More range, northwards to Glendhu, where powerful thrusts follow each other in rapid succession, bearing forward slices of the old Archæan platform with the quartzites, the new divisional planes are very prominent. Further, in the case of the dolerite dykes, new foliation-planes have been produced along the disruption lines, which are much more conspicuous than in the displaced dykes above the Glencoul Thrust-plane.

Advancing eastwards to the belt of sheared gneiss and green schist underlying the Moine Thrust-plane the evidence relating to regional metamorphism is of a most remarkable kind. The gneiss occupying this horizon between Loch More and Strathcarran possesses new divisional planes, the old ones having been almost wholly effaced. The dip of the foliation is E.S.E., being more or less parallel with that of the thrust-plane. On the foliation-surfaces close parallel lines, like those of slickensides, are met with, indicating the direction of movement, varying from 20° to 40° S. of E. The divisional planes are also coated with a thin film of sericite-mica, while "eyes" of felspar are drawn out in the direction of the movement. The pegmatites, too, have been sheared, so that their foliation-planes coincide with those of the gneiss, the original quartz and felspar appearing now as thin, close, red and white parallel streaks in the direction of the movement lines. Notwithstanding this extreme alteration of the Archæan rocks south of Loch More, the patch of limestone occurring in the heart of the mass is still recognizable as belonging to the two lowest limestone groups of Durness.

Along this same belt of sheared gneiss and green schist between Assynt and Loch Eriboll the Archæan gneiss has been rolled out into a finely laminated slate or slaty schist (mylonite), breaking into thin folia like leaves of paper. All the various stages of deformation, from the crushed Archæan gneiss on the one hand, to the laminated slate on the other, can be clearly traced. The original constituents of the gneiss have been comminuted, but here and there broken fragments of the felspars occur, which are invariably drawn out in the direction of movement. The colour of the slaty schists has been determined by the nature of the materials out of which they have been made. Where the Archæan gneiss contained much epidote, the slates or "crush-rocks" are light green; where it contained much hornblende, they are dark green; where pegmatites or granitoid gneiss have been the chief materials employed, the resultant slates are red or pink. These finely laminated schists or slates show beautiful examples of fluxion-structure; and their foliation-surfaces display closely set lines or "striping," indicating the direction of movement of the particles over each other, the general trend of the latter being E.S.E. Associated with these slates are certain belts of "frilled" dark-green schists, of precisely the same character as those so well exposed on the coast-section east of Whitten Head, Loch Eriboll. A detailed study of the remarkable structure presented by these "frilled" schists points to the conclusion that they have been formed by Post-Lower-Silurian movements mainly out of dark hornblendic gneiss, the folia having been piled on each other by minute major and minor thrusts.

Occasionally, along this belt of sheared gneiss and schist, there are lenticular masses of the original Archæan rocks, which only show partial deformation, and, in addition to these, strips and wedges of Silurian and Cambrian strata which have been completely converted into schists.

2. *Metamorphism of Cambrian Strata.*

It is interesting to note that no Cambrian strata occur among the displaced masses brought forward by the Glencoul Thrust in Sutherlandshire. They do not appear till we reach the horizon of the materials lying above the Ben-More Thrust-plane. The various changes produced by these movements in the Cambrian conglomerates, sandstones, and shales are strikingly exemplified on Ben More, on the north side of the Oykel valley, and on Sgonnan More.

Beginning with the basal conglomerate, or "Button-stone," we find that it has undergone extraordinary changes, both where it underlies the gneiss in the Oykel valley and where it overlies that rock in Corrie Mhadaidh. In its unaltered form, throughout the undisturbed Cambrian areas, this characteristic band of conglomerate is composed of more or less well-rounded pebbles of quartz-rock, gneiss, pegmatite, diorite, &c., imbedded in a loose, gritty matrix. But where it has been subjected to mechanical movement, the softer pebbles of gneiss and the fragments of the basic Archæan dykes have been crushed, flattened, and elongated in the direction of movement. Indeed, in some cases, they have been drawn out to such an extent as to form thin lenticular bands of micaceous or hornblende-schist flowing round the harder pebbles of quartz-rock. The latter still preserve their rounded form, but they are traversed by small "step" faults, tending to elongate them in the direction of movement. The original gritty matrix has been converted into a fine micaceous or green chloritic schist, showing exquisite "flow-structure," winding round the elongated pebbles in wavy lines. In short the matrix has been converted into a fine crystalline schist, and but for the presence of the deformed schistose pebbles it would probably be impossible to tell that the schist had a clastic origin.

No less remarkable is the phenomenon displayed in Corrie Mhadaidh (see fig. 23), where the foliation passes downwards from the Cambrian conglomerate into the underlying gneiss, irrespective of the bedding-planes of the former and the original foliation of the latter. The conglomerate is inclined to the W.N.W. at an angle of 20°. Along the line of junction it is welded to the old Archæan platform, so that rocks of widely different geological age practically form one mass. The planes of schistosity in the conglomerate dip to the E.S.E., more or less parallel with the plane of the Ben-More Thrust, and they are continued downwards into the gneiss, the original structures of which have been entirely effaced.

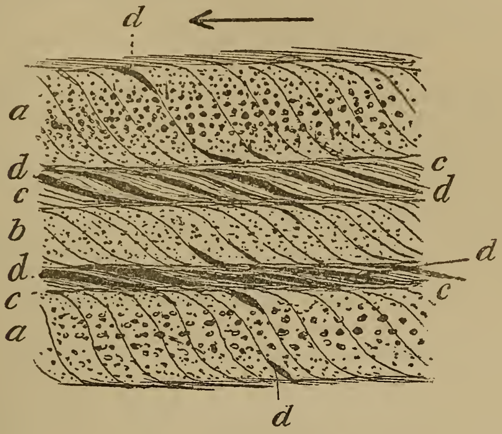
The Cambrian grits, sandstones, and shales have also been profoundly affected by these movements. Throughout them all cleavage-planes have been developed, dipping towards the E.S.E., more or less parallel with the plane of the Ben-More Thrust, at an average angle of 45°; while the original lines of bedding dip towards the W.N.W. Owing to the variable nature of the Cambrian strata, however, the cleavage is very unequally distributed, the beds of coarse grit being less distinctly cleaved, and the planes being more highly inclined than those in the finer sandstones and shaly bands. In fact, there seems to be a constant relation between the inclination of the cleavage-planes and the texture of the strata. The fine flags and shales behave, so to speak, like lines of weakness, their constituent particles having been drawn out or dragged much further than those of the grits. The planes of schistosity in the grits, flags, and shales form a series of sigmoidal curves, as represented in the accompanying section (fig. 23).

In addition to the cleavage, new minerals have been developed in the Cambrian strata. Sericite is abundant in the finer bands, so much so, indeed, that they might fitly be termed sericite-schists. At regular intervals too, along finer bands between the grits, lenticular veins of pegmatite occur, more or less parallel with the new schistose planes.

Again, on the slopes of Sgonnan More, the Cambrian flags and shales have been rendered schistose and show minute spots or knots resembling those in the knotted schists. This phenomenon is observable above the outcrop of the Ben-More Thrust-plane.

Finally, in the neighbourhood of Little Loch Broom, along the margin of the eastern schists, the Cambrian sandstones have been converted into schists, in which mica has been developed, and wherein the folia show beautiful wavy lines analogous to those in the belt of green schist already described. At this locality these Cambrian schists seem to merge into the eastern schists without any well-marked boundary line.

Fig. 23.—*Diagram of Cambrian Strata on Coinne-mheall, illustrating differential cleavage, schistosity, and formation of pegmatite in Cambrian Grits and Shales above Ben-More Thrust-plane as seen in Coinne-mheaell and River Oykel.* (Area shown about 12 yards square.)



a. Coarse Grits or Arkose.
b. Finer Grits or Arkose.
c. Shales.
d. Pegmatites.
The arrow shows the direction of movement.

3. *Metamorphism of the Silurian Strata.*

The various members of the Silurian series underlying the Glencoul Thrust-plane show little alteration, even where they have been piled on each other by minor and major thrusts. The "Fucoid-beds" are occasionally cleaved, the planes being determined by the adjacent thrusts. Not till we pass eastwards to the horizon of the materials above the Ben-More Thrust-plane is much change observable. The various powerful thrusts above this horizon, repeating wedges of the Archæan platform with various members of the Silurian series, produce marked changes in the latter. Both zones of the quartzite have been attenuated by the elongation or dragging-out of their constituent mineral particles. In the case of the false-bedded grits, the small pebbles of quartz and felspar have been drawn out to a length of three inches near Loch Strath nan Asinteach. The felspar pebbles are often cracked in the direction of the movement and the fissures are filled with secondary quartz. Again, in the "pipe-rock," the quartz-grains have been elongated and the vertical "pipes" or Annelide-tubes have been bent over, flattened, and drawn out into ribands parallel with the direction of movement. Along the divisional planes sericite has been abundantly developed, so that the strata lose all their normal characters and merge into quartz-schists. As a result of these changes, the quartzites have been reduced to a third of their usual thickness. At the base of the Stack of Glencoul and near Loch Ailsh, underneath the outcrop of the Moine Thrust-plane, these new structures are strikingly displayed. At the latter locality other members of the Silurian series share in the metamorphism. Advancing outwards from the Loch-Ailsh road to Cnoc Chaoruinn, the Silurian zones, from the false-bedded quartzites to the basal limestones, are repeated by thrusts at intervals of a few yards. At first the various zones are quite recognizable, the pipes in the quartzite being slightly bent over and the Serpulite-grit yielding Serpulites after a careful search; but with each successive displacement their characters are gradually modified, till it is impossible to distinguish them from some of the members of the eastern schists. The false-bedded quartzites merge into quartzose sericite-schists; the "pipe-rock" passes into a fine quartz-schist, in which the pipes are flattened like strips of paper, parallel with the foliation-surfaces; the original lines of bedding of the "Fucoid-beds" wholly disappear and are replaced by divisional planes, coated with white mica; the Serpulite-grit, no longer yielding Serpulites, becomes a quartz-schist, and, finally, the limestone becomes crystalline. On the new divisional planes numerous fine parallel lines are met with, indicating the direction of movement, trending generally E.S.E.; indeed this "striping" is equally apparent in the quartzites at the base of the Stack of Glencoul, at the head of Glendubh, and other localities.

4. *Metamorphism of the Igneous Rocks intrusive in the Cambrian and Silurian Strata.*

The evidence relating to regional metamorphism furnished by the great series of intrusive sheets in Assynt likewise indicates progressive alteration as we pass eastward to the Moine Thrust-plane. In the undisturbed area to the west of the Post-Lower-Silurian movements the igneous rocks of a granitoid type never show the slightest trace of a foliated or banded arrangement. The felsites, on the other hand, frequently show fluxion and spherulitic structures, where they traverse the old Archæan platform, along the margins of the dykes. Passing eastwards to the displaced Silurian zones underlying the Glencoul Thrust-plane, hardly any change is observable in the sheets, except in those instances where they have been driven along the "sole" of a major thrust. In the latter case the diorites in the limestones have been slightly cleaved and rendered schistose.

Crossing the outcrop of the Glencoul Thrust to the slopes of Coinne-mheall, we observe that some of the porphyritic felsites show a flow-structure like that of the rhyolites, and that in one case the rock has been completely reconstructed so as to become a fine-grained schist. On the crest of Coinne-mheall, just above the Ben-

More Thrust-plane, the sheets of felsite injected along the bedding-planes of the basal quartzites have been converted into soft sericite-schists, which can be cut with a penknife; and in Corrie Mhadaidh a felsite dyke on the same horizon has been cleaved parallel with the planes of schistosity in the Cambrian strata and with the plane of the Ben-More Thrust. All these changes have been developed in the dykes without much alteration in the quartzites in which they occur. Again, on the north side of the Oykel valley, a dyke of porphyritic felsite in the inverted Cambrian strata, above the Ben-More Thrust-plane, has been converted into a mica-schist, showing that peculiar "frilled" structure so marked in the green "frilled schists" of Eriboll.

Still further eastwards, in the belt of thrust and sheared Silurian strata stretching southwards from the Stack of Glencoul by the Gorm Lochs to Loch Ailsh and Allt Ealag, nearly all the dykes and sheets are beautifully foliated, the planes of schistosity being parallel with the planes of thrust. The fine-grained diorites in the limestones are now represented by green hornblende-schists and chlorite-schists; the holocrystalline rocks with porphyritic felspars set in a micro-crystalline base appear as bands of "augen-gneiss" and "augen-schist"; and finally, along a line of powerful thrust in the great granitoid sheet east of Loch Borrolan there is a belt of "augen-gneiss" with pyroxenes, which, existing originally as porphyritic crystals, now appear as "eyes" in the foliated rock. Indeed, so striking are the changes in these intrusive sheets close to the Moine Thrust-plane, that it would be almost impossible to identify them, were it not for the still recognizable zones in which they occur. Where the latter lose their distinctive characters, bands of white quartz-schist are then found, alternating with grey or green hornblende-schist.

From these various lines of evidence it is quite apparent that there is progressive metamorphism on a grand scale as the observer passes eastwards from the undisturbed western belt of ground to the horizon of the Moine Thrust-plane. It is also obvious that the crystalline rocks, where they occur in thin sheets, become schistose much more readily than the clastic rocks, and that the Cambrian sandstones and shales are more easily cleaved than the Silurian quartzites. It is also probable that the great thickness of the slice of Archæan rocks above the Glencoul thrust-plane, together with the heterogeneous character of its materials, prevented the development of new divisional planes in the thrust-gneiss, the deformation showing itself mainly in the fracture and crushing of the crystals. Not till we reach the point where powerful thrusts follow each other in rapid succession, repeating thinner slices of the old Archæan platform in the overlying quartzites, is the Post-Lower-Silurian shearing strongly marked in the Archæan rocks. At length in the zone of green schist and sheared gneiss underlying the Moine Thrust each divisional plane or foliation-surface is a shear-plane developed by these Post-Lower-Silurian movements.

5. *Succession of Strata above the Moine Thrust-plane.*

We must now describe briefly the strata overlying the Moine Thrust-plane, stretching eastwards by the Kyle of Tongue to Strathnaver. For nearly six miles there is a belt of strata of remarkably uniform character, consisting of flaggy quartzose mica-schists or fine-grained gneiss, typically developed on the Moine between Loch Eriboll and the Kyle of Tongue. These strata (the "younger gneiss" and "quartzose flagstones" of Murchison) have been traced continuously from the north coast of Sutherland to Loch Broom, showing little variation in lithological character. In the heart of the mass there is a prominent zone of hornblendic and micaceous schist, studded with garnets, traceable from the north coast to the Kyle of Tongue and thence round the north and west slopes of Ben Hope. There can be little doubt that this zone has once been an extensive sheet of igneous rock, because at various localities patches of the original igneous mass are still met with, consisting of diorite or diabase. Overlying this belt of garnetiferous schist, bands which can still be recognized as sheared Archæan gneiss can be followed for some distance.

Like the crushed slates, schists, and sheared gneiss (mylonites) underlying the Moine Thrust-plane, these flaggy crystalline schists and gneisses are inclined at gentle angles to the E.S.E. That they form an enormous pile of material is evident from the fact that they rise from the sea-level to the crest of Ben Hope (3040 feet). But a careful examination of the path along which they have travelled shows that the divisional planes or foliation-surfaces lie at an oblique angle to the thrust-plane (see fig. 20, where the Moine schists are represented as lying at an oblique angle to the plane of the Moine Thrust). It is obvious, therefore, that the thickness of the Moine schists cannot be estimated after the manner of ordinary sedimentary strata. This conclusion is confirmed by a study of the structures presented by these schists. The main divisional planes truncate minor planes, like the major and minor thrusts in the displaced Silurian strata. In other words, as the schists were being driven forward the materials were piled on each other to an enormous thickness. Further, on closer examination, it is observable that the different mineral constituents lie at an angle to the main foliation-planes. There is also evidence to show that the terrestrial movements were intermittent, because the first divisional planes in the Moine schists are frequently truncated by subsequent thrusts. During pauses in the disturbances dykes and thin sheets of various igneous (granitoid) rocks were injected across the foliation-planes, and these intrusions have been in turn sheared by later movements.

These crystalline schists and flaggy gneisses display parallel lines on the foliation-surfaces, indicating the same direction of movement as those in the sheared Silurian strata and crushed slates and schists (mylonites), while the constituent minerals are orientated along these lines. It is obvious, therefore, that the present strike, dip, and lithological characters of these crystalline schists and flaggy gneisses were developed by movements after the Lower Silurian period. They differ, however, from the mylonites underlying the Moine Thrust-plane in one important feature, viz., that their matrix is holocrystalline. In other words, the formation of the Moine schists, as Professor Lapworth has shown, has been attended by greater molecular changes. Throughout the crystalline matrix numerous "eyes" of felspars and quartz occur, belonging to the original rock out of which the schists have been formed. The holocrystalline character of the Moine schists points in all probability to the conclusion that in their case the movements took place at a more rapid rate, thus producing a higher temperature and giving rise to greater chemical changes after the movements had ceased.

To the east of the Kyle of Tongue, the Moine flaggy schists alternate with occasional bands of hornblende-schist as far as Strathan, where they are succeeded by a belt of undoubted Archæan rocks, two miles in width, stretching eastwards nearly to the river Borgie. Consisting mainly of hornblendic gneiss with masses of rudely foliated diorite and dykes of ultra-basic materials (peridotites, &c.), these rocks present many of the typical features of the Archæan gneiss west of Durness. When followed southwards, this belt thins away till it disappears to the north of Loch Creagach, near Ben Loyal.

To the south of Tongue another belt of Archæan rocks has undergone a great amount of deformation by the Post-Lower-Silurian movements, the foliation-planes coinciding in direction with those of the Moine schists. But here and there throughout the belt patches of gneiss and pegmatite, showing the Pre-Cambrian foliation, may be detected.

Advancing eastwards to the Borgie River, we find alternations of flaggy Moine schist and gneiss, Archæan hornblendic gneiss striking generally north and south and dipping to the east, overlain by a peculiar type of gneiss in Strathnaver. Consisting mainly of black micaceous gneiss in which the mica is very abundant, this zone contains "eyes," "cores," or oval-shaped masses of diorite, whereof the longer axes lie parallel with the strike of the foliation. Round these "cores," both mica and hornblende curve in wavy lines, the latter disappearing as they are followed outwards into the well-foliated gneiss. There can be little doubt that these lenticular masses, or "cores," are patches of a once continuous sheet of igneous rock, out of which the Strathnaver gneiss has been formed. A remarkable characteristic of this foliated mass is the development in it of pegmatites, mainly along the lines of foliation. Beginning as isolated knots of felspar, they gradually become continuous, giving rise to thin strings or veins and eventually increasing in size till they form bands a hundred yards across. The formation of these pegmatites evidently formed a part of the process of metamorphism whereby the eruptive igneous mass was converted into a micaceous gneiss. From the fact that bands of Moine schist or flaggy micaceous gneiss are intercalated with the Naver gneiss, it is highly probable that the deformation of this Archæan mass was mainly effected by the Post-Lower-Silurian movements.

From Bettyhill to Kirktomy there stretches a belt of flaggy micaceous gneiss, resembling part of the Moine gneiss; but to the east of the latter locality lies an area of undoubtedly Archæan rocks, several miles broad, which have only been slightly affected by the Post-Lower-Silurian movements. They consist of coarse hornblendic and micaceous gneiss with bands of diorite and gabbro, similar to the Pre-Cambrian crystalline rocks at Cape Wrath. Though the area to the east of Strathnaver has not been mapped in detail, we are at present inclined to believe that this broad belt of Archæan rocks resembles the mass of Pre-Cambrian strata at Strathan Skerray in its mode of occurrence. The latter, as we have shown, is intercalated in micaceous Moine schist or flaggy gneiss.

The Archæan rocks east of the Naver are traversed by dykes of pink and grey granite, which have been converted into granitoid gneiss by mechanical movements.

After the Moine schists and gneiss to the south of Tongue had acquired their present strike, dip, and lithological characters, in consequence of the terrestrial movements after the Lower Silurian period, the great sheet of syenite now constituting Ben Loyal was erupted, mainly along the foliation-planes. On the western slope of the mountain the schists and gneiss plunge underneath the intrusive mass with an E.S.E. dip, while along the north and south margins of the area they also pass underneath it. To the east of Ben Loyal the main body of syenite divides into several branching sheets, which are likewise intruded more or less along the foliation-planes. The boundary line traverses the western slope of Ben Loyal at a height of about 1000 feet, while the peak rises to a height of 2504 feet, so that this great intrusive mass is upwards of 1500 feet thick.

Other intrusive igneous rocks pierce the micaceous flagstones of the Moine series, consisting of dykes of diabase and mica-trap. The latter have been followed for miles through the Cromalt Hills, and in one case a dyke traverses both the Moine schists and the underlying Silurian strata of the Knockan cliff.

It is obvious that the facts now brought forward furnish a large amount of evidence in support of the theory *that regional metamorphism is due to the dynamical and chemical effects of mechanical movement acting alike on crystalline and clastic rocks.* It is further obvious that regional metamorphism need not be confined to any particular geological period, because in the North-west Highlands it occurred on a vast scale both in Pre-Cambrian time and at some period subsequent to that in which the Durness limestones were deposited.

6. *Denudation of the Land-surface before the time of the Old Red Sandstone.*

In the neighbourhood of Tongue remarkable evidence is obtained regarding the denudation of the old land-surface before the deposition of the Old Red Sandstone. Between Ben Loyal and the Kyle of Tongue various outliers of this formation, described by the present Director-General of the Geological Survey, rest on a highly eroded platform of the crystalline schists. The deposits are also met with in the islands at the mouth of the Kyle. One of these outliers, at Cnoc Craggy (1043 feet), about a mile and a quarter to the north of the northern margin of the Ben-Loyal syenite, was grouped by Professor Nicol with the Torridon sandstones, and was believed by him to be overlain by quartzite*. The platform on which it rests is about 800 feet high. Upwards of 40 per cent. of the pebbles in the conglomerate are composed of the syenite of Ben Loyal. It follows, therefore, that the latter intrusive sheet was stripped of the overlying schists, thus proving enormous denudation before the deposition of the Old Red Sandstone.

Some of these outliers, on the east side of the Kyle of Tongue, rest on the Moine flagstones produced by the Post-Lower-Silurian movements, and they contain numerous fragments of these schists. Hence it is obvious that the changes must have been completed before the time of the Lower Old Red Sandstone.

Further evidence that the outliers really belong to the Old Red Sandstone is furnished by their numerous pebbles derived from the Cambrian and Silurian formations. Amongst these, we noted Cambrian sandstones, false-bedded quartzite, "pipe-rock," Serpulite-grit, and limestone belonging to several groups of the Durness limestone, some of the blocks containing *Murchisonia*. From the inclination of the layers in the conglomerate it is evident that the pebbles were borne by currents from the W.N.W.

The detailed examination of the north-west of Sutherland has furnished important evidence regarding the glaciation of the region, showing, for example, that during the greatest extension of the ice the centre of dispersion did not coincide with the existing range of high ground. It has also thrown light on the excavation of the present valley-system, on the relation of disruption-lines and the trend of basic dykes to surface-features, and, finally, on the formation of lofty mountains by denudation. But the description of these and other phenomena is reserved for the detailed official memoirs of the Geological Survey.

Discussion.

The President observed that the communication just made to the Society was remarkable, not only for its importance, but for the mass of details it contained; it was, in fact, four or five papers rolled into one.

Professor Lapworth commented on the wonderfully descriptive character of the paper. The general conclusions arrived at were very similar to those he had himself indicated. There was this difference that when he brought forward his views such notions were novelties and were consequently regarded with suspicion. But so much has the question been ventilated within the last four years that he pre-

* Quart. Journ. Geol. Soc. vol. xvii. p. 92.

dicted for this paper a hearty reception. So well had the subject been worked out by Messrs. Peach and Horne and their colleagues, that it had been made clear that our own country contained structures which were practically unequalled as types of metamorphism. So far from lagging behind, we were now fully abreast of foreign investigation; and when the paper came to be printed, with no stint as to illustrations, it must rank as one of the highest value. Such sections are to a certain extent astounding, yet they do occur. He spoke of the fascination of these studies, and felt sure that they gave promise of a great future for British geology. He was only acquainted with the Durness-Eriboll district; but from his knowledge of the accuracy of the Authors' work there, he had every confidence in their interpretation of the other districts. The paper will also add to our knowledge as regards the theory of the origin of the Archæan rocks. He complimented the officers of the Survey on the interest and excellence of their work.

Dr. Hicks considered that the interest attaching to the district under discussion will hold as far as Loch Carron. One point in respect of the origin of the Archæan rocks he particularly noticed in the paper was the amount of alteration these rocks had undergone in Pre-Cambrian times. These features were seldom obliterated by the new movements. It would be interesting to know to what extent the central area of the Highlands was made up of the old and the new rocks. He imagined that comparatively little of the latter would be found there. He spoke of the evidence afforded in the paper of rocks other than those now known to occur in the area, testifying to an enormous amount of denudation prior to the deposition of the Torridon Sandstone. He had also noticed and referred to the presence of such rocks in the Torridon series further south. He thought the paper a credit to the Survey and to British geologists generally.

Professor Judd also congratulated the Survey on this important piece of work. Before offering any criticisms we must wait till we have an opportunity of studying it in detail. It supplied important evidence in support of a principle which had been maintained by many of the most distinguished members of the Geological Society in past times—namely, that foliation is not coincident with stratification.

Mr. Teall commented on the many points opened up, and on the immense amount of work embodied in the paper. He could say but little. What was the Archæan gneiss originally? what is its most original rock? In many instances the divisional planes are not vertical, but described as rolling at gentle angles. In such cases the strike is represented as being about N.E.; hence the so-called normal, or N.W. strike must be secondary. What do the original planes of division represent? Are they lines of segregation in a plutonic magma? He was glad to find that his petrographical work, more especially in connexion with the development of hornblende-schist out of dolerite, had been confirmed.

Mr. Hudleston said that every one who had paid any attention to the difficult subject with which this paper deals must have listened with genuine pleasure to the story of the solving of these mysteries, which even a few years ago seemed almost to defy the attempts of geologists. Persons who lived before the discovery of "thrust-planes" might well be excused for not having read aright the section at Craig-a-Knockan. It was to be hoped that in the great future which was promised to British geology some attempt would be made to explain the dynamics of these phenomena. He ventured to point out what seemed to him a discordance between certain sections through the Ben More range and the generalized section through Assynt.

Mr. Peach explained that the apparent discrepancies alluded to by Mr. Hudleston were due to a difference in the direction of the sections and in the level of the datum-line. He thanked the Society for the way in which the paper had been received, and in reply to Mr. Teall assured him that they had thought about these things, but their solution, he considered, must be left mainly to the microscopist.

Mr. Horne alluded to the value of Professor Lapworth's work, of which they had the highest appreciation, seeing that their conclusions were practically identical.

Dr. Geikie also expressed his satisfaction at the reception accorded to the paper. Referring to a remark by Dr. Hicks, the survey of the country had not yet got so far as Gairloch, where Dr. Hicks's observations had been made. He was both ready and anxious to do justice to the work of previous writers. Referring to the future progress of the Survey, he held out hopes that another paper, giving the results of the detailed study of the southern half of the belt of great complication, might be presented to the Society ere long in anticipation of the Survey Memoirs.

31. *On the* Eruptive Rocks *in the Neighbourhood of* Sarn, Caernarvonshire. By Alfred Harker, Esq., M.A., F.G.S., Fellow of St. John's College, Cambridge. (Read May 9, 1888.)

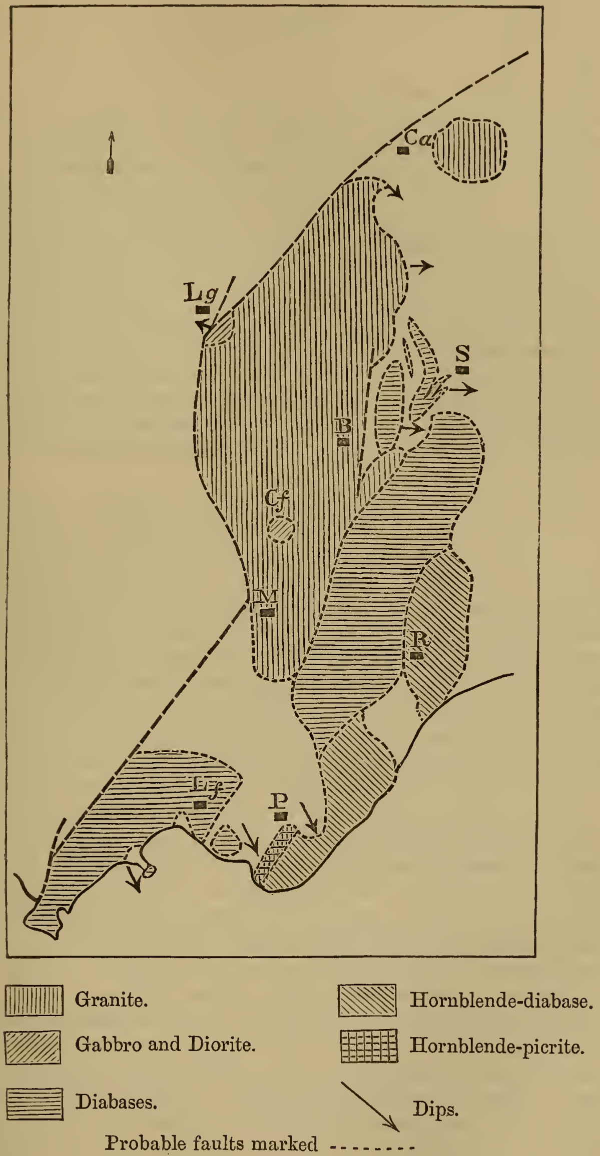
I. Introductory.

The district to be treated lies to the west and south of the village of Sarn *, near the south-western extremity of Caernarvonshire. The eruptive rocks there exposed, excluding outlying patches, occupy an area of irregular shape, which extends about 5¾ miles from north to south, and has a greatest breadth of about 2¼ miles. This part of the country has received but brief notice from Sir A. Ramsay in his memoir on the "Geology of North Wales" †, and from Dr. Hicks ‡, who claims a portion of the area for his Pre-Cambrian systems. Several specimens from the district have been described by Professor Bonney § and the late Mr. Tawney ‖, and the latter has also made a few observations on the field-relations of some of the rocks; but with these exceptions we have no published information about the western part of the Lleyn peninsula, though there are probably few districts of equal size in Britain where so many interesting rock-types are to be met with.

The rocks will be discussed in the following order:—Granite and Gneissic Granite; Gabbro, Diorite, and Gneissic Diorite; Diabase; Hornblende-Diabase; Hornblende-Picrite; and Dolerite. Some of these, however, are but little developed, and, for most purposes, the rocks of the district may be divided into two groups—an acidic, developed in the north and west, and a basic and intermediate in the east and south. Mr. Tawney and Dr. Hicks have pointed out that the map of the Geological Survey does not correctly indicate the separation between the two groups, the extent of the "greenstone" being unduly enlarged at the expense of the "syenite." The accompanying sketch-map (fig. 1) is intended to show roughly the limits of the two sets of rocks; but much of the country is obscured by drift, and accuracy is impossible without better topographical maps to serve as a basis.

* Sarn Meyllteyrn on the Survey Map, one-inch scale, sheet 76.
† Mem. Geol. Surv. Gr. Brit. vol. iii. 2nd edit. (1881).
‡ Quart. Journ. Geol. Soc. vol. xxxv. p. 298 (1879).
§ Geol. Mag. dec. ii. vol. vii. p. 207 (1880); Quart. Journ. Geol. Soc. vol. xxxv. p. 306 (1879).
‖ Geol. Mag. dec. 2, vol. vii. pp. 207–215, and p. 456 (1880); vol. x. pp. 65–68 (1883); see also Teall, 'British Petrography,' 1888.

Fig. 1.—*Sketch-map of the Sarn district.* (Scale $\frac{2}{3}$ inch=1 mile.)



Ca. Cefn-amlwch.
B. Bryn-croes.
Lf. Llanfaelrhys.
Lg. Llangwnadl.
M. Meillionydd.
P. Penarfynydd.
S. Sarn.
R. Rhiw.
Cf. Craig-y-fael.

Despite the superficial deposits, however, and notwithstanding the absence of exposures in some of the critical localities, it is possible to draw conclusions regarding the relations of the rocks, some of which may be considered reliable, while others are at least probable.

The age of the sedimentary strata is naturally the first question, and here unfortunately the evidence is very meagre. The fossils recorded by Mr. Tawney and Sir A. Ramsay from Penarfynydd and other localities near Llanfaelrhys are taken to indicate a horizon in the Upper Arenig, and, judging by the observed strike of the strata, there is no reason why the similar rocks (black shales, with occasional beds of sandstone) seen to the east of the granitic mass should not be referred to the same stage, although no organic remains have been found. If not Arenig, these strata must be referred to the lower part of the Bala series. The granite is bounded on the north and north-west by the problematical green schists, which extend from Bardsey to Porth-dinlleyn; but as the boundary is almost certainly a faulted one, it is needless to discuss here the age of those remarkable rocks. For our purpose it is sufficient to know that the beds in unfaulted contact with the eruptive masses are of Arenig or, at the latest, Lower Bala age.

II. The Granite and Gneissic Granite.

These rocks, the massive type largely predominating, cover a large area on the map. The granite builds the round hill of Mynydd Cefn-amwlch to the north-west of Sarn, and underlies the low ground towards Bryn-croes, ranging as far south probably as Meillionydd-bach, a distance of four miles. Around and to the west of Bryn-croes, where the Survey map shows "greenstone," there are no exposures; but, judging by the form of the surface, the whole is probably granite, like that to the north and south, and the two "syenite" areas of the Geological Survey are united. The outlying patch at Pyllau-giach, near Cefn-amwlch, also coloured as "greenstone," is granite, and a tongue of the same rock extends from half a mile south of Bryn-croes to the edge of the valley north of Mûriau. The only place where the gneissic type of granite is exposed is in a quarry at Meillionydd, in the extreme south of the mass; even there the character is only locally marked, and in the little hill to the east the rock is the normal granite of the district.

It is a biotite-granite or granitite, the mica partially giving place to hornblende in a few localities only. The minerals composing the rock are apatite, magnetite, pyrites, biotite, two felspars, and quartz, with a chloritoid substance, epidote, actinolite, kaolin, leucoxene, and ferruginous matter. Apatite and original iron-ores are sparingly present. Biotite occurs in ragged flakes, often bent, and sometimes showing "*Gleitflächen*." It is normally deep brown, with the usual characters of dichroism, but changes to green, giving then a bright grass-green colour for vibrations parallel to the cleavage-traces, and a very pale green for the direction at right angles. A further stage of alteration produces an indistinct brownish scaly mass, which finally becomes isotropic with the separation of magnetite-dust. The chief felspar forms rectangular crystals, with fine twin-lamellation and low extinction-angles, agreeing with those of oligoclase. Orthoclase occurs in large plates of later formation than the plagioclase; both felspars show kaolinization, beginning from the centre of the crystals. Quartz is abundantly present, often in composite grains, moulding the felspars; it contains many minute fluid-cavities of irregular shapes, with spontaneously moving bubbles.

The granite has apparently undergone some degree of secondary change connected with the operation of mechanical stresses. Some of the fluid-inclusions in the quartz, as remarked by Mr. Tawney, occur in lines which pass from grain to grain. These lines of inclusions seem to be connected with roughly parallel cracks which traverse quartz and felspar alike. There are other cracks marked by a finely granular mixture of felspar and quartz, and sealed by epidote and irony staining; this appearance may perhaps be compared with the "*Mörtelstructur*" of Törnebohm. The gliding-planes sometimes seen in the mica are probably another secondary phenomenon.

The granite and gneissic granite of Meillionydd have a character in some respects differing from the normal type. The constituents are the same as before, but their arrangement is anomalous, the usual order of consolidation being partly reversed. The felspars, chiefly a finely laminated acid plagioclase as before, are sometimes older, sometimes newer than the bulk of the quartz; a bipyramidal crystal of the latter mineral is occasionally seen included in felspar. The biotite is the latest-formed mineral. It moulds the earlier products of consolidation and fills the interstices between them, even sending out little tongues into cracks and irregular inlets in the quartz. A portion of the latter mineral, however, is sometimes of more recent formation than the biotite, and may even be posterior to the consolidation of the rock.

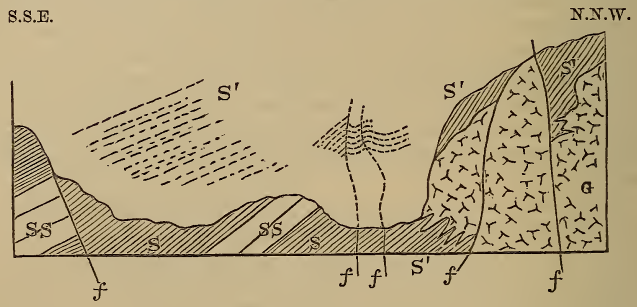
The occasional gneissic aspect of the granite at Meillionydd seems to have no necessary connexion with the peculiarities described. It consists in a local banded structure, with partial separation of the constituent minerals, seen only in large specimens. It is most probably to be referred to a certain amount of differential movement of the mass during the process of solidification, and cannot be due to any subsequent crushing of the solid granite. Little segregatory nests, rich in brown mica, occur in the rock, and these show no evidence of distortion.

The granite of Cefn-amwlch, Meillionydd, &c., is named syenite by the Geological Survey, a name which does not seem properly applicable; and it is stated that the "greenstone" of Mynydd-y-Rhiw "passes into" the "syenite." This idea of a passage, unlikely in itself, does not appear to be borne out by the evidence in the field.

Dr. Hicks, in 1879, put forward the view that the granitic mass, which he speaks of as the "Rhos Hirwain* syenite," is of Pre-Cambrian age. Mr. Tawney apparently regarded this theory with considerable doubt, but Professor Blake †, if a passing allusion of his is correctly understood, endorses it.

An examination of the whole district leads to a conclusion in favour of the earlier view, that the granite is intruded through the shales. A good section is offered by the most southerly of the quarries near Cefn-amwlch. This was figured by Mr. Tawney, who was driven to some very unnatural suppositions in order to reconcile it with the supposed Archæan age of the granite. I give, in fig. 2,

Fig. 2.—*Section in the most southerly Quarry at Cefn-amwlch.* (Length about 30 yards; vertical scale slightly exaggerated.)



S. Shale. S'. Indurated and spotted Shale. SS. Sandstone. G. Granite. *ff.* Faults.

a different version of the section. The actual contact of the two rocks is easily found, and the granite is seen to send out little tongues between the laminæ of the shale. Specimens of the latter rock, indurated and firmly adhering to the granite, may be obtained. At the back of the quarry the shale is clearly altered, and exhibits the little spots and nodules supposed to represent the incipient development of chiastolite. Another quarry, well within the boundary of the granite, shows entangled masses of baked shales. This is partly due to faulting; but here, too, good junction-specimens of the two rocks were procured. The granite in these quarries is quite typical of that which forms Mynydd Cefn-amwlch, and extends towards Sarn, Bryn-croes, and Llangwnadl.

At Meillionydd the junction is not exposed; but the quarry must be near the boundary, and the presence of fragments of indurated shale included in the granite is sufficient proof of the intrusive character of the latter rock.

The granite is therefore of more recent age than the Upper Arenig strata. To assign an upper limit to the date of its intrusion is a

* Rhos Hirwain is the low-lying tract to the west, and the conjunction of this name with the word Syenite on the Survey map is apparently unintentional.

† Report Brit. Assoc. (Birmingham meeting) 1885, p. 669.

matter of mere conjecture; but the relation of the rock to subsequent earth-movements, of probably pre-Llandovery times, renders it likely that the granite belongs to the Bala age. It is impossible to say whether this plutonic mass was connected with volcanic centres; acidic lavas and ashes are found, however, less than five miles to the east, and are associated with Bala strata.

III. The Gabbro, Diorite, and Gneissic Diorite.

These rocks, grouped together for reasons which will appear, have not been noticed before. They occur only in two small patches, and are quarried in both places, viz. in the little hill of Craig-y-fael, two miles south-west of Sarn, and on the banks of the stream at Plas Llangwnadl.

The Craig-y-fael rock is, to the eye, a medium- or rather coarse-grained rock of granitic habit, apparently either a diorite or a gabbro. A similar or identical type is exposed above Plas Llangwnadl; but going north we find the rock assuming a more or less gneissic and even almost a schistose appearance, becoming, as it seems, a hornblendic gneiss. The microscope explains clearly the relations of these various types.

The typical rock of Craig-y-fael may be described as a partially amphibolized gabbro. It consists mainly of an aggregate of somewhat altered felspars and grass-green grains of hornblende and augite, none of the constituents ever showing idiomorphic contours. The minerals seen in the thin sections are augite and diallage, hornblende and actinolite, felspar, and a black opaque mineral, presumably an iron-ore, with some pale green decomposition-products, which mostly present the characters of chloritoid.

The black mineral forms shapeless patches without any indication of leucoxenic alteration, and is probably magnetite. The felspar is a plagioclase, showing the usual albite-twinning, sometimes crossed by twin lamellæ on the pericline-law; the extinction-angles are those proper to labradorite. The crystalline plates are much strained and bent, so that the lamellæ are curved; it is possible, though not clear from the specimens examined, that the twinning may be in part induced by the strain.

The augite is in long plates of a very pale greenish tint. It shows sometimes the ordinary augite-cleavages, but other plates have a very marked diallagic structure. In spite of decomposition, it can be seen that both augite and diallage are converted at the margins into hornblende. The hornblende is of a dull green colour, and the pleochroism is expressed by:—α, very pale to almost colourless; β, grass-green, rather pale; γ, a rather deeper and bluish green. The usual prismatic cleavage-traces are seen in the more compact portions; but a part of the amphibole is in granular masses or in blade-like imperfect crystals with actinolitic structure.

There appears to be no augite or diallage in the Llangwnadl rocks, but their essential identity with the amphibolized gabbro of Craig-y-fael can scarcely be doubted after an examination of the specimens and the slides. The process of alteration has proceeded further in the rocks on the edge of the district than in those of the central part.

The rock exposed near the bridge where the main-road crosses the stream may be taken as a type of the massive diorite. The microscope shows but little of the black iron-ores, but there is a considerable quantity of sphene in brownish granules. These granules, with cleavage-traces and irregular fissures, are aggregated in small patches and strings between the grains of felspar and hornblende. The felspar is partly in granular patches, too much decomposed to show any structure. The hornblende is of a greenish-brown or brownish-green colour, and gives for the three axes of elasticity:—α, very pale to almost colourless; β, rather deep brown with greenish tinge; γ, slightly deeper tint of greenish brown. There are also very pale greenish actinolite-looking shreds amongst the felspar-grains.

Near Plas Llangwnadl the rock is more altered, and has in places a quasi-porphyritic appearance, owing to the granular felspar forming large patches. Here there is very little of the opaque iron-ore, but sphene is more abundant. The felspar has undergone a seemingly saussuritic change, but a little of it still preserves the original structure and appears to be labradorite.

Still further down the stream, approaching the boundary of the area, the schistose appearance becomes more pronounced. A slide from this portion shows no new characters, except that the black iron-ore has entirely disappeared.

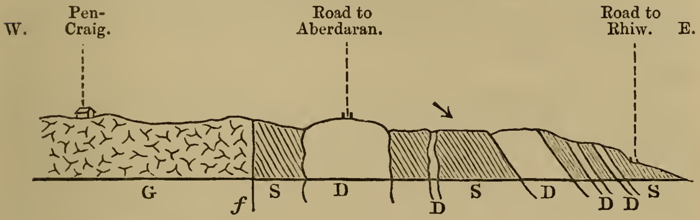
The mode of occurrence of all these rocks, both at Craig-y-fael and near Llangwnadl, proves that they were intruded through the granite, doubtless in the form of gabbro. The hornblende may be supposed to be entirely of pseudomorphic origin, the change being probably assisted by the mechanical stress to which must be ascribed the schistose structure of the rocks about Llangwnadl. At Craig-y-fael, where the gabbro was protected by a large mass of surrounding granite, the amphibolization is still imperfect. In the other mass, where the conversion is complete, the schistose character becomes more marked towards the boundary, and it may reasonably be ascribed to the movements which produced the assumed fault. In confirmation of this, it may be remarked that the strike of the gneissic and schistose structures is the same as that of the fault, and the schistosity is shared on the other side of the boundary by the ashy-looking beds which represent, near Llangwnadl church, the so-called green schists. The production of sphene in connexion with this kind of metamorphism is too well known to require comment.

The date of the gabbro and diorites is, then, more recent than that of the granite, but earlier probably than the fault; the rocks may be referred with some doubt to the Bala age.

IV. The Diabase.

The main mass of diabase in the district forms the curious conical hill named Clipiau-cilfinhir, half a mile west of Rhiw, rises in the long ridge of Mynydd-y-Rhiw to a height of 1000 feet, is quarried further north near Cadern-y-groes, and extends in a north-north-easterly direction to Tyn-y-coed, half a mile south of Sarn village. Besides this, several sheets and dykes occur just west of Sarn; and further west, at Ty-rutten, a tongue-shaped mass runs with the strike of the strata, leaving a narrow strip of shales between itself and the granite (fig. 3). This mass must abut at its southern extremity on

Fig. 3.—*Section from Pen-Craig to south of Sarn.*
(Length about $\frac{3}{4}$ mile.)



S. Shales, Upper Arenig or Lower Bala.
G. Granite.
D. Diabase, tongue at Ty-ratten, dyke and sheets near Sarn.
f. Probable faults.

the tongue of granite a little north of Mûriau; but unfortunately their junction, on the right slope of the little valley, is not exposed. There are numerous diabase sheets and small bosses in western Lleyn, which will not be considered here, though some of them, such as the sheets at Llanfaelrhys and Tyn-y-rhedyn, have probably a cognate origin with the diabase of the Sarn district.

The rocks are sufficiently alike to be described together, and present no very striking peculiarities. In hand-specimens the rock appears as a diabase of medium grain, greenish from decomposition-products, and showing distinct crystals of felspar.

The microscope shows the original constituent minerals to be the usual iron-ores, plagioclase felspar, and augite; the secondary products, leucoxene, calcite, zeolites, quartz, chloritoid minerals, and ferric oxide, do not require special notice. The magnetite and ilmenite, constantly the first-formed minerals, are fairly plentiful in rods and skeleton crystals. One or other of these constituents is always present, and frequently both in the same slide: there are not wanting signs of an intergrowth of the two minerals, or perhaps of magnetite and titaniferous magnetite.

The plagioclase occurs in lath-shaped or, at least, elongated sections, showing twin-lamellation on the albite-law. In the dykes and sheets near Sarn the felspars are often once twinned only, but in general a fine striation is seen between crossed nicols. The extinction-angles agree with those of oligoclase and labradorite.

The augite is very pale brown or almost colourless in thin sections, with the prismatic cleavage pronounced, and rarely traces of a pinacoidal cleavage. The well-known "hour-glass" structure is not uncommon. The mineral is either in ophitic plates or in grains between the felspars. Only occasionally, as at Castell Carron, does it appear with idiomorphic boundaries; sometimes it shows twinning on the orthopinacoid.

The structure of these diabases is rather variable. Sometimes they are ophitic, but the augite-plates are never of great size, and the more usual texture rather approaches the granulitic type. It does not appear that the basic rocks of this area bear out any rule associating the ophitic structure with the larger masses, and the granulitic with small dykes and sheets. The types of structure seem rather to be connected with the relative proportions of the two minerals, the ophitic rocks being those which have the most abundant augite.

These diabases afford fine examples of spheroidal jointing and the consequent weathering in concentric crusts. The spheroids vary in diameter from two or three inches to as many feet; often a cluster of small ones is included in one large shell. The spheroids are sometimes formed in the interspaces marked out by plane joints, but the most regular examples often have no such relation. The great mass of Mynydd-y-Rhiw, especially in its northern and southern portions, is largely built up of spheroidally jointed rock.

The contact-effects of the diabase upon the adjacent strata usually present no special features. In one case the strata of indurated shale show a curious modification. They are broken by joints parallel and perpendicular to the bedding into small rectangular blocks, in each of which lies an ellipsoidal nucleus. The ellipsoidal joints are from an inch or two to a foot in diameter. This is at the contact with a dyke 35 yards wide, about a quarter of a mile west of Sarn.

The relations of the diabase to the other intrusive rocks can nowhere be demonstrated by actual sections, and the age of the mass is a matter for conjecture. It can only be said that the diabase cuts through Arenig or Lower Bala strata, while no rock of similar type is certainly known in Caernarvonshire of later age than the Bala. The presumption is therefore in favour of assigning the intrusion of the rock to the Bala age.

V. The Hornblende-Diabase.

Rocks of this family are largely developed in the southern part of the district. They are seen everywhere on Mynydd Penarfynydd, with the exception of the outcrop of hornblende-picrite on the west and south-west slopes. They form the whole of Mynydd-y-graig and its outlying spurs, the extent from south-west to north-east being about 1⅔ mile. Hornblende-diabase may occur under the low ground north-west of Mynydd-y-graig, but probably the diabase extends as far as this. The same rock is found in force in the neighbourhood of Rhiw: it occurs a few hundred yards north of the church, on the east side of the diabase-ridge, and can be traced southward to the coast at Tyn-y-borth, being quarried at Treheli.

The microscopic study of these rocks reveals features of considerable interest, and they will accordingly be treated in rather more detail than the foregoing rocks. Taking the hornblende-diabases of the district as a whole, the original constituent minerals are apatite, magnetite, picotite, ilmenite, felspar, olivine, augite, and hornblende. Among the secondary products we find in various slides leucoxene, kaolin, serpentine, magnetite, actinolite, a chloritoid substance, a radiating zeolite, calcite, and quartz.

Apatite occurs but rarely, in large cross-jointed prisms. Original magnetite grains are frequent, and belong to an early stage of the consolidation. A few rounded grains, brown and slightly translucent, which accompany the magnetite, are referred to picotite. Ilmenite, in skeletons of intersecting rods, is found in one variety, otherwise abnormal. On the whole these rocks are poor in accessory minerals.

A felspar of the plagioclase series is always abundant in good crystals, showing the usual forms. The crystals are sometimes simple, generally twinned once or twice, sometimes finely lamellated, and very rarely showing a cross-twinning corresponding to the pericline-law. The extinction-angles are usually nearest to those of labradorite, but some symmetrical sections extinguish at 40° from the twin-plane, indicating anorthite. Only one rock, that of Mynydd Penarfynydd, shows in places two distinct generations of felspar. With this exception the felspar is always of earlier formation than any of the augite or hornblende.

Olivine has probably been an occasional constituent of the hornblende-diabases here as elsewhere, but it is not now detected in any of the slides, and serpentine-grains which seem to result from it are not often seen. There is, indeed, plentiful serpentine in many of the slides; but in some cases this substance clearly results from the alteration of hornblende, in others it probably comes from a rhombic pyroxene, while the mesh-structure so characteristic of pseudomorphs after olivine is rarely indicated.

The augite is found either in good crystals or in ophitic plates and shapeless grains, the latter mode of occurrence being by far the more common. When crystals occur, they show in cross-section the usual octagon, the pinacoids being rather more developed than the prism-faces, while the terminal planes seem to belong to $(\bar{1}11)$ and (001). The extinction-angle in a section parallel to the clinopinacoid is 39° or 40°. The prismatic cleavage is constantly well marked, and in a few cases pinacoidal cleavages were noticed, but never any diallagic structure. The augite is colourless or extremely pale brown in thin sections: only in one rock (summit of Mynydd-y-graig) is this seen to pass into augite of a deeper violet-brown with slight pleochroism. This and the occasional hour-glass structure recall the augite of some of the teschenites. Twinning on the usual law is sometimes observed, the orthopinacoid being twin-plane and face of composition.

The hornblende rarely forms imperfect crystals, contained by the clinopinacoid and prism-faces, without terminations: in the large majority of cases it occurs as ophitic plates, commonly including grains, cores, or nuclei of augite, as well as felspars and magnetite. The mineral is almost always deep brown in colour, with the usual pleochroism, the absorption being indicated by $\gamma \geqq \beta >> \alpha$. The maximum extinction-angle in vertical sections is 18° or 20°. A greenish-brown tint is occasionally seen with the brown. The hornblende is normally " compact " and well-cleaved, the green portions sometimes fibrous.

The relations of the hornblende and augite are worthy of notice, and prove that the same brown, compact hornblende may be either original or a product of amphibolization. When augite is included in the hornblende, there are three cases to be distinguished. In the first place, original hornblende may include augite-grains in the same way as it includes felspar-crystals or magnetite. When this is so, the enclosed grains are generally of rounded shape with a very definite and comparatively smooth boundary; there is no crystallographic relation between the two minerals, and if two or more grains occur in the same plate of hornblende, they are differently orientated. Rarely, as in the quarry on Mynydd Penarfynydd, good idiomorphic crystals of augite are included in the hornblende.

Secondly, a crystal or plate of augite becomes partially converted into hornblende, chiefly round its margin, the two minerals then having the vertical axis and plane of symmetry common. Since this amphibolization probably involves a change of chemical composition, the term paramorphism is not strictly applicable, and we must call the process pseudomorphism, or where only the border is affected, perimorphism. If the original augite had crystal-contours the secondary character of the hornblende is obvious; in other cases it can generally be inferred from the extremely intricate and ragged appearance of the boundary between the augite-core and the investing hornblende. If the augite is twinned, the resulting hornblende is twinned about the same plane. Where several cores of augite are included in one hornblende-plate, they all have, of course, one orientation. The pseudomorphic or perimorphic hornblende has precisely the same characters as the original hornblende. Sometimes we may see a crystal of augite both moulded by hornblende and partially pseudomorphosed, the two kinds of hornblende being undistinguishable from one another.

There is a third way in which hornblende may include augite, and this has rarely, I believe, been specifically described in British rocks*. It appears that while a nucleus of augite was growing the magma became so altered that after a certain point of time hornblende-substance was deposited instead of augite, this hornblende growing upon the augite kernel with the usual crystallographic relation between the two minerals. This, if I understand aright, is what Rohrbach† has described in the teschenites of Silesia under the name of "*ergänzende*" or complementary horn-

* The picrite of Inchcolm exhibits good examples; see, *e. g.*, Teall, 'British Petrography,' plate vii. (1888).

† Tschermak's 'Mittheilungen,' 1886, p. 84.

blende. It appears to differ from the more ordinary "intergrowth," in that the whole of the augite was formed before any part of the hornblende. When both the augite-nucleus and the hornblende-border are twinned, the twin-planes, though of course parallel, are not necessarily coincident. Sometimes, as on the south-east side of the crest of Mynydd-y-graig, the hornblende thus formed has idiomorphic crystal-boundaries, and its original nature is conclusively demonstrated. But when once admitted and looked for, this complementary hornblende is found to be by no means uncommon: it is distinguished from the perimorphic hornblende by its boundary against the augite being much less irregular, and from original hornblende enclosing augite-grains by the correspondence in crystallographic orientation of the two minerals. We must recognize, then, as distinct cases:—

1. Original hornblende enclosing augite-grains, without crystallographic relation;
2. Perimorphic hornblende (secondary) bordering augite-cores, with crystallographic relation; and
3. Complementary hornblende (original) surrounding augite-nuclei, with crystallographic relation.

One or more of these is found in all the slides examined; but I have not yet certainly recognized the first and third in the same specimen. This is, perhaps, in accordance with what might be expected; for we must suppose in the former case a pause between the consolidation of the augite and that of the enclosing hornblende, and such a pause would presumably be unfavourable to the formation of complementary hornblende upon nuclei of augite.

Another kind of amphibole may also be mentioned, though it is less common here than in some other hornblende-diabases, such as those of Pen-y-rhiwiau, near Clynog-fawr, Caernarvonshire, of Jersey, of Little Knott in Cumberland, and from near Llanerchymedd, in Anglesey*. This is the "secondary enlargement" hornblende of Van Hise †, first described in eruptive rocks by Becke ‡. It is a growth of hornblende-substance entirely posterior to the consolidation of the rock, but proceeding in crystalline continuity with preexisting hornblende, so as to border the original crystals, fill the interstices between them, or form a narrow and ragged fringe inside the walls of an included grain of serpentine. Evidently its deposition can only proceed concurrently with the destruction of some other mineral. This later growth of amphibole is clear and colourless or pale green; it constantly gives rather higher polarization-tints than the brown hornblende: frequently it has the cleavage-traces but little pronounced. Such hornblende, forming a "secondary enlargement" of original and perimorphic crystals, is found in several parts of the district. Becke also describes a similar hornblende-growth bordering original augite-crystals; but of this I have found no evidence in the Sarn district, though it is well seen in a

* 'Geol. Mag.' dec. 3, vol. iv. p. 552.
† 'Amer. Journ. Sci.' ser. 3, vol. xxxiii. p. 385 (1887).
‡ Tschermak's 'Mittheilungen,' vol. v. part ii. (1883).

diabase from Bodowen, Anglesey, and in many of the diabases of central Caernarvonshire.

The chief secondary products of the hornblende are magnetite, in dust and in granules, serpentine, often preserving something of the structure of the parent mineral, and sometimes a feebly polarizing pale green substance of the chloritoid family. One slide from Mynydd-y-graig shows, however, the brown compact hornblende passing over into a fibrous mineral presumably actinolite. The hornblende first becomes pale and greenish, and then breaks up into grass-green fibres, which from parallel become divergent, and are seen to be imbedded in a colourless, brightly polarizing mineral which has all the properties of the "secondary enlargement" hornblende already described. The change is accompanied by a copious separation of granular magnetite, which finally forms a dense border to the altered crystal. The augite of these rocks, being protected by the hornblende, is usually quite fresh.

All the rocks here described contain augite, as a rule partially amphibolized, and most, if not all, have original hornblende in addition. As some confusion exists with reference to the application of such terms as proterobase and epidiorite, I have judged it advisable to group all these rocks together under the more general title of hornblende-diabase. Their structure is almost without exception that of an ordinary ophitic diabase, but specimens taken at the summit of Mynydd Penarfynydd show a structure which must be called porphyritic in the sense of Rosenbusch*. There are not only two sets of felspars, but the augite also appears of two generations, the earlier one being in idiomorphic crystals. A peculiar aspect is given to some of the more felspathic varieties by a tendency of the larger felspars to collect in patches; this type of structure is, perhaps, comparable with that which Professor Judd has termed "glomero-porphyritic."

The hornblende-diabase often contains coarsely crystalline contemporaneous or segregation-veins. They are on the whole more felspathic than the surrounding rock, and contain crystals of hornblende up to one inch in length, often very perfectly formed. The geological relations of these rocks will be considered in connexion with those of the hornblende-picrite, which is intimately associated with them.

VI. The Hornblende-Picrite.

The rock which forms the western slopes of Mynydd Penarfynydd is unique in the district. Professor Bonney has given it the name of hornblende-picrite, and it must be regarded as the type of this well-marked and interesting species.

The rock occurs in distinct parallel banks to a total thickness of 200 or 250 feet, with a dip of 35° or 40° towards S. 30° E., the same as that of the neighbouring Arenig shales. Owing to this inclination, the picrite emerges from the sea under the precipitous cliffs of Trwyn-talfarach, rises on the south-west slope to a little

* 'Massigen Gesteine,' new ed., 1886.

below the signal-staff, follows the trend of the hill-side in a north-easterly direction, and crosses over the ridge, where it begins to sink towards its northern extremity. The topmost banks are overlain by the hornblende-diabase, which forms the greater part of the hill, and hornblende-diabase also occurs at the very base, thus intervening between the picrite and the subjacent strata.

In the field and in hand-specimens the appearance of this handsome rock is very striking. Most conspicuous is hornblende in large black crystals with lustrous cleavage-planes. On closer examination these planes are seen to be studded with rounded, dull spots, which represent grains of olivine more or less serpentinized. Besides this, flakes of a golden-brown mica are often plentiful, lying on the cleavage-planes of the hornblende, and some parts of the rock show white crystals of felspar.

The microscope shows the original minerals of the hornblende-picrite to be magnetite, olivine, felspar, augite, hornblende, and biotite: among the secondary products are magnetite, serpentine, hornblende, biotite, asbestos, a mineral of the chloritoid family, calcite, and dolomite, with rarely an aggregate similar to that which has been named saussurite.

Original magnetite is not common; it sometimes occurs in cubes, and is the earliest-formed constituent. Picotite has not been observed.

Olivine is always one of the most abundant minerals present; it rarely shows crystal-contours, and is almost always in rounded grains imbedded in augite or hornblende. Twinning is rare. The grains sometimes show fissures corresponding to the two pinacoidal cleavages, but more commonly are traversed by irregular cracks. Under a high magnifying-power some of the olivine shows flat rectangular cavities or "negative crystals" containing dendrites of magnetite, identical with those figured by Professor Judd in a picrite from the Isle of Rum*. As the Penarfynydd rock is probably of Upper Cambrian (Bala) age, its resemblance to a Tertiary rock, extending to such minute details, is a point of some interest. The conversion of the olivine into serpentine is seen in every stage from fresh grains of olivine to complete pseudomorphs. The process begins along the fissures with the separation of magnetite dust, which, when plentiful, collects in clotted granules and strings. Serpentine is next formed on the borders of the fissures in fibres perpendicular to the walls. This serpentine is doubly refracting and apparently uniaxal: the remaining kernels of olivine are then gradually converted into serpentine, which either shows a confused structure or is sensibly isotropic. Sometimes, as a last stage, there is a seeming reabsorption of the deposited magnetite as described by Wadsworth†. Irregular fissures sometimes radiate from the altered grains, traversing the surrounding minerals, and these fissures are injected with serpentinous matter: they may be

* Quart. Journ. Geol. Soc. vol. xli. p. 385, pl. xii. fig. 5 (1885).
† 'Lithological Studies,' p. 172, &c. (1884).

ascribed to the increase in bulk of the grains consequent upon the process of serpentinization*.

Felspar, when it occurs in the hornblende-picrite, is either in small slender crystals, simple or once twinned, or in large irregular plates enclosing olivine. The extinction-angles observed agree with anorthite. The mineral is probably always of earlier consolidation than the augite, and is moulded by the plates of hornblende.

The augite is of the usual very pale brown tint or almost colourless, and has the prismatic cleavage well marked. It is almost always in the form of irregular plates, or forms a core to the hornblende. In rare cases, however, it has crystal-outlines, the cross section being a regular octagon due to the equal development of the prism and pinacoids. The hornblende is of the same rich brown colour as in the hornblende-diabases, but this passes occasionally into green, which gives, for vibrations parallel to the axes of elasticity:—α, very pale brown; β, pale olive-green; γ, rather pale grass-green. The brown hornblende also passes, in places, into a colourless variety. The usual prismatic cleavage is well seen in the slides, and occasionally a cleavage parallel to the clinopinacoid. Twinning on the orthopinacoid is only rarely seen.

The hornblende never shows idiomorphic boundaries, and it usually occurs in close relation with augite. Either a plate of augite has a partial or complete border of hornblende, or a hornblende plate encloses a core of augite, the boundary between the two being often exceedingly ragged and labyrinthine. The hornblende and augite of each plate have the vertical or *c*-axis and the plane of symmetry common, but are apparently in reverse position to one another. This appears from the fact, verified in several instances, that in a clinopinacoidal section the extinction-angles are about 40° for the augite and 20° for the hornblende *on the same side* of the cleavage-traces. Some slides show little or no augite. The relations of the two minerals are, on the whole, in accord with the idea that the bulk of the hornblende is a later formation at the expense of augite; but it is not safe to conclude that this is so of all. Indeed, that some of the hornblende is original, is evident from the fact that it not unfrequently encloses distinct grains of augite without any definite crystallographic relation.

A brown mica with the characters of biotite is almost always present, and sometimes in such quantity as to give a distinct varietal character to the rock in which it occurs. Normally the mineral is brown, with the usual intense dichroism, but it often becomes paler and even almost bleached. It also passes at the edges of the flakes into a mineral which gives a grass-green colour for vibrations parallel to the cleavage-traces and a golden-brown for the perpendicular direction: this seems to be the substance which Mr. Teall identifies as chlorite †. The biotite has two modes of origin. It is in part original, being then usually later than the

* *Cf.* Judd, Quart. Journ. Geol. Soc. vol. xlii. p. 86 (1886).
† British Petrography, p. 98, 1888.

felspar and earlier than the hornblende. Another portion seems to be of secondary origin, and connected with a special mode of alteration of the hornblende. In some cases this mineral, as a first stage, takes on a lamellar structure parallel to the orthopinacoid, and from this the biotite-flakes are developed*. More commonly the mica is developed on the cleavage-planes of the hornblende. It is possible that this should be regarded as an original intergrowth of the two minerals, the law of association being that given by Rosenbusch and others.

The ordinary secondary products from the felspar, hornblende, and biotite demand no special notice. We may remark, however, the presence in some slides of a rather pale-green actinolite in blade-like crystals with a pinacoidal cleavage.

The hornblende-picrite presents some peculiarities of structure due to the arrangement of its constituent minerals, and these variations are much more striking in the field than in hand-specimens or thin sections. The smooth surface of boulders, both of hornblende-diabase and hornblende-picrite on the beach below Mynydd Penarfynydd and at Y Graig-ddu, often show a curious mottled aspect, which consists in a mingling of dark and light patches or a separation of white spots on a black ground. This kind of aggregation of the several constituents produces on the rock-surfaces *in situ* a pitted or honeycombed appearance due to differential weathering. When the component minerals are more evenly distributed, the rock either weathers into compact blocks, or in some parts of the picrite-mass shows a fluted or grooved aspect. This last-mentioned appearance seems to be caused by the difference between bands alternately rich and poor in olivine, a character noted by Reusch in the saussurite-gabbros of the Bergen district†. There are even distinct dark bands less than an inch in width, which under the microscope appear as veins entirely composed of partially serpentinized olivine with much secondary magnetite.

The fine section of hornblende-picrite below the trigonometrical signal-staff on Mynydd Penarfynydd shows very clearly the stratiform alternation of the honeycombed and the compact and fluted varieties. The former is in greatest force in the middle half of the section. The picrite often contains coarse segregation-veins similar to those of the hornblende-diabase.

The intrusive nature of the basic rocks of this district has never been disputed. Wherever the Arenig strata are seen in the vicinity of the eruptive rocks, their contact-alteration is very evident. The shales become hard and flaggy, losing their finely laminated structure and changing colour, while grey spots and yellowish-grey granular streaks make their appearance.

The Mynydd Penarfynydd mass, exhibiting, as it does, the picrite as well as the hornblende-diabase, may conveniently be considered first. The boundary between these two rocks is a very definite one.

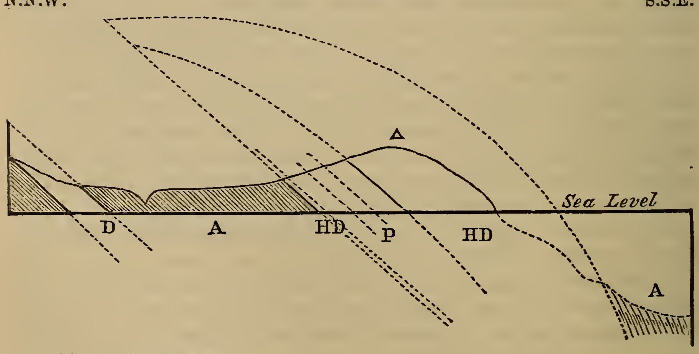
* This is well exhibited also in the hornblende-picrite of Schriesheim, where, however, both hornblende and mica are bleached.

† Fossilien-führenden krystallinischen Schiefer, &c., 1883.

We pass at once from perfectly typical hornblende-picrite to a rock in which no olivine can be detected, while felspar, instead of being locally and rather sparingly present, becomes essential and abundant. Nevertheless it cannot be doubted that the two rocks form parts of one and the same intrusive mass. Mr. Tawney, who noticed that the hornblende-diabase (" diabase " in his description) occurs both below and above the hornblende-picrite (his " olivine-diabase "), suggested doubtfully that the olivine-bearing rock was intruded into the other; but his examination of the locality was rather a cursory one, and he appears not to have distinguished between the hornblende-diabase and the felspathic variety of the picrite. The rocks have, indeed, many characters in common; but what unites most clearly the picrite and the hornblende-diabase as the products of one igneous intrusion or set of intrusions is the behaviour of the segregation-veins at the junction. These veins, already mentioned, pass from one rock to the other, so that it is impossible, where they occur, to draw any line of demarcation.

The direction of the plane of division of the hornblende-diabase and hornblende-picrite is also the direction of the banks or quasi-strata of the latter rock, marked by the alternation of different lithological types; also of the thin olivine-veins, and of the coarse segregation-veins when these show any regularity of disposition. Further, the base of the whole igneous mass is a plane parallel to the above and agreeing with the stratification of the sedimentary rocks below, so that the actual junction is a definite bedding-plane of the shales (fig. 4). The mode of occurrence of the mass is there-

Fig. 4.—*Ideal section through the southern end of Mynydd Penarfynydd.* (Length $\frac{2}{3}$ mile.)



A. Upper Arenig strata.
D. Diabase of Tyn-y-rhedyn sheet.
HD, Hornblende-diabase, and P, Hornblende-picrite of the Penarfynydd laccolite.

fore similar to that of the well-known " laccolites " of Southern Utah *, with the difference that, instead of being homogeneous, it

* " Geology of the Henry Mountains," U. S. Geol. Surv. 1880.

presents a stratified arrangement of varying lithological types. Judging by the outcrop and observed dip, the Penarfynydd laccolite must have a diameter of not less than three quarters of a mile and a thickness of more than a thousand feet. These dimensions are exceeded by many of the trachytic laccolites described by Gilbert.

On Mynydd Penarfynydd the beds which formerly arched over the roof of this great "stone-cistern" have been entirely removed by denudation. There are also complications arising from the effects of the subsequent earth-movements by which the rocks of North Wales were disturbed from their horizontal position. The injection of the laccolite between Upper Arenig strata, doubtless a process accomplished by many successive influxes of magma of varying composition, clearly took place when the strata were horizontal; and the whole mass was afterwards tilted over into an inclined position without other disturbance. Under the laccolite the shales have been protected from the lateral pressure by the stubborn resistance of the overlying eruptive mass, and present accordingly a uniform inclination. To the west of Penarfynydd, on the other hand, the strata are much disturbed, with conflicting dips at high angles, the rocks here having been crushed by the thrust from the north-west against the unyielding igneous mass.

The Penarfynydd laccolite is the only one which can be clearly made out in the field. It is, however, a reasonable conjecture that the mass of hornblende-diabase constituting Mynydd-y-graig is another and larger laccolite, injected at a later time and on a slightly higher horizon, and modified in form at its south-western edge by the mass of Mynydd Penarfynydd. The field-relations of the rocks about Rhiw are too much obscured by surface-deposits to admit of any definite conclusions. Though the hornblende-diabase never exhibits the strikingly stratiform appearance of the hornblende-picrite, there seems to be a certain constant difference between different parts of the large masses. The rock which extends from Careg-llefain along the ridge of Mynydd-y-graig is readily distinguishable from that exposed on the south-eastern slopes. The hornblende-diabase north of Rhiw resembles that of the base of the Penarfynydd laccolite, while the rock of Plas Rhiw and Treheli is of the Careg-llefain type *.

The date of the picrite and hornblende-diabase intrusions is a matter for inference only. If we suppose, with Sir A. Ramsay, that the disturbance of the strata was effected in pre-Llandovery times, these eruptive masses, which share that disturbance, must be referred to some part of the Bala age. Assuming this, the absence from the district of any contemporaneous lavas of like composition is best explained by supposing that the whole of the hornblende-diabases were injected in the form of laccolites.

* Specimens from Treheli and from Mynydd-y-graig have been described by Mr. Tawney.

VII. The Dolerite-Dykes.

The last rocks to be described, and that very briefly, occur as dykes of no great width cutting through the larger igneous intrusions of the district. These dykes are seen in various localities to intersect the granite, the diorite, and the hornblende-diabase; and although I have not recognized them as yet in the diabase, this is owing, in all probability, to the difficulty of distinguishing in the field between the latter rock and the dolerite. The larger intrusive masses and the dykes and sheets of diabase we have seen reason to assign to the Bala age; the dolerite is most likely referable to a much later period.

In hand-specimens the dolerite is of medium or fine grain, with well-pronounced ophitic structure, and of a dark colour, becoming greenish in the most weathered parts. It appears to consist of felspar, magnetite, and augite, and the microscope does not discover any other constituents.

The magnetite, either in granules or in octahedral crystals, is one of the first-formed products of consolidation, though occasionally it is seen to be penetrated by some of the smaller felspars. Of ilmenite there is no indication in the slides examined.

The felspar is constantly of two distinct generations. Of these the earlier is clearly anterior to the augite in the order of consolidation. It offers elongated sections with a fine lamellation on the albite-type and frequently Carlsbad-twinning in the same crystals. Judged by the extinction-angles the felspars are between oligoclase and labradorite. The later generation of felspars occurs in more equidimensional crystals, with rarely any trace of idiomorphic boundaries. They are never so closely lamellated as the earlier felspars, but are marked by a strong zonary banding or shading in polarized light. They belong to about the same stage of consolidation as the augite.

The augite, though pale brown, is never so nearly colourless as the augite of the diabases and hornblende-diabases of the district. It even shows in some cases a scarcely perceptible dichroism, changing from a rosy to a yellowish tint. The mineral, with the usual cleavage well pronounced, occurs in crystalline grains or ophitic plates moulding and enclosing the earlier felspars, and occasionally moulding to some extent the later felspars also.

The structure of the rocks is commonly ophitic, though there is sometimes a tendency to pass into a partly granulitic type.

Not recognizing geological age as an essential factor in lithological classification, I have applied the name dolerite to these rocks, because, by the development of a later generation of felspars, they exhibit the "porphyritic" structure of Rosenbusch, and are thus separable from the diabases, in which the felspars belong all to one stage of consolidation. From the type of diabase so largely represented in the Sarn district these rocks differ, not only in this recurrence of felspar in a second generation, but also in the characters of the felspars, in the deeper colour of the augite, and its frequent occurrence in ophitic plates of considerable extent, and in the absence or rarity of ilmenite in the dolerites. In all these and other characters the rocks in question have close affinity with the dolerites of other parts of Caernarvonshire and Anglesey. Similar dykes on the shores of the Menai Straits cut through Carboniferous strata *; and others in the Anglesey coal-field are demonstrably post-Carboniferous and pre-Permian †. Such evidence as is obtainable points, then, to the conclusion that the dolerite-dykes of the Sarn district, to which we may add some of those which intersect the neighbouring "green schists" ‡, were injected in the interval between the deposition of the Carboniferous and the Permian formations.

Waiving this point, however, and excluding the dykes and minor eruptive masses from consideration, we find that the district of Sarn, probably during the age in which the Bala rocks were laid down, was the theatre of igneous activity on a large scale. The strata were invaded by eruptive magmas of very different chemical constitutions, and rocks of widely diverse characters have resulted from the consolidation of those magmas; so that we find, speaking broadly, acidic rocks occupying the northern and western portions of the district, intermediate or sub-basic forming a broad band across the middle, and basic and ultra-basic developed in the south. These latter, the heavier materials, appear to have spread in the form of laccolites, possibly at a considerable depth; the magma which was the origin of the granite may, on the other hand, have been in connexion with some of the extrusive or volcanic outflows which are so striking a feature of the Bala stage in Caernarvonshire.

The isolated intrusions of gabbro cannot safely be correlated with other rocks in the area: their passage into hornblendic rocks, and the evident relation of that change to the coming in of the schistose character, though points of novelty in North Wales, are closely paralleled in many other districts with which geologists have been made familiar.

[*Note.*—The specimens and slides illustrating this paper are in the Woodwardian Museum at Cambridge.]

Discussion.

Mr. Teall would have been glad to have heard more of the details of the paper before attempting to criticize it. As a point of nomenclature it would be satisfactory to know if we should have different names for rocks containing primary or secondary hornblende. In the mass of diabase and picrite there seemed to be a differentiation and coming in of parallel structures; in this direction we may hope for a solution of the problem of the origin of gneisses.

* Geol. Mag. dec. 3, vol. iv. p. 409 (1887).
† Ramsay, *loc. cit.* p. 264.
‡ The igneous mass south-west of Aberdaron, terminating in the headland of Pen-y-cil, also has two generations of felspars, but differs in other respects from the dolerite of the dykes in question.

Prof. Blake had already committed himself as regards these particular rocks. His views and those of the Author in the main agreed and were adverse to Dr. Hicks's interpretation, but he had not previously known of the evidence of their being intrusive into the later formations. He doubted if the difference between the granite and the diorite was well made out. The "granite" becomes a hornblende-gneiss near the ashy series, where he thought the junction was not a faulted one. He also had his doubts as to the diabase being strictly intrusive. On the whole his conclusions were not very different from those of the Author.

Mr. Watts regarded the paper as a description of a petrographical complex, of the nature required by modern theories of metamorphism. He agreed in the making use of cleavage to ascertain the age of the rocks. As regards structural relations, he rather doubted the analogy with laccolites, which generally occur in the main anticlines of strata. The question of segregation towards the bottom of the mass was interesting if the same intrusion is really more basic towards the bottom, but there may have been distinct intrusions. Judging from recent experience in Shropshire, there appeared to be evidence of a sequence in rock-series with a regular fall in the percentage of silica.

Prof. Hughes referred to the protrusion of solid granite in explanation of some marginal faults, and to certain fossiliferous zones which defined the stratigraphical position of the sedimentary series in which the rocks described by Mr. Harker occurred. He spoke of the intermixing of the hornblende-diabase and the picrite, and thought that the boulders of hornblende-picrite of North Wales represented only portions of the well-known hornblende-diabase-dykes of the district.

Mr. Rutley said that the comparison with laccolite rather troubled him. These might be lenticular patches rather than laccolites.

The Author was disposed to accept Mr. Teall's suggestion with respect to nomenclature. The schistose granite mentioned by Prof. Blake he had not seen; he thought it might be simply fluxion-structure. Referring to the stratified appearance in the hornblende-diabase and hornblende-picrite, he thought there was no great division in time. Some small masses resembling laccolites do occur in relation to earth-movements elsewhere in Wales. His section was an ideal one; the pipes were not always laid down even in exposed laccolites. The Anglesey rocks were only locally picrites.

32. *On the* Monian System *of* Rocks. By the Rev. J. F. Blake, M.A., F.G.S. (Read March 14, 1888.)

[Plate XIII.]

Introduction.

Is there no order in Pre-Cambrian rocks? Do they consist in one area of great undulating masses of gneiss, in which those who have studied them refuse to recognize any stratigraphical sequence, and in another of tiny fragments of formations, two or three of which may be contained within an area of a few square miles? and are these types in no way connected? Such were the questions which forced themselves upon me after brief consecutive visits to the Highlands and St. David's. Consulting my friend Dr. Callaway on these points, he advised me to go to Anglesey, where I should find rocks that might fairly be compared with the gneiss of the Highlands in character, in close proximity to, if not associated with, volcanic rocks of the type of St. David's. I went; and after three years' work in summer and spring vacations have arrived at conclusions which I now venture to lay before the Society.

But in the forefront of this inquiry we are met by the fact that Sir Andrew Ramsay, who knows the district as one knows one's native hills, has declared that there are no Pre-Cambrian rocks in Anglesey at all *. Can we ignore this fact? or must we not first ascertain the reasons which have led to this conclusion? If after a study of the area, sufficiently prolonged to place one's self somewhat on a level with his knowledge of the rocks, one reads his words, they strike one as so masterly, that if his conclusions are not correct, the correction of them must be undertaken on the spots whence they were drawn, and the cause of error pointed out.

To prove the existence of Pre-Cambrian rocks in Anglesey it is necessary to establish two points. First, that the rocks we assign to that age are overlain, unconformably if possible, by true Cambrian strata; and secondly, that they are so important in development, and so distinct in character, that we cannot consider them merely lower and metamorphosed portions of the same system, separated by a mere local unconformity †. In the examination of the question, the second of the above points is naturally taken first, since it is necessary to become acquainted with the lower rocks themselves, in order to appreciate any unconformity or overlap of the Cambrian that may exist. And as the examination goes on, the importance of this point becomes so impressed upon the mind, and its proof becomes so thorough, that one is convinced that the first point must be true, whether it can actually be proved or not. But in the demonstration to others it is best to take them in the logical order.

* Mem. Geol. Survey, vol. iii.

† See Dr. A. Geikie, Quart. Journ. Geol. Soc. vol. xxxix. p. 291.

Pre-Cambrian Age of Anglesey Rocks.

It may well be considered that recent literature has already proved this point, so far as the direct evidence of unconformity is concerned. This evidence may be of two kinds, that derived from actual stratigraphical relations, and that derived from included fragments. Of the former kind we have an example in Prof. Hughes's admirable description of the basement-beds of the overlying series *. Of the latter kind, are the statements by several authors that the conglomerates near Llanfaelog contain a large proportion of pebbles derived from the neighbouring rocks †. The bearing of these observations depends on the age of the conglomerate. Now on this matter Sir A. Ramsay says, on the authority of Mr. Salter, that the "fossiliferous grits do not necessarily represent the very base of the Bala" ‡. Prof. Hughes, however, has shown that the fauna may be more correctly referred to the Arenig §. He would even introduce the Tremadoc, though Dr. Callaway has, I think, conclusively shown that this is not warranted by the facts ||. Even so, however, another statement by Sir A. Ramsay remains untouched, that "no Lingula-flags have yet been detected in the country, and it is probable that they have been unconformably overlapped before reaching this northern area. . for they are reduced . . . . between Merionethshire and Llanberis, and seem to have almost or altogether thinned away before reaching Bangor."

The whole of the above-mentioned observations, therefore, only go to prove that the rocks in question are Pre-Ordovician, a result freely admitted by Sir A. Ramsay as perfectly consistent with their Cambrian age; though he undoubtedly regarded the granite as of Post-Cambrian, though of Pre-Bala age, which is all that the conglomerates, if themselves of Bala age, would prove. It would seem as if misunderstanding had been introduced here by the use of the name Cambrian for strata which Murchison had already defined as Lower Silurian, at a time when the geology of "Cambria" was still in confusion, and which have a distinct and unconformable base-line. Thus, the Pre-Cambrian age of the Anglesey rocks is not proved by these writers.

Prof. Bonney ¶, however, in a recent paper does supply the needful proof, though he appears to rely more on differences in amount of metamorphism than on the stratigraphy. He describes the section now exposed in Baron-Hill Park, near Beaumaris. Here, in the roadside cutting, the schistose masses are seen to be suddenly replaced by a group of rocks which may with perfect safety be identified with some of the Cambrian rocks of Bangor, which lie below the felsitic conglomerate. They consist, as Prof. Bonney states, of grits, porcellanites, and hälleflintas, and, at the summit, of a red

* Quart. Journ. Geol. Soc. vol. xxxviii.
† Callaway, Quart. Journ. Geol. Soc. vol. xxxvii.; Hicks, *ibid.* vol. xl.
‡ Mem. Geol. Surv. vol. iii. 1866, p. 193.
§ Quart. Journ. Geol. Soc. vol. xxxvi.
|| *Ibid.* vol. xxxvii. ¶ *Ibid.* vol. xxxix.

felsitic conglomerate with large pebbles. The exposure of these rocks is not a large one. They form a superficial patch for about half a mile. At their northern end the schistose masses reappear within a few yards of the uppermost conglomerate, so that the junction can scarcely be anything but a fault. At the southern end, however, described by Prof. Bonney, the lowest blue grit may now be seen to have its base continuous with the surface of the older rock from which it has been taken off up to a joint face. The junction here, therefore, is not a fault, but the grit lies on the surface of the other rock, and is as much unconformable as it can be, seeing there is no definite bedding in the schistose mass. These schists are, therefore, definitely Pre-Cambrian.

Similar and confirmatory evidence can now be brought forward from the neighbourhood of Red-Wharf Bay. On the east side of this bay may be seen a "feature" which runs, on the Ordnance map, from Wern to Llaniestyn. On the south-west of this line, and forming the escarpment, we find the schistose rocks, with the orientation of their folia striking directly at the line. On the north-east, and generally at a lower level, forming another feature running thence towards Llandona, we find the same grits, hälleflintas, and conglomerates as at Beaumaris, with their bedding parallel, or nearly so, to the escarpment. For more perfect satisfaction I have examined microscopically the rocks from these two localities, and compared them with those of Bangor, and they are found to agree in character. But there is really no need for this; no one could mistake their common character, even in the field.

To my own mind, however, the most perfect proof of unconformity is derived, not from isolated sections, but from the same basal rocks lying in different localities upon different members of the older series, without the latter in any way dying out. This proof can only be afforded after obtaining an acquaintance with the sequence of the older rocks; when this has been done, it is seen that the northern patch lies on the older, and the southern on the younger portion of the series. I cannot conceive a more perfect stratigraphical proof of the point in question.

Yet it appears to me that it is the observation of a portion of these facts that led Sir A. Ramsay to exactly the opposite conclusion. He states that the "grounds on which the larger part of Anglesey is considered to consist of Cambrian rocks" are as follows:—"If we prolong the strike [of the Bangor rocks] and of the overlying Silurian beds from Bangor, under the Lavan Sands to Beaumaris, and from thence to Glan-y-ffynon at the east point of Red-Wharf Bay [exactly the two localities above described], we find an association similar to that of Bangor, black slates resting on green, grey, and purple schists and grits, which, however much foliated and contorted, still bear a strong resemblance to the Cambrian rocks of Bangor." Hence it is evident that Sir A. Ramsay has seen these Cambrian rocks in Anglesey, has recognized *their* resemblance to those of Bangor, but has conceived that there was *a passage from these rocks into the schists, instead of an unconformity between* *them.* It is here, then, that the whole difference lies. Given this starting-point, and the consequences which would naturally follow, however remarkable, might be loyally accepted. Whether the clearer section now exposed in Baron-Hill Park would have modified his views I cannot say. We may suppose from his words that he worked this district from the east, and by the gradual changes observed in descending the rocks of Bangor he was prepared for a further change into schist, and this change would be subsequently discounted in all his researches to the west. Had he commenced on the west instead, and, wearied with the monotony of the schists, come suddenly on these grits and hälleflintas, he would have been more struck by the change, and would perhaps have inquired more closely whether they were conformable or not. Nor could he have assigned the differences to metamorphism without a much freer belief in its power to change the constitution of a rock than the teachings of the microscope will now permit.

Description of the Pre-Cambrian Rocks of Anglesey.

Introduction.

The second point to be proved is the importance and distinctness of the series of rocks which thus underlie the Cambrian. From such a point of view they require a fuller and more pictorial description than if they were merely altered forms of beds well known elsewhere.

It may be thought, however, that they have been adequately described already, and certainly there are two descriptions extant, one from a Cambrian, the other from a Pre-Cambrian standpoint. The first of these, contained in vol. iii. of the Memoirs of the Geological Survey, is chiefly devoted to the illustration and explanation of the contortions and metamorphism to which the rocks have been subjected; so that, full as it is of beautiful touches which recall vividly to the reader the facts he has observed in the field, it is quite inadequate as an account of an important system of rocks. The second, by Dr. Callaway, published in the Quarterly Journal of this Society, vol. xxxvii., approximates much more closely in its general character to what is required, and were it possible to assent to his statements, this memoir might never have been written, at all events in its present form. But my interpretation of the facts observable differs so widely from his, and the resulting order of succession, both vertically and horizontally, requires so radical a change, that the only feasible plan is to begin the description again *de novo*, referring only to his descriptions and those of Sir A. Ramsay when they can be accepted so completely as to require no change.

The Pre-Cambrian rocks of Anglesey, supposing all that are about to be described are accepted as such, are divided, partly by upheaval, and partly by faulting, into no less than six distinct areas. Four of these are coloured as altered Cambrian on the Survey Map, and two as altered Silurian. These four may be called respectively the

Western, Central, Eastern, and Northern districts. Of the other two, one which lies south of Traeth Dulas and near Bodafon Mountain is naturally in association with the Central district, and the other, which lies east of Parys Mountain and north of Llanwenllwyfo, is most connected with the Northern district. It will be found most convenient to arrange the descriptions in the order thus given.

THE WESTERN DISTRICT.

HOLYHEAD ISLAND.—This island is divided geologically into two parts by a master-fault which runs in a N.W. and S.E. direction, and separates a newer series on the S.W. from the older portion on the N.E. Confining our attention at present to the latter portion, we find an order of succession very clearly made out, the well-known quartzite of Holyhead Mountain being lowest in the sequence. In this there is very clear cleavage, and on the seaward slopes every yard is shivered into a thousand fragments. Along the direction of cleavage, congregating as best they may in the intervals between the larger grains of quartz, are innumerable flakes of mica, or feebly coloured chlorite, producing a foliated rock; but there is no obvious connexion here between the foliation and bedding. The actual direction of any minor beds in this great mass is not easy to determine; but standing on one of the eminences in the wild country to the S.W., and seeing scarp after scarp descend in giant steps from the summit to the sea, one fancies a bedding on a large scale with a dip to the S.E. If these are really beds, the dip is a gentle one, whereas the cleavage is vertical. In any case it is in the direction of this dip that we must proceed to find any higher beds, and when we do find them the dip is confirmed. On the S.E. slopes of the mountain the quartzite becomes dirty and of finer grain, and gives place, where the road is reached, to solid micaceous foliated grits. These and alternating more quartzose beds rise into the summits of the low hills in the same direction, and then somewhat suddenly change into the chloritic schists, so that a clear line can be drawn after which no quartzites appear. This is rendered more evident by the occurrence of two minor faults, somewhat parallel to the master one and to the running of the greenstone-dykes. The smaller of these, on the S.W. side, brings the chloritic schists with their wavy lines close beside the massive quartzose rocks and emphasizes the contrast. The larger fault on the N.E. limits the mountain in that direction, and substitutes for it the low ground that terminates in Penryn Garw. This headland consists of the upper part of the quartzitic group, with its bands of micaceous grit, and is succeeded immediately by the chloritic schists, which are seen lying on its surface to the *west* of Porth-yr-ogof, thereby proving that there is no fault in that inlet, as supposed by Dr. Callaway. All things are here in regular succession, and the fault which separates them from the mountain may be clearly traced to the neighbourhood of the town.

The chloritic schists of Holyhead are very remarkable rocks. They were originally laminated, as is evidenced by the parallel lines of dust and fragments which are still found in them. The welding together of alternating ingredients in the process of crystallization has produced a very tough material, and subjected as it has been to enormous pressure, it refuses to cleave; it will not be faulted or broken, or bend bodily into massive folds; all it will do is to crumple, or, as Prof. Hughes calls it, to "gnarl." When seen, as it often is, on the surface of a rugged boss of rock, it gives the boss a damascened appearance by the fine and intricate patterns of its various lines. When it has been less compressed, as in the road-cutting near Porth-yr-ogof, we can follow the lines on their crinkly path and obtain the general direction of the dip. When the pressure has been mostly perpendicular to the laminæ, the rock becomes massive and slaty, and the materials are less altered, though some foliation has taken place. Thus the gnarling is a subsequent process. As we pass eastwards from Holyhead several more massive zones are encountered, containing more quartzose grains; but with this slight variation, the remainder of the island, as exposed inland on the N.E. side of the main fault, shows only these schists belonging to a stratified series. It is to be noted, however, that our general means of observation are limited to the bosses that protrude through the fields, and these, from their very mode of occurrence, are probably the more indurated and thoroughly crystalline portions of the rock, while any softer or less altered part would be hidden beneath the soil. But the sea-shore knows no such rule, and accordingly between the railway and Gorsedd-y-Penryn on the island shore the more crystalline masses are interbedded with more slaty and purple varieties, and there is a band of browner rock containing angular fragments of quartz and felspar of comparatively large size.

Before leaving Holyhead Island, we may notice a remarkable outlier of coarse conglomerate which lies on the west side of the great quarries, and forms the foundation for some buildings. The fragments are so large and the deposit so local that one thinks at first of an artificial concrete; but the matrix, on examination, is seen to be inimitable by man. The fragments are not those of the neighbouring rocks, but resemble the higher beds of the Pre-Cambrian to be presently described. This seems to die out suddenly, as by a fault, towards the sea; but towards the rifle-pits it tails off gradually, and contains more of the local quartzite. We can scarcely fail to recognize in this deposit a basal Ordovician beach-breccia, the interest of which lies in the proof it affords that the Pre-Cambrian rocks were worn down in this district to near their base during the continuance of the Cambrian era.

The area North of the Holyhead Straits.—At Porth-y-defaid, about four miles north of Valley, Dr. Callaway draws an important fault, running inland with an E.N.E. trend, which, he says, separates entirely a "slaty" series on the north from a "gneissose" series on the south. At this point also on the coast, the legend on the Survey Map is changed, the country on the south being characterized as "green and purple schists, often micaceous," while that on the north is described as "soft brown and felspathic schist with beds of quartz-rock and conglomerate." It is obvious therefore that the most important point here to determine is whether there are really two distinct series of rocks in this area, or whether one class merges gradually into another. For this purpose I have examined microscopically a considerable number (24) of the rocks which are referred to the chloritic schist, and have collected some forty other examples; but the country is so wide that even these seem hardly adequate. Nor are matters so simple as Dr. Callaway's statement that "true schists with a south-west strike occur everywhere to the south" would lead one to suppose.

In the first place a large number of the exposures show no strike at all, but the lines of division run in almost any direction, and where the strikes can apparently be determined, they are discordant from place to place. Thus, on the south of the river Alaw near Llangynghenell, it is N. 20° W., at the church E. 8° N., at Bodedern E., south of Bodedern E. 20° N., and a little further south N. 30° E. It is plain, then, that the rocks have suffered so much local disturbance as to destroy the value of the strike and to drive us to consider surface-distribution only.

The larger number of exposures inland show us fine chloritic schists, which differ considerably from those of Holyhead in being composed of much more minute particles, whether crystalline or original, and thus possessing a much more slaty aspect, though often actually foliated *. But in several places there are bands of grit of irregular development, as near Llanfihangel and near Llanddeusant. These can hardly be said to be foliated at all. At Abersant, near Llanddeusant, the other extreme is met with in a regular mica-schist. The constituents are almost entirely mica and quartz, the former in large folia, the latter completely recrystallized, and all thoroughly orientated. This is the only place in the western district in which I have met with a rock of this description; and the cause of its appearance here, unless the granite of the central district is continuous in this direction, is not easy to see. The occurrence, however, is of some importance for the correlation with other districts.

Besides the ordinary metamorphism which has produced the chlorite, we find in places proof of much change of dynamic origin, bringing about a peculiar fibrous aspect, as near Bodedern, in the valley west of Llanddeusant, and at Llanddeusant itself, where the beds are also very slaty and a large proportion of the material consists of unaltered dust. The roads between this village and Llantrisant are mended with a purplish slate, which is mixed with green in the small openings that have been made.

These observations already prove that there are considerable differences in the amount of metamorphism which the rocks have undergone, and that in some cases there is scarcely any change.

* To distinguish these from the coarser laminated rocks near Holyhead, I have called them chloritoid schists, not meaning thereby that they contain the mineral "chloritoid."

But it is to the sea-coast that we must go to see the true character of the series. Leaving the turnpike road between Valley and Holyhead, we hardly get foot on the rocks which the sea has exposed, before we receive a somewhat astonishing lesson. At first we walk on the ordinary chloritic schist, but soon this begins to have a mixed appearance, being more slaty and touched with purple; and then in little space the same bed has changed into a regular purple slate. Sometimes the change may be traced vertically, and sometimes horizontally; but by one way or the other, before the mouth of the Alaw is reached, the whole shore is a mass of purple slate. It ought rather perhaps to be called shale, since there is no definite cleavage, though the rock is divided by lines of pressure parallel to the bedding. In structure it consists of very fine dust, and, with the exception of fine flakes of sericite here and there, is in no way altered. Here, then, in the very midst of the chloritic schists, and forming part and parcel of them, we have a slate that is entirely comparable to the Cambrian. The colour, however, of the latter is usually a bluish purple, while this, like the rocks of the Longmynd, is of a reddish purple. We must certainly excuse any author who had observed these facts for being led to consider the whole of these most ancient rocks to be only altered Cambrian.

On crossing the Alaw we come again to chloritic schists which are nearly horizontal, and are associated seawards with massive grits and epidotic rocks. In these begin to be seen some scattered fragments of quartz and felspar, which are not of the same order of magnitude as the remainder of the rock, and, being quite angular, suggest a volcanic origin. The grits especially are full of these. Amongst the fragments thus contained in a rock essentially of the lower part of the series are some which may be described as quartz with many chlorite inclusions, but which are not to be confounded with chloritic schists.

Following the rocks containing these, we find, as we go north, a new type consisting apparently of the finest dust in lenticular patches, coloured brown and green, and showing no stratification beyond these lenticles. Under the microscope these are seen to consist of an excessively fine mosaic of crystalline particles with very little that is opaque, separated by segregation lines of a coarser mosaic of quartz. As the total result is a slaty rock, I propose to refer to this, which is of wide distribution, as a *marbled slate*. I conceive that it must be produced by the accumulation of volcanic dust. Further north at Peniel, we come to grey ashy beds dipping to the S.E., and these are followed on the north side of Porth-penryn-mawr by laminated schists, changing, as we have seen them do before, into purple slates, the boundaries of the latter in one instance being a pair of joints. We thus have a synclinal with the volcanic dust and ashy beds lying on the chloritic schists and their unaltered representatives. After a sharp anticlinal turning the beds over to the N.W., we find a disturbance and a fault, and then chloritic schists come on again horizontally, and are only disturbed again at Porth Delise, where there is an intrusion of epidote-rock, and a curious tongue of calcareous rock terminating like an intrusive rock amongst the schists. Hence to Porth-y-defaid the chloritic schists continue, with only minor disturbances, and mostly with beautifully ruled horizontal lines. Near that place there is a kind of pustule of hard dolomite and quartz, with specks of copper-green, which runs across the bedding, and seems to be produced by an infiltration of the mineral which has forced the laminæ asunder.

All these phenomena, which otherwise might not have required so much detail, prove how inextricably the chloritic schists are connected with the types of rock, and even with their accidents, which we shall meet with further north on the other side of Porth-y-defaid. The synclinal of ashy rocks may be also traced inland by the Holland Arms Inn, Llanfachreth, and at the crossing of the Alaw by the high road from Valley, after which it seems to die away.

At Porth-y-defaid there is undoubtedly a disturbance and a fault, as stated by Dr. Callaway, and after this we do not meet, for some time at least, with anything even remotely resembling the chloritic schists. At first the rock is soft and tufaceous; then harder green ashy rocks appear, and are succeeded as we pass into the bay by the typical marbled slate. By the occurrence of this rock we are able to trace the group inland, in a southern direction near Plas-y-glyn, as far as the Llanfwrog smithy. Hence this fault is apparently lost inland, and to the east there is no trace of it in the line of junction, which becomes less and less marked, following nearly the course of the northern branch of the river Alaw. Thus at Pont Scyphydd, on the eastern side, there is chloritic schist with a few sporadic chips; on the western, at Caerdeon, the rock is unfoliated, and contains many chips, while near at hand is a knob and reef of quartz, characteristic of the upper portion of the series. These observations do away with the importance of the Porth-y-defaid fault, and show that though we can distinguish an upper more ashy portion from a lower more schistose, one passes into the other after the manner of parts of a single series, and is not separated from it, as members of two different groups would be.

The North-western Area.—On the northern side of the line just defined the whole of the rocks appear to have a partly volcanic origin, and thus to possess characteristic irregularity of development. Only at Camawg, one mile E.S.E. of Rhydwen, have I seen any rocks resembling the foliated rocks of the south by the existence in them of continuous parallel lines. This small patch may serve to show from the other side the real continuity of the whole series. As explained before, we are only likely to meet the more indurated masses in the projecting knobs which still characterize the inland country, but are now more rare. These show a new type of rock. The rocks are dark in hue, with a sort of indigo-purple tinge, and are somewhat slaty in aspect; but there is no lamination or bedding, the whole is a solid mass in which the only separating surfaces are of subsequent origin, which may be wanting altogether or divide the rock into concave lenticles, like thickened watch-glasses. These are doubtless due to the induration of a volcanic mud, and are nearly allied to the marbled slates, but of more earthy material and quite different appearance. They are occasionally full of angular fragments of over an inch in diameter, forming a local agglomerate, and at one place they appear to be cleaved. I call them *pelite,* and when in lenticles *lenticular pelite.* Considerable quantities of chlorite or sericite in small specks are developed in many parts, so that they are as altered as their nature permits, far more so in fact than the slaty portions of the underlying series; but they are not constant in this respect. With the exception of certain peculiar developments to be noticed later, this is all we can see inland to the south of Llanrhyddlad. The coast is more instructive.

Very little of value can be made out at Porth-y-defaid itself. It is a spot of great confusion, in which the grey schists have ended in contortions along a zigzag line, beyond which we find a broken area of marbled slate, purple slate, hard blue grit, and epidote knobs. Passing north over the coarse green ashes, we find the marbled slate at the corner undisturbed. The bay is formed of softer ashy rocks, and the headland beyond Trefadog is of very tough material, weathering into honeycombed masses, as though by the solution of some mineral that had segregated into lumps. In this there is not the vestige of a dividing line of any sort beyond the modern cracks. More than a mile of sea-coast, studded with these tooth-like projections, and cliffs continuous with them, in which no stratification can be seen, and which are yet not crystalline, serves more than any place in Anglesey to impress upon the geologist the volcanic origin of these tuffs. In the scarped sides of such a modern volcano as that of Ischia, similar phenomena may be admirably seen, but in no other circumstances can they even be imagined. In the southern part of Church Bay, and also in the northern, the tuffs are very soft and earthy, and quite modern in appearance, though here and there compressed into a banded rock; but in the centre from Porth Crugmor to Porth Sutan are the lenticular pelites, passing into the marbled slates. In these variations we see the essentially local character of the several deposits. We might of course imagine that they lay in bands which we could trace inland; but this is not the case; whichever way the bands may be supposed to run, we find the supposition contradicted by the occurrence of the pelite. The softer parts, at least, are in isolated patches, which the sea has nearly consumed. Not only in their character, but also in their distribution, these deposits are of a volcanic nature, and the different masses are dependent not so much on time as the localization of successive outbursts. In one direction may be carried the finer dust, producing the marbled slates; in another the coarser, more basic mud, producing the pelites; in a third the still coarser, producing the grits; and in a fourth the ejection of large fragments may produce the agglomerates.

The country north of Llanrhyddlad is of much higher elevation; the accumulation has probably been thicker; we are nearer the centre of eruption, and the ground is cut up by pairs of trough-faults, letting in vertical wedges of black Ordovician shales. The most abundant rock here is the marbled slate, though pelites are found at the base, and form the mass of the isolated hill, the highest in these parts, and visible from all parts of the island, called the Garn. This is capped by a massive breccia, which at first I took to be an agglomerate of the series; but I am now convinced it is Ordovician, from the character of the rocks of which it is composed, and which seem to pass up on the eastern side of the hill through grits and finer breccias into ordinary shales.

We now pass to the extreme north-west beyond the trough-fault introducing the Ordovician at Ynys-y-fyddlyn. This area is much cut up, and there are signs of our being near the centre of eruption in the general coarseness of the pelites, which become recognizable ashes, in the occurrence of large masses of agglomerate, and in the intrusions of the granite and other rocks. Of this granite, which is said by Sir A. Ramsay to ramify in all directions, Dr. Callaway says it is a granitoid band of the gneiss, and he asserts that the greenish felspathic beds when followed across the strike to the north are seen gradually to change and ultimately to pass into thoroughly foliated gneiss and granitoidite. To this I cannot assent. After a careful search I can only find one band of granite in Pen-bryn-yr-Eglwys itself, and this runs from the summit of the hill towards the "sea-mark," that is, across any supposed strike of the rocks, which, however, are not sufficiently bedded to have any strike at all. This is associated on its eastern side with a hornblendic rock, which rises into the southern summit and is somewhat foliated. Much of the material surrounding these consists of brecciated rocks of similar material, much impregnated with mica or chlorite, which, being arranged in more or less parallelism, may be said to produce a mica-schist, but it is one of quite a different character from the true foliated rocks. I think there can be little question that these rocks are derived from the breaking up of coarsely crystalline igneous rocks, and are not a stage of metamorphism towards granite. Moreover there is really no passage. It may be difficult in some places to draw the exact line of junction, owing to the fracturing of the granite itself and the subsequent metamorphism; but elsewhere in the same mass we can find a vein of clean granite, bounded on both sides with chloritic breccia of a similar rock, and elsewhere a clear line of junction can be traced in the field. The granite is a fairly clean crystalline rock of large elements, and with comparatively little mica; but in places it changes into a greenish felsite very like that of St. David's, but with very few scattered crystals, and these not of quartz. Although the clean granite is limited to the line described, the whole material of the hill is composed of the breccia, which becomes more micaceous or chloritic as it nears the granite, and gets finer and finer towards the south. A little further in this direction, near Pant-yr-Eglwys, is another intrusive mass running at right angles to the first, associated with large agglomerates and ashes, shading off into the finest unaltered dust. This mass is not granite, but a true quartz-felsite with large eroded quartz- and other crystals, and with a granophyric ground-mass, and at its margin it becomes pseudoperlitic.

A third mass of granite occurs towards the east, behind the farm called Monachty. Here also the surrounding rock, away from the immediate contact, is an ashy pelite, and the line of junction is clean; but in the boss of rock exposed to the east of the farm the granite may be seen passing in strings into the pelite. It is sometimes granophyric in structure, and the quartzes have been very much squeezed. There is occasionally a difficulty in drawing the line between the two rocks, owing to the granite having been brecciated *in situ* and the cracks filled with mica, while the pelite itself develops mica in the neighbourhood of the granite.

These observations leave no doubt on my mind that the granite is an intrusive rock, of the same general age as the ashes into which it intrudes, related as the dykes of Etna might be to the mass of the mountain. And the so-called schists are alteration-products of the ashes, due practically to contact-metamorphism acting on material of a less sorted kind than usual. Later observations will be found to confirm this and yield even more decisive proofs of intrusion; yet the rock, the origin of which is thus determined by field-observations, is of the same character, presents the same differences from ordinary more recent granites, and has the same felsitic associates as at St. David's or Caernarvon, where the stratigraphy leaves it open to geologists to account for these differences by considering it an altered sedimentary rock under the name of "granitoidite."

There is no very determinate order of sequence in these rocks, and some of these central masses may be older than the circumferential; but when the volcanic débris *is* mixed with the chloritic schists, it is with their uppermost part, and even in this corner the most slaty portions, which may be considered in part sedimentary, occupy the lower positions. We may therefore conclude that the volcanic group forms the higher portion of the series, and the granite is therefore one of the youngest rocks in the district.

With regard to the relations of the series to the Ordovician, they are not always brought together by faults. There is reason to believe, as already stated, that the capping of the Garn is really a beach-breccia; but more decided and ordinary Ordovician conglomerates are found on the slopes of Pen-bryn-yr-Eglwys. These are met with on the road from Monachty, where it turns north to go to Porth Geon. They are of various kinds. One portion, which lies upon an old agglomerate, is made up of its pebbles rounded, and approximates to it in appearance *. Another portion is of large quartz-pebbles with ferruginous matrix, the size gradually decreasing till they are the size of peas, or less; and another is a compacted, perhaps less weathered, hard, bluish rock, not at all unlike that at Twt Hill. These may be traced on the ground over a limited area, bounded on two sides by faults, and passing up into brown grits, and then into hard blue slate. I have not found fossils in these rocks, but their general resemblance to the basal Ordovician in the rest of

* Very much as is the case with the agglomerates and conglomerates on Clegyr by Llyn Padarn.

the island, and the absence of Cambrian rocks in the trough-faults close at hand, points to their being of Ordovician age, and they thus supply a proof of the absence of true Cambrian deposits in this area. I expect it must be continuations of these that occur in the skerries, which I have not been able to visit, but which are marked on the Survey Map as "hard conglomerates and grits."

In the portions of the Western District now described there are three classes of rock, which from their wide distribution in the island, and their special and characteristic nature, I have reserved for particular description. They all occur isolated, and are due to actions which are limited to a small area. These are :—

1. *Epidote Infusions.*—Certain parts, both of the chloritic schists and of the higher rocks, are found to be more indurated, and to weather into round outstanding knobs, or portions of beds. They differ from the surrounding mass by being dark green in colour and finely crystalline in fracture, but without orientation of the crystals. These, on examination, turn out to be full of minute crystals of epidote scattered uniformly through the rock. I can think of no better explanation of them than that the rock has been locally saturated with some mineral water, the reaction of which on the surrounding material has produced the epidote crystals, and hence I call them "epidote infusions." They are seen at Porth Delise, north of the river Alaw, north of Porth-y-defaid, at Porth-y-corwgl, at Borth Wen, Roscolyn, and elsewhere.

2. *Quartz Knobs.*—These are the most remarkable features of all the Anglesey rocks, and their origin is a matter of great difficulty. In their characteristic form they stand up as isolated hummocks on the surface of the country, and are often nearly as high as they are long or broad. They may be merely low mounds, or may rise as high as a house, or form a good-sized hill. Usually they are elliptical in outline, but may be narrow and long, though it is doubtful whether we should refer the latter to the same category, or consider them as ordinary veins. In structure they may possess scarcely any clastic elements, or they may contain many very rounded pebbles of pure quartz, the whole or the remainder being composed of clear quartz in dusty-looking polygons of growth separated by clear lines, the dusty appearance being due to excessively fine cavities, the largest of which may possess fluid-enclosures. The only impurity is a little occasional sericite which may form round the larger pebbles where the matrix is not quite close. The purity and structure of the rock, together with its mode of occurrence, forces me to the conclusion that it has been formed on the spot where it is now found, though the pebbles may have been brought there along with the formative material. They are not veins in form or in structure, but they may have had a similar origin. The only suggestion I can offer is that they are the result of the cooling of hot water which has bubbled up and eaten away the rock into a cavity, then deposited quartz on the sides, in some cases has broken up again the first deposits, and rounded the

fragments into pebbles, and has finally filled up the cavity by the deposition of its quartz. In other words, they are the bases of Pre-Cambrian geysers, which may, or may not, have succeeded in reaching the surface and erupting. In the western district these are seen at Yr-ogo-r-arian and south of Porth-yr-hwch in the area round Pen-bryn-yr-Eglwys, on the east side of the road near Llanfaethlu, and near the river by Clwch-hir, north of Llanddeusant; but much more characteristic and important examples are found in other districts. They are always associated with the rocks which we have other reasons for concluding are of volcanic origin; and this is one reason for looking to the phenomena of such regions for their cause.

3. *Sporadic Limestones.*—These are elongated bands of crystalline limestone filling lenticular spaces in the pelites; as they are quite isolated and irregular and have no constant strike, we cannot consider them as beds which are now placed on end, but must look on them as products of infiltration or segregation. They are composed of a mosaic of small crystals, in which there may be larger crystals with abundant rhombohedral cleavage. In other districts and higher in the series we meet with limestones of more bedded character, but these may have been produced on the surface by the same waters which caused the present ones below. These sporadic limestones are seen at Llanfaethlu, where nests of umber occur in the rock; also at the telegraph-station near the same place, and on the hill-slopes to the west of Ogo Lowry. They must not be confounded with the calcitic bands in the older rocks, nor with the remarkable inburst at Porth Delise already described.

The South-Stack Series.—On the south-western side of the main fault that divides Holyhead Island into two parts, the rocks are of a different character from any we have yet seen, and ought to be more sharply marked off from the Holyhead group than they have hitherto been. I therefore designate them the South-Stack Series, as they are well seen at the South-Stack Lighthouse. In certain parts, no doubt, as at the lighthouse itself, their splendid contortions and their rugged aspect defying the stormy sea, give them an appearance of great antiquity, and it is on this account that Sir A. Ramsay considers the fault to have a downthrow on the N.E., by which the rocks of Holyhead mountain are made the younger. Much colour is lent to this view by the fact that throughout the long succession which we can elsewhere trace in the island, nothing like them is to be found. Nevertheless, the entire absence of metamorphism in considerable parts, and their resemblance to the bedded rocks of Bray, and even to some portions of the Cambrian of Wales (a resemblance which would have no weight with Sir A. Ramsay, who considered *all* to be Cambrian), inclined me from the very first to the opposite view, and I believe I can now *prove* that they are younger.

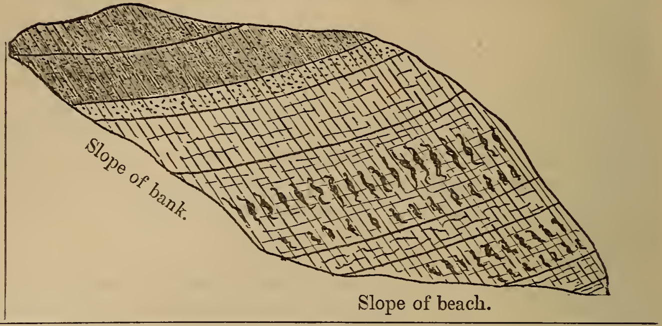
The argument from the degree of metamorphism amounts to very little. We have already seen that on the north-eastern side of the fault the chloritic schists, which are thoroughly foliated, are one with the purple slates which are not foliated at all; and on the south-western side there are parts which are both cleaved and foliated, and others which are neither. The disturbance and contortion are much greater on this side, because the rocks have yielded to the pressure. They are also cleaved in parts, because they are of suitable material. The accidents to which both parts have been subjected since their formation have affected them in different ways and in a different order; but this throws no light on their relative age, which must be determined, if possible, by stratigraphy; and if not, by correlation with deposits whose order is known.

The South-Stack Series is divided by the erosion of the sea into two distinct parts, the one from Gogarth below the Holyhead mountain to Porth-y-corwgl, the other near Roscolyn from Bwa-du to Borth Wen. The two halves do not correspond, and it is not clear whether they are alternative or consecutive.

In the Roscolyn mass we find their junction with the chloritic schists. The bounding fault comes out in the centre of Borth Wen, and an epidote-infusion marks the boundary of the chloritic schists towards the north-east. On the other side a mass of grit is brought against these schists in a low cliff in the hollow of the bay. When, now, the series is traced eastwards into the promontory, this grit is seen to lie upon a more micaceous variety, and this passes down, on the small peninsula, into a rock, which can be distinguished neither macroscopically nor microscopically from the typical chloritic schist of Holyhead. So unprepared was I for this passage, that I labelled the rock when first found "pseudochloritic," and paid a second visit to the spot to find, if possible, some fault which had been overlooked. No fault, however, occurs, and it is certain that the South-Stack Series succeeds conformably, and must therefore be the non-volcanic equivalent of the pelites of the north.

This Roscolyn area must contain the lower beds of the series, whatever the other area may be. In it we meet for the first time the phenomenon of cleavage in these rocks. As soon as we leave the chloritic schists this cleavage sets in, and along the planes of it abundant chlorite or mica is developed, so that the rock is also foliated, and on the surface of the ground the bedding is entirely masked. Under the weathering of the sea all looks alike, with vertical lines of subdivision, and stratigraphy has to be abandoned as hopeless. But in a deep cleft of the cliff, marked by a fault on the Survey Map, sudden light is afforded, and we learn that in spite of the cleavage and foliation we are dealing with well-bedded rocks, each with its distinct character and dipping in a northerly direction, *i. e.* partly towards the fault and partly in the direction that will bring in higher beds as we proceed north-westward (see fig. 1). It is the lower beds of this section that we have been passing over since leaving the chloritic schists of Borth Wen and the higher beds that rise into the summit of Mynydd Roscolyn. Thence they have already come down to the level of the top of the cliff, and shortly they occupy the whole of it. Special attention may be drawn to

Fig. 1.—*Section in Gorge below Mynydd Roscolyn.*

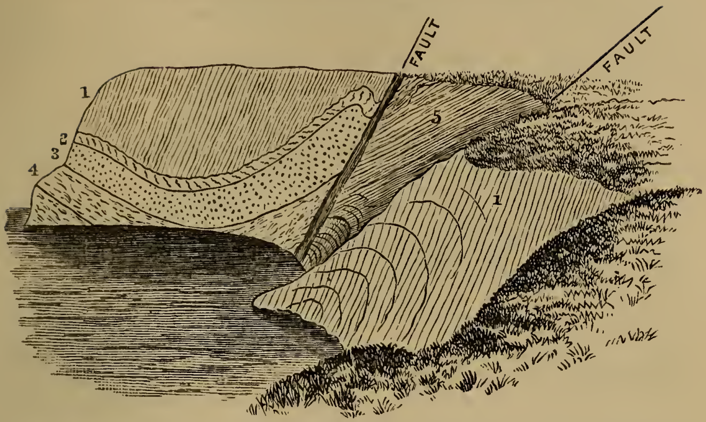


certain beds in which there are zigzag lines of quartz dying out on either side and lying obliquely to the bedding. These are referred to by Sir A. Ramsay as "foliated interlaminations of quartz and quartzose schist"; and Dr. Callaway appears to quote this when he says "there is evidence from the folding of quartz-veins that the rock has been squeezed to the fourth of its original bulk." I do not know that we have any evidence that these were ever any straighter than they are. I interpret them as cracks produced by the irregular oscillation of the overlying quartzite on the more yielding rocks below, and a subsequent infilling by silica.

As seen in the promontory of Maen-yr-esgyll, the quartzite must be 80 feet in thickness; it here has a N.W. dip of 45°, and is cleaved in the same direction at 60°. I give these details to show that we are now dealing with rocks in which such points can be determined. 80 feet more of mixed beds lie above it before we come to a second white quartzite. The series is repeated again on the other side of the fault which runs out at Borth Saint, and the upper quartzite is succeeded by grey and yellow cleaved sandstones, and so the series comes to an end against the main fault at Bwa-du. These quartzites, of which the upper may reach to more than 100 feet, are thus proved, stratigraphically, to have no connexion with that of Holyhead, but to be developments higher in the series. The undulations of these upper rocks and the development of the quartz-cracks in the beds below the quartzite are well seen in Borth Saint (see fig. 2). It is on the base of this quartzite that Dr. Callaway thinks ripple-marks are to be seen. I interpret the ridges seen, both here and elsewhere, where a massive bed overlies a softer one, to the squeezing-out produced by the cleavage-pressure, festooning the harder in the more plastic mass.

The other area, which includes the South-Stack island itself, has been well described by Sir A. Ramsay, though there are some important points still to notice. As in the Roscolyn area, the cleavage is for the most part so intense that it is difficult to make out any succession inland on the broad rolling area by the side of Holyhead mountain. West of the lighthouse there seem to be two developments of quartz, some of which are worked for china-stone; but

Fig. 2.—*View in Borth Saint, Roscolyn.*



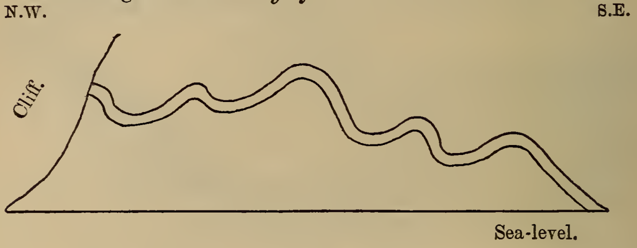
1. Upper quartzite. 2. Quartz-vein bed. 3. Red Beds.
4. Lower purplish beds. 5. Broken red slates &c.

The nearly vertical lines are lines of cleavage.

these seem to be very local; and though under the action of the weather all the surface *looks* quartzitic, there is no quartzite proper to be seen in either section or cliff. There is no other bed in the Roscolyn series sufficiently characteristic for correlation, so we are left in doubt whether all these northern beds are newer, or changed in the new area from their old form. On the whole, I regard the series as ascending from the South-Stack end, thus forming a great synclinal, of which the trough is occupied by the sea and the two ends are exposed.

On this supposition we may see the succession of the lowest beds in a deep gorge in the cliff at Gogarth. Here the beds lie in a great fold, rising on the whole to the S.E., though there is very clear cleavage to the N.W. The beds are alternately soft and hard, the softer being a massive felspathic rock, more like volcanic dust than any yet seen, and several of the harder ones showing the festoonings of the lower side from pressure. The changing character of the rocks can best be seen by looking at the cliff from the lighthouse island, where more than 80 beds, of thicknesses varying from 8 inches to 3 feet, can be counted. The undulations are here so strong that the actual dip may be doubted; but its average can be obtained by following a single bed in its passage along the cliff (see fig. 3). So far the average dip is to the S.E.. The magnificent bird-gorge, where the gulls, the kittiwakes, the razorbills, and the cormorants assemble in thousands, is occupied by a synclinal, and beyond this the shore is inaccessible; but in the deep gorges of the cliff the crests of the anticlinals of contortions point S.E., which indicates an average dip to the same point of the compass. In the nameless bay which now succeeds, the rocks are still beautifully contorted, but they are neither altered nor cleaved. The thin bands of hard shale, with their cappings of indurated rock, often tinged with iron, remind one of the Lias—the rocks are somewhat harder, and I could find no fossils, but there is little further difference. The direction of the crests is here somewhat reversed.

Fig. 3.—*Running of one Bed at South Stack.*



Passing to the next headland, the first rocks seen are sericitic slates, and these are worked inland in close proximity to the chloritic schists, to which they form a striking contrast; then succeeds a series in which cleavage and foliation have gone so far as to obliterate the bedding, except as seen from a distance. We can trace, however, the same general S.E. dip as before, varied by spaces where the contortions run more nearly horizontally. The rocks remain thoroughly bedded, when actually seen; but, as at Roscolyn, the weathering of the cleaved masses gives a uniform appearance to the whole, and there is no true quartzite. Towards Porth-y-corwgl the cleavage becomes less marked; and inland, near Porth-na-march, it is entirely absent, and unaltered grit is found in well-marked folds *.

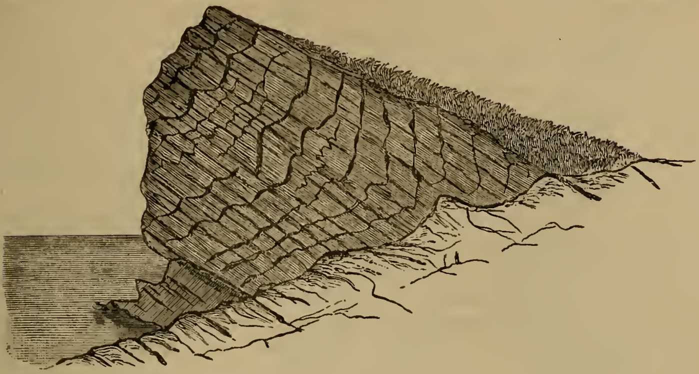
These bedded rocks have, of course, a definite thickness, but it would not be worth the labour to determine it accurately. I should estimate it (allowing for the horizontal portions) at not more than from 2000 to 3000 feet in all.

Sir A. Ramsay states matters quite differently from all the above description. He says that for three miles south of the Stack there is a high dip to the N.W., whereas I say it is to the S.E. and variable. His estimate would give from 13,000 to 14,000 feet to the rocks. It would seem rash to accuse Sir A. Ramsay of having mistaken cleavage for bedding here; but he makes no mention of cleavage in the area, though it is certainly intense; and there are several spots where the dip inserted on the map exactly describes the direction and amount of the cleavage. Perhaps the clearest of these is at a promontory east of Porth Rhyffydd (see fig. 4). In any case I am pretty certain of my own observations as above, and cannot allow an extraordinary thickness to the series.

* The greenstone dyke at Porth-y-corwgl, which runs near the fault, is beautifully jointed both in the columnar and the spheroidal style, like the pillars at the Giant's Causeway

Fig. 4.—*Promontory east of Porth Rhyffydd, showing Cleavage and Contortion.*

S.S.E. N.N.W.



The Mass of "Serpentine."—Much is already known about this from the researches of Prof. Bonney, published in vol. xxxvii. of the Journal of the Society, and it does not concern the present memoir to discuss its general points of interest. The name applied to the rocks which are coloured as "Serpentine" on the Survey Map must be taken in a very general sense as equivalent to "something peculiar, related in some way to the presence of serpentine," and even then the mapping is not quite correct*. From the mode of occurrence of the rock, and from the teaching of the junction mentioned by Prof. Bonney, it is certain we are here dealing with intrusive masses. The actual masses of igneous rock are more sporadic and isolated than marked on the map. In particular the gabbro is confined to upstanding bosses, which have the aspect of necks, and much of it is foliated on the large scale, though the diallage crystals are sufficiently irregularly distributed in its substance. These bosses are found at Ty newydd, Morfa-coeg near Cruglas, Melin Carnau, Dinas Fawr in two places, and at Ceryg-moelion. To the north this rock is drawn out into schist by dynamic agencies, and is not easily recognizable. The lower eminences are almost entirely serpentine, and this seems almost always to be interpolated between the gabbro and the schist. There are limestones also at Cruglas, behind Ceryg-moelion, and in the inlet west of Dinas Fawr; and these, when they occur, are always between the serpentine and the schist. The largest mass of true serpentine stretches southward from round the above-named inlet as far as the Roscolyn road. It would be rather remarkable if the serpentine and the gabbro were entirely independent, but they may only be related as outbursts from a common focus. In only one place is the serpentine of crystalline aspect, as in the Lizard, and in this the positions of the original olivine crystals are easily discerned. The remainder is

* There are, however, some green-coloured boundaries marked within the serpentine, which show that more than one kind of rock was recognized.

nearly pure fibrous serpentine with isolated spots of black dust. The water necessary for its production must have carried away with it the superfluous magnesia; and this we find impregnating the schists all round, in most places partially, but at the southern end so thoroughly as to produce soapstone. The limestones have every appearance of belonging to the original series and of not being connected with subsequent infiltrations from Carboniferous Limestone, which we have no reason to believe ever lay directly above them. We have seen limestone in the older part of the series at Porth Delise; other occurrences will be noticed in the central district, and in the higher portions sporadic limestones of similar mode of occurrence are common, in association with volcanic products, so we may expect them at this spot. The action of magnesian waters on them was a subsequent process, and they yielded to them some of their own materials; for on the one hand we find the limestones impregnated, especially in the cracks, with serpentine, and on the other the serpentine in their neighbourhood is highly charged with dolomite (?).

The Granite near Llyn Trefwll.—This is the spot on which Dr. Callaway chiefly relies for proof that there are two Pre-Cambrian series in Anglesey, the one unconformable to the other. He states that here, "within a quarter of an acre," there are "outcrops of three rock-systems—Gneissic, Pebidian, and Palæozoic, with proof of succession in the order here given." My interpretation of the district is entirely different, and much more nearly coincides with that of the Survey; though I cannot quite agree with the words of Sir A. Ramsay, who simply says "there is a small patch of granite, around which the rocks are much altered, being interlaced by numerous granite veins." The spot is a very interesting one, and, *primâ facie*, appears to countenance Dr. Callaway's description. But the notion of three systems occurring in this way within a quarter of an acre is so incongruous that one is bound to inquire more closely, and then it is soon seen that appearances are delusive. I present a plan of the place (fig. 5), which, if not quite correct, is certainly more so than Dr. Callaway's. The rocks stand out of a grassy surface in long irregular hummocks. On the west side are continuous exposures of the ordinary, not very highly altered, chloritic schists. The next boss on the east is a tolerably high one, composed of diabase. This is marked greenstone on the Survey Map. It is somewhat foliated here and there, but its character is perfectly distinct under the microscope. To the east of this, and separated from it, is a narrow ridge, of which the central part is granite, and the western and part of the eastern side, at least, is diabase. Dr. Callaway says there are greenish grits on the eastern side; there may be, but I did not observe them. The granite is of the same type as that seen at Pen-bryn-yr-Eglwys, but is broken up in places, and tinged with infusions of chlorite. A larger ridge appears on the S.E. side; on the western side of which there is a continuation of the diabase, and on the eastern side

Fig. 5.—*Plan of Ground west of Llyn Trefwll.*

1. Chloritic schist. 2. Diabase. 3. Granite.
4. Beach-breccia. 5. Conglomerate. 6. Lake.

it is a beach-breccia of large gneissic fragments. Close upon the junction at one spot, over an area not more than 3 feet long by 8 inches wide, the diabase becomes very slaty, and contains fragments of granite; but its true character is seen, under the microscope, to be retained. Near here, also, and enclosed in the diabase, is a small mass of diorite, with granite bands in it. To the east, again, are two smaller ridges of coarse granite-conglomerate passing into grit, and still further east, by the lake side, two tall bosses of finer conglomerate. This is all that is seen. Thus some of the slates of Dr. Callaway are diabase; and, if there is any slate at all, it is in the beach-breccia, which may very well contain such material, enclosing, it might be, even pebbles of granite *. Thus there is no part of the later series here at all, except in the form of fragments,

* I have little doubt that it was really part of this series tha yieldea the rocks examined by Prof. Bonney (Quart. Journ. Geol. Soc. vol. xl. p. 584).

unless we assign, as is most natural, the granite to this epoch. The granite is anterior to the conglomerate, and the diabase is posterior to the granite, and, possibly, also to the conglomerate. This last rock is the most interesting in the locality, since it is composed of fragments not represented elsewhere in the district. This Ordovician breccia contains many kinds of rocks, some almost approaching red sandstone, and others like an unaltered portion of the chloritic-schist group. The difficulty of assigning an early origin to all these seems to have led the surveyors to suggest a Carboniferous age for the conglomerate. However, to the east it passes into typical Ordovician shales, and most of the materials could probably be found in an extension of the South-Stack series. At the northern end, by the lake, however, the fragments are of gneiss and granite, and of other rocks such as we shall find within the granitic area in the central district. We thus learn that a similar group of rocks must have occurred here also, not far removed from sight. In other words, the synclinal which separates the two districts affects the lower rocks also, which are continuous across it at some depth.

Summary of the Western District.

The rocks in this district commence at their base with a vast development of quartzite, which more or less gradually changes, through micaceous and gritty rocks, into laminated chloritic schists, which are so sporadically metamorphosed as to remain in certain places as purple slates. These, with occasional bands of grit and isolated areas of sericitic schists, occupy a wide country to the east. Into this is intruded a large mass of gabbro and serpentine, and patches of limestone and of epidosite are occasionally found. The upward continuation of the rocks on the north is different from that on the south. In the former they pass continuously but rather rapidly into a vast accumulation of unstratified tuff and ashes, which increase in bulk as we go north, and ultimately come to a climax by the development of agglomerates and the intrusion of granite and felsite. In this volcanic material are found narrow lenticular bands of limestone, with mosaic crystallization, and also rounded upstanding knobs of quartz, which it is suggested are the bases or pipes of ancient geysers. The metamorphism of the rocks is very variable, in some much chlorite being developed. The coarser material is often compressed into lenticles, forming a lenticular pelite. The finer makes a mottled rock or marbled slate. In the southern direction the volcanic material is absent, but the chloritic schists pass up into a series of well-bedded rocks, including two thick bands of quartzite. In some parts these rocks are intensely cleaved, with foliation along the cleavage-planes; in others there is neither cleavage nor foliation, but in all there are vast undulations and contortions, forming a synclinal on the whole. They may be called the South-Stack series. At the extreme east of the district a small mass of granite is found, overlain by the Ordovician breccia, and not connected with the chloritic schists; it is probably intermediate in age between these two. The Ordovician basement-beds are found also at Holyhead, where they lie on the quartzite, at Garn, where they lie on the pelite, and at Pen-bryn-yr-Eglwys, where they lie on agglomerate. Nowhere is there found any rock like the Cambrians of Bangor. The whole series is thus proved to be a continuous Pre-Ordovician one, with two different developments in an upward direction.

The Central District.

This district is the largest and most difficult to understand. In it Dr. Callaway thinks he finds representatives of all the subdivisions of his gneissic series. My principal difficulty is with the rocks which he calls "Hälleflinta"; on these I have twice changed opinions, now reverting to that which the field-work suggested. It may be wrong, but, if so, the stratigraphy is almost infinitely complicated. According to this we must take particular notice of a line which is marked on the Survey map, and which runs from Porth-y-ly-wod on the coast nearly straight to the eastern mass of granite at Gualchmai, and thence to Bodwrog church. This is a line of fault. Its further course is doubtful, since in any case there must be a second disturbance beyond the railway. This line divides the district into an eastern and a western region.

The Eastern Region.—The basal rock in this region, occurring next to the fault, is what Dr. Callaway calls quartz-schist, and it is succeeded by a type of rock which we have not seen before, to which he gives the very descriptive name of the grey gneiss, inasmuch as it contains felspar as well as mica and quartz. I can see no necessity for distinguishing a quartz-schist, since there is felspar, though less abundant, in the most westerly samples. The rock is, for the most part, more thoroughly metamorphosed than any in the western district, so that it is difficult to distinguish any lines of original dust. The foliation, however, is very fine and well marked, not only by the chlorite but by the long axes of the other minerals. Dr. Callaway has given a good description of the development of these rocks from Porth Nobla to Aberffraw, which need not be repeated at length; suffice it to say, that more quartzose bands and more chloritic bands come on irregularly, the latter especially on the eastern side of Llangwfen Bay; but everywhere the beautiful foliation is well marked, and nowhere better than when the series is about to close on its meeting a fault close to the western promontory of Aberffraw Bay. For some distance here the lines are horizontal, but on approaching the fault they become wonderfully contorted. The rock is easily traced inland, as in the railway-cutting and to the north of it, and so on either side of the stream at Gualchmai up to the granite, and beside Bodwrog church and the old Holyhead road. The limestones, which have been noticed at Trecastle and Bodwrog, and which are truly foliated with the rest of the gneiss, are important evidence of the unity of the series. Like those around the serpentine of Valley, they are in the older portion, but they have the same sporadic character as those in the younger.

In the correlation of this group with the western district I quite agree with Dr. Callaway. Though the metamorphism is more complete, and the ingredients more minute, they are of the same character as the chloritic schists. Their more quartzose base and their more chloritic termination show that they must be conceived to correspond generally to the whole of the lower group, and no marked line can be drawn between grey gneiss and chloritic schist.

In all the district northwards from within a mile of Gualchmai, the eastern boundary of the gneiss and associated rocks is formed by basal Ordovician conglomerates and grits, which, at the crossing of the old Holyhead road, form a beautiful white rock, and these are soon followed by the ordinary black shales standing at a high angle. Still, therefore, no Cambrian rocks intervene, but the older rocks were denuded to their base in Cambrian times. These Ordovician shales are bounded on the east by a well-marked fault, bringing in again the Pre-Cambrian series. We cannot suppose that this important fault dies out exactly where it cuts off the Ordovician and brings the two portions of the Pre-Cambrian series together, as it has hitherto been inferentially represented as doing; yet there is this strange circumstance about it, that it represents a downthrow on the east as against the gneiss, and an upthrow as against the Ordovician. There are only three ways of accounting for this: either (1) the grey gneiss is really the younger rock (an untenable supposition), or (2) the fault coincides with the bedding-planes, which it does not, or (3) there was a Pre-Ordovician as well as a Post-Ordovician fault along the line, with opposite throws, which shows that the fault must be a well-marked one, but the balance of displacement need not be great. The continuation of the fault to the south can be traced on the Holyhead road between the $\frac{12}{13}$ milestone and the slopes of the hill by Glan-gors-du Fawr. Two miles to the south it passes between Tyn-y-gong and Cwlrwm, and is next seen in the railway-cutting near Bodgedwydd. A wall is built over it on the south side, all the rest of the cutting being rock. But on the north side solid green rock on the east comes suddenly to an end on a nearly vertical line, next to which is a foot or two of broken rubbish, and then we find thin-bedded micaceous rocks of the grey-gneiss series, which continue for the rest of the cutting. I give these details because Dr. Callaway says there is here a passage from the grey gneiss into the "dark schist," and the fault runs much further east, where it cannot be traced. Thence the fault passes west of the road to Aberffraw, near the church and west of the small promontory of Trwyn-du, where the rocks on the two sides are in strong contrast.

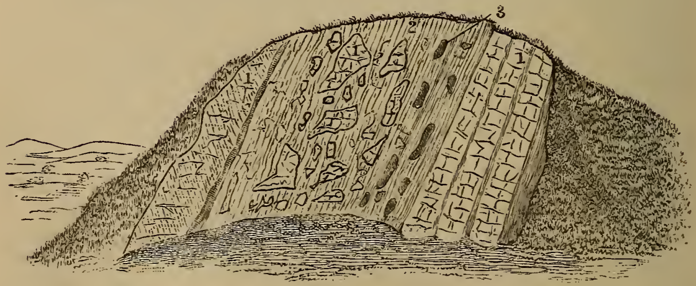
We are thus prevented from following the sequence upwards, and must start afresh with the rocks on the east side of the fault. It is not easy to make certain of their stratigraphy. Dr. Callaway divides them into two independent halves by a fault which passes from the Aberffraw sands into the eastern boundary of the Ordovician belt. This must be wrong in the north. The only possible line of division that is not immediately contradicted on the ground would run along the western branch of the river Gwna, and thence across the old Holyhead road along the N.E. branch of the river Cefni. On one side of this line most of the dips recorded are towards the east, on the other side they are mostly to the west. Since the rocks on the two sides are not the same, if any reliance is to be placed on the dips, we have the choice between an overturn to the east and a faulted synclinal. Dr. Callaway chooses the latter. The former commends itself to me—first, because no sudden change of rock, except where the grey gneiss comes on, indicates any fault; and, secondly, because, unless there is an inversion, the order of the upper part in this district would be different from that which obtains in the others. Moreover, of the many bosses of rock exposed, only a few show any recognizable dip, and hence it is not certain how far those that are observed are reliable.

I take, then, the rocks on the east of the fault to show a pretty continuous upward succession. We have seen that the throw of the fault may not be great, and the lowest rocks exposed may not be far above the grey gneiss, and they are so chloritic that they do not differ much from the lower schists to which Dr. Callaway refers them. The rock at Careg-engan-fawr, which he refers to the slaty series, is quite of the same type. Some part of these may be best placed as chloritic schist; but the point of the whole matter is that they so gradually change upwards by the introduction of scattered angular fragments that no dividing line can be drawn. Thus, though the material of the railway-cutting is very chloritic, so is the material by the Mona Inn. A green grit in the cutting is just like one at Nant-yr-lowddy, on the east of the Ordovician of the north. There are breccias on the shore close to Aberffraw, and finer breccias on the east of Llyn Coron. As a whole the rocks are more allied to the lenticular pelites than to the chloritic schists.

Passing to the east they become rapidly more ashy and irregular, especially about Llangadwaladr and to the south, while to the north slates become more abundant, and great agglomerates set in on either side of the Llangefni railway. The whole set become more and more irregular, as though produced by volcanic agencies, and in so far agree with the north-west. But the materials are coarser and more mixed with stratified deposits. As I look upon the beds as inverted, I place the grits and porcellanites of Ceryg ddwyffordd, near Llangefni, at the top of the series. After the admirable description of this portion by Dr. Callaway, under the head of the "Llangefni synclinal," I need not enter into any further details on the general development, but only call attention to points of special interest.

Amongst them are:—1. The great agglomerates, so well seen in the railway north of Llangefni, and on the coast on the south. These contain huge masses of quartzose and igneous rocks, in the wildest confusion: we cannot call them conglomerates and look to more ancient land for their source; they are not disposed after the manner of such rocks, but they contain ejected blocks from a volcano, consisting for the most part of rocks only recently formed and belonging to the same series. As these occur towards the east, and beyond them in that direction we have nothing that could so break up, whereas we can find similar rock to the west, we are led to the conclusion that these agglomerates, which actually stand vertically, are the higher portions of the series. 2. The quartz-knobs. These have the same form and character as in the western district, but some at least are much fuller of rounded pieces; still they are nearly pure quartz, with polygonal network and sericite in the intervals, but no foliation. Perhaps any one seeing one of these in this district for the first time would consider it a grit, but the above characters are not those of a grit. In the case of the mass at the Llangefni Mill, marked "greenstone" on the Survey Map, it is so large, and shows such apparent traces of bedding, and here and there in its substance small flakes of foreign material, that we may conceive that this at least was an external deposit whose last origin at least was sedimentary; but the others at Bethel, near Bodorgan, at Twll-y-mwg, one mile north of Bethel, and on the railway south of Llangefni, are typical isolated mounds of pure material. It will be noticed that all these four masses are nearly on a line coinciding with the strike. Other very quartzose knobs occur north of Cerrig Ceinwen, but they do not perhaps belong to this type of formation. 3. The sporadic limestones. The lowest of these, near the Druid Inn, on the Holyhead road, though similar to that at Bodwrog in appearance, is quite distinct in structure, and corresponds to the type found among the ashy series. It is a white massive rock, occupying a lenticle transverse to the general bedding, and most resembles in nature and occurrence the mass at Llanfaethlu. On either side of Cerrig Ceinwen there are also masses of limestone, but these at the present time are of different character. Though very local in development, they are bedded while they last; they are associated with reddish strata and with breccias of their own substance mixed with similar material (see fig. 6) and producing umber in nests. Amongst these reddish

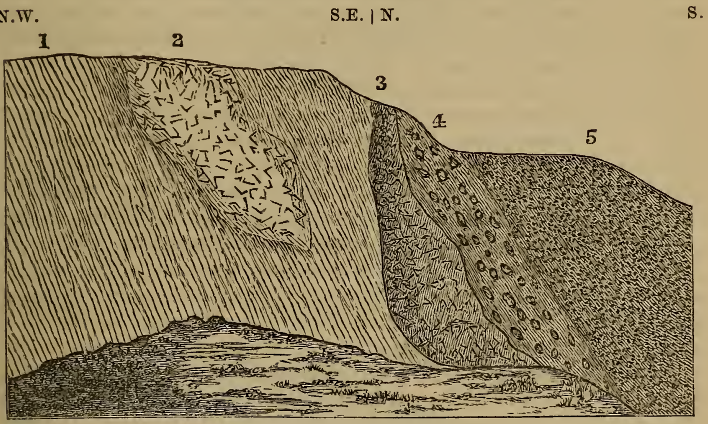
Fig. 6.—*Quarry 1¼ mile south of Cerrig Ceinwen.*



1. Crystalline limestone. 2. Reddish slates. 3. Nests of umber.

slates are some that are marked all over with nearly parallel, branching, calcareous, crystalline, cylindrical tubes, suggesting such a coral as *Syringopora*; but whether these are really the remains of corals with their internal structure obliterated it is impossible to say. South of Cerrig Ceinwen I have found no jasper associated with these limestones in mass, though most of the limestone is "jaspery;" but in the masses to the north there are bands and isolated pieces of red jasper, which behave towards the limestones exactly as flint does to chalk, and a similar origin is at least suggested. Nodules of similar jasper occur in beds of the same series further south. 4. Disturbed masses near Dinas Llwyd. In this locality the intimate relations of slates, ashes, quartz, and limestone with one another and with basic igneous rocks are beautifully shown. On the east side of the headland are slaty rocks, but on the west the rough irregular ashes and local breccias; on the western slope the following section is seen (fig. 7). The quartz here comes

Fig. 7.—*Section on west side of Dinas Llwyd.*



1. Ashes. 2. Quartz. 3. Diabase. 4. Breccia. 5. Ashy grit.

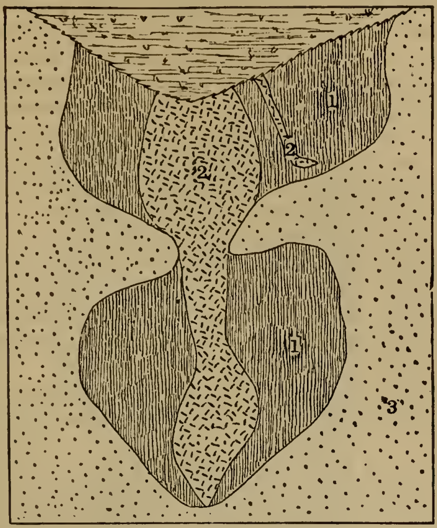
in as a thick tongue from above, and it dies out behind on the surface. Near at hand is a diabase-dyke, probably belonging to the series; beyond this are some breccias, and then more gritty rocks. Here, then, the quartz is certainly not a fragment of old land, nor is it a contorted bed, but something that has formed where now we find it. In the grits are found fragments of similar quartz, which show the polygonal structure; we may therefore even conclude that the quartz was a contemporary product. To the west, in the valley, lies a band of slate, and then comes a ridge of remarkable diabase, which is repeated in other ridges near Bodowen. Beyond this slates recur and form the headland of Trwyn-y-parc. The succeeding hollow is occupied by a limestone somewhat similar to those of Cerrig Ceinwen, and finally we come to the agglomerate of Porth Trwyn Mawr, referred to by Dr. Callaway. Comparing the relations of these several rocks with those that obtain further to the north, they are not the same, and we must therefore regard the more special types as accidents in the series. There would appear to have been two volcanic foci—one near Llangefni, and the other near this spot, which latter may be connected with the area, to be subsequently described, on the other side of Malldraeth Bay.

I gather, therefore, that we have in this district a somewhat similar development to that which occurs between Valley and Penbryn-yr-Eglwys, with local differences, of which the principal is the absence of any granite amongst the ashes or pelites of the district. I can see no reason for widely separating any part of the rocks on the east side of the fault from their neighbours.

The Western Region.—We can now consider the area which lies on the western side of the dividing line; and as the main feature of this is the granite, and our view of the stratigraphy must necessarily depend on the nature of this rock, and as it has lately been denied that it is granite, but asserted to be a metamorphic sedimentary rock, it is necessary, in the first place, to bring field-observations to prove that it is intrusive.

a. The Intrusive Occurrence of the Granite.—The proofs of this are so many that their enumeration threatens to be tedious. To adduce them all, however, is a necessity forced on us by recent literature. Commencing at the south-western end, we find the eastern side of Llyn Faelog coloured as granite. Here there are a number of bosses of rock protruding from the ground. On examining several of these, we find the two sides composed of different material; on the one side is the pelite, on the other the granite. The passage from one into the other is obscure, and from this locality alone it would be open to any one to say that they here recognized the gradual metamorphosis of the sedimentary rock into granitoidite. But we can also interpret the phenomenon as an absorption by the granite of the neighbouring rock, in circumstances under which the former was kept long heated in contact with the latter. On the coast at Porth-ceryg-defaid the pelite again contains patches of the granite, but they are both brecciated. At a small promontory between this and Porth-y-ly-wod, however, we get the first clear proof of intrusion. Here on the shore is a low boss of rock, with all its surface bare (see fig. 8). The pelite is more or less orientated in the direction of the sea. Into this, and running in the same general direction, but in more than one place crossing its structural lines, is a tongue of granite from 3 to 4 feet wide, which connects the two parts of the boss, and finally disappears with it beneath the sand. Hard by to the east is another smaller string of granite not quite parallel to the larger tongue, and also crossing the lines of the pelite, but dying out before reaching the second half of the boss, and the rocks in both parts are perfectly distinct. The granite, in structure, is seen to be much brecciated, doubtless in the subsequent compressions of the rocks; but in the unbroken parts it presents a typical holocrystalline granitic arrangement, with largish patches of original white mica.

Fig. 8.—*Plan of Shore, west of Porth-y-ly-wod.*



1. Ashy pelite. 2. Granite. 3. Sea-sand.

Passing up the eastern side, we find another junction at Melin Ddrydwy, on the slope of the west bank of the stream. Here the disposition of the granite and its neighbour is as shown in fig. 9.

Fig. 9.—*Section on West side of Stream at Melin Ddrydwy.*

1. Quartz-felspar porphyry. 2. "Hälleflinta." 3. Pathway. 4. River.

The line between the two rocks is very clearly defined, but also irregular. The granite appears on the upper, that is on the western side. It would be difficult to regard this as anything but an intrusive junction. The "granite," however, here is changed into a quartz-felspar porphyry, the porphyritic crystals showing signs of great pressure.

We next arrive at Gualchmai. Here, just west of the road leading down from the church, there is marked on the Survey map an isolated, tongue-like mass of granite, cut off on the north from another tongue which reaches down southwards from Bodwrog church. Now this tongue of granite actually exists, and is surrounded by sedimentary rocks as represented, those on the western side being different from those on the east, the former being hälleflinta and the latter grey gneiss. Of course a metamorphosed sedimentary rock *might* be got into this position by complicated faulting; but intrusion is the more obvious method. On the slopes of the granite hill, the granite and hälleflinta are inextricably mixed, after the same manner as at Llyn Faelog *.

Further north the granite comes in contact with the grey gneiss, and has ashy beds on the other side of the tongue. The actual junction is hidden beneath the road at Bodwrog church; but the grey gneiss is disturbed, where seen nearest to the granite, and is penetrated by small half-inch veins of granite. Unfortunately these veins cannot be traced beneath the roadway into the solid mass on the other side. Here, again, the simplest explanation is an intrusion.

Beyond this spot there intervenes a long belt of diorite, and I have been unable to find a junction of any kind. Dr. Callaway, however, records an exposure S.W. of Craig Llwyd, which I seem to have missed, where the "hornblende-gneiss is interstratified with granitoidite;" this may be an intrusion of the granite into the diorite. Also to the S.W. of Plas Llanfihangel there are gneissose rocks, and others of mixed character, having granite segregation-veins (?) in the midst of schistose diorite,—a sort of irregular "banded gneiss," but the whole area gives very little definite information.

On the western side the boundary of the granite is not promising, as it is overlain unconformably by the Ordovician grits. However, at the outlier near Tafarn-y-botel there is a quarry in a beautiful micaceous gneiss, which forms part of the general mass of similar rock composing this outlier; but in the quarry floor there is an irregular tongue of granite, quite distinct in character, and with clear lines of separation. I am doubtful whether this is really intrusive or due to segregation, but I strongly incline to the former view.

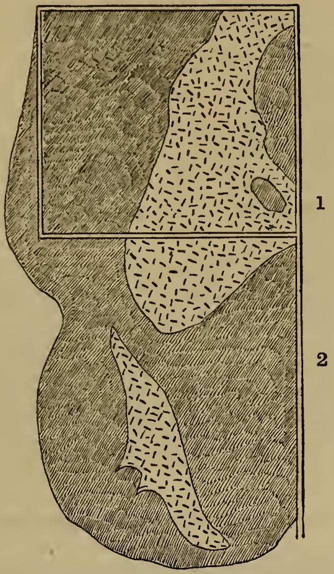
In the area between the two turnpike-roads the older rocks are exposed, and south of the Star Inn the junction of the granite with them, if not actually seen, may be determined accurately in position. Here Dr. Callaway sees a gradual change from one into the other, though the bounding rock is certainly not a dark schist; but I see an indefinite boundary such as we have elsewhere observed.

The indications to be met with in the interior of the mass are still more decisive than those on the boundary. One small patch of "Cambrian" is marked on the Survey map as occurring in the midst of the granite at the farm of Maen Gwyn. This spot I examined in the company of Prof. Sollas. In the sides of the

* This seems to be the spot described by Dr. Callaway in Geol. Mag. 1880; but the bedding he describes does not seem to be observable.

farmyard are seen masses of pelite, flaky and somewhat micaceous. This micaceous character increases towards one side of the yard, and here there is an intrusion of the granite into it (see fig. 10).

Fig. 10.—*Plan of the Farmyard of Maen Gwyn.*



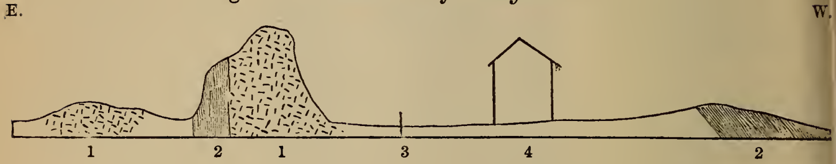
1. Granite. 2. Micaceous Pelite.

The granite occurs in one boss in a gradually narrowing vein, with a quite irregular course, and branching out it dies away in quartzose strings in the midst of the pelite which overlies and underlies it. Separate from this is another patch of granite surrounded by the pelite and crossing its structural lines. This expands from a narrow neck into a larger mass, and here entirely surrounds a kind of inlier of the pelite, or, as one might more correctly call it here, the micaceous schist. The two rocks at the contact are so distinct that both may be recognized in any small hand-specimen. Is there any escape from this?

There is a second such inlier on the Survey map, near Llecheyn-farwy; but at the spot indicated I could find no rock which ought to have been thus coloured, and certainly no granite junction. A long tongue is also indicated as running up N.E. from near Gwyndy. This I have verified, but could seldom find the actual junction; only in one knob, south-west of the farm of Y-foel, did the surface of the rock show a vein of granite running into the pelite. On the road from Gwyndy southwards the relations of the granite to its neighbour are not very clear, and resemble rather those to the south of the

Star Inn; but at the farm of Cefn-eth-groen there is a quarry in which a distinct junction may be seen. The actual piece of pelite seen must be an included fragment, since the mass of the rock is away to the west. This patch clings to a vertical surface of the granite on its eastern side (see fig. 11).

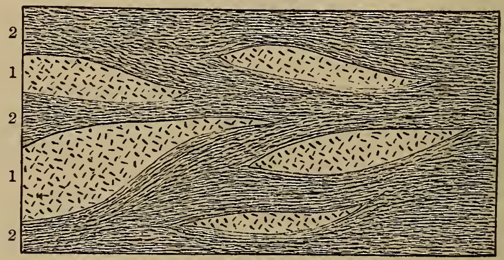
Fig. 11.—*Section at Cefn-eth-groen Farm.*



1. Granite. 2. Pelite. 3. Junction in Map. 4. Farm.

A little to the south of this we come to the region of Craig-yr-allor. Between that craig and the new Holyhead road is another eminence, called Craig Cocyn. On the surface of this craig the granite is seen in tongues, which enter the dark hornblende-schist. Sometimes these tongues are of the ordinary character, cutting across the edges of the folia of the darker rock; but at others they seem pulled out into lenticles, which in this case run with the average schistosity (as in fig. 12). Thence we may pass to a more

Fig. 12.—*Granite in Hornblende-schist, Craig Cocyn.*



1. Granite. 2. Hornblende-schist.

intimate blending of the two rocks, with the production of a form of banded gneiss. Whether or not we accept Mr. Teall's explanation of the mode of formation of such gneisses, it is to be noted that this, the most mechanical of all explanations, involves an intrusion of the granite to start with.

Finally, we come to the tongue of "Cambrian" on the map, which crosses the turnpike-road, and in this we observe the same indefiniteness of granite and pelite as is seen at Llyn Faelog, the more central portion being free from granitic material.

In some of these cases we have clear intrusive junctions, in others the junction is indefinite. The cause of this difference seems to depend partly on the nature of the neighbour and partly on its relation to the mass of the granite, which in the latter case had the power of absorption, but not in the former.

Such is the positive evidence that the granite of this district is intrusive. If it is insufficient, I can have no conception of what would suffice. If it is accepted, a lesson is read to us on the danger of relying too much on minute and indescribable differences in the microscopic structure of a rock.

b. *The Nature of the "Granite."*—I have used the term granite throughout, partly because it is so coloured on the Survey map, and partly because, if one term only is to be chosen, this is the most generally applicable. But in reality under this one term a great variety of rocks, not to mention those which are obviously distinct, must be included, though I believe them all to be connected portions of one great mass. Perhaps the most typical granite is that found at Hen-blas, near Llandrygarn, which on comparison with that from Kingstown, near Dublin, shows a resemblance amounting to almost absolute identity, the only differences being the less freshness of the mica and the smaller individuals of the quartz. One is almost tempted to ask if this can belong to a distinct and later eruption, only it is easy to recognize that some at least of the others, as that at Gualchmai, only differ by brecciation and alteration. The next in order of alteration, after this at Hen-blas, is in a mass or tongue between two diorites about a mile and a half to the north; and the next is the great mass seen in the cutting at Llanfaelog, where some of the felspars are almost porphyritic, and all the mica has either induced, or been developed in, the cracks. The granite near Craig-yr-allor is tolerably whole, but the other samples that I have examined are all more or less broken, and become in some places regular endoclastic breccias (shall we say "endoclasts"?). They are, however, mostly from places rather near the boundary. Such is the rock at Gualchmai, at Yr-ynys-goed, Coedana, and from the Llanerchymedd railway, near the ninth milestone. But the most brecciated of all that I have examined comes from the interior, at Bryn twrog, south of the railway just mentioned. The granite in the two tongues near Porth-ceryg-defaid and at Maen-gwyn differs in another way. It is not so much brecciated, but has a larger supply than usual of clean white mica, similar, in the latter case, to the mica developed in the neighbouring pelite.

All these granites differ less in their internal structure than would be expected from their external aspect. This latter is partly dependent on the size of the crystals, and partly on the brecciation, which has brought about the introduction of substances which alter the appearance, but leave the intervening granite untouched. We may take them all, therefore, to be parts of a single massif. In two places, however, we find felsitic rocks, and, probably, there are several more, as the granite has not been examined in every spot, and these may be said to have been noted by accident. They are at the junction near Melin Ddrydwy, and at Tyn-y-pwll in the centre, near Bryn twrog.

c. *The Associates of the Granite.*—These are the most difficult to understand, and I can only do my best to interpret them. The descriptions hitherto given have gone on the assumption that the rocks were of ordinary sedimentary origin, their crystalline character being due to subsequent metamorphosis.

But, so far as I can understand it, the whole is one great volcanic complex, of which we only see the base—the rocks with fluidal structure, and the scoriæ, if they were ever present, having disappeared. There are, in fact, besides the granite, four main types of rock within the area—the hälleflintas, the pelites, the gneisses, and the diorites.

1. The *Hälleflintas.* Dr. Callaway makes his hälleflinta occupy a very small area, from less than half a mile on the coast to nearly nothing at Gualchmai. It is a remarkable, compact rock, without a sign of lamination or stratification, and consists of very minute quartzose fragments. When the grey gneiss is brecciated it is hard to distinguish between the two; indeed, I think, the rock near Llangwllog, noted by Dr. Callaway, is of the latter kind; this, however, can only contain fragments of its own substance, whereas the hälleflinta contains foreign particles, of which the most easily recognized are of plagioclase felspar. This rock runs in a narrow band from the coast to Gualchmai, where it all along intervenes between the grey gneiss and the granite. It then passes on the western side of the granite tongue, and is in its most beautiful form, a blue, slaty-looking, finely false-bedded rock, by the side of the Holyhead road. It cannot be clearly recognized much beyond Tyn-rhos, on the same line, but occurs again on the other side of the granite at Gors Mill and Gwyndy. This irregular and restricted distribution is not to be wondered at in a volcanic dust, but would be very puzzling in a basal rock. It so interdigitates and shades off into the other rocks of the granite area, that I take them to be all connected, and to be brought next the grey gneiss by a fault, of which there is abundant indication in the field by the sudden change of rock *.

2. The *Pelite.* This is somewhat different from the rock so called in the western district, inasmuch as it tends more to stratification, as in the lenticular variety. It is in fact a volcanic mud, which has sometimes particles large enough to justify the title of an ash. There is usually no quartz in it, except in secondary veins, and the whole is composed of fine polarizing flakes. When the fragments are large enough to be recognized they might be derived from a granitic rock, but not from the granite itself, which in places intrudes into the pelite. It cannot, however, be always distinguished in the field from an endoclast of the granite and associated diorite. We find this rock intervening between the hälleflinta and the granite on the south shore, with an intrusive vein of the

* Drawn by Dr. Callaway in his article in the Geol. Mag. 1880.

latter. It is found in the centre between the two granite tongues at Llanfaelog, where it is called "Silurian?" in the Survey map, and skirts the east side of Llyn Faelog. It also lies next the granite near Tycroes, and is found in patches between Llanfaelog and Pen-y-carnisiog. It forms the tongue of "Cambrian" that cuts the Holyhead road and into which the diorite intrudes further north. Near Bodwrog church it lies between the hälleflinta and the grey gneiss, being separated from the latter by the granite. The rock that forms the long tongue north of Gwyndy is more of this type than any other, and it occurs on the other side of the granite near Llanerchymedd windmill. The name, however, is an inclusive one for all somewhat similar rocks which have no special character. On the whole it is found more to the west than the hälleflinta, but at Bodwrog it is next the grey gneiss.

3. The *Gneisses.* We find these, apparently graduating into the pelites, near Llecheynfarwy. They have here a banded character. Also near the farm of Mynydd Mawr the rocks are very quartzose rough gneisses not in the least like the grey gneiss. This type of rock is continued to Tafarn-y-botel, where the granite intrudes, and is the most difficult of all to understand. At the latter place it is a beautifully clean crystallized rock, composed of quartz and felspar quite fresh, and black mica, which has in part passed over into another mineral. There is nothing like this rock in the whole of Anglesey elsewhere, and the question is suggested whether we may not touch here a piece of genuine Archæan. The nearest rock to this in character occurs on the north-east near Plas Llanfihangel. In connexion with this may be mentioned a mass of rock in the centre of the granite, on the railway between Llangwllog and Llanerchymedd, which is more like grey gneiss, with an extraordinary amount of white mica and sericite, amounting to half its volume, and with which a calcareous rock is associated.

4. The *Diorites.* This is the only name I can satisfactorily give to the rocks which in many places are hornblende-schists. They appear partly as "gneiss" and partly as "greenstone" in the Survey map, and they figure in Dr. Callaway's descriptions as "dark schists." Sir A. Ramsay regards them all as metamorphic sedimentary rocks. No doubt their foliated appearance suggests sedimentation; but I find that so long ago as 1872, in Jukes's 'Manual of Geology,' it is stated of hornblende-schists that "there is reason to believe that as they occur among altered sedimentary rocks they may represent former trap-rocks;" and of recent years this conclusion has been verified by Williams in America, and by Teall in this country. It was not, however, entirely their foliation which led Sir A. Ramsay to his conclusion, since he places in the same category in the memoir the unfoliated rock which is coloured greenstone on the map, but it was rather the shading off of both this and the granite into the surrounding rock which convinced him that the one was the derivative of the other. It is for the microscope to decide which is the original rock. If it was the sedimentary one, then as we approached the crystalline, isolated crystals would appear

in the unaltered sediment, and these would gradually increase in number till, leaving no interval between them, they occupied the whole rock. It is an approach to this that we see in the case of contact-metamorphism. If, on the other hand, the crystalline rock was the original, and the other produced from it by brecciation, we should find the cracks increasing as we approached the margin, till at last the rock was a mass of crystalline fragments, which might get smaller and fewer as the sedimentary rock received other ingredients. Between these two phenomena there is a very clear difference, and in the present case the answer of the microscope is entirely in favour of the latter. This, however, does not dispose of the idea of the "dark schist" being an altered sedimentary rock of an older series. Such a contention would have to be proved on the clearest stratigraphical evidence, for beyond being both "schists" and both "dark," there is nothing lithologically in common between these and the Holyhead rocks; the one set are composed of quartz and chlorite, and the other of plagioclase and hornblende. No stratigraphical evidence, however, can here be brought forward, since the diorite only approaches the grey gneiss in one spot, near the stream north of Llangwllog, and then it is on the wrong side.

There are four areas in which these dioritic rocks occur. The best known is that round Craig-yr-allor. Here Dr. Callaway states that "grey gneiss passes up through the dark type into the granitoidite." I could find, however, no grey gneiss here at all. The country is rather low and marshy, and out of it stand up several bosses of rock. Some of these are composed of the ashy pelite containing granite veins, and in one place there is apparently an intrusion of the diorite. This rock is mostly confined to the centre, where it is schistose in some bosses, and not so in others. In the southern boss it is veined by granite, as before described. In parts the hornblende and plagioclase are so intimately mixed that the rock is uniformly dark; in others the lighter-coloured felspar has segregated into lenticular flakes, but in such cases there are no signs of movement in the material of the rock. Nothing is ever seen below the diorite, of which the boundary is fairly marked on the Survey map. All round it are the clastic rocks, some, as in the northern tongue, being produced by its brecciation, the hornblende having mostly turned into chlorite and calcite. The rocks to the west are of the same ashy character, but usually develop more mica.

A second area runs from near Pont-rhyd-defaid as far as Llecheynfarwy. This consists partly of good crystalline diorite, partly of altered varieties of the same, in which a few particles of quartz and the alteration of hornblende into chlorite begin an approach to rocks of another type, from which, however, they are still distinguished, by their build, by the prevalence of plagioclase and the presence of sphene.

A third area, connected with the first, according to Dr. Callaway, by exposures of diorite near Pentrefelin, runs from Llandrygarn farm to Mynydd-Mawr farm, thus escaping from the surrounding granite, and being overlain by the Ordovician grits. The arrangement of the rocks is here very complicated. From Llandrygarn to Ynys Dodyn there are good diorites, with a band of granite in the centre at the latter place; but round Mynydd Mawr the diorites are inextricably mixed with the quartzose gneiss, and can scarcely be anything but intrusive.

The fourth dioritic area is that long tongue which skirts the east side of the granite, and figures truly as greenstone on the Survey map. As seen on the east side of Plas Llanfihangel this is in every way comparable to the rocks at Craig-yr-allor, where the foliated hornblendic rock is spotted with lighter flakes of felspar. Between this spot and the granite it is a very complex rock with well-marked granitic segregation-veins, which may serve to throw light on the origin of some of the smaller veins and flakes which spot the diorite breccias near Llecheynfarwy and elsewhere. At Yr-ynys-goed the "greenstone" is a broken mass, infiltrated with chlorite-veins, of quartz- and mica-particles so arranged as to suggest that it may be really a brecciated form of the grey gneiss. A little further to the south we come on the true grey gneiss with the diorite lying to the west, but just on the other side of the stream it is so broken up as to suggest a fault.

Besides the above four types of rock there is a granitic-looking rock at Bryngolen, and a remarkable andesitic rock just north of Lecheynfarwy; and Prof. Bonney has indicated that some parts in the hälleflinta-band consist of quartz-felsite.

These observations are not sufficient to give a complete idea of the granitic area, which would require the microscopical examination of every single exposure; but they are enough to show that no stratigraphical sequence can be truly made out, as every one that is suggested by one district will be contradicted by another. Hence, considering the nature of the rocks, we may regard the whole as showing the characteristic irregularity of an eruptive centre, in which acid and basic intrusions take place in basic and acid ashes and mud, and subsequent or consequent disturbances break up and mingle them all in confusion. The order of events would seem to be, first the protrusion of the diorite, under the influence of foliating forces; then the production of the hälleflinta, perhaps from the fragments of the grey gneiss, and of the pelite from the materials of the diorite, and these perhaps took place more or less simultaneously and repeatedly; but after all this came the intrusion of the granite, which is thus the most recent rock of the whole development.

The relation in age of the granite and its associates to the grey gneiss and other rocks of the eastern region cannot directly be proved; but that the former are younger is *à priori* probable, because in the Western District volcanic rocks form the upper part, and here also they are followed by the Ordovician; while it would require very complicated stratigraphy to make the grey gneiss the younger, to say nothing of the probable intrusion, in more places than one, of the granite into that rock itself.

d. *Bodafon Mountain to Llanerchymedd.*—The rocks which lie beyond the granite to the north-east are, with the exception of

Bodafon mountain and Craig Fryr, considered by Dr. Callaway to belong to his slaty series. In this, I think, he is right; they are the continuations northward of the hälleflintas and the pelites, while Bodafon mountain and Craig Fryr are modifications of the grey gneiss. The two most remarkable features in these pelites are the comparative fineness of the materials, and the unusual amount of sericite or chlorite developed in the interstices. With regard to the upper group the same kind of fine orientated dust which occurs in the extreme south here again produced dull sericitic slates with well-developed cleavage, such as are best seen at Man-addwyn and Trewyn, while to the north the great shoulder of Bodafon called Clegyr is a more compact and hälleflintoid variety of the same. The slopes on the west side of Bodafon are coarse and more quartzose, and recall the hälleflinta of Tycroes and Gualchmai, but they are very chloritic and also foliated. These are so comparable under the microscope with the finer-grained chloritic schists (though the latter are less altered) that one is tempted to include them in the lower series; but their microscopic aspect is not schistose, and their relations to the Bodafon quartzite is not one of conformable stratification. There is an interesting variation at the fork of the roads near Clorach bach, in the form of a pink massive limestone, now brecciated, and the fine dust-rock in the neighbourhood is largely impregnated with calcite. This feature reminds one of Cerrig Ceinwen and other sporadic limestones, but I have found no quartz-knobs here. A coarse grit-band occurs near the line of junction at Man-addwyn, and there is reason to believe that there are, or have been, other grit-bands in the series still coarser and more felspathic. In other areas the rocks most similar to these in general character are the dust-rock at Pant-yr-Eglwys, and the slates on the railway north of Llangefni.

The relations of these rocks to those of Bodafon mountain seem to be everywhere those brought about by a fault. This has been shown by Dr. Callaway for the south-west end, and it is equally true at Clegyr, where the fine-grained slate and the grey quartzite are seen side by side with not a foot's breadth between them. But I am not quite certain of the character and age of this fault. The Bodafon quartzite is a highly foliated rock with a large proportion of other ingredients than quartz, and the grains of the latter are of small size. It thus approaches in character some varieties of the grey gneiss, but, lacking any recognizable felspar, may properly be referred to the lower part, on the horizon of the Holyhead quartzite. It in no way resembles even the most stratified in appearance of the quartz-knobs. Seen from certain aspects, the bedding with a low dip to the S.E. seems evident. Thus it ought to be followed by chloritic schist, and so pass up to the finer shales; but it does not; on the eastern side fragments of the slate lie on it, which, though broken as now found, must have been the next succeeding rock. It is possible therefore that the fault may have taken place in connexion with the eruptive outbreak, and the finer dust-rocks have been deposited against the cliff thus formed. No doubt it has been faulted again—Craig Fryr has been cut off, Bodafon has been divided; but the original arrangement of the rock seems to be that of an unconformity as well as of a fault. This does not make the two rocks belong to two distinct and independent series. The circumstances, of course, had changed; but the eruption of large masses of rock must be accompanied by such changes. It is not at all to be assumed that there was only one eruption; the varieties of the "granite" indicate that there were several, and some portions of the dust-rocks may be subsequent to or derived from the earlier masses.

To the north-east of Llanerchymedd there is a lofty hill called Y Foel. It is used as a trigonometrical station, and largely quarried for road-stone. It consists of Ordovician conglomerate*. On the eastern side it passes into a great beach-breccia, in which there are numerous kinds of rock, of which I made a small collection, and found them to agree, each with each, with samples collected from the slaty series to the east, with the exception of a coarse blue grit, which as yet, I have not found among them. At the commencement, therefore, of the Ordovician era these older rocks must have been already carved into hills and valleys. Between Foel-fach and Tyddyn-bach is seen one of these hills in the form of brecciated grey gneiss, which may be traced some way round the southern slopes of the hill. We thus have a continuation of the older part of the series to the north, and an indication that the Ordovician here forms little more than a skin on the surface. Sir A. Ramsay speculates on the "greenstone" masses to the north of Llandyfrydog being also relics of the more ancient rocks; but those I have examined are examples of the black, highly crystalline diorites, in some cases picrites, which everywhere jut up amongst the more modern as well as the more ancient rocks, and seem to be of much later date than the latter.

Summary of the Central District.

This is divisible into two parts. In the eastern region we have an interrupted upward succession, commencing with a grey gneiss, whose lower part, at least, and its representative further north, in Bodafon mountain, is comparable to the quartz-schists of Holyhead, while its upper part may be more or less the representative of the chloritic schists. These rocks are continued on the other side of a fault by dark, chloritic ashes intermingled with slates and grits and other sedimentary deposits. At either end of this range they develop great agglomerates, and in the southern promontory exhibit the irregularity of volcanic eruptions, mingled with basic lavas. They contain also sporadic limestones, some of which are bedded and possibly fossiliferous and contain nests of jasper. There are also quartz-knobs, which may attain a large size and approximate to stratified deposits. The series may thus be compared with that which lies towards the north in the western district. In the western region we have the largest and most complex volcanic group

* Described by Prof. Hughes, Quart. Journ. Geol. Soc. vol. xxxviii.

in the island, the base of which is now exposed by denudation; as its central mass there is a great variety of granite-rocks, which are intrusive in many cases into those around them. Some of these surrounding rocks may be absorbed by the granite, and some may have been produced by its brecciation. But anterior to the granite, and intruded into by it, is a highly foliated diorite, which now occurs in more or less isolated areas. There are no agglomerates in this region, but the ashes are everywhere minute, whether in the more acid form, as hälleflintas, or the less acid, as pelites; and they are much impregnated with secondary minerals. Calcareous bands are also present among them. Some of the rocks found exposed between the masses of granite are of obscure origin, and by their thoroughly crystalline and foliated character, and yet their distinctness from the grey gneiss, suggest the possibility of their being truly Archæan. With very few exceptions the whole of the rocks in this district are composed of finer ingredients, and are more metamorphosed than those of the western district. They are overlain in all but their eastern margin by the basal rocks of the Ordovician, which everywhere contain their fragments. In spite of the separation by faulting, and the apparent unconformability at Bodafon, there is a unity of character and intimate association amongst all the parts that prevents us separating any part more widely from another than as earlier and later developments of one great system.

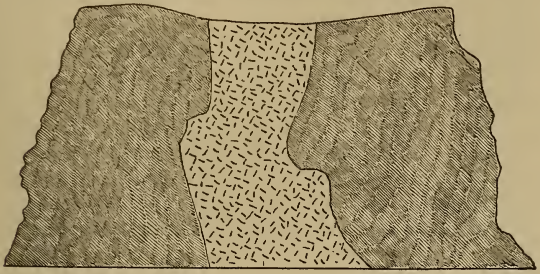
The District West of Traeth Dulas.

This is a small and entirely isolated area which, from its proximity to Bodafon mountain, is naturally described in the present order. It figures on the Survey map as "altered Silurian," though no reason for this is assigned in the memoir. Dr. Roberts has shown that to the west of Pen-lon a conglomerate which he calls Cambrian, but which is really the Ordovician basement-bed, lies over the granite. This is, in fact, carried on to the top of the granite area somewhat as marked in the Survey map, and is continued all along the northern boundary as far as Llaneiddog; on the southern side grits are seen at the junction in the road from Wern, and also in the stream that runs out at Traeth Dulas. It is thus surrounded by Ordovician basement-beds, and there can be no doubt of its being Pre-Ordovician. The conglomerate, however, which is in two or three bands, is not composed of the immediately underlying rock, but of quartz and jasper.

The district is not noticed by Dr. Callaway, and the sole description by Sir A. Ramsay is as follows:—"The granite is necessarily mapped chiefly as one mass with several smaller patches, piercing the associated highly metamorphic gneissic mica-schist on the south; but in reality they are inseparable from each other, so intimately do they seem to be interlaced."

This old island is, in fact, a mass of granite intruding into what appears to represent the grey gneiss. We have seen the latter come up as far as Llanerchymedd, and all the rocks that I have examined which are not granite are very clean gneisses of felspar, quartz, and white mica, for the most part beautifully foliated, but in one instance, in which the rock has a felsitic aspect macroscopically, entirely without foliation, though otherwise of exactly the same structure. Others not microscopically examined have a more slaty or pelitic appearance, and one, at least, is composed of such granitic materials as to suggest derivation from granite. Yet at the only spot where the contact is seen it has a thoroughly intrusive appearance (see fig. 13). The granite itself, which is best seen at Pen-lon, and

Fig. 13.—*Section in Quarry east of Pen-lon.*



1. Granite. 2. Schistose micaceous rock.

at Llaneiddog Bach, is different from that in any other district, being nearly pure white, of fine grain, and abundantly supplied with crystals of white mica. It has a very slight tendency to foliation; even this, however, is subject to variation, and the above description applies best to the variety at Llaneiddog Bach. Possibly this may be an older mass than any other, composed of the same material which supplied the grey gneiss, before the dioritic eruptions had commenced. It is remarkable that this district is one of the very few Pre-Cambrian ones in which lead-ores occur, though these are probably of Post-Ordovician date.

The Eastern District.

In spite of its easy accessibility this district has been sadly neglected. In many respects it is the most interesting, and in some respects certainly the most difficult of all to understand. Neither Sir A. Ramsay nor Dr. Callaway tell us much about it, and there is much more to tell.

Origin of the Hornblende-schists.—For the right interpretation of the larger part of the area the first necessity is to come to a conclusion with respect to the so-called "gneiss" or "dark schist." And the conclusion to which I have been drawn, much against previous prejudices, is, that it is all of igneous origin. And this I must commence by demonstrating*. Now the mass to the north of Holland Arms to a great extent lacks foliation, and is composed of large crystals of green hornblende, mingled irregularly with dusty felspar, in this respect agreeing with the less foliated masses at Craig-yr-allor. In the hill to the north of Y-graig there is a parallel arrangement of the more hornblendic and the more felspathic portions, producing a lenticularly banded rock, again to be matched at Craig-yr-allor and other localities in the central district. These hornblendes pass, in places, at their edges into a bright-blue tinted mineral, and the felspar into epidote. At the edge of this mass, on the south side of Y-graig, the hornblende, partially converted into chlorite, appears in isolated needles, mingled with numerous grains of epidote, the minute portion intervening being quite clear, and possibly quartz or felspar. This mass is clearly isolated in the midst of the grey gneiss to be presently described. To the east are two other apparently isolated patches at, and to the north of, the Gaerwen windmill. In one we have the lenticularly banded diorite, and in the other the same network of hornblende-needles and epidote grains, in part foliated and in part not. Now rocks of this type, for the most part beautifully and finely foliated, with exquisite contortions, pass into the glaucophane-rock which I have lately described †. A map of the distribution of these rocks amongst the mica-schists shows that they are mostly sporadic; so that though it might be possible to conceive of such an arrangement by complicated folding in more than one direction, the far more natural explanation is that of their being intrusive masses, especially as there is, within certain limits, considerable variation in their respective neighbours. Again, though some of these patches are foliated, others are not, and therein they agree with the rocks at Gaerwen, as they do in all other respects. These observations alone might suggest the igneous origin of the rock, but fortunately in the two cuttings made by the railway we get decisive proof. In that near Llangaffo, which I examined in the company of Prof. Sollas, we have the following section (see fig. 14). Entering from the east, we find the micaceous grey gneiss slightly dipping E., and it soon becomes contorted. This contortion is seen to be in connexion with a dark foliated rock, which intrudes upon it in an irregular manner. This is followed by another smaller intrusion, and in all the neighbourhood of these the gneiss is much disturbed; its folia are lost in immediate contact with the intrusion, and it looks almost like a hälleflinta, but is still gneissose in structure. Further west these phenomena disappear; the grey

* Prof. Bonney, indeed, calls one example submitted to him a diorite (Geol. Mag. 1880, p. 127); and Dr. Callaway has lately shown that the foliated rock at Gaerwen is of the same character (Brit. Assoc. Rep. 1887). Further than this no one seems to have considered the possibility of an igneous origin for these schists.

† Geol. Mag. dec. 3, vol. v. p. 125.

gneiss becomes nearly horizontal, and finally turns up and becomes darker at the end of the cutting. Now this intrusive rock is of similar structure to the patches we have been considering further west—with the same needles of chloritized hornblende and the same epidote-spots, and in part it is foliated and in part it is not. A similar section is seen in the cutting between Gaerwen and Holland Arms.

From these facts I can see no escape. The rock which thus behaves carries with it the igneous origin of all the rocks in the neighbourhood which are of similar character, and which surrounding circumstances prove may be intrusive.

In particular it must be mentioned that the rock which is coloured as "greenstone" on the Survey map, and runs in a narrow band from Tanhirion to Plasgwyn Lodge, is of the same character, as is that on the summit of Mynydd Llwyddiart and in the other bands in those hills, which run, so far as I have been able to trace them, irregularly among the gneisses.

The Gneisses and Mica-schists.—The grey gneiss of the Eastern has essentially the same characters as that of the Central District, and there can be no hesitation in correlating them. Nevertheless the mica in the former is on a larger scale, it is less constantly parallel, and there are often layers of crystalline granules apparently derivative. On the large scale we find three distinct varieties, dependent on the circumstances in which the rock is found. The normal type has the planes of foliation regular and distinct, and forms an easily recognizable brownish rock. It is often banded in more or less siliceous layers, and is subject to contortion without losing its character. This form is most prevalent on the eastern side. Secondly, when in the neighbourhood of the diorite, it may be compacted into a mass with the external aspect of a felsite, though its internal character is unobliterated. Such a mass is seen within a few feet of the diorite at Y-graig, and in actual contact with it in

Fig. 14.—*Section in Llangaffo Cutting.*

1. Foliated hornblende-epidote rock. 2. Grey gneiss. 3. Darker gneiss.

the Llangaffo cutting, and yet they are remarkably clean and perfectly distinct from their intrusive neighbour. This occurs in many different examples from various localities, most of which are near the margin of the visible diorite. A third and perhaps the most prevalent variety is that in which there is a great development of secondary mica. There may also be difference in constitution in these, since felspar seems to be less abundant, and they may with propriety be called simple mica-schists. In many of these the mica may be seen passing over into chlorite, and in this case the resemblance to the most altered forms of the chlorite-schists is very close. When they are greatly disturbed they lose all signs of bedding and become like bundles of pencils, whose points stand out like teeth from the fractured end of the rock.

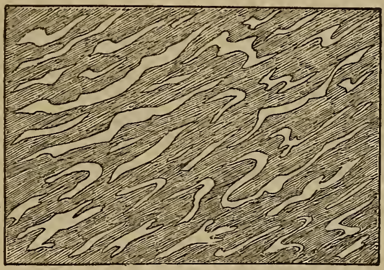
Such is the material which, with a remarkable exception to be hereafter described, and with its associate, the diorite, occupies the whole of the district south of the Holyhead road, and from thence on the western side of a line from Llansadwrn to Llaniestyn. On the continuation to the north it rises into the wild rngion of Mynydd Llwyddiart, where it has a far more quartzose aspect, which may in part be due to weathering; and on the east it forms the ragged ground of Mynydd Crwgarth, where the pencil-variety is most abundant.

It is on the edge of these rocks from Wern to Minffordd that the Cambrian rocks repose, and on the other side also they form the basis on which the Ordovician rocks repose. These latter consist of grits, well seen both south and north of the Holyhead road. To the N.E. of Llanfihangel Esgeifiog, at the farm of Rhyd-yr-arian, the basal conglomerates are seen, and in the roadside a great thickness of hard brown slates. Sir A. Ramsay records in these rocks at Plas Berw several fossils which he assigns to the Bala series. They are the same, however, that occur at Treiorwerth, and the earliest date that can be assigned to them is Arenig. We thus have evidence that the Cambrians came no further than the area of grey gneiss, and thus nearly the whole of Anglesey was dry land during the whole of the Cambrian Period.

The Northern Succession.—The upward continuation of the grey gneisses is mostly cut off by the intrusion of the diorite, and where this appears to die away on the north a rather wide valley separates the exposures of rocks. But as one or two spots on the east of the diorite, as Tyn-y-gors, are still like the grey gneiss in internal structure, though very unlike in external aspect, we may assume that there is a gradual passage. The rocks round Menai Bridge are of that irregular fine-grained type which is seen on the mainland in the western district, and is very distinct from the laminated true chloritic schists. They are therefore but little below the commencement of the pyroclastic series, yet it is impossible to draw any real line where one begins and the other ends (though it has to be drawn on the map). South of a line from Dinas to Garth Ferry they are most crystalline in structure and may thus be marked off from the rest. Yet in none of these, except at Tros-y-gors, is any regular foliation found. The plates lie any way, and are composed of the finest crystalline flakes. Beyond this line are various rocks, some intimately crystalline, such as those at Clawd-y-parc, north of Llandegfan, and at Coed Cadw, but the majority of those examined, as types of the rest, are either full of angular fragments or consist of fine unaltered dust. Of the first kind are the rock at Pen-y-parc, described by Prof. Bonney, that at Ty-gwyn south of Llandegfan, at Bryn Minceg, about a mile to the north, and at Coed Mawr, near Leanfaes; of the latter are the rocks at Ty Garw, near Pen-y-parc, at Llyn Bodgolched, and at Tyddyn, north of Beaumaris. As it is impossible to tell the structure of a rock without looking at it microscopically, I cannot say how far these are really typical of the rest, but only that the whole much more resembles the upper part of the series in both the Western and Central Districts than the lower or even than the fine-grained chloritic schists of the mainland. The characteristic features, however, sometimes come out far better in viewing the rock on a large scale than in a hand-specimen or a slide. Thus on the road between Garth Ferry and Beaumaris the roadside cliffs show most beautifully the arrangement of the materials, and it is certainly not that of an ordinary stratified rock, however contorted (see fig. 15). I take the twisted lenticles of

Fig. 15.—*Weathered surface of Rock, north of Garth Ferry.*

2



1 2

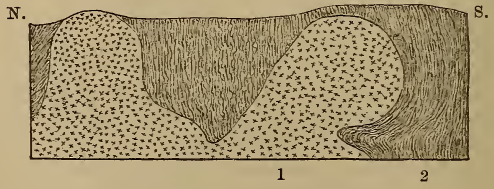
1. Quartz. 2. Schist.

quartz to be authigenetic, and caused by a kind of quivering, under pressure, of an ill-compacted, practically tufaceous rock. A kind of succession may also here be traced, for after this comes some compact rock, like the marbled slate, then some slaty bands dipping northwards and without cleavage. After this, in the road-cutting above, before referred to, are some beds with large quartz-lumps, then some disturbed rocks with much chlorite, such as is seen also at Gallow's Point, and, finally some lenticular pelite. No such variations as these are seen in the lower part of the series, and though agglomerates are apparently wanting here, we can still look to eruptive sources as the most probable origin for the material. Similar instructive varieties, of a slaty or marbled kind, with calcareous and quartzose bands, may be traced in the valleys north of Coed Mawr, where the rocks are beautifully displayed.

But the most important feature is the occurrence of the sporadic limestones and quartz-knobs. Of the former we have several examples. There are two on the road between Garth Ferry and Beaumaris; of these the northern one, at the letters "is" of Tyddyn-isaf, stands out into the road and is limited to a horizontal breadth of about 10 yards. It is broken by joints, and contains a purple slate band, which is torn into tongues and shreds in its midst and includes within it fragments of the limestone, which is compact and reddish in tint, like that at Cerrig Ceinwen. Had this rock been composed of the materials of an igneous rock, we should have had no hesitation in calling it intrusive. As it is, we may regard it perhaps as two adjacent lenticles, themselves, it may be, precipitated from calcareous springs, and which have subsequently been bent and broken, and carried the slate with them. It is not often that the actual relations of the limestone to the surrounding rocks can be seen so well as here; but even then we are not entirely resolved as to its origin. There is another limestone-knob of somewhat larger size, which is quarried near the upper road at Tyddyn-isaf itself; there are some which almost amount to pure limestones in the valley below Bryn-cogel, north of Beaumaris, and at a quarry now worked out where the limestone used to be burnt at Rhyd Eilian, west of Llandegfan. This limestone is mosaic in structure, and most like that near the Druid Inn.

The only quartz-knobs I have seen are one in Cadnant Vale, which is more like a reef, and that at Pen-y-parc described by Prof. Bonney. I certainly regard this latter as having the same origin as the other quartz-knobs, on account of the mode in which it occurs. The view of the north side of the pit, which has been worked for the quartz, is correctly described by the words "the upper surface is rather uneven;" but the appearances of the south and east sides are not adequately represented by this phrase. The eastern face is represented in fig. 16. Here the structural lines of the schist are

Fig. 16.—*Eastern face of Quartz-knob, Pen-y-Parc, Beaumaris.*



1. Quartz. 2. Schist.

vertical between the two branches of the knob, and curve round it on the southern side, where they also contain some lenticles of quartz. The southern face also shows the lines of the schist rising to and meeting the quartz-knob, and bent into a small synclinal between its two branches. The rock therefore has the characteristic behaviour of all these quartz-knobs, and has the special value that it shows more clearly than any other its relation to surrounding rocks. Besides these limestones and quartzes, there are seen some intrusive rocks of diabase-aspect, and others whose structure is of a pepper-and-salt pattern, and which I do not understand.

It is on these higher members of the series that the Cambrians here rest, instead of on the lower ones, as they do near Red-Wharf Bay; and we thus see how by tracing the sequence in these lower rocks we can best appreciate the unconformity of the overlying series.

The Area south-west of Mynydd Llwyddiart—This area is probably an isolated portion of the Central District, as it is on the other side of the great bounding fault which brings in the Ordovician between it and Mynydd Llwyddiart, and is intermediate in vertical position between the two districts. I do not think it is itself divided by a fault of any consequence, though doubtless it is broken. Commencing on the west, we find at Bryngwallen, near Llanffinnan, at Ty-hen and as far as Hendre, near Pentreath, the same kind of irregular chloritic slates that may be seen near the Mona Inn and also near Menai Bridge, that is, just below the commencement of the distinctly volcanic group, and these are followed to the east by the slates and breccias so well described by Dr. Callaway. He also refers to the limestones; these occur at Wugan-bach and at Pentreath, on the same line of strike, and jasper accompanies them, as at Cerrig Ceinwen. We are thus led to see that we have an undisturbed succession. The importance of this is the indirect evidence it affords of the essential unity of the whole series, since the appearance of one portion belonging to the lower part is always followed, if there be room, by a portion belonging to the upper part. The mode of occurrence of the limestone is also instructive here, running, as it does, amidst the purple slate in a curious pattern, and catching up fragments of the latter into its substance. I think there must be some fault also in connexion with the diorite-band, because there are associated with it on the western side some rocks which have the appearance of marbled slate, but are rich in the débris of the diorite, whereas on the eastern side the grey gneiss is close at hand. It may be, however, that the marbled rock is only a reassorted endoclast or, in other words, a fine fault-breccia.

Volcanic Group of Careg Gwladys.—At the other end of the district there is a remarkable development of rocks, which must, indeed, have been seen by Sir A. Ramsay as surveyor, but which does not seem to have impressed him, or to have attracted the attention of any other geologist. To my mind they are the most extraordinary and interesting in the whole island.

As we pass southwards from the railway at Llangaffo, over the well-exposed rocks overlooking Malldraeth marsh, we find, in about a mile, that slaty rocks of compact and banded aspect, which are distinct, under every aspect, from the grey gneiss, set in on the west, and are well seen near the farm of Glanmorfa. Passing south of Hafodty the two are seen on the opposite sides of the farm, the area of the former broadening out. Continuing the line thus indicated, though it is lost beneath the sands of Newborough Warren, we notice that it runs to the west of all the visible bosses of the schistose diorite. On the east of the line, where the road to Bodorgan starts across the marsh, is a quarry of reddish-purple slate, in which no crystallization has taken place; and similar reddish-purple slates occur in the hills and hollows behind Y Rholdy, and darker ones on the shore at that spot. Further south, we pass, by an unbroken sequence traceable all the way, through schistose ashes into the remarkable rocks now about to be described. Since the succession thus noted does not correspond to that on the north-east, since there is no sign of an anticlinal in the Llangaffo cutting, but rather the reverse, since the change in the rocks is rapid, and since the new rocks belong more to the central facies than to the eastern, I judge that they are cut off by a fault and thus correspond to the outlier on the north.

On the Survey map are marked some narrow bands of "greenstone" cutting across the cliff, and apparently less important than those on the other side of the bay at Dinas Llwyd. At the latter place we seem to be on the outskirts of an eruptive area; but here at Careg Gwladys we reach the very centre, and are reminded of the beautiful phenomena of Pen-maen-melyn near St. David's, which are here surpassed. The rocks are exposed in a series of what may be called buried cliffs and stacks, once washed and laid bare by the sea, but now covered with the drifting sand, which has rendered Newborough Warren as remarkable for its rabbits as for its grass-made brooms and mats. The bosses which here and there stand uncovered provide all that is needed by the geologist.

The first rock that we notice is a massive green one, which becomes more important as we pass on, till in a low mound on the

Fig. 17.—*View of Rock at Careg Gwladys.*

1. Diabase. 2. Limestone-slate.

level ground we find it surrounding and running in bands across a purple rock, the two so intimately blended that they seem but one. But the purple rock is sedimentary and calcareous, it is cracked in numerous lines, and the cracks are filled with calcite. The green rock, on the contrary, is a spherulitic diabase, while the purple rock in the immediate neighbourhood of the green is filled with streaks of andalusite crystals. We thus have before us the base of a lava-stream which has broken the rock into fragments, infused itself into their cracks, and moved them along in its stream (see fig. 17). Further on, this green and purple mixture rises up into a conspicuous mound, visible for several miles, standing out against the horizon. Here perhaps we have the surface of the stream, for it has the aspect of a Cyclopean rubbish-heap, with the fragments of both rocks buried in comminuted dust and weathering out in utter confusion. Nothing can compare with this but the termination of a torn torrent of lava, which has pressed and broken against its own débris and mingled lava, agglomerate, and ash in one frowning front. Still further south the diabase assumes greater importance in bulk, and weathers into some beautiful large spheroids, the interstices between which are filled with radiating zeolites, which weather into the aspect of a coral. It finally becomes a continuous ridge, which forms the promontory, and passes over into the east side of the island of Llanddwyn, but it by no means occupies a constant position in the series.

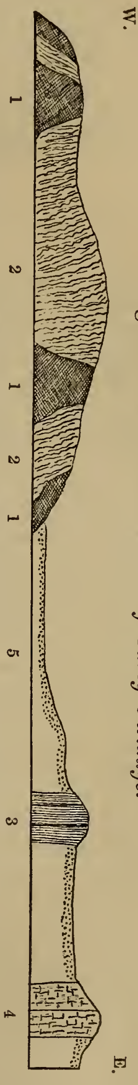


Fig. 18.—*Section on west side of Careg Gwladys.*

1. Diabase. 2. Calcareous slate. 3. Blue slate. 4. Limestone. 5. Sand.

Starting again at the first exposure of volcanic rock, we find the following section (fig. 18)—that is to say, the broken limestone-slate is followed to the east by a boss of blue slate, and that by a boss of limestone of the Cerrig Ceinwen type. The slate is the most Ordovician-looking slate I have seen anywhere in the series, but the interest centres in the limestone. Here it looks stratified, like that at Cerrig Ceinwen, since it stands parallel to the strike of the slate; but further south its mode of occurrence is not such as to suggest stratification at all, but rather to supply a problem difficult of solution. In the next outstanding boss (fig. 19), as seen from the south, the main mass of the rock is purple and green ash, not unlike in its structure to other ashy rocks seen at Dinas Llwyd; but in the centre there are two lenticular patches of calcite, and two other masses whose base is not seen, and round some of the edges of the calcite the ash is

Fig. 19.—*Section looking north, Careg Gwladys.*

1. Limestone, with slate-fragments. 2. Purple and green ashes and slates.
3. Redder ditto.

reddened, and looks shaly. In the same line, further south, are some bedded-looking calcite-rocks. Further still to the south, another boss, when looked at from the east, shows a large mass of calcite running irregularly and in strings amongst the ashes, which are also reddened in its neighbourhood. In the same boss, on the southern side, is a curious quartz-knob, of small size, ending upwards in a swelling, like the handle of an umbrella, and having the ashes or shales clinging round it. These intrusive-looking limestones are, in a certain sense, also calcareous breccias, since imbedded in them there are larger and smaller fragments of red shale up to one or two inches in diameter.

In attempting to account for these phenomena we can scarcely look to an organic origin for the limestone in its present state, and certainly not for the quartz. The crystals must have been formed from solution in water. In the case of the breccia, the fragments of which are not in the least arranged in bands, unless these were ejected volcanically, there must have been motion in the water. Any supposed folding of the beds which should produce the appearance of fig. 19 would be most extraordinary, and difficult to imagine in face of the uncontorted character of the blue slates. The only method by which I can explain the circumstances is to consider the limestones the product of calcareous springs, as I consider the quartz-knobs to be the result of siliceous ones. The red colouring is produced by oxidation in contact with the oxygen-carrying water. The fragments fall from the roof, or are broken off, and come at last to be imbedded where the precipitation takes place. If the final precipitation is external, we may have bedded limestones in which it would not be impossible to find organisms; if internal, the limestones will take curious forms according to the shape of the fissures which the water depositing them may be able to make. There is no reason why some of these bedded limestones may not be of great extent, like the travertines of Rome.

There are, in fact, in this very spot large masses besides those already described. Among the sand hills, to the east of the cliff, there is one long range of brown limestone and another of smaller size, but their relations to the other rocks are not seen. I have found some also on Llanddwyn Island, which shows too the agglomerates, diabases, and slates. The constant association of these limestones with rocks which we have independent reasons to believe are of volcanic origin, or show great local disturbance, indicates a relationship between them, just as we find calcareous springs most frequent and powerful in modern volcanic districts.

Such are the principal phenomena of this wonderful region, which is well worthy of a visit by any one interested in the ways of rocks whether of Pre-Cambrian or of modern date. Its nearest point is situated about four miles from Bodörgan Station.

Summary of the Eastern District.

The governing feature of this district is the existence of numerous masses of foliated diorite of peculiar constitution, which passes into the ordinary form near Holland Arms, and is proved to be of igneous origin by its identity with an intrusive rock seen in Llangaffo cutting. The main rocks into which this diorite intrudes are grey gneiss and mica-schist, the former rather to the west, and the latter, as its disturbed representative, in the east, and both rising into considerable heights in Mynydd Llwyddiart. The result of the intrusion is sometimes to indurate and give a felsitic aspect to the gneiss, and sometimes to produce contortions with a greater development of mica and chlorite. Towards the north-west these gneisses pass first into irregular chloritic rocks, comparable to those on the mainland in the western district, and then into a series of irregular ashes and marbled slates, which have the usual accompaniments of sporadic limestones and quartz-knobs, with occasional diabase-flows. On the western side, at either end, are found slices belonging really to the central district, being intermediate in vertical position between this and the eastern. In the north it commences with chloritic ashes and ends with the slates and limestones, showing the same association as in the north-east. In the south there is an extraordinary development of rocks, which behave in a manner only to be matched in the heart of modern volcanic districts. Different parts of the series are overlain by the basement Cambrian on the east.

The Northern District.

We are now in a position to examine the Northern District. Its description would perhaps have come more naturally between those of the Western and Central; but, in face of the doubts which its want of metamorphism has produced, we can study it with more confidence when justified by the results obtained in other areas. We have, on the one hand, Dr. Callaway referring the whole to his slaty series, and, on the other, Prof. Hughes suggesting that the rocks succeed the black slates of the Ordovician in time, as they do in space, and are consequently no older than the Bala group.

Boundary of the District.—It is stated by Sir A. Ramsay that its southern boundary is a remarkable curved fault, and this, Dr. Callaway, at considerable trouble, has confirmed. Nevertheless, according to the views of Prof. Hughes, this fault, if it occurs, can be of little stratigraphical importance, and Dr. Roberts has attempted to prove, by the evidence of two isolated inland localities, that it cannot exist. It is not, however, upon evidence of this kind that such a fault can be satisfactorily proved or disproved; we must have recourse to the general stratigraphy. Now in this Northern District a very definite sequence of rocks may be demonstrated. Being less metamorphosed, they are also, with few exceptions, less disturbed; and we can follow the strike of each with considerable accuracy. Now, whatever part of the series we may be on, from the lowest to the highest, and therefore, whatever class of rock is on the northern side of the fault, as soon as we overstep that boundary, we are immediately landed in black shales, which have a pretty uniform character throughout. This leaves no alternative but a fault or an unconformity; if it were an unconformity, the upper group would run parallel to the boundary, which it does not; and we might expect to find a conglomerate somewhere at the line of junction; but we never do. On the contrary, as Dr. Callaway has shown, the conglomerates are in the Ordovician, and they contain fragments of Cemmaes-limestone and of other rocks of the northern series. These observations and the fact that where the junction is actually seen, either at Porth-yr-ysgraff on the west or at Porth-yr-corwg on the east, it is admitted by all to be faulted, seem to be satisfactory proof that there is a bounding-fault throughout. Still no evidence beyond the fragments in the conglomerate is produced as to the direction of the throw, and the Northern District, so far as stratigraphy goes, might have been let down and not pushed up. In fact, at both ends where the fault is seen it hades to the north. We should thus have to consider it reversed, if the northern series be the older. This, of course, is no difficulty, but it shows that the age of the series cannot be entirely determined by the stratigraphy, but must be dependent on the character of the rocks themselves.

The Sedimentary Series.—This portion of the district, though subject to local contortions, has on the whole a pretty uniform dip towards the north, though variable in amount. Towards the west it is low and inclines somewhat to the east; in the centre some dips may be measured at 60°; and in the east, where any can be made out, they approach to 90°. We may therefore expect to find the lowest beds of the series at the southernmost bend of the fault, that is, at Llanflewin. Here the northern and western districts approach within a mile of each other, and the rocks in the former are thoroughly foliated and gnarled chloritic schists, more like the rocks of Holyhead than those of the neighbouring western district, yet really of the same type; and if any value is to be attached to lithological characters, either on the large or small scale, there can be no reason for not recognizing that in this Northern District the base corresponds to some part, probably rather the upper part, of the long chloritic series. The more or less quartzose rocks, such as those that form the rugged slopes of Mynydd Mechell, and the finer sediment, more impregnated with sericite, constitute the two principal types, irregularly distributed.

These more crystalline portions extend northwards to about the parallel of Bodewryd, near to Llanfechell, and south of Llanfairynghornwy. It is true that a number of felsite and greenstone dykes cross this area; but rocks already crystalline cannot be much altered by such dykes, and in fact they make but little difference either one way or the other.

The first rock in the ascending series which we can usefully associate with those above is the Llanfechell Grit of Dr. Callaway. This is much more fragmentary, and compares best with the ashy rocks seen at the crossing of the river Alaw, south of Llanfachreth. It certainly contains what may be fragments which resemble certain parts of rocks referred to the chloritic schists; but we find such parts in the rocks of Mynydd Mechell, and such fragments occur, though of smaller size, in some of the chloritic schists of the western district themselves. Some of these fragments, from their angular form and variation in character and size, may be volcanic contributions, others vein-substances; but none are indubitably schists, and we need not therefore suppose any unconformity, of which there is no stratigraphical evidence, between the rocks of Llanfechell and those of Mynydd Mechell. These grits are local and pass westward towards Mynydd Ithall.

Following these, on the rise, is a considerable mass of slates, of which some are ashy, some purple, and some sericitic and smooth to the touch, with an occasional band of grit. This includes the Rhosbeirio Shales of Dr. Callaway. They are well developed on the northern coast, between Cerrig Dehisgryn and Camlyn Bay, where they are more like blue Ordovician slates than any in the island, except those in the South-Stack Series and at Careg Gwladys. At the base they are coarser, and towards the top are several bands of grit with indurated cappings seen near Camlyn Point. Some of these, inland, are very silky, as at Bodewryd turret, and some have angular fragments of quartz and felspar sporadically distributed, so that volcanic contributions continued to be made. Similar rocks continue to Hafod Onen on the east, where they are somewhat altered by neighbouring dykes. It is here that Dr. Roberts supposes a passage to the Ordovician slates; but the rocks are very much broken.

The rocks which succeed are not very different in character, as a whole, but are greener in tint and more compact. They form a band which, commencing in Camlyn Bay, is three quarters of a mile broad at Cemmaes, and continues past Amlwch to the headland of Point Ælianus. When these are undisturbed they are singularly like the ordinary Cambrian or Ordovician slates, though not like such of the latter as are found in Anglesey itself; and there seem to be no reason why fossils should not occur, since no cleavage exists. This undisturbed state is continued as far as Amlwch, to the east of which wonderful contortions set in. That they are the same set of rocks which we find contorted on the east, and have been tracing uncontorted from the west, is seen from the fact that they are continuous on the strike, that there are a few spots on the west where similar contortions occur, and a few on the east where they are uncontorted, as for instance at Tal-drws, and that we can see the contortions gradually set in by tracing the rocks along the coast. I think these contortions afford a proof that the bounding fault is a push-fault and not a slip-fault; for in the latter case what is there to develop them more at this spot than any other? but in the former, if the thrust took place after the extrusion of the felsites of Parys Mountain, as it certainly did after the granitic outburst further east, these would afford a buttress against which the rocks could only be contorted, since they could not bodily move, while further west the soft Ordovician shales would offer no resistance; and it may be noted that the cross-fault which breaks the main one runs exactly on the boundary of the contorted and uncontorted portions.

Sir A. Ramsay is at great pains to show that foliation is here developed obliquely to the bedding. Unfortunately an examination of the ground leads to the conviction that he has taken the cracks which are naturally produced along the crests of the folds for the last relics of bedding, and the banding of the rock for foliation. These folds may be traced from mere undulations to sharp, and then to broken, contortions; and, strictly speaking, the rocks are not foliated at all; they are only banded slates in which some alteration by the development of flakes of sericite has taken place. There is a considerable variation in the fineness of the material. It is only where it is coarser, as at Crogan Goch, that cracks are produced. Where it is finer, like that which produces the marbled slate, the contortions produce a most beautiful damascened pattern, without a trace of cracking, as at the junction of the roads near Ty Newydd. Any such bedding as Sir A. Ramsay supposes would, moreover, be quite irreconcilable with the surrounding stratigraphy.

Towards Llaneilian and Point Ælianus still coarser beds set in on the same strike, and are well exposed on all the cliffs of this sea-torn promontory. These are practically ashes, since they contain angular fragments of quartz and felspar in a much finer matrix, in which also there is abundant sericite. The supposed cross-foliation here described by Sir A. Ramsay is very evident on the ground; but when a sample of the rock exhibiting it is examined microscopically, it is seen that the supposed lines of foliation are, in reality, well-marked secondary cracks in which a distinct formation of sericite has taken place, but which in no respect interfere with the structure of the intervening substance. True foliation is only general in the lower part of the series round Mynydd Mechell; in all the rest there is but one type of material, in which sedimentary dust is more or less mingled with angular fragments of apparently volcanic origin, indiscriminately introduced.

The sporadic and intrusive rocks associated with these sedimentary deposits are of considerable interest. Among the former, we find that the mass marked "greenstone," to the south of Llanfechell, is partly serpentine and partly a brecciated purple limestone, once worked as Mona marble. Another mass, marked "serpentine," at Tregela, is no longer exposed ; and the only rock that can be found there is a solid purple limestone like that of Cerrig Ceinwen. I have found no quartz-knobs in this portion of the series. There are also numerous intrusive dykes of both basic and acid character. Among these are the "greenstones" and "felsites" in the west, as well as sundry isolated bosses, not marked upon the Survey map. Most of these may be referred to a later portion of the same period, partly because they cease at the fault, and partly because, in the case of the felsites, they show peculiarities of structure similar to those of known Pre-Cambrian eruptions. Some of them may, however, be of the age of the Parys-Mountain felsites. They cannot here be described.

The disturbed Volcanic Group.—This is by far the most interesting portion of the district. The rocks composing it must have been formed during a period of much greater activity, either volcanic or disturbing. The line of separation between these and the more sedimentary facies is much more clearly marked on the west than on the east. A rapid and almost sudden change may be observed when we pass a line which cuts off the northern corner of the promontory on the east side of Camlyn Bay, and then runs from Porth-y-gwarthog near the shore to the north side of Cemmaes pier, thence near the Amlwch road, and so on to Porth Llechog on Bull Bay. The district north of this line may be roughly described as full of agglomerates, coarse ashes, quartz-knobs, limestones, and conglomerates.

Beginning at the west, we find agglomerates on the headland of Trwyn-pen-careg. In the next bay a return is made to the slates, but in the succeeding headland north of Porth-y-gwarthog agglomerates recommence, and ultimately in Porth-wnal there is wild confusion in the rocks. The most remarkable feature is the occurrence of great quartz-lumps, which are of all sizes and shapes, and lie promiscuously in agglomerates of slates, grit, and dust; and the whole is intruded upon by greenstone dykes, which are both banded and prismatically jointed. These lumps appear to have been thrown into their present position; but, as there is nothing like them in the neighbourhood except those which occur under similar circumstances, we must seek their first origin not far from their present site. They must have been in existence previous to the formation of the agglomerate, which we cannot here refer to the action of a crush-fault. The nearest quartz-knob, which, like all the others, is quite isolated, is at Mynydd Wylfa. In Porth-yr-wylfa is a long tongue of limestone, ending off roundly in the ashes, and marked with browner patches, as if it were sporadically dolomitized. And then in the headland of Pen-y-parc we get another agglomerate of quartz-lumps and ash, as in fig. 20.

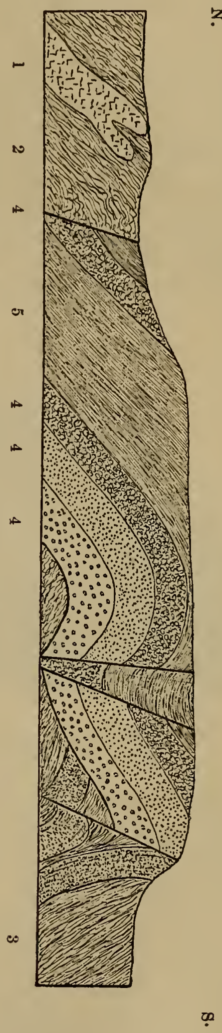
Fig. 20.—*View of Pen-y-parc, Cemmaes, looking east.*

1. Quartz. 2. Unstratified ash.

Similar phenomena are seen along the coast all the way to Cemmaes, sometimes with irregular curling masses of limestone, and sometimes with similar ones of quartz.

On the east side of Cemmaes matters are on a larger scale. First we have the great limestone-quarries of Trwyn-y-parc, in which there are two bands of tolerably pure limestone, separated by a narrow band of calcareous shale. There does not seem to be a trace of any organism in it, and it is entirely crystalline in structure. It is here, no doubt, in the form of a lenticular bed. On the north side of this we again reach a district which is cut up by trough-faults like that around Penbryn yr Eglwys—the very reverse of the state of things on the east of Amlwch. Fortunately the Ordovician shales are black, and can be easily recognized. One of these slices we find in Porth Badric, in the midst of irregular ashy rocks. Beyond this comes a quartz-knob, forming the promontory Trwyn-y-baurth; it is, as usual, isolated, and the ashes are in no way altered in appearance by its presence, but are soft and easily decayed. Moreover, the phenomena here are those of ordinary faulting, resulting, not from pressure, but from tension. We cannot get this quartz-knob into its place by folding.

The coast at Llanbadrig church is one of the most remarkable and instructive spots in the island. The groundwork is ashy, as before, and some of the ashes are calcareous and show structural planes; amongst these intrude (there is no other word to use) the masses of crystalline limestone which run out into the headlands. In this there is no stratification and no constancy of direction, and it runs across the lines of the ashes, or carries portions of them along with it. It is occasionally dolomitic, and the whole is intruded on by some parallel narrow dykes. The most remarkable feature, however, in the limestone is the oolitic character of some parts. The interior of the grains is not organic, but consists of finely crystalline mosaic limestone, like fragments of the limestone itself and like the matrix in which the grains are imbedded; such fragments are surrounded by two or three bands of more earthy limestone, and there are often two or three grains within another grain. In fact, larger fragments of the rock with several scattered grains may themselves be coated with earthy limestone, and be imbedded in a more crystalline matrix. Such material forms a very considerable portion of the rock. We can understand its formation by the action of calcareous springs, which first deposit, then break up and roll the fragments, and coat them with calcareous matter. Such oolites are formed by the calcareous springs of the Solfatara, and I can conceive of no other origin for these limestones. They are obviously subsequent to the ashes.



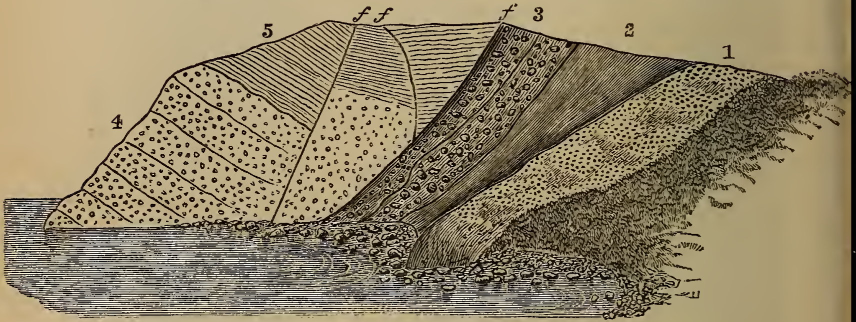
1. Limestone. 2. Shale. 3. Ashes. 4. Conglomerate. 5. Black shale.

Fig. 21.—*Section at Ogo-gyfwr.*

The next promontory, forming the eastern face of Ogo-gyfwr, brings us to the summit of the series and introduces the overlying rocks, which, though they have not been searched for fossils, we may recognize as the Ordovician as soon as the basement-beds have given place to slates. By climbing down the face of the cliff and clambering over the rocky ledges the following section (fig. 21) may be examined bed by bed. Here the ashes on the south are nearly vertical, and finish off by an infusion of quartz against a strong fault now indicated by a slanting cave. On the north side of this fault we find horizontally undulating conglomerates lying on well-bedded quartzose rocks of the ashy group, and terminating against the fault. The lowest conglomerate is of small pebbles; above this are variable grits, and then a larger conglomerate. After an interesting interruption in the shape of a pair of trough-faults letting in a synclinally disposed slice of black slates resting on a coarse conglomerate, the series is continued upwards by a mass of black slates continuing for some distance, and finally appears another band of conglomerate. Here the sequence of these rocks ends, and their place is taken by contorted slaty rocks of the older group which become gradually calcareous, and pass into the familiar limestone. We thus assume a fault between the conglomerate and contorted slates; the shore is inaccessible, but there is an open cave in the proper position. The importance of this section is, first, that it shows that the Ordovician slates here seen are near the base, and that they are underlain by conglomerates; secondly, that we can compare the rocks, which here correspond in character with the Ordovician elsewhere, with the underlying ashy series, and see that they still remain perfectly distinct; and thirdly, that we can trace an unconformity. The pebbles of the conglomerate are chiefly quartzose, such as might have been derived from the underlying beds; but they have no special character which should limit them to such a source.

A little further east, conglomerates appear in association with the slates, and then comes on again a mass of limestone, possibly faulted into its present position and forming the western side of Porth Llanlliana. On the east side of this bay we find another section, greatly differing from the last, and introducing this new conglomerate in its place, as seen in fig. 22. On the south side, that

Fig. 22.—*View in Porth Llanlliana, looking east.*

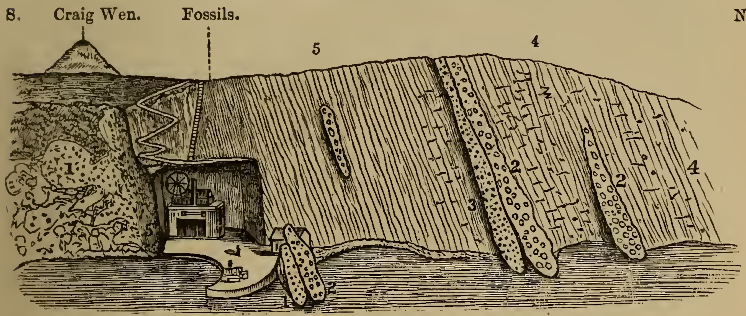


1. Quartz-knob. 2. Purple shale. 3. Great conglomerate. 4. Finer conglomerate. 5. Grey shale. *f.* Faults.

is, at the base of the sequence, is seen a mass of quartzite; above this is a wedge of ashy rock getting smaller at the base—and this is followed by a great band of red jasper-conglomerate, the pebbles in which are very large. The series is then cut off by a fault, and the rocks on the other side are broken. First comes a wedge of purplish slate, apparently faulted in, then a slice which has grey shales on the top, and seems to rest on a conglomerate at the inaccessible base; then another fault, and then some similar shales lying certainly on a considerable quantity of conglomerate of finer character, which continues to the base of the cliff. We may safely take the upper conglomerate and shale (4, 5) here to be Ordovician, though the latter is not black; but the great red conglomerate below seems to be too intimately connected with the quartz-knob to belong to a distinct system; and if it does not, then we lose all sight of the basal Ordovician before reaching Hells Mouth, where only the quartz is left, and the basal Ordovician never appears in the same form again. The quartz-knob, like others of its kind, dies out on the east side; and *below* its expected position are some very Ordovician-looking slates, though not like the black slates of the district nor the grey shales just seen; and in these there is a lode of copper.

A little further east rises the greatest quartz-knob of the district, called Craig Wen, and worked for "China stone." This lies, as regards position, above the slates just mentioned, and some red quartz-conglomerates cling closely to its western side. It is immediately to the north of this quartz-knob that the ashy slates which have proved fossiliferous occur. We might expect some light to be thrown on the sequence in the cliffs of Borth Wen; but, unfortunately, both quartz and conglomerate die out before reaching it.

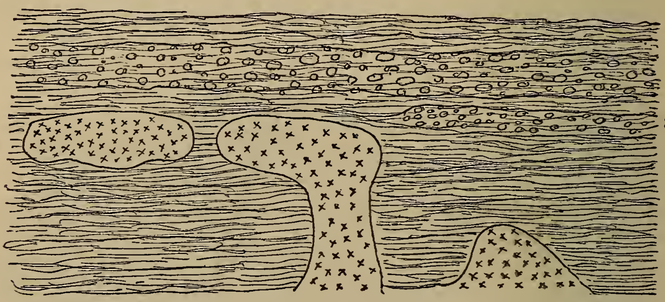
Fig. 23.—*View of Borth Wen, west side.*



1. Quartz. 2. Red conglomerate. 3. Fine conglomerate. 4. Ashes. 5. Slaty ashes.

What we actually do see is exhibited in fig. 23. On the south side the rocks appear thoroughly confused, masses of quartz roaming about, under no law, among beds of a soft and incoherent character. This might perhaps be attributed to disturbance, but it is much more suggestive of the irregularity caused by the motion and deposit due to siliceous waters, in fact the underground branchings of the quartz-knob. To the north come on, rather rapidly, more regular slaty rocks, of ashy character. I found it impossible to determine the exact way in which these are connected with the disturbed rocks below; certainly the boundary is not a clean one, and no additional disturbance can be made out. It is in these rocks, at the top of the tramway, that Prof. Hughes has discovered fossils. On the shore, by the pier, stands a mass of quartz, and on its northern side a large mass of coarse red conglomerate. These are followed on the shore by similar ashy shales, and these ashy-looking rocks continue to the end of the cliff, becoming very irregular and losing apparent stratification, and containing several bands of finer and coarser conglomerate, dying out above, as marked in the figure. Before attempting to discuss this section, we must obtain the data offered by the continuation of the series on the eastern side of the Borth. Passing round the shore, we encounter several knobs of quartz and limestone, which now add nothing to our information, and then at Porth Pridd we find another of the Ordovician slices let down by faults. This fragment consists of the ordinary black shales with indurated bands, showing that the true Ordovician remains constant here. The fault on the north is an overthrust fault, and the rocks beyond it are the ashy shales, with fragments of limestone cemented in the fault. In these shales we soon find small quartz-knobs, and further east these form a well-marked crest. This crest is so instructive that a plan of it is given in fig. 24.

Fig. 24.—*Plan of the Hill-crest, west of Porth Llechog.*



1. Laminated ashes. 2. Quartz. 3. Quartz-conglomerate.

Here the direction of the lines of subdivision in the ashy slates, which are parallel to the bedding, as indicated by the changes, is along the length of the crest; there is no disturbance or irregularity. The quartz-knobs may be seen on the lower slope and creeping up the hill across the bedding, and then turning round and lying in the direction of the bedding, the several beds coming directly against them. Beyond these quartzites, and therefore higher in the series, yet closely associated with them, is a band of coarse conglomerates whose pebbles have been derived from the quartzite itself; they come in with the quartz, and they disappear with the quartz, and the size of the pebbles diminishes as we pass upwards from the quartz. The natural interpretation of these phenomena is that the quartz has been forced across the edges of the ashes; and the simplest method of accounting for this is by hot siliceous springs, the quartz of which has immediately consolidated, and has then been broken up and rounded by the waves without any cessation of the ordinary deposits. In structure this quartz-knob is one of the purest, there being no recognizable rounded pebbles, but all being composed of the polygonal network.

Traced further to the east, this quartz dies out with the crest; but on the south side of the line there are several smaller quartz-knobs at various horizons, and on the north beds of finer conglomerate are intermingled with the ashy slates, which have a strong resemblance to those of Borth Wen, and these continue to the coast. The whole of the ashes and conglomerates of this group are highly cleaved, with a cleavage-strike parallel to their bedding. Neither conglomerate nor quartz-knob is to be found in the coast-section of Bull Bay; and, in spite of a careful search, on two or three occasions, between the slates of Amlwch and the ashy rocks of Trwyn Melyn, I have not been able to fix on any line of break at all.

In considering the bearing of these facts, it must be admitted that if no fossils had been found I should unhesitatingly have considered all the rocks seen east of Porth Llanlliana, except the undoubted Ordovician slice at Porth Pridd, as belonging to the Pre-Cambrian series. The occurrence of conglomerates naturally suggests a new series; but when the rocks above and below the conglomerates are so similar, and every attempt to find a line of separation on the coast, where all is clear, has failed, one is fain to admit a conformable succession through the whole; and this view I still hold to be most probable, and am quite ready, if possible, to receive the fossils as characteristic of the system. Against the belief that these are true Bala fossils we have the fact that they are not like any other fossils in the island, though Bala beds are supposed to be found elsewhere; and the rocks that contain them are not like the other fossiliferous beds, which are found so close at hand. Even if they were Bala fossils, they could not possibly carry all the rocks of the northern district with them, since these are so clearly identical with those in the eastern district which are overlain by Cambrian, and they are in this very neighbourhood overlain by typical Ordovician. We should therefore have to find a fault or unconformity somewhere; none has yet been found, though it *might* be obscured by cleavage, and conglomerates might suggest it; but even thus it would be difficult to account for the neighbouring Ordovician conglomerate at Ogo-gyfwr, &c.

As regards the fossils themselves, they are referred to *Orthis Bailyana* by Prof. Hughes, and this fossil is said by Davidson to be associated in Wexford with *Leptœna sericea* and other undoubted Ordovician fossils. By the kindness of Prof. Hughes I have been able to examine his fossils, and one of them is undoubtedly *O. Bailyana*, while others do not seem identifiable with any described species. It will therefore become of importance to examine the true stratigraphical position and age of the rocks in Wexford in which this fossil occurs.

Summary of the Northern District.

The district is isolated by a curved fault, which is broken near Parys Mountain, and has a general hade to the north, along which the older groups have been pushed up over the black Ordovician shales. The lowest beds are true chloritic schists, not far removed in character from the nearest rocks of the same kind in the western district. They become coarser, more quartzose, and more contorted in the heights of Mynydd Mechell, but ultimately obtain a pretty uniform E. and W. strike. They are followed by ashy grits and sericitic shales, and then by a broad band of green slates, which are undisturbed and younger-looking in the west; but in the east, where the Parys Mountain has interfered with the motion, they have become greatly contorted. Towards the far east they become gritty again. They contain sporadic nests of limestone, and are scored by dykes, which were intruded previous to the faulting. The higher part of the series consists of laminated and, often, cleaved ashy rocks, which become agglomerates in the west, and contain large deposits of precipitated limestone and pure quartz-knobs, irregularly placed and crossing the bedding. Above these knobs, and derived from them, there are large conglomerates; but they are succeeded in most places by ashy rocks similar to those below, which, in one place, have yielded fossils. The whole series is unconformably overlain by another set of conglomerates leading up into black shales, which are, in other places, let down between faults and contain Ordovician fossils.

The District East of Parys Mountain.

Proofs of the Pre-Cambrian Age of the Rocks.—This district is entirely isolated from the northern, though by a very narrow band. It is coloured on the Survey Map as "altered Silurian." It is therefore necessary to prove that it is rightly included in the description of Pre-Cambrian rocks. This is not so easy a matter as in the case of the neighbouring district to the south of Traeth Dulas, since here there are no obviously overlying basal Ordovicians, but the main boundaries are faults. These faults, as seen on the sea-shore, have been well determined by Sir A. Ramsay, and have been again more recently described by Prof. Hughes*. Tracing the northern fault inland, we find it pretty correctly laid down on the Survey map, and the rocks on the two sides remain everywhere most distinct, as is well seen on the road between Rhos-manarch-mawr and Rhos-manarch-ganol, and by the cottages of Pen-rallt. Further on we find a strip of dark Ordovician shale between this belt and the Parys Mountain. The boundary on the other side of the belt is obscure, but black Ordovician shale is seen quite close to the granite in Nebo Street. Tracing the southern fault inland, it is not so clear, but the beds are disturbed and broken, and no conglomerate is seen. There is thus only left the boundary between Plas Ucha and Nebo, which is in a direction at right angles to the other boundaries, and is not therefore their natural continuation, and need not be faulted. It is along this line that the quarries quoted by Dr. Callaway, at Nebo, are worked in the basal Ordovician conglomerate, which is immediately followed

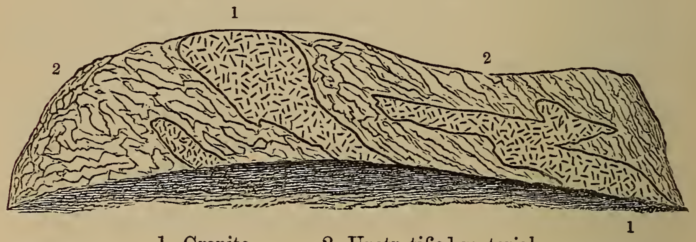
* Quart. Journ. Geol. Soc. vol. xxxviii.

by the black shale. There cannot now be the slightest question as to the character and age of this conglomerate. Unfortunately the line is so much broken by small faults that it is unfitted to lead to any stratigraphical conclusions. Still the basal conglomerate is there; on one side is a large area of Ordovician, on the other a large area of another group of rocks. Thus, in horizontal distribution, the conglomerate is intermediate between the two, and it seems impossible that the second group of rocks should be younger than it. Thus there is reasonable ground for treating this district as not "altered Silurian," but as Pre-Ordovician; and if Pre-Ordovician, from what we have elsewhere seen, then Pre-Cambrian. But there are still some difficulties on this head to be overcome. If we draw a line from Nebo quarries in the direction of the general faulting, we find the conglomerate continued at least a little way along it; and where it emerges on Porth Lygan, there are strewed on the shore immense blocks of the same kind of conglomerate, hiding, with other blocks, the solid rocks below. At this spot, too, Sir A. Ramsay states that there are 60 or 70 feet of black Ordovician shales, not now exposed, and the valley, which here descends to the shore, indicates soft rocks. There would thus appear to be a band of Ordovician running through the heart of the district, and we cannot wonder that Prof. Ramsay considered the granite intrusive in its midst. But, as we shall see, the district is not all granite, and such a band would not correspond with the lie of the other rocks. We may therefore better account for this strip by another parallel fault to bound it on the east. But, again, there is marked on the Survey map a tongue of granite running across the fault on the northern side and into the Ordovician shales. If this were correct, the granite, at least, would have to be late Ordovician in date. I have therefore examined the ground with care. The supposed tongue lies entirely in a large grass-field, and very little live rock can be found. The only knob in which anything is seen consists of a gritty band of the Ordovician, and not of granite. I conceive therefore that this tongue is simply an error, which would be of slight importance if the granite had been proved Ordovician elsewhere.

Description of the Rocks.—At first sight the rocks of this district seem entirely different from anything we have seen before; but this is because the examination naturally begins on the sea-coast, where their true character is revealed by weathering. But, seen inland, we do not lose all clue. At Dryslwyn, south of Parys Mountain, and not much more than a mile from Pen-lon, the aspect of the rock is that of a pelite; but when examined microscopically it is seen to consist of tolerably clean foliated quartz and felspar with mica in parallel lines; in other words, it corresponds to the ordinary grey gneiss, differing only in not being quite so clean. Then by the outer rows of evaporating pools in the low ground we find granite passing into mica-schist, reminding one of the district south of Traeth Dulas; and the low parallel mounds yield a dark foliated rock, which is micaceous diorite, only differing in the presence of mica from the coarser varieties of Craig-yr-allor or Holland Arms. This does not appear to reach the coast, nor even to cross the Nebo road. In some parts the felspar is so separated from the darker ingredients in patches as to give the rock the aspect of an impure granite; and the granite itself, at its purest in this immediate neighbourhood, only differs in having little or no hornblende. Thus, as noted by Mr. Allport, quoted by Dr. Callaway, there is a passage from one into the other which we have nowhere else seen. There is also here a quantity of indurated rock in which no mica is developed. None of this is ordinary or metamorphosed sedimentary material except, perhaps, the grey gneiss of Dryslwyn.

The type of granite in the main mass to the north of Nebo is of a different character. It contains no ferruginous ingredient, and its mica is white. It thus corresponds to the granite of the district south of Traeth Dulas; but when well preserved it is seen to be much coarser in the grain, and its felspars are brownish in tint, giving the rock a peculiar colour. Moreover, where the rock is most massive, mica appears to be absent. This granite is represented in the map as running in several separate tongues; but these tongues must not be taken as actually representing where the granite is, which would be impossible. Thus, in a quarry near Pant-y-bwlet, visited in company with Prof. Green (see fig. 25), the

Fig. 25.—*Quarry near Pant-y-bwlet.*



1. Granite. 2. Unstratified material.

granite is seen to be running in numerous bands of irregular form and in no special direction in the midst of material without character, which may pass under the general name of pelite. The centres of the granite portions are quite clean, but there is no definite boundary between one rock and the other. This behaviour of the granite is more interesting than its nature, and we find the same kind of thing wherever a fresh exposure of rock enables us to see the two kinds in conjunction. Thus, at Bryn-fuches and at Rhos-manarch certain portions of the rock-face might be called granite or other crystalline igneous rock; but how it ends or where it goes it is utterly impossible to say. The rest is the same unspecialized pelite, which may become micaceous and so appear schistose in places; so also near the Nebo quarries there is a boss of the brownish granite. Standing isolated in the Ordovician, and between the boss and the road, there is another, in which quartzose, micaceous, and calcareous materials are inextricably mixed. All the exposures inland are of this general character, one kind or other of the materials prevailing; but near the boundary along the northern fault the rock next the granite is clearly foliated, and under the microscope is seen to differ from ordinary grey gneiss only in having certain patches decomposed, and containing much more felspar than quartz.

We are now in a position to examine the coast. Here nothing is covered; every inch of the rocks for more than a mile is visible and accessible; if there is any confusion, it must arise from the nature of the rocks. It is well nigh impossible adequately to describe the extraordinary phenomena here revealed. The description by Sir A. Ramsay is very faithful; but Dr. Callaway seems to have been altogether led astray. If, however, we really saw on this coast the proof that metamorphism could produce these rocks out of the neighbouring black shales or their associates, it would be a still more wonderful place than it is. The main feature is the extraordinary way in which the harder and more crystalline portions go in and out and lose themselves in the softer and more stratified. At one place we find the whole cliff-side for many yards composed of crystalline rocks; from this they pass over into isolated knobs on the surface, and so to lumps or strings amongst the softer material, and the lumps may degenerate in size until they are no larger than pebbles. It is thus that such confusion is produced; but it is seen to be a confusion due to their origin, and not to disturbance. They have undoubtedly been squeezed, the spectral polarization of their constituents proves that; but if this has brought about their foliation, it has also contorted the lines of foliation, which are related to the occurrence of the more crystalline masses, and do not amount to folds. This is particularly the case with the portion south of Porth Lygan, where the harder parts are fewer.

The microscopic structure of these rocks will not allow us to look to progressive or sporadic metamorphism to account for the differences within the mass, still less, therefore, for the mass itself. The rocks, which look in one place like pelites, in another like mica-schists, are, in fact, not like any of the rocks so named before; they consist of the same minerals as the crystalline rocks themselves. Quartz is one of these, and is perfectly clear in both, only larger in the crystalline portions. Felspar, spotted with spangles of calcite or sericite till there is scarcely any original felspar left, is the next abundant mineral in the crystalline portions; but there is often no felspar left or produced in the ground-mass of the others. The main difference is the indefinite amount of mica produced in the schistose and the corresponding amount of unaltered dust in the non-schistose rocks; another important difference is the development of garnets in those that cannot be called granitic. From this we learn that there are actually more varieties of minerals in the non-granitic than in the granitic masses, and these are such as require fresh ingredients. We cannot, therefore, call the latter more metamorphosed. We may, however, look upon the entirely crystalline portions as having taken up their character under the influence of heat, and so rendered themselves less alterable by the aqueous agents of metamorphism, which would act upon the less crystalline portions in a different manner, and so introduce fresh minerals, and bring with them, if necessary, the fresh ingredients required. But what can be that form of heat that shall thus act so sporadically? In considering this, we must not forget the stratigraphy, nor overlook the minor indications which special forms of rocks may afford. Now, besides the hornblendic rocks further west by the side of Parys Mountain, there is, near Porth-y-gwichiad, a mass of rather fresh holocrystalline rock which is composed of calcite, enstatite, and augite, apparently belonging to the series, and not a later dyke; and not far from the same spot there is also a mass of fine felsitic dust, with parallel flakes of sericite, just like a rock we find at Pant-yr-Eglwys; and these so-called granites themselves contain more acid and more basic varieties. How can we account for all these by the agency of heat upon the same set of rocks? But all of them are of such materials as are found in volcanic regions, and the whole would be accounted for if the holocrystalline portions represented the lavas, and the other parts the ashes of an eruptive area. The question then arises, Are the products of a modern volcano of similar size inextricably mixed in the same way as these are, and is it as difficult there to separate one part which may be called a lava from one which is an ash? To solve this question I visited last spring the volcanos of Southern Italy. Here, in the Phlegræan fields and in the Island of Ischia, I found the crystalline and fragmentary portions and the eruptions, when occurring together, to be in the same confusion. The trachyte has no clear boundary from the trachyte-tuff. The finer materials become stratified, and in the more compact and less stratified portions irregular hard lumps occur composed of similar but more crystalline materials. Still closer resemblances are seen in the miniature volcanos of the Lipari Islands, where the great variety of rocks which unite to form the cones and surrounding heaps in Lipari itself and in Panaria, though occasionally separable enough into lava-flows and ashes towards the centres of eruption, are inextricably mixed up at their margins, and the same confusion arises. The geologist in Anglesey is puzzled to account for the curious association of rocks of different structure, yet of similar materials, that he there finds brought together, and the geologist among the volcanos of the Mediterranean is equally puzzled to explain how similar materials are likewise arranged; but the problem is the same in both cases, and we may safely here apply the principle, though it be not of universal application, that similar results arise from similar causes. This, at least, is the most probable solution. In other words, the rocks near Llanenllwyfo are not of ordinary sedimentary origin, but are the products of a small and, for the most part, ash-producing volcano; and the confusion and apparent mixture of more and less crystalline materials is incidental to such an origin. This conclusion, based on what is seen where the rocks are best exposed, affords a confirmation of the interpretation put upon similar rocks when their surroundings and relations are less clear.

Exclusion of Parys Mountain from the Series.—Both Dr. Callaway and Dr. Hicks insert this "mountain" as Pre-Cambrian on their maps, and the former gives a description of its volcanic rocks. He admits, however, that they "are quite distinguishable from any other rocks in Anglesey," and has no better reason to assign for their age than that they are not unlike some Pre-Cambrian rocks in Shropshire and at St. David's. I cannot see the slightest reason for their Pre-Ordovician age. Dr. Roberts says there is a gradual passage from the contorted rocks of Amlwch into the slates of Parys Mountain; but this has been shown to be incompatible with the stratigraphy, and the change seems to me to be both sudden and marked. The admirable description of this "mountain" in Phillips's 'Ore-deposits' shows that the higher part is due to a long reef of quartzite and two parallel bands of felsite, between which is the copper-bearing nest with black shale" in which Prof. Hughes records Ordovician Graptolites. The quartzite is full of crystals of iron-pyrites, and the felsites weather into slate-like bands; but I do not recognize any resemblance to any Pre-Cambrian rock that I happen to know. Moreover, as Dr. Callaway has already shown, the northern end of the felsite at Pensarn is brecciated, and the knob a little beyond is a rhyolite, facts which indicate a contemporaneous origin. In these parts they most resemble the intrusive felsites of Mynydd Mechell, and, if similarity is to be any guide, might well be referred to the same age. But here they are wholly surrounded by Ordovician rocks, and the mere fact of their being volcanic is certainly no proof that they are earlier in age.

There is, however, beyond the Parys Mountain to the south-west, a remarkable quartz-knob, not at all like the neighbouring quartzite. Had this occurred in the neighbourhood of Bull Bay, I should have unhesitatingly recognized it as the ordinary knob to which we are by this time accustomed. It is one of the toughest, and the quartz is very pure and shows throughout the polygonal structure. There are, however, signs of banding in fragments which lie scattered in all directions, and are tightly cemented together by more quartz. This I should interpret, as before, as a kind of geyser-formation, the banded portions being the earlier deposits on the pipe broken off and carried up. Of course, there is no reason why such a formation should be confined to Pre-Cambrian times, and it may be a phenomenon of the locality rather than of any definite epoch. Its occurrence amongst Ordovician shales here may even be made to throw doubt on the earlier period of the formation of the others; but considering that this is quite exceptional, it seems more probable that we have here an isolated relic of an older rock, like that of

Llangefni. The principal difficulty is that there is another small quartz-knob near Nebo, and a more reef-like mass near Caeau Hen, both in the midst of Ordovician, and it might be difficult to give convincing reasons for separating the larger one near Parys Mountain from the other two, or to believe that there were three masses of old rock here. Still, this looks like the knobs elsewhere, and the other two do not.

Summary of the District.

This district is bounded by faults except between Nebo and Plas Ucha, where it is only broken and has basal Ordovician apparently between it and the black shales. Rocks resembling grey gneiss may be found on the boundaries on both sides, but the main mass of the district is composed of a volcanic accumulation, or of granitic and dioritic rocks, inextricably mixed with fragments derivable from similar rocks, which have undergone metamorphosis and become mica-schists of a peculiar type. The rocks of Parys Mountain are not in any way connected with the district and are not Pre-Cambrian, but there is a quartz-knob to the south-west which probably belongs to the series.

Description of Correlated Rocks in neighbouring Areas.

District of the Lleyn Peninsula (see Pl. XIII. fig. 2).—This is so far removed from Anglesey that no stratigraphical connexions are to be expected, but the lithological resemblance of the rocks in the two areas is so great that by common consent they have always been included in the same series. The Lleyn district is so much more inaccessible that I have not been able to afford it so detailed an examination as the other districts, of which, however, it is in every way worthy.

The boundary of the rocks considered Pre-Cambrian is the straight line marked on the Survey map, which there is every reason to believe is a line of fault. This is indicated at the northern end by the sudden change in the rocks in the neighbourhood of Nevin, and at the southern end, on the east side of Aberdaron Bay, the fault is actually seen. It has been accurately figured and described by Sir A. Ramsay.

The main mass of the rocks in this district belongs to the upper or volcanic portion of the series as seen in Anglesey, though largely mixed with rocks of a more slaty but still ashy character. Sir A. Ramsay's description of these is very graphic and leaves little to be desired. There is the same development of sporadic limestones and quartz-knobs, with associated purple slates, that we have seen in other districts. The general strike, so far as can be made out, cuts the fault obliquely, and the dip seems to be such that the higher portions come on towards the north, but there need not be any very great thickness. The reason of this is, that they are so irregularly stratified that it is difficult to make out any sequence, and the varieties may be related to horizontal and not to vertical position. One of the most schistose portions is in Abergeirch, where one is almost tempted to believe that the chloritic schists are reached, but the rock when examined is still very ashy. There are numerous dykes marked on the map, to which Sir A. Ramsay calls attention. All of these that I could identify seemed not to be of later date, but true associates of the ashes, being the more crystalline portions and, in some cases, perhaps actual flows, in others due to infiltration. In particular the masses marked "serpentine" are for the most part diabases with associated hard bands, which are often calcareous. This is the case, as has been shown by Prof. Bonney, at Porthdinlleyn, so it is at Trefgraig, and at Ty-hen, near Bodferin. The masses further south are very much mixed and include several kinds of rock, some of which are calcareous, but all are such as we might expect to form part of basic eruptions. On the higher parts of Mynydd Anelwog they are more siliceous and might be called felspathic ashes. The centre of eruption seems to have been at the southern extremity of the peninsula, to judge from the enormous size of some of the ejected blocks. The headland of Uwch Mynydd, as seen from the sea, is a mass of large agglomerates with calcareous and quartzose patches, such as may be seen on the northern coast of Anglesey. Similar rocks to these I have been able to examine on the eastern side of Bardsey Island, and there is no doubt of their character; they are often in contorted beds, and some parts in their midst are quite slaty; on the western side the slates prevail and are of purple and green colours; amongst them, on the slope of the hill and by the lighthouse, are low quartz-knobs of the usual isolated form and characteristic structure; limestones also occur sporadically on the east. There is much more that is of interest in this portion, at which I have only had time to glance.

The great mass marked "syenite," to the east of Llangwnadl, and another to the south, I believe to be continuous. Nothing is to be seen between the two masses in the peat-covered ground, and a "feature" seems to pass from one to the other. The southern mass does not extend so far as marked, but the higher slopes of the hill are occupied by a massive diabase, which rises into a little isolated peak called Clip y cefinhir, which is a perfect picture of a volcanic neck, with beautiful columns, sloping sharply to the east. The figure of "Alesna" in the Mount Tabor region, given in the 6th Annual Report of the United States Geological Survey, might well stand for its portrait. Nor is this mass certainly separated from the ashy group by a corner of the Ordovician, as marked on the Survey map, since no rocks are exposed in the interval, which is low and marshy. Where this mass is seen in the neighbourhood of the ashes, its relations appear to be those of an intrusive rock, since the latter become more micaceous and altered near the junction, but this is not actually seen. It thus becomes an assumption, so far as stratigraphy is concerned, that the mass is of Pre-Cambrian age, even admitting that the ashes are. If it be right to consider it so *, it

* These words stand as they were written, Dec. 1887. Mr. Harker has since shown that the granite is intrusive also into the slate rocks to the east, and cannot therefore be Pre-Cambrian.

must be faulted up along with the rest, which would require very little modification of the lines on the map, and those only in places where nothing is seen. Though its association with the rocks of Pre-Cambrian character suggests its age, the only positive evidence adducible is its similarity of structure to the corresponding associates elsewhere. Where it is in its greatest mass, on Mynydd Cefn Amlwch, it is a very quartzose, coarse, granitic rock, with very little mica, thus corresponding to the granite of Porth Lygan and to that of Twt Hill. Further west it becomes smaller-grained, there is more banded felspar, and the mica appears more commonly to have passed over into chlorite, giving this portion a singular resemblance to the rock of Bryn-y-garn, St. David's *. At the western summit or Garn, we appear to be near the edge, as bands of broken material render the aspect somewhat fissile, but the rock maintains its character, though somewhat broken.

On the western base it has put on a very different aspect; it is coarse again, the quartz is less abundant, and the chlorite derived from mica is in large conspicuous patches. This is on the border of the mass. Further south, at Llangwnadl, we find more border-types in which the quartz is first arranged in strings, so as to give a gneissic appearance, and the chlorite seems to have originated in epidote; and next, the rock is so full of hornblende and chlorite that it becomes a hornblende-schist, but still retains its quartz, differing therein from most of those which have been called diorites.

Similar phenomena appear on the shoulder called Bwlch-y-clawdd, overlooking Meillonydd farm, in the mass on the south. This is never quite so clean, and always contains a certain proportion of black mica, so that it may fairly be called a granite. There is no sign of foliation in the main mass, but on the slopes it becomes beautifully banded. Near at hand where broken bands are found in it, the quartz is again reduced to a minimum, and epidote and hornblende are added to the mica. As these phenomena of foliation, and the introduction of new, more basic minerals, are in both cases confined to the edge of the mass, dying off in 20 yards or so from the adjacent ashes, I regard them as due to the contact by which some portion of the surrounding material was introduced into the substance of the intruder, and the arrangement common to the edges of large volcanic dykes was brought about. All these rocks are granitic in structure, and the only place where I have seen anything like a felsite in connexion with them is on the eastern edge near Meyllteyrn †.

Besides these masses, which are marked on the Survey map, there is a patch of a rather different kind of granite, inasmuch as its mica is white, along the road from Llwydiartan southwards, and forming the eastern margin of Mynydd Ystum. A remarkable feature in this is that though so near the other granites, which show scarcely

* As this is still true, though the rock is now proved not to be Pre-Cambrian, it shows how cautious we must be in judging age by rock-character in such a case as this.

† See Hicks, Quart. Journ. Geol. Soc. vol. xxxv.

any signs of pressure, it is terribly squeezed and broken, the spectral polarization being most beautifully developed. It is possibly, therefore, of greater age.

In association with this is the only part of the district where any portion of the older schists can be recognized. The mass of the rounded elevation called Mynydd Ystum consists of dark foliated mica-schists, which are terribly broken, but contain nothing but quartz and white mica, and compare exactly with the more contorted examples met with in the Eastern District, while in microscopic appearance they resemble the rock near the Gualchmai turnpike. This material, even more broken, continues as far as Llwydiartan, where it is lost beneath the peat.

Other Caernarvonshire Districts.

A considerable number of isolated areas scattered about Caernarvonshire have been in times past claimed by various authors as Pre-Cambrian. The most important of these is that which lies between Bangor and Caernarvon, and next to it is the quartz-felsite of Llanberis and Moel Tryfaen. The examination of the true age and character of these rocks has required so much detailed observation, and the resulting balance in favour of Pre-Cambrian rocks is so small, that I have discussed these questions in a separate paper (see Quart. Journ. Geol. Soc. vol. xliv. p. 271). In this I have of necessity described the portions which I still consider may be Pre-Cambrian, and to that description I have nothing to add. It is now, however, possible to refer to the close resemblance which the granite of Twt Hill bears to the Porth-Lygan granite, which latter we have independent reasons for considering eruptive, and to remark on the association in both places of quartz-felsite with the granite. But in their character these felsites will not strictly compare with any in Anglesey. The common characters of all quartz-porphyries may be seen in some portions of the granite-mass in the Central District; but in their great development and in their association with breccias they still stand alone. I have also shown that the felsites of Llanberis and Moel Tryfaen are of Cambrian age, and therefore have no relation to Pre-Cambrian rocks.

I have now to consider those other masses to the south which have been claimed by Dr. Hicks as Pre-Cambrian *. These are the volcanic rocks of Bwlch Mawr, Pen-llechog, Yr Eifl, Mynydd Nevin, Carn Boduan, Pwllheli, and Llanfihangel Bachiellaeth, the last of which I have not examined. It has been stated that these have been so claimed on "purely theoretical grounds," and certainly I can find no others, nor is the theory in these cases a possible one. Of Mynydd-y-Cennin Dr. Hicks observes that Sir A. Ramsay describes it as a quartz-porphyry, similar to that of Llyn Padarn, and that "this is therefore undoubtedly . . . . like it, of Pre-Cambrian age." As the Llyn Padarn porphyry has now been proved to be not Pre-Cambrian, this theory now leads the other way. The *only* other evidence given

* *Loc. cit.*

is the statement that the Cambrian rocks have been faulted down, and are not in the slightest degree altered at the junction. This supposed fault would have to be a circular or elliptical one, and we are not told whether the junction rocks have been examined by the microscope, or whether they are brecciated. Of Bwlch Mawr, Pen-llechog, and Yr Eifl, Dr. Hicks writes, "the rocks are in some respects unlike the rocks already described, but yet clearly of that type and age," and "Upper Cambrian rocks are faulted against these masses and are in no case altered, except near dykes." This is the theory, presented without stratigraphical proof. The object appears to be to show that the rocks in question are lava-flows and eruptive products, and not intrusive masses. The same arguments are used respecting the masses at Nevin, Boduan, and Pwllheli. Now with regard to several of these areas, especially Yr Eifl and Boduan, it may be at once admitted that they are probably eruptive and not intrusive. The masses coloured red on the map are complex, and though some parts are coarsely crystalline, others are more felsitic and banded, and may well be contemporaneous eruptions. But this does not show at what time they were poured out, and in fact the mass at Boduan is succeeded by a slate containing its pebbles, obtained by contemporaneous erosion. Their age we must learn by their stratigraphy. Now as to any supposed faults, either the Survey mapping is all wrong, or else the course of the faults would be most remarkable, curving round corners and running into tongues. But I have satisfied myself that within half a mile on either side of the road from Nevin to Clynnog Fawr, which includes some of the most remarkable of the supposed curved faults, the mapping is quite right. Moreover, in Carn Boduan on the west side, in the Mynydd Nevin near Pistill, on the north side of Yr Eifl, overlooking the highroad, all of which I have examined close at hand, and looked at from a distance; and on Pen-llechog and Ystum Llech, so far as their deep stream-worn gorges reveal their structure to a distant observer on the road—in all these places the fault would have to be horizontal, for in all of them the igneous rocks are seen overlying the slates. In other words the stratigraphy proves conclusively that they are of later date than the underlying portion of the Ordovician, and the argument from their similarity to known Pre-Cambrian rocks, an argument which on both points is untenable, entirely falls to the ground.

Howth Hill and Bray Head.

The rocks of these localities are so well known, and so admirably described in the Memoirs of the Irish Geological Survey and elsewhere, that they do not need any further description, except from the point of view of their relation to the rocks of Anglesey, to which they are nearest on the west. That they have been thought to have some relation to these is obvious, from the fact that those who look upon the Anglesey rocks as Cambrian have placed these Irish rocks in the same system; while those who have found Pre-Cambrian rocks in Wales have looked upon the Howth rocks at least as part of the series. These latter are the most important for connecting the two areas; for after becoming tolerably familiar with the South-Stack series, but not expecting to find them again on the opposite side of the Channel, I was immediately struck with their resemblance to those at Howth, when I visited the latter in the company of Prof. Sollas. In the northern part of the promontory there is a good coast-section, showing slates and grits of very metamorphosed character. They are highly cleaved, which somewhat obscures their bedding inland; but the beds are obvious on inspection of the cliffs, where they show the same contortions and general succession as at South Stack. The sericitic slates that come on near the lighthouse are exactly matched in Holyhead Island; and further south, in Needles Bay, are found the same kind of bedded earthy rocks as we find at Porth-y-grug, each bed being only 3 or 4 inches thick and showing a hardened capping, and entirely without metamorphism. Again, there are the large masses of quartzite, which occur in a very irregular manner, and which seem to have no bedding in themselves, but to interfere with the regularity of the others. These are certainly somewhat different from most of those in Anglesey; they are too large to be thought to be quartz-knobs, and though we might compare them with the Holyhead quartzite, they are not followed by chloritic schists. On the other hand the quartzites of Roscolyn are bedded rocks, and the only masses in Anglesey to compare them with are those which stand out from the surface near South Stack itself. But whether they can be exactly matched or not, it is in Anglesey, and there alone in England, that we must look for phenomena of this kind at all. All these points, in which the Howth beds resemble the South-Stack series and not any true Cambrian rocks, lead to the conclusion that they are the continuation of the former across the Channel.

But this correlation leads us a step further. The rocks of Howth, though in some respects very distinct from those of Bray Head, are yet linked to them so closely by position and by general character that we cannot separate them widely. The latter differ in being more closely bedded, the beds being grits of a few feet in thickness and alternating with more slaty rocks; they are not cleaved, therein resembling the less altered or more earthy rocks of Howth. They contain much chlorite, and towards the south thinner and more slaty beds come in, and the slate-rocks on Carrickgologan are very similar to those of Howth. Above all, there are the same great quartz-masses; these seem, at Bray Head, to cut completely across the bedding, a fact which is represented on the map by a fault, of which I could find no further evidence. The mass of Carrickgologan in the same way comes in in defiance of stratigraphy. In certain parts its rocks show banding, but these furnish no assistance, as the rocks if disposed according to such bands must be faulted on all sides. I have not been able to make out the true nature of these quartz-masses as yet; but whatever they are, they are again a great bond of union between these rocks and those of Anglesey. These rocks have been called Cambrian, but why? Certainly not on the principle of identification by organic remains; for what fossils there are in the Bray-Head rocks, omitting the doubtful *Oldhamia*, are not those of the Cambrian rocks of Wales, or of any other place where such rocks lie conformably beneath Ordovician. Nor can they be correlated by similarity of lithology with true Cambrian rocks. No doubt they are more like Cambrian than Ordovician, but they are most like the rocks of Anglesey, and this is, in fact, all that geologists have meant by their identification.

Arrangement of the Groups in their Relative Order.

This is by no means an easy task, nor is it possible that conclusions should be final. The first point to determine is, which group of rocks we are to consider the lowest. The choice lies between the grey gneiss and the bedded quartzite. In the Western District we have the quartzite passing up into the chloritic schist, and in the Eastern we have the grey gneiss behaving in the same way. In the Central District there is a break in the succession above the grey gneiss; but yet there is an isolated mass of bedded quartzite in Bodafon mountain. This therefore is the only district in which the two occur together, and here they are not in association. The more quartzose variety of the grey gneiss seen at Gualchmai and referred by Dr. Callaway to the quartzite is not worth considering,—it is an unimportant accident. We are thus left to general considerations. From these it seems to me most satisfactory to conclude that the grey gneiss is the basal rock.

The reasons are as follows:—In the Central District the grey gneiss makes a long band in the south until it meets the granite, and even after that we get traces of it north of Llanwyllog, possibly at Tafarn-y-botel, at Llanerchymedd, in the district south of Traeth Dulas, and even perhaps in that to the east of Parys Mountain; all this apparently consecutive series of exposures leads past the crest of Bodafon mountain, and the general lie of the rocks in the district does not afford much expectation of finding it on the east of that mountain. Thus, in geographical position, the quartzite here lies between the grey gneiss and the higher chloritic rocks, and if the geological arrangement were different, the method of transposition would be very difficult to conceive, and the conception would be highly improbable. Again, a quartzite is exactly the style of rock we might expect in an episode, and the masses themselves are characteristically limited. If, then, we consider them to have this character, the absence of any representative in the Eastern District is not remarkable, especially as we have there a group of very quartzose mica-schists which occupy their place, and in the heights of Mynydd Llwyddiart even approach them in appearance; on the other hand the absence of so important and wide-spread a group as the grey gneiss in the Western District, between the quartzite and the chloritic schist, can hardly be accounted for, the fault which Dr. Callaway thought he had discovered being actually non-existent.

Again, we find quartzites in the series coming in again and again as episodes, and these are not essentially different in character from the masses at Holyhead and Bodafon; but the grey gneiss is never repeated. These considerations are independent of the amount of metamorphism, which is a somewhat dangerous criterion of age; yet it must be remarked that there is no more beautifully foliated rock, every particle being crystalline, to be found in the whole of Anglesey than some parts of the grey gneiss, and if we can associate with it the rock of Tafarn-y-botel, we see an approach even to the gneiss of the Highlands. On the other hand the quartzites are dirty rocks, where great fragments of quartz, with no pretence at metamorphosis, lie in dusty material more laminated than foliated, and only partially changed to chlorite and quartz. This is due, no doubt, in part, to the nature of the material, since there is more foliation in the overlying chloritic schists; but this cannot account for the whole.

Regarding, then, the grey gneiss as the base, a rock characterized by the presence of all the three minerals of granite, the next succeeding normal rock is the mica-schist of the eastern district, and of Mynydd Ystum in the Lleyn, of which the quartzites of Holyhead and Bodafon are the episodal equivalents. In these there are present only quartz and either mica or its representative chlorite.

In succession to these come the chloritic schists. In the Island of Holyhead these are clearly laminated and highly foliated, and retain but few original fragments; but as we pass eastwards and northwards they change character, the original deposits are irregular, and the fragments more numerous, till finally they attain quite a breccia- or ash-like character. In the continuous succession of the Eastern District, it is hard to find any representatives of the former facies; but we seem to come at once, after the mica-schists, to the latter less regularly foliated form: under these circumstances, we must look either to thinning-out of deposits, or to the mica-schists representing in part the chloritic schists, as the solution. If we distinguish the latter facies as the "chloritoid," instead of the "chloritic schists," though they are still chloritic, matters become clearer; we can thus say that in the central districts the chloritic schists are faulted out of sight, except perhaps near Aberffraw, and that the succeeding rocks are the chloritoid schists. These chloritoid schists are likewise represented from Llanflewin to Mynydd Mechell in the Northern District.

The succeeding rocks are of different character in the different districts. This I interpret as due to the occurrence or non-occurrence of volcanic eruptions in the particular area. The period at which such eruptions took place, in some instances at least, can only be suggested, since proofs appear to be lacking. The earliest perhaps, are the basic eruptions of the Central and Eastern Districts, whose foci may be found at Craig-yr-allor and the neighbourhood, and at Holland Arms; and with these may be associated the unextruded hornblende-schists of the east and perhaps the serpentines and gabbros of the west. As their clastic equivalents, partly consisting of fine dust transported from the centre, and partly of the agglomerates formed by local eruptions, we must take the marbled slates and lenticular pelites of the west, the pelites and hälleflintas round Craig-yr-allor, the long band which passes on the west side of Llangefni to Aberffraw Warren, the outlier at Pentreath, the north-western margin of the Eastern District, and the district of the Lleyn. For the ordinary sediments of this period we must look to the South-Stack series; and for the stratified, but volcanically derived material, to the slates and grits of the Northern District, and other special localities. It would be towards the close of this period, but continuous with it, as it in turn is continuous with that of the chloritic schists below, that the remarkable group of agglomerates and disturbed masses were formed, such as we find to the north of Cemmaes, at Careg Gwladys and Dinas Llwyd, and perhaps also in Bardsey Island. It would appear to be at a later date than the earliest of these volcanic eruptions, and probably not far from their close, that the acid intrusions and eruptions took place; though these may have been, and probably were, widely scattered in age. To these belong the granite of Penbryn-yr-Eglwys, the large mass in the Central District, the white granite of the Traeth Dulas district, the whole development east of Parys Mountain (the corresponding rocks and their associated pyroclasts here reaching the surface), the granite of Twt Hill, and (perhaps at a later part of the period) the quartz-felsites of Dinorwig.

We nowhere see here the uppermost rocks which might represent passage-beds to the Cambrian; nor is it likely we should. The Cambrians and Ordovicians lying on these unconformably, there may be any amount of intervening deposits elsewhere, and such we find at Bray Head. Correlating the Howth rocks with those of the South-Stack series, the succeeding rocks at Bray represent a higher horizon of the same continuous series.

Founded on these considerations, some of which are very strong, producing a feeling of certainty, and others weaker, leaving a more or less wide margin within which the conclusions are probably correct, I present the following comparative table (p. 539) of all the districts.

The interval between the lines must not be taken in any way to denote thickness. I have no data worth anything to determine this. If all were sedimentary and fairly continuous, an estimate might be attempted: but what is the thickness of a volcano or of an eruptive mass of granite? The importance of a group of rocks when all are in the same district and therefore probably treated somewhat alike, may be better measured by their surface. If, however, I were pressed for an estimate of their equivalent value in sedimentary rocks, I should say that 20,000 feet was a very extravagant one for the whole of them except Bray Head, and that 10,000 feet or 12,000 feet was probably much nearer the truth.

Establishment of the Monian System.

Adoption of a Name.—This vast and varied series of deposits, which is proved to be Pre-Cambrian in age, cannot remain nameless.

Table of the Distribution of the Rocks.

<table>
<tr><th>Dublin Division.</th><th colspan="2">Western Division.</th><th>Central Division.</th><th>Traeth Dulas and East of Parys Mountain.</th><th>Eastern Division.</th><th>Northern Division.</th><th>Lleyn.</th><th>Caernarvon.</th></tr>
<tr><td>Bray Head rocks.</td><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td><td>Quartz felsite.</td></tr>
<tr><td rowspan="2">South-Stack series of Howth.</td><td rowspan="2">South-Stack series.</td><td>Granite.</td><td>Granite.</td><td rowspan="2">Granite and eruptive rocks.</td><td>Eruptive rocks.</td><td>Eruptive rocks.</td><td>Granite and eruptive rocks.</td><td>Granite.</td></tr>
<tr><td>Ashy slates.</td><td>Ashy slates.</td><td>Ashy slates.</td><td>Ashy slates.</td><td>Ashy slates.</td><td></td></tr>
<tr><td></td><td colspan="2">Chloritoid schists.</td><td>Chloritoid schists.</td><td></td><td>Chloritoid schists.</td><td>Chloritoid schists.</td><td></td><td></td></tr>
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<tr><td></td><td colspan="2">Quartzite.</td><td>Quartzite.</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2"></td><td>Grey gneiss.</td><td>Grey gneiss.</td><td>Grey gneiss.</td><td></td><td>Grey gneiss.</td><td></td></tr>
</table>

It must not be left to wander in Archæan chaos, but as in former days the "unfossiliferous greywacke" was made to deliver up, first Siluria and then Cambria, so must the fragments below the Cambrian be gathered together into harmonious and consistent systems, so soon as we can do it.

It may, no doubt, be thought that we have too many such systems already; but this will obviously depend on the nature of the so-called systems. Dr. Callaway, in describing these rocks of Anglesey, gives them no new name, but refers them to two distinct groups, the Gneissic and the Slaty. These are descriptive names and are not intended, like his "Uriconian," to be used as appellatives. Moreover, all the preceding detailed descriptions have gone to prove that there is but one great series, of which the terms gneissic and slaty are only partially descriptive of integral parts.

But we have the long-established and better-known names of Dr. Hicks:—Dimetian, Arvonian, Pebidian; the latter name, at least, as that of a well-marked Pre-Cambrian group, has attained a wide circulation. Where, then, is the objection to the use of these terms?

They are intended by their author to represent systems equivalent to the Silurian or Cambrian on the one hand, and to the Lewisian or Laurentian on the other. As such, they stand in Mr. Etheridge's Presidential Address for 1881, and in Dr. Hicks's popular article in the same year in the 'Popular Science Review.' But what are they actually? The Dimetian is an intrusive granite, occupying a very small area anywhere. The Arvonian is a portion of the contemporaneous volcanic rocks of more than one epoch, some Cambrian and some Pre-Cambrian; and there is only left the Pebidian, which is the remainder of the volcanic products and associated deposits of Pre-Cambrian age. In the whole series of connected rocks it represents only Nos. 5 and 6 of the preceding list. Hence the only name that it would be possible to use covers only a small portion of the series, and has no pretension really to designate a "System." The only way would be to enlarge its meaning and to make it cover the whole of the system of rocks of which it forms a part. I think this plan would lead to great confusion. The name was established, and has been continued to be used as the antithesis to the Dimetian. It could not lead to clearness to use the same term to cover the Dimetian, the Arvonian, and much more besides. It might be retained as the name of a minor subdivision, like the Bala among the Ordovicians, or the Corallian among the Jurassics; but it cannot be used as a name for the whole.

Then there are the American names, Huronian, Montalban, Norian, and I know not what besides. To adopt one of these would be to beg the question of correlation, which has not as yet been so much as seriously attempted. We may hope, perhaps, to trace a group of rocks across Europe, but to fix where they will come in America beforehand would be fatal to progress. The same reason would apply to the adoption of any local European name, used for rocks whose relations have not been clearly made out, such as Hercynian.

There is no alternative left but to propose a new name which shall at once represent the whole group, be taken from the locality where its relations to other groups have been worked out, and shall have some affinity to the names already given to these other groups. As, then, from Siluria we pass downwards geologically and westwards geographically to come to Ordovicia, and from Ordovicia we pass similarly downwards and westwards to arrive at Cambria, so passing on still downwards and westwards from Cambria we come to the Isle of Mona, and here we find rocks developed which we may suitably group together as the MONIAN SYSTEM *.

* See Brit. Assoc. Reports, vol. lvi. p 669.

Is the Monian System Archæan? This, of course, depends on the definition of Archæan. If we define it as being unfossiliferous, and if I am right in assigning the rocks of Bray Head to it, or if the fossils of Borth Wen are of Monian age, then certainly the system cannot be Archæan. If it is defined as crystalline, then much of the Monian is not crystalline; nor, for that matter, are the Huronian rocks of Georgian Bay crystalline. If it is *not* defined, but used simply for "Pre-Cambrian," *then only* are these rocks Archæan. The separation between them and the Cambrian is one of unconformity; but this unconformity seems scarcely of so great importance as the overlap of the Ordovician. Hence I regard the system as an ordinary stratified system, perhaps fossiliferous on more than one horizon, and constituting the lowest member of the sedimentary series. Towards its base it is metamorphosed, and changes of greater or less amount have passed over every part; but at their minimum they are no greater, indeed they are less, than in many parts of higher systems; and these minima occur at nearly every portion of the series.

Subdivisions of the Monian System.

Although the rocks of the entire system merge one into the other in an imperceptible manner, yet as a sequence may be made out in them, we may usefully divide off one part from another by artificial lines. We have at the base the grey gneiss, with its episode the quartzites, and then the chloritic and chloritoid schists. The metamorphosis of these is for the most part nearly complete, though in the two latter there are patches which are in their original state of purple slates. The whole of them are unbedded, except for the bands of grit which here and there occur, and the feeble indications of bedding to be seen at a distance in the quartzites. The chlorites were certainly laminated, and the fine lines in the grey gneiss have probably a similar origin. At all events they are not lines of cleavage, and they are parallel to what, from stratigraphy, in many cases is certainly the surface of deposit. They thus all produce essentially lineated rocks, the lines being for the most part also lines of foliation, and under pressure they do not readily fault or cleave, except the quartzites, but crinkle or gnarl. The grey gneiss is felspathic and micaceous, the rest consist of quartz or dust with chlorite or sericite. If a name is required for these we may call them the Holyhead Group (a name unfortunately used before by Dr. Hicks in another sense, as are all the suitable ones), or we may use the term Lower Monian.

The next succeeding group presents two types. One of these, the most widely spread, is distinguished by the abundance and variety of angular fragments of the rocks, though these are often of minute size. It is also usually marked by want of regularity in the stratification. Nevertheless some parts are thoroughly slaty or gritty, and in others there is no stratification at all. All this is due to the proximity of volcanic centres, which are sometimes indicated by great agglomerates, sometimes by contemporaneous lava-streams, sometimes by the bursting forth of siliceous or calcareous springs, which have produced sporadic limestones or quartz-rocks. The volcanic eruptions seem to have been most localized towards the close. Thus the lower portions are formed from the fine dust of some large eruption; the higher show the centres at various fixed spots. To this group properly belongs the title Pebidian; but so far as the intrusive rocks associated with volcanic products can be assigned to the same age as their hosts, it must include the so-called Dimetian also; and some of the lava-flows of the period have been called Arvonian. If the name Pebidian is to be retained, it must be for this only, or, since it corresponds to the rocks which alone occur at St. David's, it might be called the St. David's Group. It is probable that to this group we must assign the fossiliferous ashes of Borth Wen, in which case it possesses characteristic fossils, one of which is *Orthis Bailyana*. The other type, which is related to the first somewhat in the same way that the Caradoc sandstone is to the Bala ashes, is limited to the island of Holyhead, on the south side of the great fault. It has been called in this memoir the South-Stack Series. A small amount of volcanic débris may have contributed to this series at Gogarth, but otherwise it is well stratified and bedded. It is also contorted on the large scale and greatly cleaved, and foliation is developed along the cleavage and not along the bedding-planes. It is also characterized by masses of white quartzite, which, in some cases, are certainly bedded, but in others are of obscure origin. On the whole it is a slaty series, and contains soft bands, while many of the beds are comparatively thin, and have to be measured in inches rather than in feet. This series extends across the Irish Channel to Howth Head, where it exhibits similar characters, the slaty portions being to the north, and the more ashy to the south. No fossils have yet been discovered in this group. These two types are believed to be contemporaneous, because the chloritoid schists are continuous with both, one on the one side and the other on the other. Moreover there is a certain resemblance between some portions of them, as when we compare the northern slaty district with the South-Stack Series. These types therefore form the Middle Monian.

The third group is not found in Anglesey or at St. David's, in both which places the basal Cambrians rest on no higher rocks than the middle or volcanic group; but on the other side of the Channel the well-known rocks of Bray Head succeed those of Howth, and are yet of a different character. They are massive grits and slates, some strongly cleaved, but most are uncleaved. The beds are thick; there are great quartzite-masses, and chlorite is still developed. These form the Bray-Head Group. The fossils which have been found in them become characteristic fossils of the Upper Monian.

Development of Monian Rocks in other Areas.

The principal area in England which, it is probable, consists of Monian rocks is the Longmynd. The slates and grits of this area are unconformable beneath the Stiper Stones, and they are not seen to pass into any other group. They have been referred to the Cambrian simply on account of their infra-position and their unfossiliferous nature. The fossils which actually occur, being found also at Bray Head, correlate the Longmynd rocks with these. They will therefore be Upper Monian. The Volcanic group of St. David's belongs entirely to the Middle Monian, and the occurrence there of the same kind of granite, which is probably also intrusive, seems to indicate that this rock is to be regarded as essentially part of the series. The "Uriconian" rocks of the Wrekin, with the granites and altered rocks of Primrose Hill, form another isolated mass of Middle Monian rocks. The Charnwood-Forest rocks do not show sufficient similarity to any rocks in Anglesey to afford any great certainty in their correlation. If they are really of Monian age, the Volcanic portions will belong to the Middle Group and the slates of Swithland to the Upper. What further rocks may in future be found comparable with these in the Highlands or elsewhere, cannot be foretold; but if massive quartzites with little bedding and great irregularity of development are taken to characterize the system, it is probable that some, at least, may be found to belong to it. The occurrence of *Oldhamia* (though it may not be a fossil) in the so-called Cambrians of the Ardennes may indicate the extension of the Upper Monian at least as far as Belgium.

Physical History of the Monian Rocks of Anglesey and the Neighbourhood.

In conclusion, I may attempt the difficult task of interpreting the succession of the rocks as indicating the history of their formation and subsequent alterations.

When a series is fully known, we expect to find somewhere a conglomerate at its base; but if I am right in placing the grey gneiss at the base, or even if the quartzite were the true base, we find no such conglomerates in Anglesey. Whether any such rock as the Torridon Sandstone will ever be recognized as the true base can scarcely be foretold; but at present there is no base to be found, and the lowest rock yet recognized indicates a rather remote source, being metamorphosed fine sediment. The Archæan rocks, so far as we know, lie to the west, and this must have been the direction whence the materials were derived. The cause of the episode, of which the quartzites are the result, is very difficult to conceive. The remarkable accumulation of so much quartz in one place may suggest a siliceous spring, whose deposits were first produced and then broken up and stratified in the neighbourhood. An early sandbank is the only alternative hypothesis. After this the deposits were made in shallower water, and subject to variations in the source, which caused them to be laminated, but soon the material became finer. The subsequent history is different in the various parts of the island, according as volcanic eruptions intervened or not. Where they did not, the varying deposits of quartz and slate in the South-Stack Series indicate a shallow sea subject to variations, but sometimes becoming deep. In other areas some great centres of eruption must have supplied the angular fragments and the dust to all the districts. One centre could not have been far from the western district, where the mud is unstratified; while the spot where the current-washed materials were deposited was the present Northern District, then still further north. We can, perhaps, scarcely look to the same source for the materials in the Eastern District; still less can we suppose the Lleyn to have been dependent on Anglesey. Where, then, are the eruptive centres? In the places where we should naturally look for them we often find masses of granite. Possibly, then, the granite occupies the eruptive centre, and has, at a later date, intruded itself into the space thus left and amongst the remnants that lay close to the source. Whether we can thus fix the sources or not, we must recognize that in the end the volcanic forces became localized in minor and separate spots, where they are indicated by the presence of agglomerates, such as are seen near Pen-bryn-yr-Eglwys, on the west side of Cemmaes, near Llangefni, at Dinas Llwyd, at Careg Gwladys, and in Bardsey Island. Since we have granite in association with some of these rocks at Pen-bryn-yr-Eglwys, we may be justified in looking upon other minor outbursts as of similar age, such as those south of Traeth Dulas, east of Parys Mountain, and at Llyn Trefwll. It may have been also at the same time that all the granite was intruded. It was possibly at a later date that the felsites, south of Bangor, were poured out. Apparently during the continuance of these minor outbursts, hot siliceous springs in some places, and calcareous ones in others, burst up through the previously laid ashes and formed the quartz-knobs and sporadic limestones. The crystalline material, when formed in the sea, which, as ever, was most powerful in the north, was soon broken up and rolled; the calcite produced the oolite of Llanbadrig, and the quartz the conglomerates of Borth Wen, but the outburst of ashes still continued.

Volcanos usually indicate land or, at least, the borders of the land. After their formation we have no more deposits here, but at a remoter distance deposits still continued, at Bray on the one hand, and in the Longmynd or the other. The end of the period will have to be sought out in these localities; but it is probable that where the Monian is thickest the succeeding Cambrian will be thinnest or absent.

The greater part of Anglesey remained dry land throughout the Cambrian period, the deposits of the latter not reaching much beyond its eastern border. Anglesey doubtless, indeed, from its later products, supplied the materials of the Cambrian slates and grits, of which the lower ones still bear recognizable evidence of their source. We need not suppose that the materials were derived from those of newer rocks than any now seen; for where the grey gneiss is exposed, a vast mass of material must have been removed, and it was certainly removed in Cambrian times, since the basal Ordovician rests on the grey gneiss.

These Ordovician beds prove that the sea once more crept over all the land, transgressing far beyond the limit of the Cambrians, and lying everywhere in Anglesey and the east of Ireland on the Monian. This era is well known to have been one of wide-spread depression, as Arenig rocks form the base of the series in so many countries. In Anglesey the earliest sea-shore is often seen with the huge fragments forming beach-breccias, such as are found near Holyhead Mountain, the Garn, and at Llanerchymedd, but these are very local; usually the ancient rocks have been well ground down and turned into quartz-conglomerates, as at Nebo, Pen-bryn-yr-Eglwys, and near Gaerwen, or even into grits, as on the west side of Llyn-faelog, and south of Holland Arms. Though the Monian rocks had now been formed, they were not left in peace. They were probably raised into land before Silurian times, and they formed the margin of the sea in the Devonian, Carboniferous, and Permian Periods. At the time of England's great disquietude, the Monian rocks were cut up and sliced, huge faults were brought about, and the northern district pushed over the Ordovician. In the volcanic districts the rocks gaped asunder and let down small slices into their midst. The result of these movements was to raise the area to land once more; and so it has remained, to all appearance, ever since, if we except the supposed submergence of the glacial epoch.

It is not easy to determine the age of the metamorphism of the Monian rocks: stated generally, the earliest moment which theoretical considerations will permit would suit best with the facts. The materials, in fact, in most cases, seem to be specially suitable for crystallization, and even the upper part contains fragments already crystalline. Much therefore of the metamorphism must have been immediate.

Such is the history of the Monian rocks, as read by the light of the facts observed, and it is one which impresses itself strongly on the mind of a worker on the ground. Whether we stand on an eminence in Anglesey and look eastward on the long Snowdonian range, towering into the sky, or rest on the slopes of Llanberis and turn our eyes westward over the island plain, the contrast is marvellous. Why are those old rocks plains, and these, more modern, mountains? The difference dates from an early time. In Anglesey the great volcanos, casting out their ashes and melting the rocks into diorites and granites, have formed a great ge-anticlinal. But beneath the range of Snowdon lie 3000 ft. of Cambrian, which has come from Anglesey and the west. This, then, at least was the height of the mountains formed by Monian rocks, and it was probably much more. This mass has formed a buttress; the earth-stresses to which it has been subject have riven it to fragments, but have been unable to remove it; against it the newer rocks have been pressed and they have been turned on end and raised into the air. Thus Mona created Cambria and raised it above herself.

In return for this, geologists have made the Cambrian system obscure the Monian, and declare it was only an altered representative of the former—the mother the altered representative of the child! But this great system of rocks is not metamorphosed Cambrian, and it is not Archæan, but it is the basis and foundation, so far as we have yet discovered, of all our systems of stratified rocks on this side of the Atlantic.

EXPLANATION OF PLATE XIII.

Fig. 1. Map of the distribution of the rocks of the Monian System and associated rocks in the island of Anglesey. (Scale $\frac{1}{3}$ in. to 1 mile.)

Fig. 2. Map of the distribution of the rocks of the Monian System and associated rocks in the Lleyn Peninsula. (Scale $\frac{1}{3}$ in. to 1 mile.)

Discussion.

The President spoke of the interest attaching to this paper, and the vastness of the subject. He thought, however, that a new system should be proved over a larger area than Anglesey. If the Author's system is a real entity it will be found elsewhere in Europe.

Dr. Hicks thought that the Author had by no means evolved order out of chaos. If there was anything in Anglesey worth naming, it would be found at St. David's and elsewhere. He regarded his own three series, for purposes of correlation, as of equal value. There was hardly a rock in Anglesey which he had not found in Caernarvonshire, either *in situ*, or in the Cambrian conglomerates. He denied the Author's right to speak of all the beds above the conglomerate as Ordovician; he considered the conglomerate to be Pre-Ordovician; there was a great series under the Tremadocs in that very area. So far from no names having been suggested, he had called one group the Holyhead Series, another the Menai Series: the main portion of the Pebidian was still newer. Dealing with the question of the granitoid rocks, these, he believed, were originally of igneous origin, but pebbles derived from such rocks were found in beds very much older than the Tremadocs. The Anglesey granite was unlike the Killiney granite, but resembled the Pre-Cambrian granitoid rocks of St. David's, the Lleyn, and Caernarvon. After referring to the character of Arvonian and Pebidian rocks, and more especially to their discovery as rolled pebbles in the neighbouring conglomerates, he said that the greatest disagreement was as to the central granite-boss. He had always maintained that it did not protrude and alter the Silurian or Cambrian rocks; he had shown that it was Pre-Cambrian, as proved by its derivatives. He considered that the evidence of intrusion even into the older rocks adduced by the Author was fallacious. He believed the granite to be one of the oldest rocks in Anglesey, and to have been much crushed and changed in Pre-Cambrian times. He was more disposed to regard the diorite as intrusive into the granite.

Prof. Hull was sure that the Author had left no stone unturned in order to arrive at his conclusions. Some six years ago he had accompanied Sir A. Ramsay over the district of the Menai Straits, and the latter concluded that he had not been mistaken in his


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Baron Hill
Penyparc
Llandegfan
BEAUMARI
Menai Bridge
Mynyd
Bardsey Is.

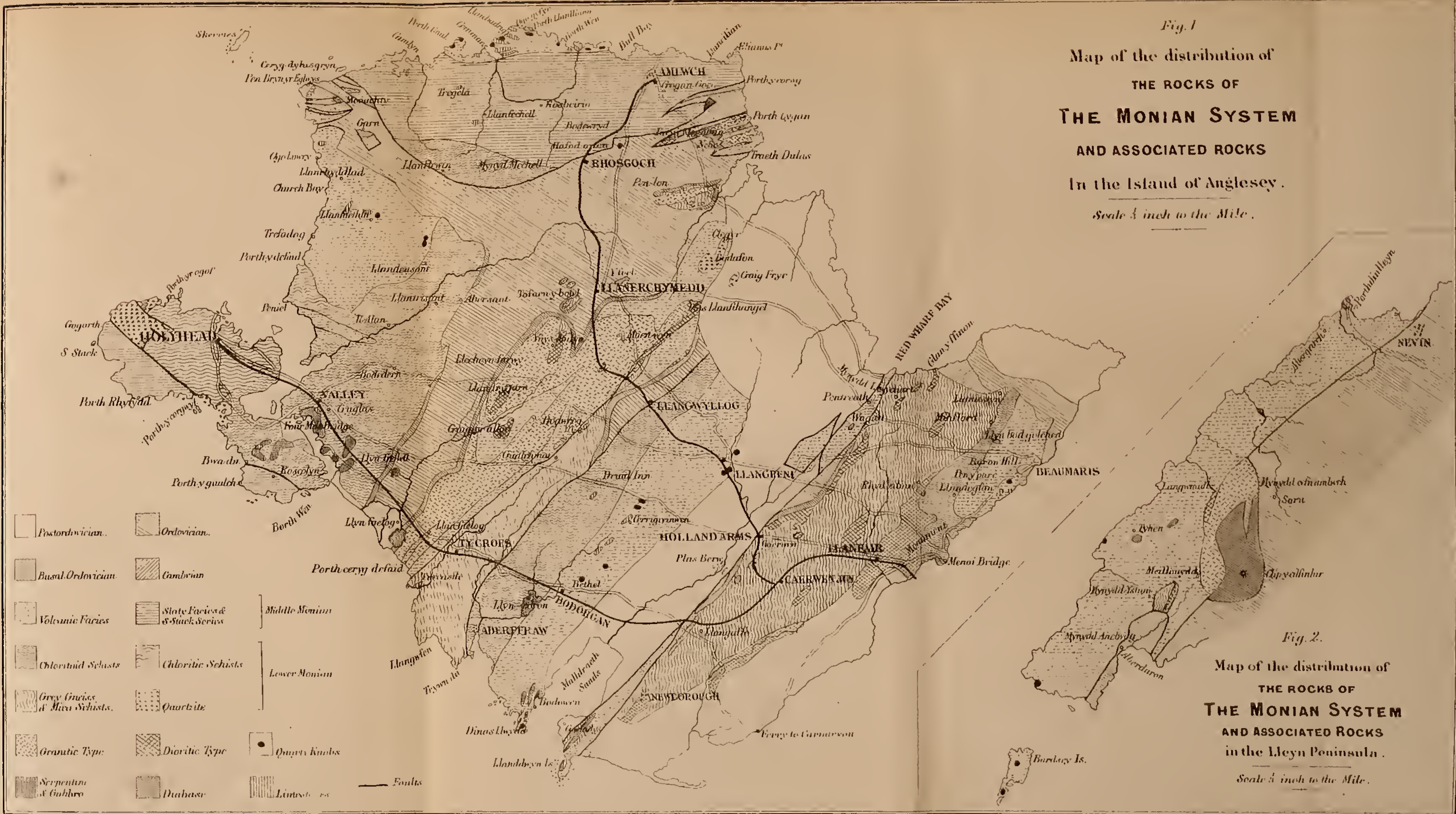


Fig. 1
Map of the distribution of
THE ROCKS OF
THE MONIAN SYSTEM
AND ASSOCIATED ROCKS
In the Island of Anglesey.
Scale ¼ inch to the Mile.
Fig. 2.
Map of the distribution of
THE ROCKS OF
THE MONIAN SYSTEM
AND ASSOCIATED ROCKS
in the Lleyn Peninsula.
Scale ¼ inch to the Mile.
Postordovician.
Ordovician.
Basal Ordovician.
Cambrian.
Volcanic Facies
Slate Facies & S. Stack Series
Middle Monian
Chloritoid Schists
Chloritic Schists
Lower Monian
Grey Gneiss & Mica Schists.
Quartzite
Granitic Type
Dioritic Type
Quartz Knobs
Serpentine & Gabbro
Diabase
Faults
AMLWCH
BHOSGOCH
HOLYHEAD
VALLEY
LLANERCHYMEDD
LLANGWYLLOG
LLANGEFNI
BEAUMARIS
HOLLAND ARMS
LLANFAIR
GAERWEN JN.
TY CROES
BODORGAN
ABERFFRAW
NEWBOROUGH
RED WHARF BAY
NEVIN
S. Stack
Porth Rhyfydd
Menai Bridge
Bardsey Is.
Ferry to Carnarvon
Church Bay
Bull Bay
Traeth Dulas

interpretation of the country. The rocks of Howth were determined as Cambrian, mainly because they lie unconformably below Lower Silurians (or Ordovicians).

Prof. Bonney would like to have had stronger evidence as to the interbedding of schists and slates; he thought that the phenomena might be explained by intense local pressure, whereby a "slatified schist," so to say, was produced. This was the case elsewhere in Anglesey and in the Alps. Professor Blake had made confusion out of his explanation of the serpentine-calcite rock in Holyhead Island. What he did say in his published paper was that after great crushing, the downward percolation from the once overlying Carboniferous Limestone had helped to cement the serpentine breccias in the Roscolyn district. A similar thing might be observed in the Apennines, with this difference, that there the limestone had not been removed by denudation. The hälleflinta of the Porth-Nobla district was crushed-up rock of gneissic origin. He thought there was no necessity for the establishment of the Monian system, and endorsed all the President had said on this subject. The Anglesey crystalline rocks were so much modified by subsequent earth-movements that they were generally not very well suited for types.

The Author, in reply, thanked the Society for the reception accorded to his paper. He admitted the force of the President's remarks, but said that all systems must be based on the careful examination of a single area. He had aimed at simplifying matters by absorbing a number of smaller systems. He instanced the rocks of the Longmynd and some in Belgium as members of the Upper Monian, and the Wrekin area and St. David's as containing Middle Monian rocks, and suggested that the rocks of the Lizard might be Lower Monian. He thought that Dr. Hicks's criticisms did not leave much to reply to; on many points they were agreed, except as to the intrusive nature of the granite. He considered that the specimen exhibited, which contained no diorite, satisfied Dr. Hicks's demand.

He was glad to hear from Prof. Hull the explanation of the Howth beds having been called Cambrian, because it would be equally applicable to prove them Monian. To Prof. Bonney he replied, with reference to the change from slates to schists, that no amount of folding could have done this, since the beds where it occurs are not folded at all. There was plenty of crushed schist in the neighbourhood, but not of that character. Some hälleflintas might be of gneissic origin, but not all; very fine fragmentary matter may be produced by the action of volcanos as well as by crushing. He stated that his conclusions had been modified time after time by further knowledge of these Anglesey rocks, and he was now convinced that they really constitute one great system.

33. *On the* Spheroid-bearing Granite *of* Mullaghderg, Co. Donegal. By Frederick H. Hatch, Ph.D., F.G.S., of the Geological Survey. (Read May 23, 1888.)

[Communicated by permission of the Director-General of the Geological Survey.]

[Plate XIV.]

On returning from a recent inspection of the field-work of the Geological Survey in Ireland, Prof. A. Geikie brought with him some remarkable specimens of spheroidal concretions, which, on account of their interesting structure, he thought worthy of detailed examination and description. For this purpose they were entrusted to me, and the present paper records my observations.

These bodies were found by Mr. J. R. Kilroe, of the Geological Survey of Ireland, in granite at Mullaghderg, Dungloe, Co. Donegal. According to Mr. Kilroe, they occur in a mass, measuring 5 or 6 cubic yards, which lies in coarse granite. It consists "of concretionary balls, varying in size up to 6 inches in diameter. The balls are usually flattened and lie almost contiguously, the interstices being filled by granite, which is similar in character to, though much finer-grained than, that surrounding the entire mass."

In a letter I have since received from Mr. Kilroe he informs me that dykes are numerous in the locality where the spheroids occur. One of these passes quite close to the mass containing the concretions; but since the latter are confined to a small space and do not follow the dyke, I see no reason for connecting their formation with its intrusion *.

The Normal Granite.—Of the granite referred to above, Mr. Kilroe was kind enough to furnish me with specimens.

It is a coarse-grained rock, varying in colour from a pale flesh-tint to a reddish brown. The specimens in my possession have a somewhat loose and crumbly texture, which, if general, would

* I have examined a section of the rock from this dyke. It is a porphyrite, consisting mainly of a microcrystalline aggregate of felspar and quartz, the latter being subordinate. The sections of the felspar are bounded partly by rectilinear, partly by irregular contours. Some of the grains are striated; others, on the other hand, show no trace of twinning. It is therefore not improbable that orthoclase is associated with the plagioclase. The quartz-grains may be distinguished from the felspars by their greater pellucidity, their more irregular shape, and by the fact that occasionally a uniaxial interference-figure may be obtained. Traces of micropegmatite are not unfrequent.
Imbedded in this ground-mass are isolated porphyritic crystals of striated felspar, characterized by a marked zonal structure. The extinction-angles reach a rather high value; and from analogy with other porphyrites of this character, the felspar is probably labradorite. Scattered somewhat sparingly through the section are ragged blades and plates of a green small-angled mica. This mineral shows strong pleochroism:—a=pale yellow; β and γ=dark olive-green. Associated with the mica are scales of chlorite, grains of epidote and occasionally of sphene, iron-ore in isolated granules, and apatite in slender prisms.

considerably curtail its application as a decorative building-stone. Its essential components are quartz, potash-felspar, soda-lime-felspar, hornblende, and black mica, with sphene as an accessory constituent. Since there is no white mica the rock must be classed with the granitites. It is in fact a *sphene-bearing hornblende-granitite.* The dominant felspar occurs in irregularly contoured masses, which are sometimes of such considerable dimensions as almost to give the rock a granito-porphyritic structure. The colour of this mineral, which depends on the amount of weathering, determines the prevalent tint of the rock. Reflections from cleaved surfaces show that almost every crystal is made up of the two hemitropic components of a Carlsbad twin. Its specific gravity, determined by means of Sonstadt's solution and the Westphal's balance, is 2·57. These are the figures assigned by Tschermak to a felspar of the composition $Or_3\ Ab_1$*.

Examined under the microscope, a considerable proportion of this felspar is found to be microcline, presenting, between crossed nicols, the rectangular intersection of spindle-shaped striæ characteristic of this mineral. In addition to this structure, suitably directed sections (viz. those in the zone P : M.) show a system of small irregular lamellæ of triclinic felspar (albite or oligoclase), intercalated along the prismatic or macropinacoidal planes. To this intergrowth of orthoclase or microcline with a felspar of the albite-oligoclase series, F. Becke † has given the name of microperthite. Irregular grains of striated felspar (oligoclase) also occur as inclusions in the microcline; less frequent are lamellæ and grains of quartz. This is probably the "*quartz d'infiltration*" of French geologists.

Felspar presenting no striated structure is also abundant. Such felspar, according to the usual practice, is to be referred to orthoclase. A. Michel-Lévy ‡ has indeed made it appear likely that orthoclase and microcline are identical, by showing that the optical properties of orthoclase are such as would be expected to result from an intimate intergrowth of microcline-lamellæ on the albite- and pericline-types. But the identity has not yet been *proved.*

A curious phenomenon, which has been described and figured by Becke §, is also well shown by an isolated section of this felspar. This section is nearly parallel to the orthopinacoid, since it presents the emergence of an axis of elasticity (a), and contains two sets of fine, sharply marked cleavage-lines, crossing one another at an angle of 106°. These are the cleavages of P and M, the divergence from rectangularity being caused by the position of the section. An

* Tschermak, "Die Feldspath-gruppe," Sitzungsber. der k. Akad. der Wissens. Wien, Bd. l. Abth. 1 (1864), p. 579.

"Or" stands for one molecule of orthoclase (K_2O, Al_2O_3 $(SiO_2)_6$), and "Ab" for one molecule of albite (Na_2O, Al_2O_3 $(SiO_2)_6$).

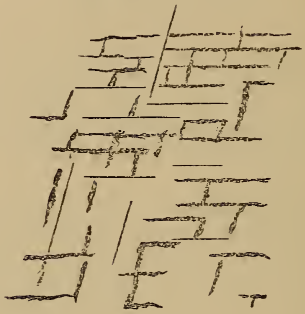
† "Die Gneissformation des niederösterreichischen Waldviertels," Tschermak's Min. und Petr. Mitth., Bd. iv. 1882.

‡ "Identité probable du microcline et de l'orthose," Bull. de la Soc. Minéralog. de Fr. (1879), tome ii. p. 135.

§ *Loc. cit.* p. 199.

examination in convergent polarized light shows that the trace of the optic axial plane is coincident with one of the cleavages (P). Parallel to the cleavage-lines are two sets of straight, strongly refractive markings, reticulated as in fig. 1. These lines are dark

Fig. 1.—*Section of Felspar showing the cleavages* P *and* M *and the markings parallel thereto.*



in transmitted, and white in reflected light. They do not extinguish with the main mass of the felspar, the latter becoming dark between crossed nicols at an angle of 5°, the former at one of 14° with the basal cleavage-lines. As Becke has already pointed out, this lineation has nothing to do with microperthitic structure. It may perhaps be due to a deposit of secondary crystalline material along the cleavage-planes.

The decomposition of the orthoclase shows itself in the formation of cumulous aggregates of minute flakes of a brightly polarizing substance—muscovite or kaolin.

The oligoclase occurs only in isolated crystals of rather small dimensions; in colour it is white. Easily recognized by its sharply defined twin-lineation, its place in the soda-lime-series is at once given by its small-angled extinction. Its specific gravity is 2·648. These figures fall within the limits assigned by Tschermak and Max Schuster * to oligoclase, viz., 2·645, 2·671.

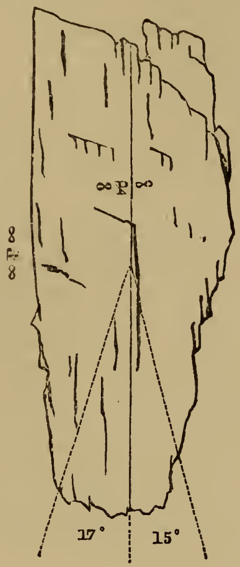
The quartz, distinguishable by its pellucidity and its numerous liquid-inclusions, belongs to two phases of crystallization, since it occurs both in large allotriomorphic masses and as infillings of the small irregularly shaped interspaces between the larger grains. This younger quartz, representing the residual magma of the rock, is also found sending tongue-like processes into the quartz of earlier origin, thus affording ocular demonstration of their separation in point of time.

The hornblende and mica are scarcely to be separated with the unaided eye. They are generally aggregated in little patches of black shining scales. Isolated and examined in convergent polarized

* "Ueber die optische Orientirung der Plagioclase," Tschermak's Min. und Petr. Mitth., Bd. iii. 1881, p. 153.

light, the mica presents an interference-figure which is practically uniaxial. It belongs accordingly to the biotite-group. Its absorption is exceedingly strong, viz., α = pale yellow; β and γ = black. The hornblende occurs either alone or associated with the mica or with a small quantity of magnetic iron-ore. Its maximum extinction-angle, measured to the vertical axis in the prismatic zone, is 17°. The pleochroism is marked, viz.: α = pale yellow,

Fig. 2.—*A twinned Crystal of Hornblende, showing the extinction-angles of the two halves, measured to the trace of the plane of twinning* (∞ P ∞).



β = deep brownish green, γ = deep olive-green. Twinned crystals occur occasionally, the twinning-plane being ∞ P ∞ (100). Fig. 2 shows such a twin. Traces of a cleavage parallel to a positive orthodome will also be observed in this figure. A cleavage parallel to the face P ∞ (101) has been observed in hornblende by C. Whitman Cross *.

Produced probably by the hydration of the mica, are scales of a bright green chlorite. Sphene occurs in large but isolated grains enclosing granules of magnetite and, in one case, a well-contoured crystal of oligoclase. Occurring as a secondary product in the altered felspar are granules of epidote.

Of all these minerals the oligoclase shows perhaps the greatest tendency to the assumption of crystalline contours. It is, however, nearly equalled in this respect by the hornblende. This, combined with the fact of its occurrence as an inclusion in sphene, should

* "Studien über bretonische Gesteine," Min. und Petr. Mitth. iii. (1881), p. 386.

place oligoclase high up in the order of consolidation of minerals in granite.

The matrix intervening between the balls differs but little from the granite just described. Its texture is a little finer, and it contains perhaps a somewhat greater proportion of oligoclase.

The Spheroids.—The most perfect of the concretionary bodies submitted to me for examination is a somewhat flattened spheroid, the greatest diameter of which is about four inches, and the smallest three. A thin layer of reddish felspar, with which abundant glistening plates of a dark-coloured mica are associated, is the only remnant of the enveloping matrix remaining attached to the peripheral surface. This felspar is orthoclase of specific gravity 2·571, which, it will be seen, is almost identical with that of the orthoclase in the surrounding granite. The mica, too, presents optical properties similar to those of the mineral described above.

In order to investigate its internal structure, the spheroid was cut through the centre, and one of the halves polished. Sections * showing both central and marginal portions of this and other spheroids were also prepared.

Two distinct parts were then clearly to be made out:—a pink felspathic nucleus, and a dark-coloured peripheral shell. Measured in section, the diameter of the nucleus is about $1\frac{1}{2}$ inch; while the width of the external zonal portion is about 1 inch. The outer periphery of the spheroid is regular and sharply defined, being marked off from the granitic matrix in which it is imbedded by the dark colour of the marginal portion. A closer examination discloses the fact that this dark colour is not, as at first sight appears, uniformly diffused; for the main mass is found to consist of a colourless and transparent mineral, enclosing innumerable granules of a black, opaque substance, with metallic lustre. Nor are the granules without order in their distribution, being disposed in more or less definite rings so as to produce a marked concentric structure (see fig. 1, Pl. XIV.).

The boundary of the nucleus, on the other hand, is irregular and wanting in sharpness. This is caused by an almost imperceptible transition (due to a gradual increase in the number of black granules) of the nucleus into the outer zonal portion.

Submitted to microscopic examination, the nucleus is found to consist of an irregular hypidiomorphic granular aggregate, chiefly of triclinic felspar, presenting well-defined twin-striation often on both albite- and pericline-types. This twinning is extremely sporadic in its occurrence, one and the same grain often showing no trace of striation in one place, while in another the twinning is well marked. Though occasionally clear and fresh, the felspar has often suffered from kaolinization, turbid patches being developed in consequence. Such alteration generally follows the cleavage-cracks, but in some

* I have great pleasure in expressing my admiration of the way in which these sections have been prepared by Mr. J. Young in the laboratory of the Geological Survey at Edinburgh. Though of unusually large size, they are of sufficient thinness to show the minutest structural details.

cases prefers the twinning-planes. A few grains of unstriated felspar are possibly orthoclase. Wedged in between the felspar-masses, and evidently of later consolidation, is allotriomorphic quartz with liquid-inclusions. Accessory grains of sphene are also peculiar to this part of the spheroid.

As the outer zone is approached, granules of the black opaque mineral and plates of brown mica become more and more frequent; at the same time the quartz gradually ceases to occur. The bulk of this portion of the spheroid consists also of plagioclase felspar, differing from that of the nucleus only in the mode of arrangement. For the most part, it appears, under the microscope, in wedge-shaped sections, the longer sides of which converge towards the centre. Of the remaining two sides, the broader base forms part of the external periphery, while the other end terminates irregularly or unites with the felspar of the nucleus. This radial orientation of the felspar is distinctly indicated in certain parts of the section by an approximate coincidence of the twin-striæ (when viewed between crossed nicols, or when marked by an alternation of turbid and clear lamellæ) with the direction of the radii of the spheroid (see fig. 4, Pl. XIV.). Such cuneate sections must represent rudely conical or pyramidal masses of felspar which radiate from the nucleus, their broad bases forming part of the external surface of the spheroid. In the polished specimen the sections of the felspar-cones are easily recognizable by the unaided eye. They are distinguished from the intervening material by a faint chatoyant lustre, apparently caused by reflection from internal surfaces. When the conical masses are contiguous, the line of junction appears, in thin section, as a series of steps, which are well brought out by the contrast of the different polarization-tints. Cross-twinning, on the albite- and pericline-types, is not unfrequent, the more persistent striation being, almost without exception, in the radial direction. Many of the wedge-shaped masses are, however, entirely free from polysynthetic twinning.

Scattered plentifully through the sections are grains of the opaque mineral. These are of elongated form, being often 10 or 12 times as long as broad, and show, here and there, octahedral terminations. Disposed invariably with their long axes in the radial direction, they appear, at first sight, distributed irregularly over the section. A nearer examination, however, discloses the fact that, in more than one instance, they are ranged, at equal distances from the centre, side by side so as to produce the concentric marking referred to above (see figs. 1, 3, Pl. XIV.). This phenomenon clearly indicates simultaneous separation of the opaque granules in concentric zones of growth, the latter evidently proceeding from the central portion outwards.

More sparingly present are small plates of the brown mica. This mineral shows strong absorption, and, since it possesses an extremely small optic angle, may be classed with the biotites. Still less frequent are scales of a green chlorite-like substance, resulting, most likely, from the alteration of the mica. An isolated flake of colourless muscovite was also observed.

In order to determine the nature of the felspar and of the black opaque mineral, a portion of the spheroid was detached and, after being freed from its outer coating of orthoclase, crushed in a steel mortar. From the powder small fragments of about 1 cubic millim. were sifted out, and of these a few selected which were as free as possible from the opaque inclusions. Tested for their flame-reactions by Szabó's method, these fragments gave results indicating a lime-soda-felspar of intermediate composition. The fusibility, on Szabó's scale, is 4.

The fragments were now further crushed until the whole powder was sufficiently fine-grained to pass through a piece of fine cambric, stretched across the mouth of a beaker to serve as a sieve. On going over the powder carefully with a small bar-magnet, the black opaque granules were easily removed, and were found to be completely soluble in hot hydrochloric acid. These are properties of magnetic iron-ore. The total weight of the powder was 3·07 grm., that of the magnetite removed ·37 grm., or 12·1 $^0/_0$.

The remaining powder was then introduced into a Sonstadt's solution of such strength that in it calcite (sp. gr. 2·715) just remained suspended. On standing, a dark powder separated, and was removed. This, examined under the microscope, was found to consist mainly of biotite, but mixed with fragments of felspar (rendered specifically heavier by minute inclusions of magnetite) and a small quantity of isolated magnetite.

The solution was then carefully diluted until the remaining powder (felspar) appeared neither to sink nor to rise. The specific gravity of this solution, taken at 15° C. by means of a Westphal's balance, was 2·649. This is almost identical with the result obtained for the specific gravity of the plagioclase of the surrounding granite (*vide ut supra*). In a solution in which orthoclase (of sp. g. 2·571) floated, the whole powder sank to the bottom, proving conclusively that no orthoclase is present in the zonal portion of the spheroid.

A chemical analysis of this powder gave the following results :—

SiO_2	60·99
Al_2O_3 (with a little Fe_2O_3)	25·56
CaO	4·88
Na_2O *	7·73
Loss on ignition	·84
	100·00

* By difference.

This agrees very nearly with the theoretical composition of an oligoclase of the formula Ab_3An_1 †.

To sum up shortly these results, we find that the spheroids consist of two parts :—a pinkish central portion (the *nucleus*) and a

† Oligoclase of the formula Ab_3 An_1 has the following composition :— Si_2O=61·9; Al_2O_3=24·2; CaO=5·2; Na_2O=8·7. Tschermak, *l. c.*

broad dark-coloured *peripheral shell.* They are evidently more basic than the surrounding granite; while of the spheroids themselves the marginal portion is more basic than the nucleus, the latter consisting principally of triclinic felspar together with a little quartz and possibly orthoclase, the former of oligoclase with abundant included plates of biotite and over 12 °/₀ of magnetic iron-ore. The felspar of the zonal portion is disposed radially, the iron-ore radially and concentrically, while no fixed law appears to govern the distribution of the mica. The concentric accumulation of the magnetite may be compared to the zonal inclusion of foreign minerals in leucite or in the felspars of andesitic rocks.

Literature.—Concretionary bodies have long been known to occur in granite; but these, though often of spheroidal shape, have generally been described as destitute of radial structure. A concentrically laminated structure, frequently only rendered visible by weathering, is, however, not uncommon.

The first mention I have been able to find of such bodies is in Leopold v. Buch's 'Geognostische Beobachtungen auf Reisen durch Deutschland und Italien'*. On p. 16 he describes, as occurring in an intrusive granite of the Riesengebirge ("Felsen des Kynasts" near Warmbrunn, Silesia), balls of a very fine-grained granitic material, which towards the exterior are richer in mica than in the central portion. Gustav Rose †, in 1842, gave a more detailed description of these bodies. His specimens were derived from Schwarzbach and the Kynast. He describes balls of 6 inches diameter. The central portion of these is formed by one or more twinned crystals of orthoclase, around which lies a narrow zone of albite and mica.

Curious concretionary spheroids in the granite of Chanteloube (Département de la Haute-Vienne) are described by Alluaud ‡. The dimensions of these bodies are from 50 cm. to 1–2 metres. They consist essentially of a nucleus of orthoclase, surrounded by a finely granular aggregate of quartz and felspar, the quartz gradually diminishing in quantity towards the periphery.

Charpentier §, Collomb ||, Jokély ¶, and von Andrian ** mention similar bodies.

Zirkel †† describes, in the granite of Clark's Peak, Medicine Bow Range, U.S., small aggregates of granular magnetite surrounded by a fine-grained zone of quartz, felspar, and muscovite.

Not unfrequently the concretions consist, for the most part, of

* Vol. i. (1802).

† Poggend. Ann. vol. lvi. 1842, p. 624; and J. Roth, Erläuterungen zu der geognost. Karte vom niederschles. Geb. &c. 1867, p. 63.

‡ Bull. de la Soc. géol. de Fr. (2), vii. 1850, p. 230.

§ 'Essai sur la constitution géognostique des Pyrenées,' 1823, p. 132.

|| Bull. de la Soc. géol. de France (2), vii. 1850, p. 297.

¶ "Geognost. Verhältnisse in einem Theile des mittleren Böhmens," Jahrb. k.-k. geol. Reichsansst. 1855, p. 375.

** "Beiträge zur Geologie des Kaurimer und Taborer Kreises in Böhmen," Jahrb. k.-k. geol. Reichsansst. 1863, p. 166.

†† Microscopical Petrography of the 40th Parallel, 1876, p. 53.

concentrically arranged scales of biotite or dark hornblende. This, for instance, is the case in the Pudding-granite of Craftsbury, Vermont *, where, in addition to the biotite, they contain small quantities of muscovite, quartz, felspar, and calcite †.

In an interesting paper read before this Society in 1879 the late Mr. J. A. Phillips ‡ gave the results of a series of careful investigations into the nature of the dark-coloured, so-called "concretionary patches." His conclusions show that these bodies differ from the enclosing rock, first, by containing a larger proportion of dark mica and hornblende; secondly, by their greater basicity, the orthoclase of the matrix being replaced by plagioclase in the concretion, or by the latter being poorer in quartz than the matrix. Although several of the concretions described by this author are spheroidal or ovoidal in shape, they present neither radial nor concentric structure.

Vom Rath § has mentioned the occurrence of flattened spheroids, of 6–8 centim. diameter, in the hornblende-granitite of Slätmossa, Kirchspiel Järeda, Kalmalen, in Sweden. These bodies have a granular nucleus, composed of the granite-forming minerals, and a narrow peripheral zone, showing radiate structure. The latter is further subdivided into an inner felspathic layer and an outer darker shell rich in biotite and hornblende. The same author || has described similar bodies in the granite of Fonni, in Sardinia. They were originally discovered by Prof. Lovisato ¶, while on a visit to the island. The balls occur, as at Mullaghderg, packed together in a small space, scarcely exceeding two cubic metres in extent.

The spheroids from Fonni have quite recently been submitted to a careful examination by Fouqué **; and his description of them shows that they exhibit several striking points of resemblance to the Irish specimens. Like the latter they consist of two parts:—(1) a nucleus, similar in composition to the surrounding rock; (2) a marginal portion composed of plagioclase felspar (albite) and biotite, the felspar being in divergent rays, and the mica in concentric zones, in which the individual plates are disposed in a tangential manner with respect to the nucleus ††.

* Report on the Geology of Vermont, by Ed. Hitchcock and others, vol. ii. (1861), pp. 564, 721.
Also, G. W. Hawes, Concordia, 1878, pp. 190–204.

† M. K. de Kroustschoff, Bull. de la Soc. Minéral. de Fr., vol. viii (1885), p. 138.

‡ Quart. Journ. Geol. Soc. vol. xxxv. 1879, p. 1.

§ Sitzungsber. der niederrhein. Ges., Dec. 1874, p. 206. See also a paper by N. O. Holst and F. Erichstädt—Geol. Fören. Stockh. Förhandl. No. 86. Bd. vii. Häft. 2 (1884), p. 134—where the Slätmossa rock is incorrectly designated *Klotdiorit*.

|| Sitzungsber. der niederrhein. Ges., Juni 1885, p. 201.

¶ *Ibid.*, Juni 1883, p. 131.

** "Sur les nodules de la Granulite de Ghistorrai près Fonni (Sardaigne)," Bull. de la Soc. Minéral. de France, tome x. (1887), pp. 57–63.

†† Prof. Judd has kindly lent me, for comparison, a specimen of these spheroids. It is considerably flattened: the largest diameter is about 4½ inches, the shortest not more than 2 inches. The zonal portion, which is about 1 inch in width, contains dark mica, but only in the outermost layers, the remainder being composed of pure felspar in divergent rays.

An interesting variety of spheroid has lately been discovered in the Stockholm granite of the Scandinavian peninsula, and has been the subject of a searching examination and detailed description by W. C. Brögger and H. Bäckström *. The spheroids occur in several distinct masses in a granitite consisting of orthoclase (in part microcline), oligoclase, quartz, and dark mica. Each ball is made up of a dark nucleus and an outer light-coloured zone. The former is composed of the same minerals as the surrounding rock, the latter principally of felspar (plagioclase, orthoclase, and microcline) together with quartz. Dark minerals (mica, &c.) are entirely absent from this portion of the spheroid. The texture of the outer zone is granular, but finer-grained than the nucleus or the surrounding granite. A radially divergent structure was observed by Brögger in one instance only. The nucleus passes by imperceptible gradations into the peripheral portion; the latter, however, is sharply separated from the granite. No fixed proportion exists between inner kernel and outer zone. In some few cases the granitic material of the nucleus was found to be replaced by a single large individual of felspar (microcline), as in the spheroids described by G. Rose (cited above).

Conclusions.—The concretionary bodies, briefly described in the above *résumé*, may be classed as follows:—

I. Local accumulations of dark mica, hornblende, and a little triclinic felspar, generally of irregular shape, but sometimes rudely spheroidal. These are the "*concretionary patches*" of Phillips.

II. Spheroids composed of quartz, felspar, and mica or hornblende (*i. e.* the same minerals that compose the surrounding rock) in granular aggregation. These bodies possess an inner kernel and an outer zone, the latter sometimes exhibiting concentric structure. Brögger † subdivides them into (1) those having a nucleus relatively rich in dark minerals (biotite, hornblende, &c.) with a peripheral portion relatively poor in, or free from, dark minerals; (2) those with a peripheral zone rich in dark minerals. The whole group may perhaps be classed with Vogelsang's *granospherites* ‡.

III. Spheroidal aggregations of triclinic felspar with dark mica, hornblende, or magnetite around a central nucleus. This variety is characterized by the possession of both radial and concentric structure, and may be referred to the *belonospherites* of Vogelsang §. To this group belong the spheroids from Mullaghderg, as also those from Fonni.

The nucleus of the spheroids is extremely variable, both as regards size and composition. It may consist of a portion of normally con-

* "Om förekomsten af 'klotgranit' i Vasastaden, Stockholm," Geol. Fören. Stockh. Förhandl. no. 110, Bd. ix. Häft. 5, p. 307.

I am indebted to Prof. Törnebohm for directing my attention to this important paper, as also for kindly supplying me with specimens, for the purpose of comparison, from both the Swedish localities (Slätmossa and Vasastaden).

† *Loc. cit.* p. 351.

‡ 'Die Krystalliten,' Bonn, 1885, p. 134.

§ *Loc. cit.*

stituted granite, or of one or more crystals of orthoclase; or, again, of an aggregate of plagioclase grains. Sometimes it is an accumulation of granules of magnetite *; sometimes one of the dark micaceous nodules of group I †. As the concretion forms round the original nodule, its irregularities are gradually equalized; so that the spheroidal or ellipsoidal character is soon acquired.

With regard to the genesis of the spheroids, there can be little doubt that they have been formed by concretion during the consolidation of the granite-magma; they must, consequently, be regarded as an example of zonal and, in the case of the belonospherites, radial crystallization around an earlier-formed nucleus. As one of the conditions for the development of such a crystallization a quiescent condition seems *à priori* to be essential. Differential movements in the granite-magma, which have resulted in a considerable distortion of the spheroids, must in some cases, however, have taken place before the final consolidation of the rock ‡. We have here an instance of fluxion-structure, which, in granite, is undoubtedly a rare phenomenon. Chemical composition appears also to be a determining factor; for in at least two of the above classes the concretions are more basic than the enclosing granite, the intervening material, on the other hand, being of normal constitution. A deficiency in silica would thus seem to favour the development of spheroids in granite. Whether the occurrence of basic patches be due to the absorption of pre-existing basic material or to some process of segregation, must remain, for the present, an open question. Brögger §, on the other hand, hazards the conjecture that the spheroidal structure is preferably developed along the marginal portion of the granite area, *i. e.* in those portions where the magma first consolidates. This, he says, would be analogous to the occurrence of granophyric or porphyritic structure in the marginal portions or in the apophyses of granite or syenite. The balance of evidence however, scarcely seems to favour this hypothesis. It certainly will not explain, for example, the occurrence at Mullaghderg, Co. Donegal; for this locality lies right in the midst of the granite-area ||.

With reference to the formation of these remarkable bodies, perhaps it would be not unprofitable to recall to mind Vogelsang's explanation of similar phenomena, given in his admirable paper describing the concretionary balls of the *Kugeldiorit* (Napoleonite) and *Kugelporphyr* of Corsica ¶:—"When a molten magma consolidates, an irregular (*ungleichmässig*) cooling may produce greater contraction of the mass at certain points; and this may lead, later on, to a spheroidal separation. If this condition is arrived at after

* Zirkel, *l. c.*

† Vom Rath, *l. c.*

‡ Brögger, *l. c.* pp. 323, 327.

§ *Loc. cit.* p. 344.

|| Mr. Kilroe writes:—"The mass of spheroidal concretions does not occur at or near the margin of the granitic area. The point is almost equidistant from quartzite, occurring in mass some miles away on either side, through which the granite has been intruded. Small isolated masses of quartzite and schist are included in the granite in various places, but none near the special point referred to."

¶ Sitzungsber. d. niederrhein. Ges. 1862, xix. p. 185.

the point of consolidation of the several minerals has been passed, and, therefore, after their separation is complete, we get, indeed, a concentrically laminated body, but one without a definite arrangement of the constituents: this is the well-known spheroidal structure of many eruptive rocks. If, on the other hand, the tendency to form spheroids is developed during the period in which a differentiation of the magma into the various minerals can still take place, the latter will naturally undergo a definite arrangement with regard to the central point."

The first case, as pointed out by Vogelsang, offers a rational explanation of that form of spheroidal structure in which there is no definite arrangement of the constituents *. The latter case describes what most probably took place during the formation of spheroids with zonal or radial structure.

EXPLANATION OF PLATE XIV.

Fig. 1. A portion of a spheroid, cut through the centre and polished. It shows the light-coloured nucleus, the dark zonal portion, and a small quantity of the granitic matrix attached to the periphery. (Nat. size.)

2 †. A portion of the nucleus, viewed in thin section under a low power and between crossed nicols. The striated mineral is oligoclase; the interstitial colourless substance, quartz; and the opaque grains, magnetite.

3. Section through the zonal portion of the spheroid, seen under a low power. The light portions are felspar (oligoclase); the black grains, magnetite. The latter have their long axes in the direction of the radii of the spheroid. The dark line in the zonal portion of fig. 1 traverses here the middle of the field, and is seen to be produced by the approximation of the black grains.

4. Section through the zonal portion of the spheroid, viewed under a low power and between crossed nicols. As in fig. 3, the main mass is oligoclase, and the black grains are magnetite. The felspar is seen to be twinned, the twin-lamellæ being orientated in the direction of the radii of the spheroid.

Discussion.

Mr. Rutley spoke of the difficulty of doing justice to the immense amount of careful work involved in this paper. The Author had wisely avoided theoretical views, and yet it was tempting to speculate on the causes which set up crystallization, and to inquire why there was no radial structure in the central portions of the spheroids.

Prof. Bonney regarded the paper as a very useful piece of work. He thought difference of structure proved a discontinuity of some

* In connexion with this point, Prof. Bonney's papers on "Columnar, Fissile, and Spheroidal Structures" (Q. J. G. S. xxxii. p. 140) and "On certain rock structures as illustrated by the pitchstones and felsites of Arran" (Geol. Mag. 1877, iv. p. 429) should be consulted.

† The microscopic sections are drawn, with the kind assistance of Mr. J. G. Goodchild, F.G.S., of the Geological Survey, from photographs taken by Mr. G. Barrow, F.G.S., of the Geological Survey.

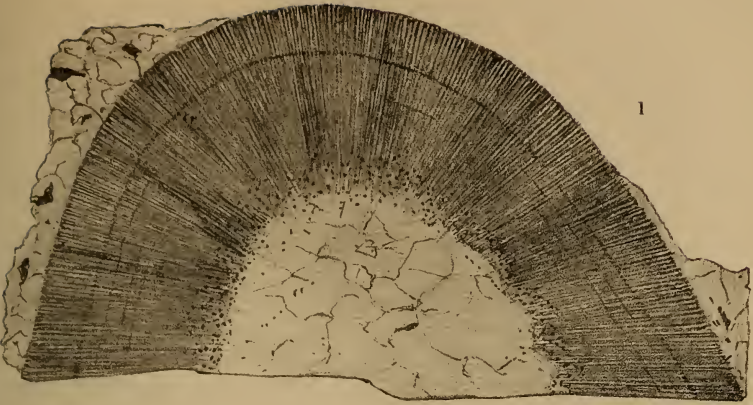
sort. The concentric concretionary structure is not confined to melted rocks. He referred to certain slates in the Lake District in which such a structure occurs. In the case of these spheroids a molecular movement had taken place, showing that a certain amount of plasticity had been retained in a rock which had never been in a fluid condition.

Dr. Hicks suggested that the proximity of intrusive rocks might have set up some action of this kind by the production of cavities; that the spheroids may therefore be considered as of secretionary rather than of concretionary origin.

Prof. Judd remarked that this was the first occasion in which both radial and concentric structure had been found in any spheroids in granite in the British Islands. The Society was to be congratulated on these specimens having fallen into such good hands, and being so admirably described. He asked if the microperthitic structure occurred in the felspars of the granite, and not in those of the nodules.

The Author observed, with regard to the suggestions of Dr. Hicks, that the spheroids occur in a very small compass, and probably bore no relation to the dyke. The minerals were not secondary products. Prof. Judd was quite correct in supposing that there was microperthitic structure in the granite, but none in the spheroid.

1



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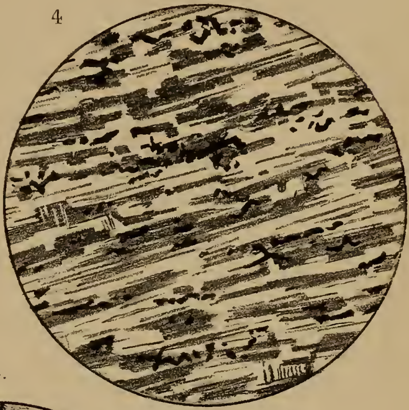

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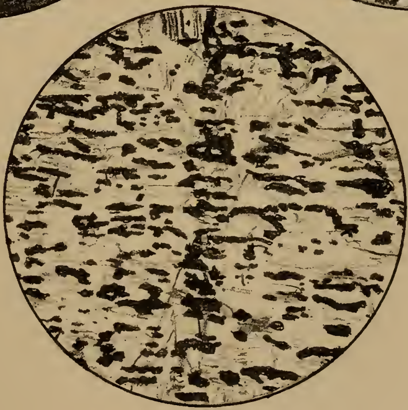

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MULLAGHDERG GRANITE.

34. *On the* Cae Gwyn Cave, North Wales. By Henry Hicks, M.D., F.R.S., F.G.S. *With a* Note by C. E. De Rance, Esq., F.G.S. (Read April 11, 1888.)

It has been thought advisable by those who have superintended the explorations at the Cae Gwyn Cave that a full account of the researches carried on there in the latter part of 1885, and during 1886 and 1887, should be laid before the Society. In a former paper (Quart. Journ. Geol. Soc., Feb. 1886) I gave the main results obtained up to the end of June 1885. The excavations were then entirely under the superintendence of E. Bouverie Luxmoore, Esq., M.A., F.G.S., P. P. Pennant, Esq., M.A., J.P., Edwin Morgan, Esq., J.P. (all of whom reside in the immediate neighbourhood), and myself. I was constantly present at the explorations to the end of June, when we had reached a distance of about 135 feet from the entrance. At this time the Cavern was visited also by Mr. C. E. De Rance, F.G.S.

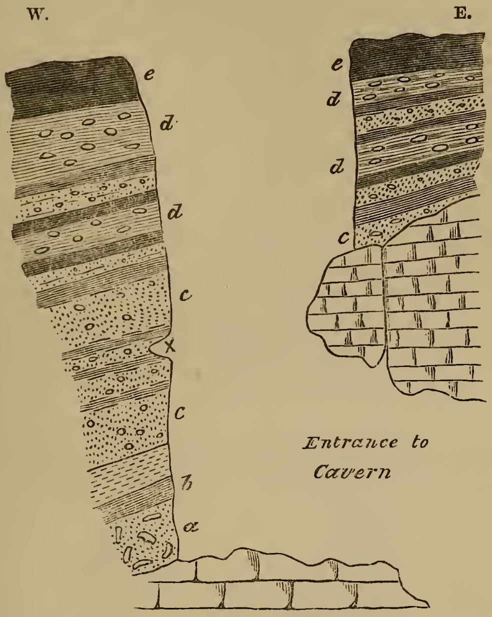
The sandy layer was well marked at this point, and the workmen were requested by us at the time to remove several shovelfuls, which we examined and found to have all the characters of true marine sand. The other deposits occurred in the order in which they had been found elsewhere throughout the cavern. The further researches in that year were superintended by Messrs. Luxmoore, Pennant, and Morgan, and the results were constantly communicated to me. The tunnel was found to be of nearly the same average width and height for about 10 feet further inwards, when it gradually widened into what was then supposed to be a chamber. Of the last portion of the cavern explored I stated in my paper (*loc. cit.* p. 14): "The last chamber reached in this cavern has not been fully examined, and as its roof has partially fallen in, it will have to be shored up before the explorations can be proceeded with in that direction. It is possible that a line of fissure has been reached, but this is not clear yet. The cavern up to this point is a true tunnel-cavern, with well-smoothed roof and sides." I also mentioned that the bones occurred throughout at the same general horizon, that the bone-earth contained in many places much sandy and gravelly material, many large angular masses of limestone, and also pieces of thick stalagmite and broken stalactites, sometimes lying horizontally, but more often tilted, like the bones, at a high angle. Overlying the bone-earth throughout occurred a considerable thickness of fine laminated clay, which contained no Pleistocene remains or large angular fragments of limestone or stalagmite. In the last twenty feet or so of the tunnel and in the supposed chamber the laminated clay was overlain by layers of sand and gravel. Throughout the supposed chamber the latter attained an average thickness of from $2\frac{1}{2}$ to 3 feet. What was supposed to be a broken roof or line of fissure turned out on further exploration to be the line of the limestone cliff over another entrance to the cavern. Before it was known that this so-called chamber was the widening of the cavern towards the new entrance, the following dimensions were sent to me by Mr. Luxmoore:—passage leading to chamber, height 6 feet 6 inches, width 6 feet; supposed chamber, height 9 feet, width 9 feet 6 inches, length 11 feet 3 inches. The deposits in the chamber were an increased thickness of the bone-earth, with imbedded blocks of limestone, as in the passage leading to it and in other parts of the cavern, laminated clay, continuous with that found in the passage, and upon the latter stratified marine sands and gravels. The section, it was stated, was perfectly clear, and all the deposits could be traced right across the so-called chamber. The cavern was visited by Prof. Boyd Dawkins in September, and in a letter he wrote to me on December 11, 1885, the following passage occurs:—"I have carefully compared the sand and gravel found in the upper cave (Cae Gwyn), and sand sometimes adherent to the bones, with the glacial sand and gravel which occurs in the valley a little way above, and find that in every particular they agree. I have also compared them with the glacial sands and gravels near Bryn Asaph and find that all three are composed in the main of quartz, quartzites, and Silurian fragments." Up to this time, and for some months after the work was suspended, the surface of the field remained perfectly even, and there were no indications of any sinking of the ground. During the winter months, however, after a heavy fall of snow, some of the materials slipped inwards into the so-called chamber, and the surface of the field over the spot gradually sank.

Researches in 1886.

For the purpose of continuing the researches in 1886 a grant was obtained from the British Association for the Advancement of Science, and the following Committee was appointed, viz.:—Prof. T. McKenny Hughes, Dr. H. Hicks, Dr. H. Woodward, and Messrs. C. B. Luxmoore, P. P. Pennant, and Edwin Morgan.

Work was resumed during the last week in May under the superintendence of Messrs. Luxmoore, Pennant, and Morgan, and I joined them a few days later. It was thought advisable to sink a shaft from the surface of the field, over the depressed part, so as to uncover the supposed chamber. Much to our surprise, after a few days' work, we found that what had appeared from within the cavern to be a broken roof, or line of fissure, was the abrupt termination of the limestone in a cliff with an opening below into the cavern. Further researches revealed the fact that this opening was a wide entrance, over 11 feet across and with a height of from 6 to 8 feet. As the shaft was only about five feet across at the bottom at this time, a perfectly clear section of the deposits as they extended into the cavern could be seen, and the particulars now shown in fig. 1 were then carefully noted. Mr. C. E. De Rance, F.G.S., of the Geological Survey, was at that time in the neighbourhood and, at my request, visited the cavern and kindly assisted us in taking correct measurements in the pit. The section was perfectly clear all round, and the various bands were traced continuously across both into the entrance and over the cavern. The measurements were taken from a ladder placed against the vertical face.

Fig. 1.—*Section across Shaft, showing the continuation of the Beds over the entrance* (June, 1886). (Scale 8 ft. to 1 inch.)



a. Bone-earth. *b.* Laminated clay.
c. Sand and gravel.
d. Clay with boulders and bands of sand and gravel.
e. Soil. × Rabbit-burrow.

The rabbit-hole shown in fig. 1 indicates the track which extended direct from the cavern to the opposite side of the shaft, in a band of clean marine sand. The pit, which had been carried to a depth of 20 feet, was only 9 feet wide at the top and 5 feet at the bottom. It was subsequently widened, but all the important measurements were taken before this was done. The evidence that the deposits extended continuously into the cavern was so clear, and had been seen by so many observers, that it did not occur to us that anyone could possibly doubt it, otherwise we should most decidedly have allowed one side to remain undisturbed. Feeling, however, that the fact was established beyond the possibility of doubt, we decided to proceed with the examination of the brecciated bone-earth at the bottom, and in doing so we burrowed under the drift-face and by that means caused some falls to take place, necessitating a further widening of the shaft. I wrote to Prof. Hughes on several occasions in June, telling him the results, and strongly urging him to visit the section. Unfortunately, however, he was not able to do so until the work had been stopped (the grant from the British Association having been exhausted), and most of the section had been shored up with timber for the season, to prevent further falls. We were anxious that as many geologists as possible should visit the section when the surface was fresh and each band distinct, knowing well that a few showers of rain, by washing the soil from above over the face, would blind some of the evidence; therefore I wrote to a considerable number of geologists, who I felt would be interested in the subject, asking them to visit the cave if possible. Those who saw the section before the ground was sloped back at the top were Mr. De Rance, Dr. Stolterforth, Mr. Shone, and Mr. Morton, and later Prof. Hughes, Prof. Boyd Dawkins, and Mr. Strahan. In the bone-earth at the bottom of the shaft many teeth and bones occurred; and one tooth of Rhinoceros was found six feet in front of the overhanging roof of the cavern, measured from the outer edge.

On June 28th, when Mr. G. H. Morton, F.G.S., visited the cavern, one of the workmen in digging in the bone-earth turned up in our presence, along with teeth of Hyæna and Reindeer, a well-worked flint-flake, nearly two inches in length and half an inch wide (fig. 2).

Fig. 2.—*Flint-flake found under Drift, outside the covered entrance.* (Natural size.)

It is of a white, porcellaneous appearance, like the implements which we found in the Ffynnon Beuno cave; and at the last meeting of the British Association Mr. Pengelly stated that it resembled some found by him in the lower deposits in Kent's Cavern. Its position was about 18 inches below the lowest bed of sand, in a vertical face of the section, a little outside the line of the entrance and slightly to the south of the opening. It was found near one of the large angular blocks occurring in the bone-earth, but it is an entire mistake to say that it was itself covered by a block. Indeed, nothing could be clearer than the evidence of its position, for we had made a clean face to the section just before, to show how the sandy bands and the laminated clay passed in under the shelving rock, and we were burrowing under those bands when the flake was found. Some portions of the rock at the edge of the entrance, which were rather loose, were removed just before; but the flake was well outside these and in the bone-earth under the deposits in regular sequence in the section. The material in which it was found was exactly like that occurring at this horizon throughout the cavern—a reddish sandy clay, with here and there fragments of stalactites, stalagmites, and angular blocks of limestone. With regard to these angular blocks of limestone, it is necessary to say that although they were more numerous outside the entrance than in the cavern, yet similar blocks were constantly met with in the cavern, and even at the entrance to chamber C (see Plan, p. 573) they were so large that they had to be blasted before they could be removed. Nothing could be more incorrect than to say that they formed a barrier at the entrance, giving evidence of a broken side to the cavern. These blocks (except those removed at the sides, which happened to be loose, although in their original position as forming part of the limestone cliff) were all under the laminated clay and the sandy bands, and could not be removed without disturbing the latter deposits at every point examined. The very few blocks found higher in the section were of the character of boulders, and, as could be made out in most cases, had been derived from beds at a different horizon from those at the entrance.

At the close of our work in 1886 it was thought advisable to slope the upper portion of the section around the pit, to prevent falls into it during the winter, and the sides were carefully timbered for the lower 12 feet, except at the south angle. Here a few steps were placed to enable the cavern to be reached from that end, and an excavation was made in the field to a depth of about 8 feet on that side leading to the steps. As has already been stated, there was not the slightest sinking of the ground until after the rains and a very heavy fall of snow in the winter; and when the pit was dug out in June, only the part immediately above the central portion of the opening into the cavern was found to have sunk in, leaving the section at each end of the opening perfectly undisturbed. The materials found in sinking the shaft were exactly in the order in which they could be traced in the undisturbed deposits, and it was clear beyond the possibility of doubt that each band had extended right across, before that portion had been depressed during the previous winter, and that the dip of the beds was everywhere away from the cliff face and from the entrance to the cavern. When it is considered what an immense quantity of material had been removed from the cavern before the pit was dug out, it becomes at once evident that it could not have been carried in through a swallow-hole which had left no evidence whatever of its existence. It must not be forgotten also that the various sediments in the cavern retained their relative sequence throughout; moreover this sequence continued uninterruptedly from the cavern into the drift section on the outside. I have taken some pains to make a calculation of the amount of material (not taking into consideration the blocks of limestone, &c.) which had been removed from the cavern before we reached the new entrance, therefore before any of the deposits in the pit had been touched, and I find that it could not have been less than about 150 cartloads, consisting of gravel, sand, laminated clay, and sandy clay. This must have been conveyed into the cavern before the entrance or entrances were blocked up by the glacial deposits which extended across the valley. That the deposits in the cavern were conveyed in by marine action seems to me, after constantly watching the conditions exhibited throughout the explorations from the commencement, to be beyond the possibility of doubt. The position of the caverns shows that they could not have been under the influence of any other force (since they had been occupied as dens by the animals) of a sufficiently powerful nature to break up the thick stalagmite floor which had at one time covered over the remains (as was abundantly evident by finding bones attached to the under side of broken pieces) and to have thrown large masses of this, frequently over a foot in thickness, into all positions in the deposits. Large bones were also thrust into fissures and tilted up at all angles. In the sand also some fragments of marine shells were found, as mentioned in my previous papers. I believe the main entrance to the cavern to have been the one recently discovered under the drift section. It is the widest and most lofty entrance, and there are indications that the one first found, which had been exposed by quarrying operations, must have gradually ended, before the portion in the quarry had been removed, in a fissure, somewhat like that in which the tunnel on the east side of chamber C (see Plan) has been found to end. The vertical brecciated face, which evidently formed one side of the portion of the cavern removed by quarrying, tends strongly to show that this was not the main entrance, even if there was an opening here into the cavern from the limestone-cliff at the edge of the valley.

Researches in 1887.

A further grant having been obtained from the British Association, work was resumed on June 6th, under the superintendence of Messrs. Luxmoore, Pennant, Morgan, Morton (who was added to the Committee), and myself, and a few days afterwards we were joined by Prof. Hughes. Mr. Morton stayed at the inn close by, so that he might be constantly present at the excavations.

Up to this time no objections had been raised to the notion which we had, as we thought, established beyond the possibility of doubt during the explorations in the previous year, that the deposits from the drift-section passed directly into the cavern, and that the bone-earth extended for a considerable distance outwards even to a point 14 feet from the inner wall of the cavern, measured by a line taken directly outwards. That Prof. Hughes was not at that time inclined to contest these points seems evident from the following quotation, taken from his lecture delivered at Chester and reported in the 'Chester Chronicle,' November 6, 1886. After referring to the finding of the flint-flake, in the presence of Mr. Morton and myself, in the bone-earth, which he describes as "a limestone-breccia containing a few bones," he goes on to say that "a similar deposit extended under the sandy drift with boulders, as far out as the excavation was carried. This is conclusive against the drift which rested on it being the undisturbed marine Clwydian drift, as it is quite impossible that the lashing waves on the rock-bound shore exposed to the north-west winds should not have swept such loose débris into the deep fiord below." His object at that time evidently was, as in some succeeding papers, to show that the drift was not in the position in which it had been deposited, but *remanié* "rainwash" like the "mixed mud and sand and gravel which we find everywhere overlying the Clwydian drift crumbling down the hillside." It is also stated that no shells had been found "in any of these deposits;" and attention is called to the line of an old fence, as showing how rapidly the deposits are creeping down the hill. Most of these remarks were reproduced in papers in the Geol. Mag., November 1886, and in the Quart. Journ. Geol. Soc., February 1887. As to the statements in regard to the so-called fence, I was greatly puzzled at first to know what they meant, and was inclined to think that they must relate to the old fence (as distinguished from that which we had placed as a boundary to the cavern) along the edge of the valley, against which we had heaped materials obtained from the cavern. When I realized that Prof. Hughes meant the rather steep grassy slope in the field (which, according to a statement in his last paper, carried a fence which was removed about ten years ago), I determined that a cutting should be made across it beyond the point where any material had been thrown down, and our earliest operations this year were directed to that purpose. A cutting, which was carried in a S.S.W. direction from the shaft at the mouth of the cavern, was now made, varying from 5 to 10 feet in width, the narrowest part being at the furthest point from the cavern. In the face exposed in front of the entrance, and for a distance in the cutting from there of about 25 feet, the soil varied in depth from 18 inches to 2 feet, but at the slope it thickened considerably, probably from having been thrown there in levelling the old fence. Underlying this throughout the whole length of the cutting, and in the part of the field examined beyond this point, a Boulder-clay of a reddish-brown colour was exposed. This Boulder-clay contained numerous erratics and thin seams of sand which were traceable along the whole section. The general dip of the beds was at an angle of about 15° away from the cliff face.

On June 10th some fragments of shells were obtained by us out of a band of reddish sandy clay, in the cutting near the shaft, at a depth of about 7 feet from the surface. Additional fragments and some perfect specimens were discovered on subsequent days, and the following list was given in my report to the British Association*:—*Ostrea* sp., *Mytilus* sp., *Nucula nucleus*, *Cardium echinatum*, *C. edule*, *Cyprina islandica*, *Astarte borealis*, *Artemis exoleta*, *Venus gallina*?, *Tellina balthica*, *Psammobia ferröensis*, *Donax*?, *Mya truncata*, *Littorina* sp., *Turritella terebra*, *Buccinum undatum*. Below the Boulder-clay, at a depth of about 9 feet from the surface, there was exposed some sandy gravel and fine banded sand with a total thickness of over 6 feet, and under the latter a well-defined band of finely laminated reddish clay.

Below the laminated clay the brecciated bone-earth was found to extend as far as the cutting was made in front of the entrance, and also for a distance of 7 feet in a southerly direction from the entrance. Beyond that point the cutting was made deep enough to reach the sandy gravel under the Boulder-clay, and at different parts test-holes were sunk still deeper into the gravel and sand. One hole was also sunk in the field in front of the cutting at a distance of over 35 feet from the entrance to the cavern. The deposits here were found to be similar to those in the cutting and in front of the cavern, but the depth of soil over the Boulder-clay was only from 1 foot to 18 inches. A very large number of smoothed and ice-scratched boulders were found, many of considerable size, the majority being fragments of Wenlock shale from the neighbourhood, and Lower Silurian rocks from the Snowdonian area. Amongst them also were fragments of granite, gneiss, quartzites, flint, diorites, basalts, Carboniferous rocks, &c. To expose the section in front of the entrance down to the limestone-floor, it was found necessary to remove the timber placed there the year before, and the cutting was widened here sufficiently to show a vertical face of undisturbed deposits. The timber supporting the north-east face was at that time allowed to remain. The finding of marine shells in considerable abundance in a continuous band in the section and round the pit proves that the upper portion of the drift in which they were found, resting on the gravel and sand, is, as I contended in my former papers, the so-called Upper Boulder-clay of the Clwyd valley, *i. e.* where it has not been re-assorted by the action of fresh water, as in some places about St. Asaph and elsewhere along the borders of the channels carved out by the important rivers Elwy and Clwyd. As these shells are found in the deposits belonging to the Glacial period in many areas, and occur in the high-level sands of Moel Tryfaen (1360 feet) and Macclesfield (1200 feet), it seems to be perfectly clear either that the beds were deposited during a great submergence, which took place in Mid-Glacial time or at the close of the Glacial epoch, or that a great ice-sheet passed over this area subsequent to the occupation of the cavern by the animals and by man. The section was visited by Mr. Tiddeman, F.G.S., and Mr. Clement Reid, F.G.S., both of the Geological Survey, on June 15th, 16th, and 17th, and after a very

* The specimens were handed to Mrs. McKenny Hughes, who kindly offered to identify them for us.

careful examination they came to the conclusion that the deposits were correctly classed with those belonging to the Glacial epoch and that they were in position as originally deposited. These gentlemen were also shown the brecciated bone-earth underlying the gravel and sand in front of the entrance and at the south-west end of the pit, 7 *feet from the edge of the entrance*, and they admitted that it clearly passed under the drift-section. Indeed, some blocks of limestone were removed from the brecciated bone-earth, which caused the overlying sand to fall, thereby exposing at the south-west end, and quite near to the cliff face, a remarkably clear section of stratified sand dipping away from the cavern. The evidence obtained during the excavations in June demolished so completely all the objections previously raised that for some time we were fain to believe that no further opposition to our views would be made. In this, however, we were mistaken, for during a visit of a few hours paid to the section in September by General Pitt-Rivers and Dr. John Evans, accompanied by Prof. Hughes, after the section had been exposed to the weather for between two and three months, they noticed that some of the uppermost deposits at one or two points had slipped a little towards the pit; and the idea seemed then to have occurred to them that this was an indication that there must have been a swallow-hole at the point where the shaft was sunk. When I was informed of this, although I knew that it must have been an entirely recent change, I decided to have that portion of the shaft which had not been exposed during the June excavations re-examined, so that there may be no doubt whatever as to the conditions behind the timber placed there at the close of the work in 1886. Permission for this to be done was most kindly granted by the owner Mr. Morgan, and, as in former explorations, he, Mr. Luxmoore, and Mr. Pennant assisted in the supervision of the work, Prof. Hughes and myself being also present during most of the time. Work was resumed on September 29th. After the timber and the material which had been thrown behind it to support the face, here 20 feet in depth, had been removed, a section of the deposits, as left by us in our researches in June 1886, was exposed, as well as some of the brecciated bone-earth which had not then been removed from the bottom of the shaft. On making a fresh face to the section at the parts where the recent looping down of the upper deposits had taken place, it was at once seen that this was due to a recent slip, and that the deposits behind and below were entirely unaffected by it. It is hardly necessary again to mention the fact that all the observers who saw the section when the shaft was first opened state emphatically that there was no looping down to be seen at those points at that time, nor when the upper part of the opening was widened and sloped at the close of the work in 1886.

The photographs which were taken by Mr. Helsby, of Denbigh, on October 1st, show most conclusively that the bone-earth passed directly under the vertical drift-section; and it was proved by explorations subsequent to the day when the photographs were taken that it extended for a considerable distance beyond that point; indeed, the end of it was not reached when the work was suspended. This fact, even if we had not obtained similar evidence at the south-west end of the cutting at a distance of about 22 feet from the point above referred to, and also at every foot in that length either in front of the entrance or along the cliff-face, it might have been supposed, would alone have been sufficiently convincing evidence that the theoretical swallow-hole, or a broken wall of the cavern subsequent to the deposition of the marine deposits, could not possibly have produced such a regular sequence in the deposits from the bone-earth upwards. Moreover, as already stated, all the angular blocks of limestone were buried in the sandy clay which contained the bones, always under the laminated clay and the stratified sand. The photographs show also that the bedded sand belonging to the so-called marine drift *has not* sunk in towards the theoretical swallow-hole, but that it (as well as the overlying deposits and the underlying laminated clay) dips everywhere away from the cliff and from the mouth of the cavern. Bones were discovered at this time under the drift at the north-east end of the cutting at a point 3 feet outwards from the edge of the overhanging rock, and it is important to remember that the sand passed under and abutted against this edge in an undisturbed condition when the section was reopened this year (fig. 3).

Fig. 3.—*Section at North-east end of Excavation, as seen October* 3, 1887. (Scale 8 feet to 1 inch.)

a. Brecciated bone-earth. *b.* Laminated clay.
c. Sand and gravel.
d. Clay with boulders and bands of sand and gravel.
e. Soil. × Shell-beds. * Fissure.

Dr. Geikie visited the cavern at the request of Prof. Hughes and myself on October 10th, Messrs. Hughes, Luxmoore, Morgan, De Rance, and Hilton Price being also present. Unfortunately I was unable to be there. Subsequently Dr. Geikie kindly furnished us with the following report:—

"The question on which my opinion was asked with reference to this cave was, I understand, the following:—whether the glacial beds lie undisturbed upon the bone-earth at the end of the cave, or whether their present position is due to the fall of the roof or wall of the cave, and their consequent descent upon the cavern floor. Accordingly I visited the cave on the 10th instant and examined the section laid open in the pit that was dug in the glacial deposits. The conclusions I formed may be thus summarized:—

"1. The bone-earth projects beyond the present limits of the cave, but it probably never did so originally; hence I have no doubt that the roof or wall of the cavern has given way. The large masses of limestone lying at the bottom of the pit no doubt represent a portion of the fallen material.

"2. These fallen blocks lie on the bone-earth. The material resting upon them has, of course, been removed in the excavation of the pit; but I observed that the block nearest the northern wall of the pit passed under the base of the undisturbed glacial beds.

"3. Against the lower part of the face of limestone on the northern side of the pit there is undoubted evidence of slipping, the lower layers of pebbly sand and clay being vertical against the wall of rock. This disturbance, however, I could trace only a few inches outward from the rock-boundary. It does not affect the main mass of glacial deposits, and is referable, I think, to solution of the limestone along its outer surface. The various layers of glacial sands and clays were traced by me continuously across the pit. I could see no evidence that they had ever subsided into a cavity caused by the fall of the limestone into the cavern.

"4. From the data presented by the pit-section I would infer that the fall of the roof or wall of the cave took place before the deposition of the glacial deposits, and that during a period of subsidence these marine strata were subsequently laid down against the limestone-bank so as to conceal this entrance to the cavern."

Mr. Morton also visited the section, and has kindly sent me the following note giving the results of his observations in June and October:—

"In June last, during the progress of the excavation in front of the original entrance to Cae Gwyn Cave, I stayed at the inn close by for eleven days, besides visiting it on other occasions before and since. During that time I had, of course, ample opportunity of constantly observing the Boulder-clay, as well as the sand and gravel, and other beds beneath it. From the first time I saw the section I felt convinced that all the beds were *strictly in situ*. The bone-earth had evidently been disturbed, and a stalagmitic floor broken up, and the fragments, often large blocks, mixed up in it. The laminated clay had evidently been tranquilly deposited over it.

The sand and gravel were over the laminated clay, but current-bedded as such so-called 'Middle sands' often are. Finally, the Boulder-clay occurred over the sand and gravel, without any evidences of disturbance or rearrangement of any kind. The top of the Boulder-clay formed the surface of a nearly flat field, there being no higher ground near from which débris could have been derived; and there is no reason for supposing that the surface over the cave was ever deeply covered with clay. The entrance to the cave is in a buried limestone-cliff, from which the Boulder-clay dips, but so gradually that nothing of the nature of a talus is suggested, especially considering the rapid fall of the ground in the same direction. The Boulder-clay appeared to me as good an example of undisturbed clay as seen anywhere in the Vale of Clwyd, Cheshire, or Lancashire, while the erratics are very similar. As to the age of the clay, it seems to be the Upper Boulder-clay—that is, some of the latest deposited during a period of glacial submergence. In the surrounding country there are no evidences of an earlier part of the Glacial period than that of the deposition of the Boulder-clay; for the occasional striæ on the rocks seem to have been caused by ice-bergs and icefields towards the latter end of the submergence, and I have not seen any deposit indicating a period of land-glaciation. Consequently, the Boulder-clay, in my opinion, represents the Glacial period, and if it were considered to be Post-glacial, we should have no glacial deposits whatever in the district. Nothing need be said as to deposits in distant parts of the country, and I am not aware that the mountainous region of North Wales, with its glacial moraines, throws any light on the subject.

"The remains of Mammalia found in the bone-earth were evidently deposited in the cave before the deposition of the Boulder-clay, and there are no indications of any Inter-glacial period between it and a still earlier period of supposed land-glaciation. The broken up stalagmite associated with the bone-earth seems to prove that the latter was an ancient deposit before the glacial subsidence. In this western portion of Britain no traces of the Hyæna, Lion, Elephant, and Reindeer have been found in any Post-glacial deposit, and the inference is that all the bone-caves, on both sides of the Vale of Clwyd, are Pre-glacial, though the drift about them has been for the most part denuded in Post-glacial times, and many of them invaded by animals still living or not long extinct in the country."

It has been supposed that the cavern may extend for some distance in a north-east direction under the overhanging ledge of rock; but it appeared clear to me that that extension was rather a rock-shelter than a cavern, as it is only a narrow space, between three and four feet in height, containing loose blocks of limestone in the bone-earth, but *with no rock-wall on the outside.* There was a narrow fissure, about six inches across, by the side of the rock-face; but this was found to be a continuation of the joint in the limestone which we had noticed in the floor in front of the entrance, and it did not indicate any prolongation of the cavern in that direction (see Plan, fig. 4). As Mr. Morgan and Mr. De Rance were the last to see the conditions before the place was finally covered over, I will give their evidence as communicated to me :—

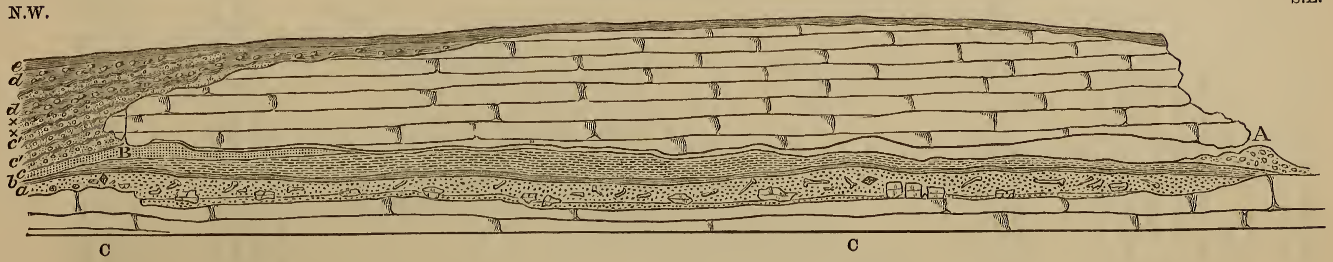
Mr. Morgan wrote that "the day after Dr. Geikie was here, Mr. De Rance came over to make a sketch, and just before the men began to fill in the pit he got Robert to make a fresh cut at the place," *i. e.* the north-east end by the side of the block of limestone, and under the overhanging rocks. He further says that happening to go down there just at the time, he noticed that "there were layers of sand which we had not seen before, and instead of being vertical they were quite the opposite, the layers going right across."

Fig. 4.—*Ground-plan of the Cae Gwyn Cave, and of the Excavation in the Drift in front of the covered entrance.* (Scale about 50 ft. to 1 inch.)

A. Old entrance.
B. New entrance, uncovered under drift.
C. Chamber in which flint-scraper was found.
D, E, F. Outside line of excavation; from D to E the drift was removed to the limestone-floor; from E to F in parts only.
* Position of flint-flakes.

The results obtained by Mr. De Rance are given in his Note (p. 576). The section (fig. 5) is intended to show the sequence of the deposits as they were observed throughout the cavern, and in their extension

Fig. 5.—*Section through Cae Gwyn Cavern, showing the Deposits found during the explorations in* 1884, 1885, 1886, *and* 1887.
(Scale 25 ft. to 1 inch.)



a. Bone-earth, with remains of lion, hyæna, wolf, bear, Irish deer, red deer, roebuck, reindeer, horse, woolly rhinoceros, mammoth, &c.
b. Laminated clay and reddish loamy clay.
c. Fine banded sand. *c'.* Sand and gravel.
d. Clay with boulders and bands of sand and gravel.
e. Soil. × Shell-beds.
A. Entrance discovered in 1884, nearly closed by bank of talus.
B. Entrance filled up with drift, &c., discovered in 1886.
C. Positions where flint-implements were found.

outwards into the drift-plateau in front of the hidden entrance. The entrance from the quarry was almost completely blocked up by materials which had evidently been thrown there, when I first crept into it, and at that time it was impossible to penetrate inwards for a distance of more than about 50 feet. Beyond that point the deposits reached to within a few inches from the roof, and as they were comparatively in an unusually dry condition along the whole length of the main tunnel, it is evident that this space was due to the contraction of the deposits by the loss of moisture. This is proved also by the fact that in the side channel, where the deposits were in a moist condition, they filled it up completely to the roof. As there are abundant evidences in the portion of the cavern next to the quarry, in crevices along the sides up to the roof, that that portion had been completely filled up originally, it may be presumed that when the cavern was exposed in quarrying-operations the workmen probably cleared out that portion sufficiently to enable them to creep in for shelter, and had therefore prepared it to become, as we found it, a resort for burrowing animals.

Summary.

The recent researches at Cae Gwyn have proved most conclusively that there was no foundation for the views of those who contended that the drift which crossed over the entrance and extended into the cavern was *remanié*, and had gradually crept down the hill. They have shown beyond the possibility of doubt that the deposits which overlie the bone-earth are *in situ*, and are identical with the typical glacial deposits of the area. It was found also that these deposits had at one time extended continuously across the valley above this elevation (400 feet above ordnance datum), and that the caverns had consequently been completely buried beneath them. The explorations carried on in 1885, 1886, and 1887, in the Cae Gwyn and Ffynnon Beuno caverns, show that they must have been occupied by the animals before any of the Glacial deposits now found there had accumulated, also that a thick floor of stalagmite had formed over these remains before the caverns were subjected to water-action. This action broke up the floor and completely re-sorted the materials, evidently washing out some, but also adding sandy and gravelly material to the deposits. Very large blocks of limestone, which were found at many points in the caverns, had evidently been disturbed by the same force, and had in many cases protected the original contents; they were, however, invariably found in the lowest deposits, and were covered over by laminated clay, sands, and gravels. It is certain that the caverns had been completely filled up with these materials, and in the case of the Cae Gwyn cave it would appear that they must have been conveyed in mainly through the entrance recently discovered under the drift. The stratification at this entrance was so marked and could be traced so continuously inwards over the bone-earth that there can be no doubt that it was the main entrance to the cavern. There was not the slightest evidence that any portion of the material had been conveyed in through a swallow-hole, and the conditions witnessed throughout were such as to preclude any such idea. The presence of Reindeer remains in these caverns, in conjunction with those of the so-called Older Pleistocene Mammalia, showed that they had reached this area long before the period of so-called submergence, and evidently at an early stage in the Glacial period. Man, as is proved by the implements found, was also present at this time; therefore it is natural to suppose that he migrated into this area, in company with the Reindeer, from some northern source, as no direct evidence of his presence at an earlier period in this country has as yet been found. It is important to remember that Reindeer-remains have also been found in the oldest river-gravels in which implements have been discovered. Although Man reached this country in company with the Reindeer and other northern animals, this does not, of course, preclude the idea that he may also have reached it from some eastern or southern source, perhaps even at an earlier period.

NOTE.—Mr. De Rance, F.G.S., writes as follows:—"When I assisted you in constructing the plan of the cave published in Quart. Journ. Geol. Soc. Feb. 1886, the working-face was excavated to within ten feet of the supposed chamber B of that plan, and the uppermost deposit was a fine yellow sand, its surface being within six inches of the roof-arch, and resembling the Glacial Drift sands of the pits in the neighbourhood and those of Mostyn and Bagilt. There was no trace of subsidence on the surface of the field above the point B. In June 1886 the entrance to the cavern had been discovered, and a vertical shaft, 20 feet deep, disclosed Boulder-clay resting on Drift-sand, which passed continuously into the cavern itself, while the underlying bone-earth similarly passed outside the cavern, and formed the base of the cutting, as far as it was then carried. In June 1887 the pit in the Drift was cut still further back, the bone-earth still continuing to form the base of the Glacial Drift; the north side of the cutting was boarded up and considered dangerous. In October of the same year the timbering had been removed; on the 10th of that month I accompanied Dr. Geikie, F.R.S., and a vertical band of clay and sand on the west side of a mass of limestone at the base of the north face of the pit was pointed out, also a clay-joint against the vertical face of rock forming the side of the hill adjacent to the mouth of the cavern. On the 11th of October, in the presence of Mr. Edwin Morgan, J.P., I made some excavations at the north side of the pit and three sketches of the same. I found that the mass of limestone before referred to was a tumbled rock from above, that bone-earth occurred behind it and beyond it, and up to four inches above it, where occurred a tooth of Hyæna, that above this occurred a horizontal band, five inches thick, of washed sand passing directly up to the clay-pipe against the limestone wall, and which afforded a sort of material for the sand-pipe by the big block, the sand-bed passing across and cutting off its upward prolongation."

Discussion.

Dr. Evans, notwithstanding the fresh evidence now adduced, could not adopt Dr. Hicks's views. If the bone-earth had been formed before the submergence, the sea would have cleared out the cave-deposits; they could not have been formed during the submergence, and were therefore subsequent to it. Dr. Hicks's opinion as to the original entrance appeared to have changed; his own impression was that a number of limestone-blocks occurred at the north-west extremity, and that this was not the original entrance. After the submergence the cave was occupied by animals, and the laminated clay afterwards formed by percolating water, and a certain amount of sand was also introduced by the gradual passage of water, of the results of which he had seen traces at the north-west end.

The archæological evidence was against Dr. Hicks's views. The narrow scraper was of a character not usually found in gravel-beds of river-valleys, but was characteristic of the later caves of the Pleistocene period. The other implement was like some from Kent's Cavern. In the Clwyd Valley there are distinctly Post-glacial cave-deposits with implements of an older type than those of Cae Gwyn, and which were similar to such as occur in undoubted Post-glacial deposits of the east of England.

At Drucat, near Abbeville, Prof. Prestwich has described a pit, 90 feet deep, which had been formed in the chalk by chemical action since the deposition of the gravel containing flint implements; and sufficient allowance had not been made for the dissolution of the limestone at Cae Gwyn.

Mr. Morton regarded the drifts as identical with those of the neighbouring counties, the shells of which were mostly of living species. He agreed with Dr. Hicks as to water-action having disturbed the bone-earth and stalagmite, and saw no signs of the looping of the drift or of a swallow-hole. The fauna was different from the Post-glacial fauna of the vicinity.

Mr. Clement Reid considered that Dr. Hicks tried to assign too high an antiquity to the bone-earth. Interglacial deposits with mammals occurred in the east of England, and with plants in Scotland, and he would suggest the correlation of the bone-earth with these. The absence of a lower Boulder-clay in this district might be accidental.

Mr. Strahan believed that the drifts of the mouth of the cave were part of the northern drift which he had mapped over a large part of Denbighshire, Flintshire, and Cheshire, and that the bone-earth lay beneath them.

Dr. Hicks, in reply, stated that he had not, in this paper, suggested that the bone-earth was actually Preglacial, but only below the Glacial deposits of the area. That the bone-earth was older than the Glacial deposits was now proved beyond the possibility of doubt. He could not agree with Dr. Evans that the fauna associated with the implements at Cae Gwyn was Post-glacial in England, and considered the implements themselves of such a character as might have been formed at any stage since man first began to fabricate implements from flint.

35. *The* Upper Eocene, *comprising the* Barton *and* Upper Bagshot Formations. By J. Starkie Gardner, Esq., F.G.S., F.L.S., Henry Keeping, Esq., and H. W. Monckton, Esq., F.G.S. (Read March 28, 1888.)

The introduction of the Oligocene stage into our classification has necessitated a partial revision of the grouping of our older British Tertiaries. Whether this introduction of a new primary division into the Tertiary system was necessary or expedient may still be questioned; but it has been generally adopted and is, for the time being, established. The division does not coincide in England with a marked change in either fauna or flora, though the series seems nevertheless tolerably complete and well developed; its limits, however widely stretched, show that the Oligocene stage compares neither with the Eocene nor the Miocene in importance.

Opinions have differed as to where the line of division should be drawn; whether this should be as low down as the top of the Barton Beds or at the base of the Headon Beds, or even higher. For our part, we think it desirable to uphold the view which places the demarcation between the top of the Bagshot Sands of Alum Bay and the base of the Lower Headon Series, though it is perfectly obvious that any such line in the midst of our series must be a purely artificial one.

An almost necessary consequence of the change in the classification has been the readjustment of the divisions of our truncated Eocene, only the middle and lower division remaining, so that the term "Middle" without an Upper Eocene would no longer be an appropriate one. But the Middle Eocene, embracing as it does such formations as the Nummulitic and the *Calcaire grossier*, has a literature of immense importance, which it appears to us in the highest degree inexpedient to disturb or render obsolete. We therefore propose to adopt the view which reconstructs an Upper Eocene from the Barton and Upper Bagshot Beds, and to show that they form a sufficiently natural and well-marked group*. Neither the Upper nor the Middle Eocene, however, will then continue to equal the Lower Eocene in importance, and we cannot but look on the necessity for any revision as unfortunate. The Eocene, as it stood, was a compact, useful, and by no means unwieldy group, with a literature and history that should have preserved it from dismemberment. The Upper Eocene was by no means so preponderating or so distinct as to render its removal expedient, and the transition beds were either satisfactorily located or might easily have been so. Finally the flora of the Oligocene, on which some stress has been laid, is so

* A paper by Prof. Prestwich has been published (Quart. Journ. Geol. Soc. vol. xliv. p. 88) since this was written. He treats the classification we propose here as the one already established, *vide* table p. 88. This would render further insistance on its expediency unnecessary, did he not propose, *l. c.* p. 108, to suppress this classification by totally abolishing the Middle Eocene.

distinctly Eocene in facies that the flora of Bournemouth, which is at the base of the Middle Eocene, may be said to be the typical flora of the Oligocene in Europe.

The Upper Eocene in England will, according to our views, comprise the Barton Series and the Upper Bagshot Series, the inferior limit being the Bracklesham, and the superior limit the Headon Beds. We have gathered conclusive evidence that the Upper Bagshot Series of the London basin is, to a large extent, the equivalent of the Barton Series of the Hampshire basin, and represents, indeed, rather its lower than its upper bed. This fact, again, has rendered revision necessary, and the classification which, we submit, best meets the requirements is the following:—

Upper Eocene.

	London Basin.	Hampshire Basin.
Upper Bagshot Series.	Unrepresented.	Becton-Bunny Beds. *Chama*-Beds.
	Upper Bagshot Sands.	Barton Beds. Highcliff Beds.

The base-line of the formation is, it must be confessed, not too well marked, but it almost coincides with the disappearance of Nummulites in our area, and with a considerable change in the character of the fauna, through the disappearance of a number of subtropical forms. Deposition was so continuous here during the Eocene time that it is not always easy to draw strongly marked lines of division, for such, in this case, would only occur where there had been great changes of level, or where an arm of the sea became landlocked and dry. It would thus be perfectly easy, say, to distinguish between early Pliocene deposits in Italy and those forming in historic times along the margin of the Adriatic; but if the whole basin of the Adriatic were upheaved, and escarpments cut through it, as in Hampshire, it might be very difficult to draw satisfactory lines between the Pliocene and the recent beds.

Literature.—We have not compiled any list of works on the Upper Bagshot Beds, as those of importance are referred to further on. The splendid preservation and abundance of the fossils in the Barton Beds attracted the attention of Mr. Brander, Curator of the British Museum, and, in 1766, a work upon them was so admirably illustrated that all the 85 species of Mollusca described in it by Dr. Solander can readily be identified. Professor Prestwich communicated descriptions of the Barton Beds to this Society in 1847–1854; and a Geological Survey Memoir on the Isle of Wight, dealing with the Barton Beds at Alum and Whitecliff Bays, appeared in 1862. Prof. Prestwich also described the Bagshot Beds of the London area in 1847 *, placing the Upper Sands provisionally somewhere between the Bracklesham and Headon Series; and Trimmer included both the Barton and Bracklesham Beds in the Middle

* Quart. Journ. Geol. Soc. vol. iii. p. 384.

Bagshots*. But Prof. Prestwich, when again dealing with the subject in 1856, still considered the question unsettled; for he says:—"How far the Upper Bagshot Sands are related to the Bracklesham series it is difficult to say. The few fossils I have found in those sands are not sufficiently distinctive to enable me to pronounce a decided opinion. As, however, the fossiliferous Middle Bagshot Sands are very thin, and represent apparently only the lower or middle part of the Bracklesham Series, I think it probable that it is the upper beds of sand and clay of the latter which pass northward into the thick sands of the Upper Bagshot Sands. Still, it is possible that part of them may represent the Barton Series; for we see at Barton how shifting the upper part of that series is, how clay predominates at one place and sands at another" †. The Geological Survey Memoir of 1872 on the London basin contributed little further evidence as to the age of the beds under consideration, and to the present day Prof. Prestwich regards it as an open question ‡. Dumont, however, classed the Barton Beds with the Upper Bagshot Sands, and they have been generally regarded as more or less equivalent in age.

Area.—The Upper Bagshot Sands are chiefly restricted in the London basin to what is termed the "main mass" of the formation at and around Bagshot Heath, and extend from the eastern end of Berkshire into Surrey and Hampshire. In the Hampshire basin the Barton Beds occupy the coast-section in Christchurch Bay for about three miles; they have been traced inland to a little east of Ringwood, near the village of Powner, and the *Corbula*-zone has been recognized in brick-pits at Bramsgrove, not quite halfway between Powner and the coast. The *Chama*-beds have been seen at Binstead Manor, on the Compton estates, a mile north of Lyndhurst § (by the Rev. J. Compton, Rev. O. Fisher, and by Mr. Keeping). In the Isle of Wight they crop out and are well exhibited at Alum Bay, and are equally present at the other extremity, Whitecliff Bay. Mr. Bristow records that he met with Barton fossils at Gunvelle, north of Carisbrooke, and the clays without fossils have been identified at one or two other spots in the island. The area over which they extend is remarkably limited, considering their importance. Prof. Prestwich correlated them with the Sables de Beauchamp in France ‖ and the Laekenian system in Belgium ¶, and the accuracy of his views in this case has never been disputed.

Thickness.—The thickness of the Upper Bagshot Sand in the London basin nowhere greatly exceeds 200 feet, and is usually much less, owing to denudation. It is, except the gravels, the highest formation in the area. In the Hampshire cliffs the whole series, from the pebble-bed at the base to the top of the Long-Mead-

* Journ. Royal Agricult. Soc. vol. xii. p. 445 (1851).

† Quart. Journ. Geol. Soc. vol. xiii. p. 132.

‡ In his latest works, Quart. Journ. Geol. Soc. vol. xliv. (1888), p. 107, and Geology, vol. ii. p. 363, he still regards the question as unsettled.

§ Mem. Geol. Surv. I. of Wight, Bristow, 1862, p. 46.

‖ Quart. Journ. Geol. Soc. vol. iii. (1847) p. 354. "On the probable Age of the London Clay and its relations to the Hampshire and Paris Basin Tertiary System."

¶ *Ibid.* vol. xiii. (1857) p. 107.

End beds, is about 200 feet thick. Our first measurements gave a total of 190 feet, and our second of 200 feet. Dr. Wright made a total of 210 feet. Prof. Prestwich's measurements agree, except that he makes the Middle Barton Clay 150 feet instead of 50 feet. Prof. Judd underestimated the thickness of the upper part, for he implies that the whole of the Headon group at Hordwell *, including everything above the Barton Beds (presumably the top of the *Chama*-bed), is only 100 feet thick, whereas our measurements, to the top of the Lower Headon only, show 144 feet. The thickness of the Barton and Upper Bagshot Series at Alum Bay is 380 feet, according to Prestwich; but Mr. Fisher subtracts 40 feet from the base to add to the Bracklesham, and the sands were not actually proved to be 100 feet thick, and may, from the position they occupy, have been folded or contorted.

At Whitecliff Bay the entire formation is nearly 350 feet thick.

Deposition.—The series, like the entire British Eocene, is distinctly fluviatile and estuarine, and in correlating it we must bear in mind that it is physically impossible for any one quality of sediment to have been deposited synchronously over any very extended area by such agencies. Though the beds of the Hampshire, the London, and the Paris basins present a broad similarity, the resemblance in most cases disappears when we come to detailed comparisons, and we have to rely rather on the faunas and floras contained in them. When these are alike, we regard the beds as synchronous, or on the same horizon, but with such deposits we should not perhaps trust too implicitly to fossils. The Upper Bagshot Sands of the London basin are such as might have been accumulated in a large bight or bay of open sea; but in Hampshire the series was evidently laid down within the influence of a considerable river †. It commences with a sand-and-shingle bank with much floated wood, and ends in the silts of the higher reaches of a river. In working through the beds, we start among the breakers of a bar far out to sea, and gradually make our way up into the smooth and purely freshwater reaches of a tidal river. The succession could only have been brought about by a sustained movement of upheaval, and we can best interpret the meaning of the repeated changes in the quality of sediment to be described by endeavouring first to realize what would be exposed if the sediments now forming at the mouth of such a river as even the Thames were similarly upheaved.

If a slow, sustained elevation set in between the Isles of Thanet and Foulness, the first effect would be an inward movement of the littoral zones of sand and shingle, which would overcreep the previous homogeneous sea or estuarine mud, the thickness of the former, of course, depending on the rate of upheaval. Unless this

* Judd, Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 171.

† Mr. Sorby came to this conclusion many years ago, and believed the currents which deposited the Barton Clay near Muddiford to have been N. 76° E. and S. 74° W. In the upper part of the Barton Beds (at Alum Bay) he found no traces of currents, and inferred that the sea was too deep for the sediment to be moved (Edinb. New Phil. Journ. n. s. vol. v. p. 289).

were very gradual, the passage from blue or greenish mud or clay to coarse sand would be abrupt, but if very gradual indeed, every gradation from fine clay to sand, and from a relatively deep-water to a between-tide fauna, might be preserved. If the river continued to discharge its waters in the same direction, these would keep channels open in which no deposit formed; and as the water continued to shoal, banks and shoals would accumulate like those of the Nore, through which fresh channels are perpetually being cut and old ones silted up, presenting, when upheaved, a drifted, changeable, and confused bedding. The same kind of beds, but less in area, and with a fauna gradually passing from marine to more and more brackish, would extend a long way up the tideway of the river. They would also become more muddy in character, like the deposits off Sheerness and the Medway, because relatively more sheltered from the sifting action of rough and disturbed water. Still higher the more contracted channel would be kept open, but be flanked by extensive sheets of sediment evenly and distinctly bedded, because deposited intermittently by overflowing water, and perhaps interstratified with beds full of decayed vegetation, such as were seen in the section in Tilbury Flats. Most of this vegetation was rush-like, but in still higher reaches the brackish-swamp plants would be replaced by deciduous and other kinds of leaves &c., which might extend up the river as far as the influence of the tides and the lowness of the banks permitted. A transverse section across a valley once occupied by such a river would present a centre core of lenticular bedding, where the actual channel had been filled in, margined by horizontal beds of clay with stratified layers of vegetable débris and, probably, distinct layers of differing animal remains.

With our hypothetical very gradual but sustained elevation, each of these descriptions of sediment would in turn be laid down over the same spot, presenting a vertical sequence strikingly similar to that met with at Barton at the present day*. That this is so relatively simple and easily interpreted is truly remarkable when we consider that had the channel shifted and the river meandered greatly, all the first deposits might have been cut away and altered, while if there had been great oscillation of level the bedding must have become infinitely complicated.

The Barton Series, in fact, commences with a great mass of white sand, with lines of well-rolled pebbles, indicating raised banks in shallow water; and since the main mass of the underlying Bracklesham seen at Hengistbury was undoubtedly formed in more open

* In the London Clay it is easy to realize that deposition took place in a broad estuary or tract of sea, such as the German Ocean 50 or 100 miles off Harwich. We can trace where great drifts of fruits and seeds, such as those met with by Moseley, 70 miles from the mouth of the Amboynah river, New Guinea, became habitually water-logged and sank, how far beyond this macerated twigs alone floated, where certain types of Crustacea and Mollusca lived and died, the various depths of the water and proximity to shore at different localities, the main-channels strewed with terrestrial débris, and the wider regions into which these were never wafted.

sea, as indicated by the prevalence of sharks' teeth and fish-palates in it, the period ushering in the Barton must have been one of upheaval. We cannot expect to trace our base-line of sand and shingle in all localities, because the same amount of upheaval taking place in deeper water would merely result in a diminution of depth with, perhaps, but a slight change in the character of the sediment and nature of the fauna. The passage in the Isle of Wight, and probably in the direction of the New Forest, between the Barton and Bracklesham Series is, in fact, an almost imperceptible one, and in some places they appear a practically continuous formation. This mass of sand and shingle is, at Highcliff, followed by dark green sandy clay, similar to that of the Bracklesham beds, but full of drifted wood, fruits, and fir-cones, and coniferous twigs, and comprising a thin band with *Nummulites elegans*, fish-teeth, and, more rarely, bony plates of Chelonians and Crocodiles. This assemblage, confined, apparently, so far as vegetation goes, to objects with considerable powers of flotation, should give a great insight into the conditions of deposition, were observations of the necessary kind in existing estuaries not so scanty. A ferruginous band marks, perhaps, a considerable shift when the deposition of mud was almost suspended, and preceded a change which ushered in the stiff drab clay of the Highcliff Beds proper. That the water still remained shallow is apparent, since the shells, unless minute, are broken into small fragments and drifted with sand into pockets. A shore-crab, described by Dr. Woodward, was probably from a zone of pinkish clay in this part of the series. A small Echinoderm is abundant near the base, and first *Psammobia* and then *Pholadomya* become common, and are always found in the vertical position assumed by them in life. Next we have the Middle or true Barton Clay, at first glauconitic and then plastic, with its rich assemblages of shells, many of large size, and ending with great and wide-spread drifts of shell-matter, chiefly comminuted and in an irony matrix. This is succeeded by a mass of sand crowded with Chamas and a peculiar fauna, which appears for the first time and as suddenly disappears, giving place to the truly estuarine Becton-Bunny Beds, which in turn pass upward into the brackish Long-Mead-End Beds, and then into the fluviatile Lower Headons.

Great interest attaches to the Barton Series on account of its fauna, which is both rich and, to a large extent, peculiar. Prof. Prestwich long since remarked on the more northern character of its Mollusca, contrasted with those of the Brackleshams*. The submergence implied by him seems, in fact, to have destroyed some narrow barrier or isthmus which for a long period had kept the Southern Eocene sea, of which the Brackleshams are the earliest

* "The Barton-clay sea seems again to have been more connected with water opening to the northward than did that of the Bracklesham Sands; for several species of the London-clay sea . . . that had disappeared in the intermediate Bracklesham period, reappear in the Barton series. In fact, the fauna of this group, together with that of the Sables Moyens, has not so southern an aspect as that of the Calcaire grossier and Bracklesham period." (Quart. Journ. Geol. Soc. vol. xiii. p. 131.)

British representatives, isolated from the more northern basin in which the London Clay was formed. The mingling of the seas apparently lowered the temperature of the water to an extent sufficient to drive away such essentially tropical forms as the larger Cones, Cowries, Bullas, Harps, &c.*, without, however, greatly affecting the character of the contemporary land vegetation.

We cannot say that the whole period was one of sustained and continuous elevation, but the drifts of broken shells at the close of the Middle Bartons indicate an upheaval and the presence of strong currents. These shell-drifts thicken and become more numerous to the east and north. The protracted elevation soon afterwards forced back the sea, and converted the former estuary into a brackish-water reach of our great Eocene river. The Middle and Lower Bartons were evidently deposited in almost pure sea-water, though the considerable number of rare freshwater shells occurring in Edwards's list, even from Highcliff, would imply a river-current strong enough to have carried them along. Prestwich, moreover, mentions the occurrence of *Cyrena obovata* and *Potamides cinctus* in them at both Alum and Whitecliff Bays. It seems almost superfluous to point out that if the Barton Beds were estuarine, quite different deposits would be forming synchronously in the higher reaches of the river as well as further out to sea. Something not very different in quality from the freshwater Eocenes, which occur below as well as above them, must, in fact, have been forming in their vicinity or at no great distance; while the oceanic deposits of this period are probably preserved in the bed of the Atlantic, and have not been exposed to view. In dealing with our Eocenes it neither follows that distant beds are synchronous because they are similar, nor that they were separated by any intervals of time because they are dissimilar.

Description of the Beds.

The Barton Section (fig. 2, facing p. 594).

Of all the sections exposed, by far the most important and the classic one is that occupying the fine open bay of Christchurch, facing the Needles, and terminated westward by Hengistbury Head, and eastward by Hurst Castle. Towards the centre of the bay, where the Bartons are developed, the cliffs average little short of, and in places exceed, one hundred feet in height. Their summits are nearly level, and they terminate rather abruptly near Muddiford to

* The following are the principal types driven away or extinguished, and all of them have a highly tropical aspect:—*Cypræa Bowerbankii, C. tuberculosa, C. globularis*; *Voluta cithara* and *V. muricina*; *Conus deperditus* and *C. diadema*; *Pleurotoma attenuata*; *Harpa*, all sp.; *Cassis gigantica*; *Natica cepacea, N. hybrida, N. ponderosa, N. pachycheila*; *Turritella sulcifera*; *Dentalium grande*; *Cerithium giganteum*; *Bulla Edwardsii*; *Hipponyx cornucopiæ*; *Sanguinolaria Hollowaysii, Cardita planicosta, Arca Branderi*; also the corals *Oculina, Siderastræa*, &c. Some of the more temperate of the London-clay genera, such as *Trivia*, reappear, but not *Astarte, Cyprina, Verticordia, Vermetus*. The only species of large size to appear for the first time in the Bartons is *Voluta luctatrix*.

the west, and sink more gradually on the east. In composition they are clay or sandy clay, capped by gravel-deposits, twenty and even thirty feet thick in places, which constantly founder and partially obscure the Eocene beds below. The beds forming this coast-line begin well in the Bracklesham series to the west, and end in the Middle Headon, at Paddy's Gap, to the east. The cliffs occupied by the true Barton Series form ruined terraces, and the beds, with few exceptions, can only be seen *in situ* here and there along the sea-margin. The sea, however, which is rougher than at Bournemouth, regularly washes the base of the cliffs in the middle of the bay, and exposes an unending succession of fossils. On the other hand, the Hampshire Avon, which for several years swept along the base of Highcliff and threatened to undermine the Castle, has again shifted the direction of its outfall, and left such vast masses and bars of shingle behind, that the sea no longer reaches the cliffs under Highcliff; and these are consequently assuming an angle of repose, and becoming so overgrown that their stratigraphy, formerly clearly defined, cannot now be made out. This fact helped to decide us to redescribe the Barton Beds without delay.

The section has been frequently described and measured. There are some slight discrepancies in the thicknesses arrived at, but absolute identity cannot be hoped for in dealing with beds whose thickness may vary within a few feet. Our measurements were checked on each occasion, the second time by Mr. Geo. Harris, F.G.S. The results are tabulated below, and, for easier comparison, we have taken the *maxima* and, in some cases, bracketed two or three subdivisions of other authors together. We have adopted a tripartite system, each division of which is characterized by peculiar fossils and distinct lithological characters.

	Wright.	Prestwich.	Gardner and Keeping.	Gardner and Harris.	
Becton-Bunny Beds } Clay, no. 18, Wright	25	30	23	26	Upper Barton, *b* of Prestwich.
Becton-Bunny Beds } Sand, no. 19, Wright	20	30	19	26	
Chama-bed, no. 20, Wright	15	20	15	18	
Barton Clay, no. 21, Wright	50	150*	50	53	Middle Barton, part *a* of Prestwich.
Highcliff Beds, nos. 22, 23, 24, base according to Wright	80	70	50	49	Lower Barton, part *a* of Prestwich.
Green sandy clay and pebble-bed ...	—	15	14	10	
Total	190	315*	171	182	
Bracklesham	...	...	...	45	

The Bracklesham Beds at Highcliff form a vertical escarpment 45 feet high, of compact white sand, with an admixture of carbo-

* This measurement appears due to a *lapsus calami.*

naceous matter and a band of ironstone Septaria throughout a part of their horizontal extent. The base is not visible here, but can be seen at Hengistbury Head *. Eight feet above the beach there is a scattered line of typical Bracklesham pebbles, and another more considerable layer of the same capping the white sand †. The flints are moderate in size, either quite white or black, and mixed with small quartz-pebbles and grains, and lignitic matter abraded and worn into pellets. The upper layer is imbedded in warm-drab loamy sand, with pale green grains and sulphur-yellow partings and pipes, giving a green streak to the tool. Casts of bivalves abound in the upper pebble-bed, and, like the pebbles themselves, are most numerous at the base. The pebbles extend upwards throughout nearly 3 of the 4 feet of loamy sand composing the bed. Mr. Osmond Fisher looked on the upper pebble-bed as indicating a natural physical break, though he added ‡, "the division is probably in reality one of convenience only, the two groups forming a continuous series, changing gradually throughout in its lithological character and fauna." Prestwich considered that there was no break between the two formations. A dozen fossils were determined by Fisher from the sand, and 18 from the pebble-bed, only 4 of which are Gasteropods. The last 10 feet is very green, stiff, sandy clay, rifle-green when fractured, but of a bright green colour when scraped. It abounds with wood, mostly *Teredo*-bored, and well-preserved fir-cones are not uncommon in it. Its angle of repose is very steep, and the abundance of green grains enables it to be distinguished easily from the overlying series. Casts of Mollusca abound in this part of the series, and are seen to belong to species that pass into the Bracklesham below as well as the Barton above §.

At this horizon there is a band 9 inches thick of ferruginous loam or imperfectly formed ironstone, mottled with green and containing grains and small pebbles of quartz. It was described by Prestwich as a band of tabular soft Septaria mixed with green-sand ||;

* "Description and correlation of the Bournemouth Beds.—Part I. Marine Series, by J. S. Gardner," Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 214.

† This is coarse quartz-sand of largish subangular to rounded grains, mixed with very minute grains.

‡ Quart. Journ. Geol. Soc. vol. xviii. (1861) p. 88.

§ Osmond Fisher, *l. c.*, gives the following list:—*Fusus pyrus*, *Pyrula nexilis*, *Voluta nodosa*, *Dentalium*, *Cardium semistriatum*, *Cardita* (small ribbed), *Cytherea* (a Barton species), *Crassatella costata*, *Corbula pisum*. An analysis of the beds is also given, p. 86:—

Water	10·02
Silica	50·11
Iron protoxide	25·04
Alumina	6·12
Magnesia	3·14
Potash	5·17
	99·60

|| Quart. Journ. Geol. Soc. vol. v. (1849) p. 45.

and is the "foxy" band of Fisher, underlying and defining the zone of *Nummulites elegans**.

THE LOWER BARTON, OR HIGHCLIFF BEDS.

The Nummulite-band forming the base of the Barton Series is only 8 inches thick, and green sandy clay, identical with that of the Bracklesham Series beneath, continues upward, with fewer casts of fossils, for another 10 feet, when it passes insensibly into a fine and stiff, very plastic, drab clay, mottled darker and paler, and with a peculiar pinkish band, as if burnt, about 4 feet from the top. The *Goniocypoda Edwardsi*, H. Woodw., described as a true Shore-crab, and said to be from "the Red Marl of the Plastic Clay of Highcliff," must have been from this band †. Casts of an Echinoderm, whole and broken up, abound, together with otolites, spines, teeth, and other fish-remains. Ledas and Corbulas are very commonly drifted with quantities of broken shell-matter; and the Mollusca generally seem, like the casts below, to be of species common to both the Barton and Bracklesham Series. Among the more frequent are *Turritella*, *Voluta athleta*, *Cancellaria*, *Cassidaria ambigua*, *Rostellaria ampla*, *Trochita*, *Cardita*. The most distinctly Barton form is, perhaps, *Pleurotoma rostrata*. About 20 feet above the Nummulite-band the bed gradually becomes of a paler drab, rather plentifully mixed with patches or drifts of sand, the latter causing it to founder and form the conspicuous lower terrace at Highcliff. This latter condition of the bed is 13 feet thick.

The Highcliff Beds end in the Highcliff sands, a fairly well-marked division, consisting of a glauconitic clayey sand, interrupted by lines and pockets of very compact fine sand, composed of fine-grained and angular quartz, crowded with small and beautifully preserved shells. The sands are intermittent, often reduced to a mere trace, but swelling again and again into pockets, which never exceed 2 feet in thickness. The variety of the species in them is large, particularly among the genera *Bulla*, *Odostomia*, *Rissoa*, *Turbonilla*, *Bayania*, *Eulima*, *Pyramidella*, &c. The green grains soon disappear, leaving the clay palish drab, but the pockets of sand continue scattered through it for a thickness of 10 feet, with this important difference to the collector, however, that the higher ones are merely filled with *Corbula* and, occasionally, *Ditrupa*, mixed with the comminuted remains of larger shells, some of which also appear in the clay itself

* "I find a bed containing *Nummulina Prestwichiana* [*elegans*] at High Cliff, analogous to that at Alum Bay. I believe it has hitherto been overlooked, but it may easily be recognized by the following indication:—There will be observed, extending along all the central portion of High Cliff, not far overhead, as you walk upon the beach, a narrow band of hard marly clay, not quite a foot thick, weathering of a reddish foxy tint, and projecting slightly beyond the general face of the cliff. Immediately above this, in marked contrast of colour, is a narrow green band of coarse sandy clay, about 8 inches thick. This is the *Nummulina Prestwichiana* [*elegans*] bed. It is much thinner than at Alum Bay, and the Nummulites are less profusely scattered in it. At this place they are pyritized."—Fisher, *l. c.* p. 87.

† Geol. Mag. vol. iv. p. 529, pl. xxi. fig. 1 (1867).

in a more or less perfect state. *Psammobia* occurs in it in the position assumed by the shell when living, and *Ophiura* is met with, but not very commonly. Among the species that do not ascend beyond this horizon are *Cassidaria ambigua* and *Fusus errans*.

The Highcliff or Lower Barton Series closes with a dark drab sandy clay, mottled with glauconitic sand*, 4 feet thick, which weathers a rusty colour. It was tenanted when forming by numerous *Pholadomyæ*, and includes many dead shells of *Cytherea elegans*. The actual line of separation between it and the Middle Barton is drawn at a dotted layer of large, round, dark-coloured Septaria, which become more dispersed in proceeding west†.

Except in the terrace and the green clays at the base, the beds usually maintain an angle of about 35°. The fauna of this division of the Barton Series is very rich, numbering between 300 and 400, and, possibly, a considerably greater number of species. For those peculiar to it we have to search among the more minute shells of the Highcliff sands, foremost among them being the well-marked *Strombus bartonensis* and *Buccinum canaliculatum*, *Acera striatella*, *Volvaria acutiuscula*, &c. *Cassis ambigua* is confined to it in the Barton Beds, but reappears in the Middle Headon. We may also mention *Schizaster d'Urbani* and the *Ophiura* as characteristic species. There is a host of species which come up from the Upper Bracklesham, but do not pass beyond the upper limits of the Lower Barton, among such being the typical *Terebellum fusiforme*, *Fusus errans*, *F. interruptus*, *Cerithium angulatum*, *Nucula lissa*, *Cytherea elegans*, *Nummulites elegans*, &c. These species, taken together, are sufficiently abundant to furnish in the field an undeniable index as to the division of the Bartons we are in.

The Middle Barton, or Barton Clay proper.

Within 5 feet of the Septaria-band last mentioned, and taken as the base of the Middle Barton, a second and more strongly marked one occurs, the Septaria being equally dark in colour, and round and massive in appearance. Both bands are fossiliferous. Though

* Mr. Grenville Cole describes the sand as fairly rounded, the grains containing liquid-enclosures with moving bubbles. The dark green grains are very numerous, and there are also agglutinated sand-grains. The clay effervesces somewhat in cold acid.

† The section of the Highcliff Beds, according to Prestwich, Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 108, is as follows:—

	ft.
Grey clay with seams of yellow sands and shells ...	20
Grey sandy clay, with *Echini*, *Cassidaria*, &c.	50
Mixed clay and green sands, impressions of shells .	14
Bed of flint pebbles in sand, size moderate	1
	85

Dr. Wright omits the two lowest of these beds from the Barton Series, and gives the remainder a slightly greater thickness (8 feet more), distinguishing them as beds 22, 23, 24 (Proc. Cotteswold Naturalists' Club, vol. i. pp. 129–133, 1853). Our first measurement came to 64, and our second to 59 feet, after accurately reducing them to the vertical.

the clayey matrix between them remains the same, the important species *Voluta suspensa* and a *Fusus* are confined to this particular horizon, and several fruit-spikes of a peculiar kind have quite recently been met with in it by Daniel Flynn, of the Coastguard, a very keen and good collector of Barton fossils. Above the Septaria the clay becomes glauconitic and sandy, with few and generally much crushed and eroded fossils, but about 30 feet up we come suddenly on two particularly rich zones, 18 inches apart, from which the coastguardsmen collect in heavy weather. Chief among the fossils are *Rostellaria ampla*, *Voluta luctatrix*, *Fusus pyrus*, *F. longævus*, *Murex minax*, *Cassidaria nodosa*, and *Ostrea gigantea.* A few feet below these zones is a conspicuous band of larger, flattened, light-coloured Septaria, which dips beneath the shingle opposite the Coastguard Station. Succeeding this is dark gritty clay, quickly passing into a fine unctuous pale slate or dark-coloured clay, free from grit and green grains, but weathering slightly rusty and greenish at the partings. Most of the shells in it are small and delicate, and collected into pockets, *Corbula pisum* and *Turritella* in particular abounding. The bed is 10 to 12 feet thick, and includes another less well-marked zone of flat, light-coloured Septaria, 4 feet from the top. The Middle Barton Clays end in a very distinct shell-bed, made up of comminuted fragments, mainly of *Turritella*, in a rusty matrix, with occasional fragments of larger shells. In the cliffs it appears as a fulvous band, but it sets, under the influence of salt water, into a very hard stone, and when in this state the flat slabs, a foot or more thick, are hauled up the cliffs and used for the foundations of houses. Perfect specimens of *Tellina ambigua* and *T. Branderi* are not uncommon on their upper surfaces. The shell-beds are only a foot or two thick at Highcliff, and increase eastward to possibly as much as 15 feet.

The Middle Barton Clays include all the Septaria-bands that occur in the Barton Series, the lowest of these forming a good landmark for the inferior junction, and the shell-bed an unmistakable line of demarcation for the superior limit. They are about 50 feet thick*, relatively homogeneous, and form the slopes represented in the figure (fig. 2). The middle terrace is formed in the more sandy clay above the lower line of Septaria.

The fauna of the Middle Division of the Bartons is nearly as rich as that of the lower, and far more characteristic, consisting of upwards of 250 species. Very few of those peculiar to this stage are, however, either common or conspicuous, and perhaps the only one worth citing is *Fusus lima.* Some of the grandest species, as *Rostellaria ampla*, *Fusus longævus*, and *Murex minax*, range from the Bracklesham right through the Barton, but attain their finest development here. Others, such as *Cassidaria nodosa*, *Ficula nexilis*, *Triton argutum*, and *Fusus regularis*, pass upward from the Bracklesham, but do not range beyond the limits of this division. The finest

* This division is the "Barton Clay" of Dr. Wright, who regards it as 50′ thick, our measurements being respectively 50′ and 53′, but it appears as 150′ thick in Prestwich. It is described as a "mass of compact bluish-grey clay with Septaria."

specimens of the strictly Barton fossils, *Voluta luctatrix*, *Crassatella sulcata*, and *Limopsis scalaris*, are obtained here, while others, such as *Voluta ambigua* and *Pleurotoma rostrata*, cannot be collected at all above this zone. Finally, several small but well-known species, such as *Conus dormitor* and *Buccinum desertum*, make their first appearance here.

The Upper Bartons, or Chama and Becton-Bunny Beds.

Between the shell-bed with *Tellina ambigua* and *T. Branderi* and the *Chama*-bed, there are a few feet of buff sandy clay, breaking up into cubes from 3 to 9 inches square, which are full of a peculiar variety of *Turritella*. It is in this bed that *Scalaria acuta*, *Fusus turgidus*, and *Voluta subambigua* are found.

The *Chama*-bed is a mass of steel-grey (commonly called blue) sand, with a slight mixture of clay, the proportion of the latter decreasing upwards. Mr. Grenville Cole describes it as angular and sometimes very minute sand, with much fine brown mud and a few green grains. It forms almost a running sand in the cliff, at a very low angle, and is therefore invariably buried under masses of gravel and mud fallen from above, and exceedingly difficult to measure. Dr. Wright found it to be from 10 to 15 feet thick, and Prestwich estimated it at 20 feet. Though we failed to obtain any measurement at first, we subsequently found the base resting on the shell-bed in a drain cut under the Coastguard Station, and were able to get a fairly satisfactory measurement, showing a thickness of 18 feet. A perhaps even more accurate measurement was obtained by taking the outcrop along the shore, between the uppermost Septaria-zone and the top of the *Chama*-bed, a distance of 268 yards, at a dip of $2\frac{1}{2}°$, when, after making all allowances, the thickness also came out at 18 feet*.

The beds are unfossiliferous everywhere, unless capped by the stiff clay of the Becton-Bunny Beds, and they dip under the beach somewhere about 100 yards east of the fence dividing the lands of Col. Clinton from the Hinton-Admiral estates. Where fossiliferous, the Chamas occur in extraordinary profusion, especially towards the top, with the valves most frequently united, while Turritellas abound no less towards the base. Chamas are excessively rare in the lower, and none are found in the middle division of the Barton, and this is the last appearance of the genus in England. Their presence is very remarkable, and suggestive of a change in the physical condition of the sea-bed, for they inhabit tropical seas, especially among coral reefs. Many interesting and beautiful shells make their first, or almost first, appearance in the 7 or 8 feet of clayey sand at the base of this bed, such as *Typhis fistulosus*, *Conus scabriculus*, *Voluta costata*, *V. humerosa*, *Murex defossus*, *Mitra scabra*, *Trochus nodulosus*, and *Cypræa bartonensis*. Above these we find *Terebellum sopitum* and *Vulsella*. Still higher, in the more sandy bed, among

* 268 yds. at $2\frac{1}{2}° = 35' - 15'$, of Middle Barton $= 20' - 2'$, difference of level at the two extremities $= 18'$.

the Chamas, an assemblage of splendidly preserved bivalves comprises many species of *Tellina*, *Lucina*, *Axinus*, *Anomia*, *Cardium* (*porulosum*), *Panopæa*, *Solen*, *Terebratula*, &c., most having the valves united, as if they had died *in sitû*. On the other hand, nearly all the vast array of Barton species of *Pleurotoma* and *Scalaria*, most of the *Fusi*, together with all the species of *Ficula*, *Terebra*, *Triton*, *Littorina*, *Cassidaria*, and many others are absent from it. Other species become scarce and stunted, such as *Murex asper*, *Typhis pungens*, *Fusus porrectus*; others, again, like *Voluta luctatrix*, are represented by modified forms, whilst others, like *Murex minax* and *Voluta athleta*, seem to be derived and waterworn. It contains, moreover, hardly any of the minute species which so abound in the lower beds, except some of the *Bullæ* and their allies. The fauna contains altogether 170 known species, and differs, as a whole, more from that of the Lower and even Middle Barton than does that of the Lower Barton from the Upper Bracklesham. The change is, indeed, far greater than appears in the tabulated list; for though stray specimens of so many species lingered on or are derived, and therefore occur in the column of Upper Barton fossils, practically the entire fauna, except some bivalves, is different. The bulk of what may be considered the typical Barton species, including such forms as *Fusus longævus*, *Rostellaria ampla*, *Voluta luctatrix*, *V. ambigua*, *V. athleta*, *Murex minax*, *Cassidaria nodosa*, &c., have disappeared. It is difficult to say positively whether the change was from deeper to shallower water or the reverse; but the shell-bed preceding the *Chama*-bed plainly indicates a long period when no mud was being deposited, and the *Chama*-bed itself was formed in clear water. The fact of the bed being crowded throughout with full-grown, thick-shelled Mollusca, is corroborative evidence that it was formed very slowly. The river, with its turbid water, must therefore have been diverted, and the previous fauna, fitted to rest on an oozy bottom, suddenly gave place to one requiring bright water and cleaner sand. The *Chama* and Cowry are preeminently such; and the substitution of fresh species of *Voluta*, *Typhis*, *Murex*, &c. for those preexisting may be taken to mean an immigration of species consequent on this change, rather than evolutionary progress. The bed is altogether as remarkable as any in the Eocene, and cuts into the series as unexpectedly as the Lower Bracklesham Beds, or the coral zone at Brockenhurst. It shows, like so many other abrupt transitions in the Eocene, that a relatively slight change in physical conditions makes a far greater impression on the succession of life in a formation, than would be occasioned by an enormous lapse of time without such a change.

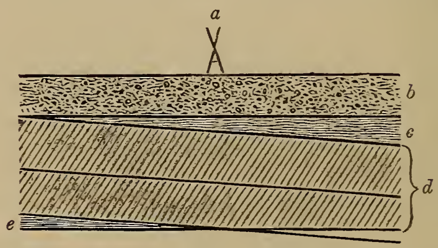
The *Becton-Bunny Beds* mark another change, so abrupt that opinions have been divided as to whether the Barton series should end here, excluding these and the overlying sands, hitherto called Upper Bagshot in Hampshire. Prestwich* agreed with Wright, and included the latter in the Barton Series, because they are highly

* Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 109.

fossiliferous here and at Whitecliff Bay, and contain many Barton types. Judd, on the other hand, while admitting that "these beds graduate so imperceptibly into the underlying Barton Clays that it is difficult to fix the exact limits between them"*, decided to separate them on account of their more estuarine character, and would have them called the "Headon Hill Sands." They seem to us, however, to be more closely related to the Barton below than to the Headon above, and we prefer to retain them in the former, distinguishing them locally as the *Becton-Bunny Beds.*

They are divisible into an upper and a lower division. The latter rests on the *Chama*-bed, the separating line being well marked, and consists of a mass from 20 to 25 feet thick, of fine, at first ashy grey, piped, unfossiliferous, very angular sand, in which Mr. Cole detects numerous flakes of Muscovite mica, becoming almost pure white and then pale grey, mottled with darker grey. This sand contains much alum, is feebly plastic, maintains itself at a high angle, and is not loosened and blown by the wind. Its upper surface is very uneven, and it is piped throughout, as if it had been thickly inhabited by large bivalves and Annelids. It is overlain by sand of an earthy colour, full of casts of shells, and then by a stiff sandy clay of blackish or bluish colour†, becoming more and more sandy and full of shells. Towards the bottom the prevailing forms are *Oliva Branderi*, *Cerithium variabile*, *Vicarya*, *Ancillaria*, *Natica*, *Cardita*, *Lucina*, *Mactra*, *Tellina*. In the upper part of the bed a more distinctly brackish-water assemblage appears, including *Cerithium* and *Marginella*, *Cyrena*, *Mytilus*, *Dreissena*, and *Potamomya*. The accompanying diagram (fig. 1) will enable them to be identified

Fig. 1.—*Section of Becton-Bunny Beds.*



a. High fence between Col. Clinton's and the Hinton-Admiral estate.
b. Gravel. *c.* Long-Mead-End Bed.
d. Becton-Bunny Beds: *Oliva-Branderi* zone. *e.* *Chama*-bed.

in the cliffs themselves. The bed terminates with a band, 10 inches thick, of dark olive-green sandy clay, containing some of the above fossils, together with *Neritina concava*, *Lucina*, &c. This part of the

* Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 475.

† Mr. Grenville Cole describes this as a very fine, sticky clay, when not containing minute plates and rod-like particles, with some angular grained sand.

series has been described in some detail by Tawney and Keeping*. The zone of *Oliva Branderi* can be traced half a mile west of the boundary; but as soon as it overlaps the protecting clay above, it becomes unfossiliferous. The underlying sand-bed also, in its turn, loses its alum and plasticity and becomes loosened and carried away by the wind as well as stained by the gravel as soon as it passes beyond the limits of the clay. The *Chama*-bed likewise becomes altered by percolating water as soon as the dip brings it near to the top of the section, and it is then undistinguishable from the beds above. The Upper Bartons continue in this state, in considerable thickness under the gravels, to at least Barton Lane End, the curve in the bay moderating the dip and causing them to maintain their position for so great a distance †.

Dr. Wright drew the line between his Lower Marine Formation and Estuary Formation at this horizon; but Prof. Prestwich included the overlying 15 or 20 feet of sands with the Barton Beds, because, where fossiliferous, as here and at Whitecliff Bay, they continue to contain Barton types. We entirely endorse this view, believing it to be impossible to draw any line of division at this particular point, and greatly preferring to take the Lignite-band at the base of the Lower Headon just above, as the limit of the Barton Series.

The *Long-Mead-End Sands* rest upon these, and we found their vertical thickness to be 20 feet, and their angle 46°. The base is slightly clayey, white sand, with mixed roundish and fractured grains, some of which, as Mr. Cole observes, still show surfaces of conchoidal fracture. The bed becomes purer and tawny for 15 feet and is without fossils; but towards the top shells become abundant, and are drifted into pockets. *Psammobia rudis* is the first to appear, followed by *Cerithium concavum*, *Ancillaria perita*, *Oliva Branderi*, *Lucina gibbosula*, *Cyrena gibbosula*, *Melania fasciata*, and remains of large and small turtles. There is an uneven junction, followed by rather more than 2 feet of darker tawny sand, also highly fossiliferous. The series closes with a little less than a foot of very dark olive-green sandy clay, with *Cerithium*, *Marginella*, *Natica*, *Lucina*, *Cyrena*, &c.

These beds have been described as "Upper Bagshot" and "Headon Hill Sands," and the measurements taken vary from 15 to 20 feet. A list of works bearing upon them was given by Tawney ‡ when he dissented from a proposal to place them in the Headon

* Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 573.

† The lower of the two Becton-Bunny Beds is Wright's no. 19, grey sand without fossils, 20 feet thick. It is present from west of Becton Bunny to beyond the Coastguard Station. The upper bed is no. 18, tea-green coloured clay, about 25 feet thick, with *Oliva*, said to differ from all other qualities of bed. It rises on the shore near Long Mead End. and maintains itself to a quarter of a mile east of Becton Bunny, near Barton Gang. Wright, Ann. & Mag. Nat. Hist. ser. 2, vol. vii. (1851) p. 441, and also Proc. Cotteswold Naturalists' Club, vol. i. pp. 129–133 (1853). It is section *b* of Prestwich, Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 108.

‡ Proc. Cambr. Phil. Soc. vol. iv. part iii. p. 140.

Series, laying stress on the presence of *Oliva Branderi* and other Barton types in their fauna, and maintaining that the so-called *Cerithium concavum* of this zone is really Lamarck's *C. pleurotomoides*. From a table appended to his paper, it appears that of 28 species 15 are Barton and only 8 Middle Headon. Eliminating those which are common to both these formations, there remained 4·34 % of the Long-Mead-End species common to the Barton Beds and only 21·3 % to the Middle Headon. "As far as fossil evidence is concerned, therefore, these sands are more related to the Barton Beds than they are to the Headon." The fossiliferous beds rise 300 yards west of Mead End, and run out at Becton Bunny; and the unfossiliferous sand rises a quarter of a mile east of Becton Bunny, and disappears beyond Barton Gang. They are the estuary formation of Wright, beds 16 and 17*, and the yellow and white siliceous sands in *b* of Prestwich †. Their most distinctive fossils may be considered to be *Cerithium pleurotomides*, *Melania hordeacea*, and *Corbula Edwardsii* ‡.

The Barton Series ends at this horizon, where all that is most characteristic of the Barton fauna finally disappears. It is, indeed, at this point, if anywhere in England, that any approach to a separating line between Eocene and Oligocene can be drawn.

We do not propose to describe the remainder of the Hordwell section in detail, but as the cliff-line is continuous, we have given a section with measurements of the Headon Beds in fig. 4. The beds change with the dividing line from brackish to fluviatile, the junction being a bed of black stratified, lignitic clay, 4 feet thick, containing *Potamomya*, *Dreissena*, *Cerithium pyrgatum*, &c. Some 17 feet higher up is the *Leaf-bed*, the exact position of which is not well known, and which we are anxious to take this opportunity of identifying with regard to forthcoming notices of its flora. It was known to Dr. Wright as a slate-coloured clay, with impressions of Dicotyledons in considerable number and variety of species, and with fossil fruits and the stems of plants, but no shells. He described it as a well-marked bed, 18 inches thick, rising nearly opposite Hordwell House, and running out at Long Mead End. In the Mammal-bed underneath he had also detected a "small black capsular seed with a corrugated integument," as well as *Chara medicaginula*, *Carpolithes ovulum*, and *C. thalictroides* §. Wise also describes it as 18 inches thick ||; but where we have made excavations it has exceeded 3 feet. The flora comprises *Equisetum*, *Salvinia*, *Chrysodeum*, Rushes, large Feather-Palms, *Arthrotaxis Couttsiæ*, a leaf known as *Populus Zaddachi*, the latter and some very abundant fruit-spikes being identical with Reading forms.

* Ann. & Mag. Nat. Hist. ser. 2, vol. vii. (1851) p. 441.

† Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 108.

‡ Among the Barton species are *Buccinum lavatum*, *Oliva Branderi*, *Trochita aperta*, *Bulla Lamarckii*, and *Cytherea tenuistria*; other forms are *Melania hordeacea*, *Melanopsis fusiformis*, *Ringicula ringens*, *Nucula tumescens*, and *Strigilla colvellensis*.

§ Ann. & Mag. Nat. Hist. ser. 2, vol. vii. (1851) p. 441.

|| Wise, New Forest, 1867, p. 239.

[*To face* p. 594.

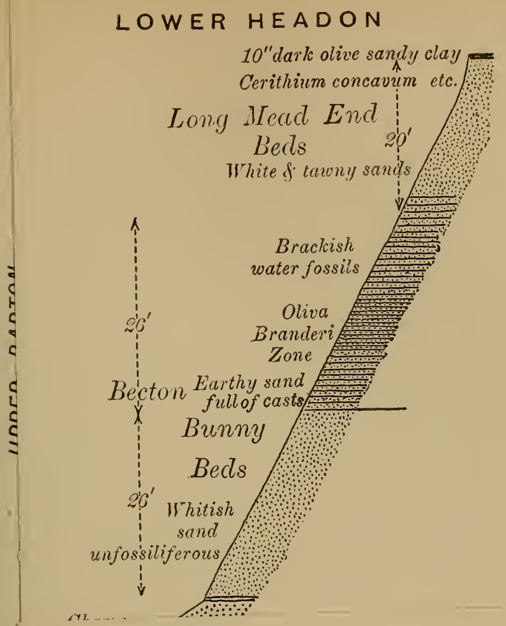
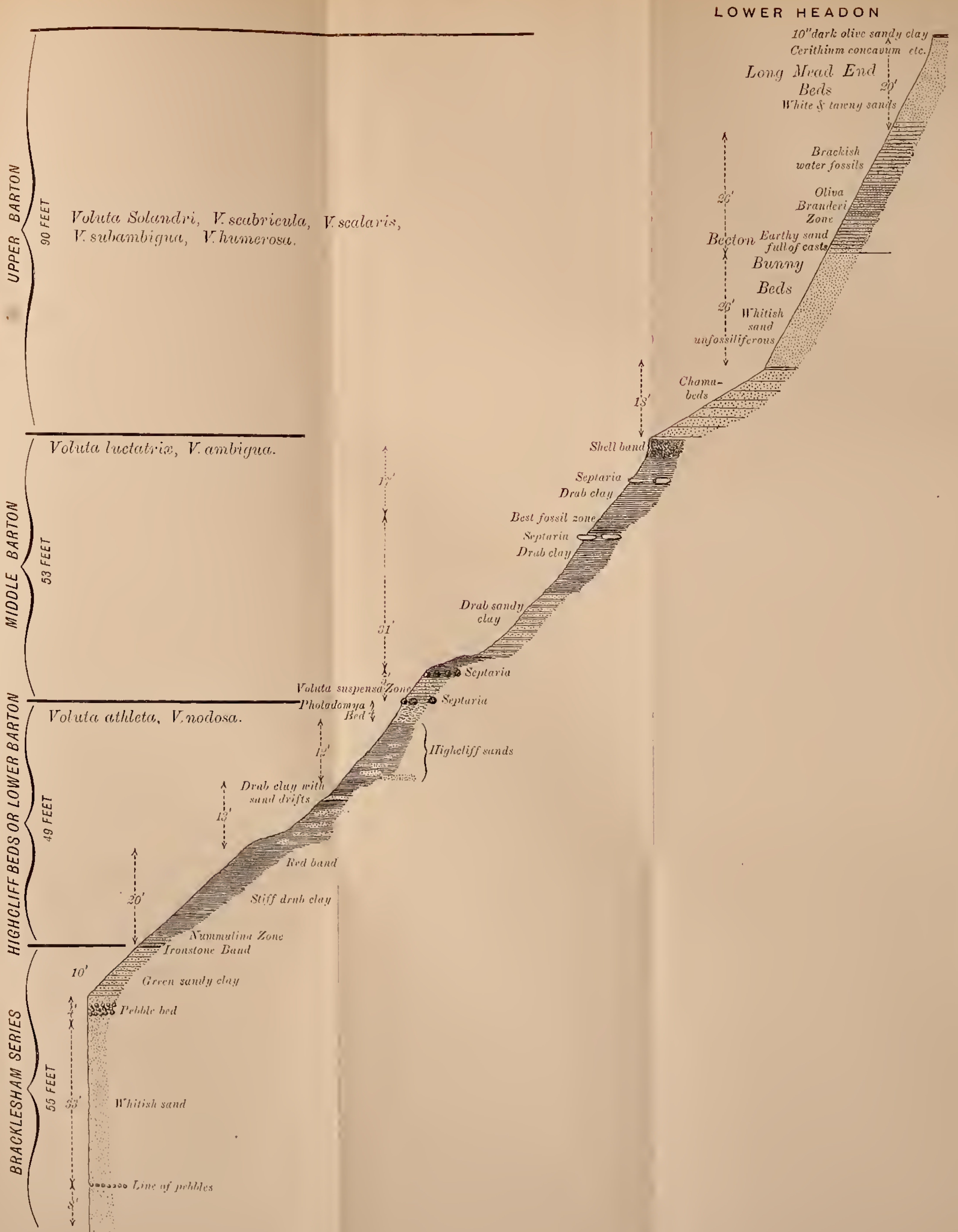
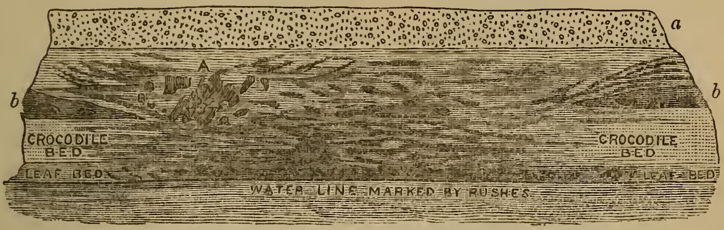

LOWER HEADON
10" dark olive sandy clay
Cerithium concavum etc.
Long Mead End
Beds
20'
White & tawny sands
Brackish
water fossils
26'
Oliva
Branderi
Zone
Becton
Earthy sand
full of casts
Bunny
Beds
26'
Whitish
sand
unfossiliferous

Fig. 2.—*Section of the Barton Cliff.*



We would also call attention to the singular interruption to the bedding which occurs a little west of Long Mead End, where the Leaf-bed and Crocodile-bed are cut through, and replaced by a confused mass of clay and sand with drift-wood, a large piece of which is seen to have been anchored vertically in the mud (fig. 3).

Fig. 3.—*Section at Hordwell (just west of Long Mead End).*



a. Gravel; *b.* Greën clay with iron.

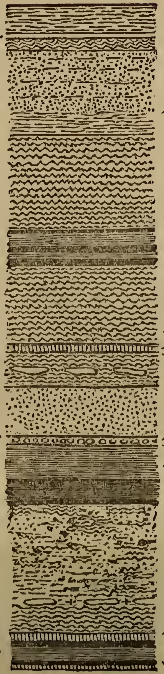
This section of an old channel occurs a little west of Long Mead End, and is about 200 yards in length. The green clays thin out, but the Crocodile-beds are dovetailed into the lignitic sands and clays. All zones are lost, and the whole cliff looks like black or dark ash-coloured sand. It is very shaly, full of wood for the higher 16 feet, and becomes more sandy towards the base. A band of white concretionary clay-stone, with pieces of wood imbedded in white plastic clay occurs, 16″ thick. The sands are rather false-bedded and twisted, but seldom dip more than 10°, and the whole is very full of wood, especially towards the base. At A, the mass of wood is vertical, and gives the appearance of vertical bedding at that spot. The green clay is also penetrated by wood in the same direction. A good many ligneous fruits are to be found near the two extremities after rain.

This is obviously the channel of an old river, similar to the estuary channel, filled with oysters, which cuts through the "Venus bed," between Colwell and Totland Bays, and such can frequently be traced in estuaries and fluviatile beds when these are of any extent*.

Note explanatory of Section through the Lower Headon at Hordwell (fig. 4).—The section from the top as far down as the *Chara*-bed was made nearly dúe south of Hordwell House. The rest, to the Lignite at the base, was measured about 450 feet east of Long Mead End. At that point the 10 feet or so of beds visible above the *Chara*-zone, and immediately under the gravel, are considerably

* Mud-beds, teeming with molluscous life, such as those of the Headons, could only be formed on the banks of a tidal river or estuary with extensive flats subject to overflow. Any change of level, whether by modifying the depth of water, making it more or less salt, or altering the quality of sediment deposited, might profoundly modify the fauna; and a section through such an area might disclose many minor, but constant, parallel zones of sediment, differing from each other and characterized by quite peculiar forms of life. So long as the section coincides with the direction of the flow of the estuary, the beds are continuous for long distances, but when it becomes transverse we find a channel of confused bedding, with a recurrence of the regular bedding on each side.

Fig. 4.—*Section through the Lower Headon, at Hordwell.*



altered and appear of a whity and ochreous colour, very sandy, and without fossils, except some layers of *Paludina* quite at the base. The Lignite Beds themselves were measured at Long Mead End. The beds appear to be very variable, as the detailed measurements differ considerably from those previously made, though the principal beds remain as land-marks. The thicknesses have been variously recorded:—Marchioness of Hastings 78 ft. to 94 ft. 10 in.; Dr. Wright 64 ft.; Tawney and Keeping (Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 567) 83½ ft.

SECTION ALONG THE NEW LINE FROM BROCKENHURST TO CHRISTCHURCH (fig. 5).

The cuttings for the new line from Brockenhurst to Christchurch present us with a second section in some degree parallel with the coast-line, but several miles inland. Our friend, Mr. George Harris, after checking with us our previous measurements along the coast, aided in measuring the entire length of this cutting, and our section is prepared from the notes taken concurrently by each of us on the spot. The new exposure shows that the shell-beds are greatly thickened and maintain their character and position above the Septaria for a long way inland. It further enables us to check off the thickness of the *Chama*-bed, which, though unfossiliferous, is unchanged as to its matrix*. The Becton-Bunny Beds seem, however, to disappear

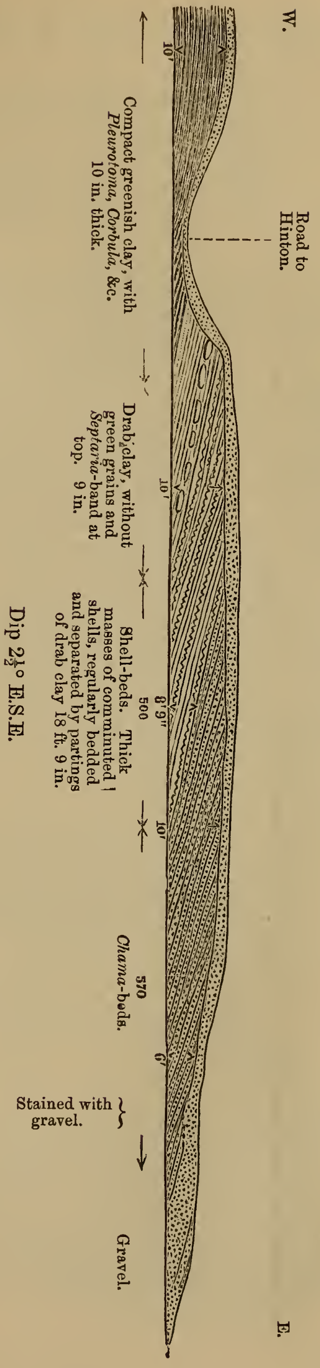


Fig. 5.—*Section of the Barton Beds, north face of Cutting in new line near Hinton Admiral.*

* Mr. Cole has examined this, and reports that it is a bed of very angular rather coarse sand with some few green grains. There is some clay with it, but less than would be expected from its general appearance.

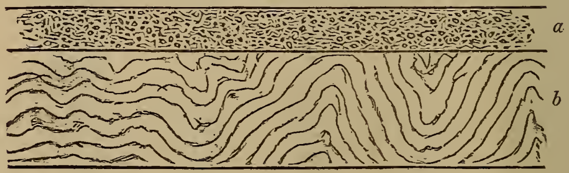
as at Alum Bay, and the whole series of Upper Bartons above the *Chama*-beds is obscured by weathering and by gravels. The vertical section is:—

	ft.	in.
Chama-beds, partly stained by gravel, about	18	0
Drab clay	1	6
Shelly bed	22	0
Septaria	1	0
Drab clay	9	0
Greenish compact clay, no base seen	10	9
	62	3

The fossils met with were numerous, but small, most of them being species common to the Middle and Lower Bartons. Among them, however, were *Pleurotoma exorta* and *P. macilenta*, two of the most characteristic shells of the Middle Barton. If the bottom bed is Lower Barton, as appears probable, the Middle Bartons are reduced to a little over 30 feet thick.

The outcome of the true Bartons is limited to a relatively short distance, but it is probable that the Becton-Bunny and Long-Mead-End Beds may occupy a tract between two and three miles wide. They only show in the cutting for a distance of over 1200 yards as yellow sands, rising from 1 to 8 feet, under a capping of 20 or more feet of gravel; but these are succeeded in the next hill by a greater thickness of whity-drab clays, extending for a further distance of 2700 yards. The *Paludina*-beds of the Lower Headon appear in a depression beyond this point, but their actual junction could not be traced at the time of our visits. The beds must be nearly horizontal, for they extend for the next 2 miles with little change, except that they are violently squeezed and contorted for a distance of 400 yards out of the last half-mile (fig. 6).

Fig. 6.—*Contorted Lower-Headon Beds, about* 2330 *yards west of the Brockenhurst Road.*



a. Gravel.
b. Light steel-grey clay, with shelly bands of crushed *Paludinæ*, &c.

Nothing further is visible, except gravel, for about a mile, when some white sand, some small patches of lignite and crimson-mottled clay are visible; but the bedding is disturbed and confused, as if thrust up from below, and we can only conjecture that the sand may represent the horizon of the Crocodile-beds. They extend horizontally for 500 yards, the lignites occurring close to the bridge over which the Brockenhurst Road is carried. The section ends with 18 feet of green clay mottled with shells, and 6 or 7 feet of compact pale green sand, the combined horizontal extent being 700 yards. This must, we believe, represent the beds immediately below, as well as partly the *Unio*-beds of our Hordwell section, for the Middle Headons occur somewhere in the next rising ground on the Brockenhurst side.

THE ALUM-BAY SECTION (fig. 7).

The section at Alum Bay is but 6 miles from Barton, and being through lofty cliffs with vertical bedding, is extremely easy to measure and understand. Measurements taken by Prof. Prestwich were published in his "Memoir on the Isle of Wight Tertiaries," in 1846, the entire series forming the 29th and 30th beds of his section, with a thickness of 380 feet*, inclusive of 100 feet of siliceous sand. In 1857 he separated the formation into three not very well characterized beds as group *a*, and made the overlying siliceous sands his division *b*. Mr. Bristow, with Mr. Gibbs, measured it again, the results published in the Survey Memoirs of 1856 and 1862 showing a total thickness of 300 feet, exclusive of the siliceous sands. We think that this is a little over-estimated and that the measurement of 380 feet is nearly correct. Mr. Fisher, in 1861, reduced the thickness shown by Prestwich by 43 feet, placing the beds below the *Nummulites elegans*, var *Prestwichiana*, in

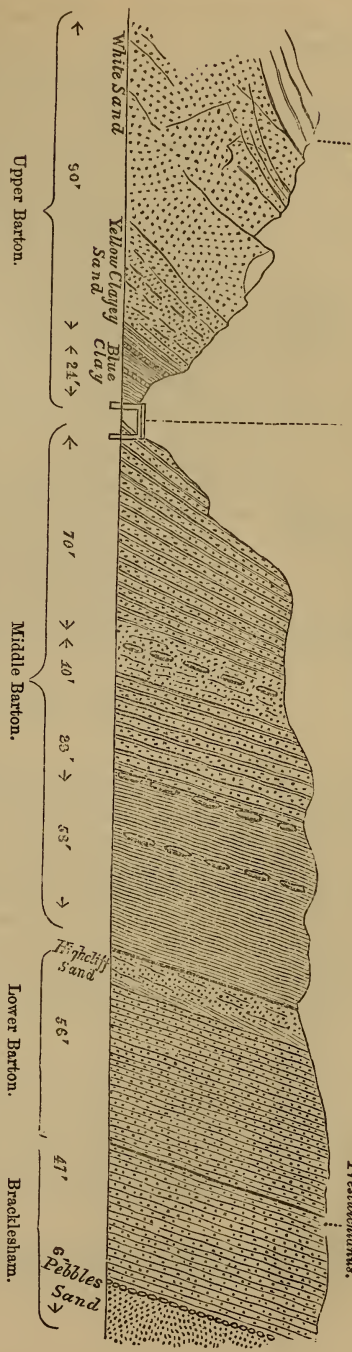


Fig. 7.—The Alum-Bay Section.

* Quart. Journ. Geol. Soc. vol. ii. p. 109.

the Bracklesham series. We make the section (fig. 7) to be as follows:—

		ft.	in.
Upper Barton.	White sand, becoming clayey and yellow towards the base, about	90	0
	Dark-blue clay, with one band of ironstone a foot thick, 6 feet from top, and a similar band 4 feet lower down; numerous fossils *	24	0
Middle Barton.	Pale and ferruginous yellow sandy clays, green in the upper part, Lignite, Corals, *Dentalium*, *Ostrea*, *Corbula*, *Pleurotoma*, common, and of several species, pale yellow sand at base †	70	0
	Layer of tabular Septaria, with many sharks' teeth, pebbles, fragments of wood, &c., and layer of scattered pebbles beneath in green sand	10	0
	Grey and brown sandy clay, with numerous casts of fossils of Middle Barton species, the shells being preserved in the lower 7 feet only	29	0
	Drab clay, with band of Septaria at top, and a second one 16 feet lower down. *Corbula*, sharks' teeth, and lignite †	58	0
Lower Barton.	Dark bluish-green clay, with sands in patches at the top, containing *Buccinum canaliculatum*, *Volvaria acutiuscula*, *Mitra parva*, &c. The whole capped with 9 feet of pale grey loamy sand	56	0
	The same with *Nummulites elegans*, var. *Prestwichiana*	1	0
Bracklesham.	Glauconitic sandy clay, the upper 10 feet with *Corbula*, &c., then about 15 feet in which casts of fossils are numerous, and the rest unfossiliferous ‡	47	6
	Pebble bed	0	6
	White sand.		
		386	0

(inclusive of 48 feet of Bracklesham).

The white sands at the top of this section have been quarried for glass-making, and as the change from the vertical position, in which the Bartons occur, to the nearly horizontal bedding of the Lower Headons takes place within the thickness of these sands, they cannot now be very accurately measured. They were estimated by Prestwich to be 100 feet, and by Bristow at as much as 140 to 200 feet, but we doubt if they even reach the former estimate. Though quite unfossiliferous, they represent the Becton-Bunny and Long-Mead-End Beds of the opposite coast.

The *Chama*-bed should appear beneath them, and one of us has found something very like it, but rarely exposed, at low water, just

* These agree almost precisely with Bristow's observations, Mem. Geol. Survey I. of W. p. 48.

† Bristow, *l. c.*, adds a band of small pebbles of white quartz and with sharks' teeth, 2 inches thick, 3 feet below the Septaria, and a third large layer of Septaria 5 feet from the base. Also a band of fossils 13 feet from the base, and a band of lignite 10 feet from the base. His base is, however, 9 feet above ours, the latter thickness being separated as pale grey, loamy sand, thinly laminated.

‡ Bristow mentions that a fossiliferous bed of indurated marl, 6 inches thick, occurs 30 feet 6 inches from the top; lignite bands at 1 foot 3 inches and 19 feet, and a layer of Septaria 28 feet from the upper part.

north-west of the pier, with *Turritella* and *Chama squamosa*, but not massed together. We could not trace it in the cliff, though the iron-bands seem to occupy the proper horizon of the shell-beds. The Middle Bartons seem abnormally developed, being more than three times the thickness seen at Highcliff, and nearly twice that at Whitecliff; but our junction is only 9 feet above the Highcliff sands, perhaps considerably (12 to 20 feet) too low down. We have taken the Survey measurement for the lowest bed of the Upper Barton and to some extent for the Upper Bed of the Middle Barton, as the road to the pier has been so considerably widened that these divisions are now cut out, only three beds of Septaria being now visible, and no lignite. Many rare species, not met with on the mainland, are confined to these beds. The Lower Bartons maintain their normal thickness and physical features, the pockets of sand, with drifted shells, occurring precisely as at Highcliff, with the chief characteristic species; but the beds being vertical and squeezed are not so favourably situated for collecting*. The shells in it are small and confined to the upper part, gradually giving place to casts for a few feet, after which the beds become unfossiliferous. The last distinct zone of fossils is the *Nummulites-elegans* bed. The quantity of ferruginous and carbonaceous matter indicates, perhaps, shallow water. In comparing the section generally we are unable to recognize any of the subdivisions of the Upper Barton on the mainland, the beds having become, perhaps owing to their vertical position, more uniformly sandy and unfossiliferous; the Middle Barton maintains its characters, but is enormously thicker, even making some allowance for the obliquity of the section: the Lower Barton has not increased to any appreciable extent.

The Section at Whitecliff Bay (fig. 8).

The most perfect section through the Eocene formation in England, and perhaps in Europe, is exhibited at Whitecliff Bay, in the Isle of Wight. The only beds at all concealed are those of the Barton Series, which have been hidden for years by slips and growths of herbage and brambles.

It is apparent, in glancing along the cliffs, that if the strata had chanced to have been plotted out into divisions on this spot, instead of elsewhere, a very different arrangement from that which exists would have been arrived at. All the Brackleshams above the drab clay, with seams of lignite and rootlets, must have been included in the Bartons, and the Brackleshams, as a marine formation, must have been limited to the beds with *Nummulites lævigatus*, &c., 66 feet lower down than the *Pecten-corneus* zone. It is far from certain that such a division would not have proved more natural than that which obtains, for not only is there evidence of intervening dry land and freshwater deposits, but the fauna of the Lower Brackle-

* Bristow mentions *Dentalium striatum*, *Fusus longævus*, *Voluta spinosa*, *Solarium*, *Cardium*, *Natica* (2 sp.), *Fusus pyrus*, *Rostellaria*, *Cancellaria*, *Pleurotoma*, *Mitra*, from this bed.

shams, with its giant Nummulites, Bullas, and Cowries, and its wealth of corals, differs far more from that of the Upper Bracklesham, than the latter does from that of the Bartons. Had the Barton Series been described from the Highcliff section first, and then been followed from west to east, taking first Alum Bay and then Whitecliff Bay, the entire Upper Bracklesham Series would have found a place in it, and the base-line been drawn where a decided physical change existed. The accidental circumstance that Mr. Fisher began to plot the Bracklesham Series at Selsey, led him to place their limits very high instead of very low. The whole of the strata on both sides of the Bill down to the London Clay were placed in the Bracklesham, perhaps chiefly because the thick freshwater sands and clays, which cut them in two, are unfossiliferous and seldom or never exposed on the shore. The highest beds at Selsey were traced to the New Forest, where still higher beds with similar species overlay them, and, finally, a small zone, containing a particular variety of *Nummulites elegans*, was fixed upon as the upper limit of the Bracklesham Series. That the line is drawn in "passage beds" is admitted by Prestwich and by Fisher himself, and it is thus less satisfactory than one coinciding with a physical break. As no better line of separation can be found, however, without trenching very considerably on the Bracklesham, we propose to retain the base-line in the zone of *Nummulites elegans*, var. *Prestwichiana*. In retaining the present divisions of the Bracklesham, we must remember that the lower is very different from the upper, and that the latter passes insensibly into the overlying Bartons.

The section at Whitecliff Bay (fig. 8) commences with mottled clay resting on chalk; then follows an eroded surface with scattered pebbles; some loamy sand and the *Ditrupa*-bed ushering in the London Clay. This is nearly 400 feet thick, and at 50 feet from the top we can recognize layers of soft concretions, crammed with *Pectunculus*, representing the Bognor Beds. It is capped with 100 feet of buff sand with a few bands of scattered pebbles. The section is very oblique to the outcrop, so that all these beds have an exaggerated thickness. The Lower Bagshots consist of 137 feet of finely laminated clays and sands with vegetable impressions, and end a little below a bed of *Cardita planicosta*, marking the base of the Lower Brackleshams. These consist in turn of 56 feet of greenish sandy clay, evidently marine; 52 feet of laminated clays, with some lignite of doubtful origin; 90 feet of greenish sand, marine; 37 feet of the same with *Nummulites lævigatus*; 66 feet of clay, with belts of lignite and underclay with roots; and then the *Pecten-corneus* zone of the Upper Bracklesham. The "Brook Bed" of Fisher follows, 23 feet thick, greenish marine sandy clay; sandstone 5 feet; *Nummulites-variolarius* zone 34 feet 6 inches; 93 feet of Huntingbridge Beds, not very well exposed; terminating with the zone of *N. elegans*, var. *Prestwichiana*, taken as the line of junction with the Barton Series.

The Barton Beds were not separated by Prestwich in 1846, when he described the section*, but are given as "Headon-Hill Sands," 202 feet; 37 feet of laminated clayey sand; 44 feet of bright yellow sand; 162 feet of imperfectly exhibited brown and grey clays, &c.; 32 feet of fossiliferous brown clay resting on 4 feet of sandstone. The latter is placed in the Bracklesham by Fisher, and the junction somewhere in the 162 feet of clays (Quart. Journ. Geol. Soc. vol. xviii. (1861) p. 68). The artificial nature of the dividing line is shown by the fact that no observer previous to Fisher had ever thought of dividing up the almost homogeneous mass of fossiliferous clay which is now classified as 93 feet of Bracklesham Beds and 60 feet of Bartons.

Whilst preparing this communication, one of us visited Whitecliff Bay and found the Barton Series exposed between tide-levels in an unusual, if not an unprecedented, manner. The section was measured, and the corresponding beds subsequently exposed by digging at the base of the cliff, when the first measurements were checked off. The result was published in the Geological Magazine†. It must be remembered that the section is not quite at right angles to the outcrop, and a diagonal direction may somewhat exaggerate the thickness. The measurements are for the most part reproduced from the work cited, as we believe them to be more accurate in the case of the Barton Beds proper than those

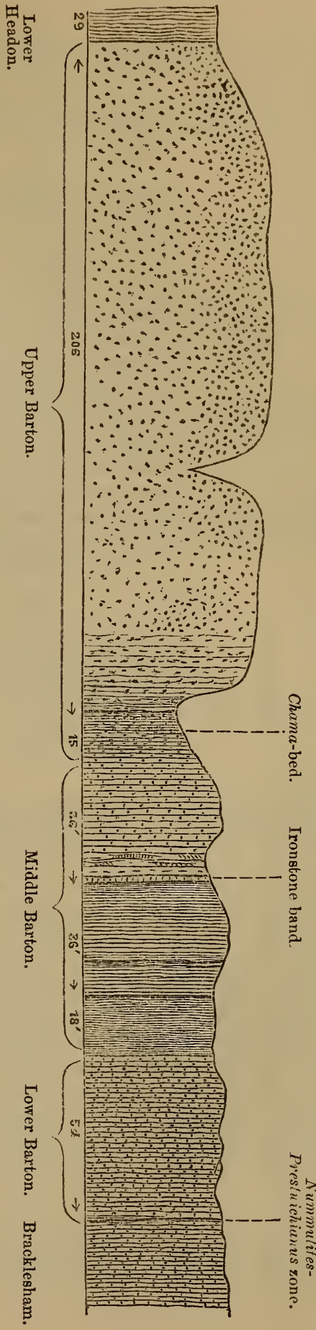


Fig. 8.—*Section at Whitecliff Bay.*

* Quart. Journ. Geol. Soc. vol. ii. p. 224. The Barton series is comprised in beds 17–20.

† "On the Discovery of the *Nummulina-elegans* zone at Whitecliff Bay, by H. Keeping," Geol. Mag. Decade iii. vol. iv. p. 70.

arrived at subsequently by two of us under less favourable conditions, and which we found to differ. The total is within a very few feet of that arrived at by Prestwich in 1846 and 1857. We have further grouped and correlated the beds with the three divisions seen in our typical section (fig. 2, facing p. 594).

Section at Whitecliff Bay (fig. 8).

		ft.	in.
Lower Headon	Lower Headon	29	0
Upper Barton	Buff sand, with darker clayey beds towards base	206	0
	Bluish sandy clay, with *Chama squamosa*, *Terebellum sopitum*, *Voluta humerosa*, &c.	15	0
Middle Barton	Blue sandy clays, with mottled-brown patches of soft earthy ironstone and ironstone band 3 feet thick at base	38	0
	Greyish-blue clays, with fawn-coloured bands near base	36	0
	Stiff laminated clay, with few, if any, fossils ...	18	0
Lower Barton...	Blue and yellow sandy clays, with few badly preserved fossils	54	0
	Dark green glauconitic sandy clays, crowded with *Nummulites elegans*, var. *Prestwichiana*	1	1
	Total	368	1
Upper Bracklesham	Coarse earthy sand, with *Ostrea plicata*	0	7
	Dark green glauconitic sandy clays	70	0
	Ditto, crowded with *Nummulites elegans*, var. *variolaria*	20	0
	Grey sandstone or "*Tellina*-bed" of Selsey	5	0
	Brook Bed	—	—

It will be seen that the Upper Bartons have enormously thickened since we last saw them at Alum Bay; but it is by no means certain that they are so uniform in character as they appear. The buff colour is probably greatly due to weathering, as these beds assume a precisely similar appearance when exposed for any length of time in the Barton section. By digging some distance in, the more or less clayey nature and darker colour of some of the beds become revealed, but no clean siliceous sands appear. At 66 feet from the top we found casts of *Cardita oblonga* and *Cytherea* *. The junction between this and the *Chama*-bed cannot be made out clearly in the cliff without digging to some depth; but it is very distinct at low water when the beds are visible. Still the *Chama*-bed is less sharply separated than at Highcliff, and the matrix is darker and more clayey and the Chamas far less abundant. The fossils collected from it were as follows:—

* Prof. Judd (Q. J. G. S. vol. xxxvi. (1880) p. 171) believes that they represent the Lower Headon. Prof. Forbes also found an abundance of impressions of marine shells which he considered might be Barton species.

Terebellum sopitum.
Voluta humerosa.
Ficula nexilis.
Natica, sp.
Trochita aperta.
Ostrea plicata.
Pecten carinatus.
——, sp.
Lima, sp.
Avicula media.
Arca, sp.
Pectunculus deletus.
Limopsis scalaris.
Nucula bisulcata.
Chama squamosa.
Cardium porulosum.
Lucina gibbosula.
Crassatella tenuisulcata.
Anisocardia, sp.
Cardita oblonga.
Cytherea.
Tellina ambigua?
Corbula ficus?
Panopæa corrugata.
Schizaster D'Urbani.
Ditrupa.

The ironstone band at the base of the next division seems to occupy somewhat the position of the shell-band at Barton. The total thickness we assign to the middle Barton here is 90 feet; but the subdivisions cannot be exactly correlated, and we were not able to make any collection of fossils from this part of the series. The thickness, 55 feet, assigned to the Lower Barton approximates to that measured at Highcliff, and the beds yielded a considerable fauna, though nearly all the species collected also range up into the Middle division. The *Nummulites-elegans* zone, taken as the base, is very distinct and the fossils in good preservation. It is 13 inches thick, and contains the following fossils:—

Typhis pungens.
Fusus pyrus.
Buccinum Solandri.
Pleurotoma exorta.
Voluta luctatrix.
—— scabricula.
Mitra parva.
Trochita aperta.
Dentalium striatum.
Bulla, sp.
Corbula pisum.
Crassatella sulcata.
Nemocardium turgidum.
Leda minima.
Ostrea plicata.
Nummulites elegans.

There is scarcely any lithological change in the beds as they pass into the Bracklesham, and the first break occurs at the bed of sandstone 90 feet lower down.

The Bracklesham, Stubbington, and Huntingbridge Sections.

The highest bed that can be identified at Selsey is the *Nummulites-variolarius* bed, locally known as the "Clibs." Higher beds certainly exist, but there is no record of their having been seen by any geologist. The transition in the fauna seems to commence in the "*Cypræa* bed" of Dixon, in which a large proportion of Barton species occur, such as *Cassidaria nodosa*, *Triton argutus*, *Pleurotoma inarata*, *Fusus pyrus*, *Rimella rimosa*, *Littorina sulcata*, *Voluta athleta*, *V. scabricula*, &c. With these are *Conus diadema*, *Cypræa Bowerbankii*, and *Pleurotoma attenuata*. The bed is remarkable as being fairly studded with the remains of *Posidonia*, a marine Monocotyledon which rooted in the sand. This is valuable as an indication of depth; for the existing Mediterranean species, hardly distinguishable from it, grows in the *bas-fonds* in from 10 to 20 feet of water. Above this is the "Hard Bed," in which *Tellina* *textilis*, *T. plagia*, &c. abound with their original colouring distinctly preserved, together with *Solen obliquus*, *Mactra compressa*, *Cardium porulosum*, a few broken univalves, and *Belemnosepia*. Lastly, we have the *Nummulites-variolarius* bed. At Stubbington Mr. Fisher was able to trace the beds upward for another 30 feet, and at Huntingbridge still further up*. The Huntingbridge fauna† is truly transitional ‡, but contains among many Barton forms *Pseudoliva ovalis*, *Voluta labrella*, *Fusus Noæ*, and *Cassidaria coronata*, with a few others distinctive of the Upper Bracklesham Beds. A section through much of the overlying Barton Beds could probably be obtained by excavating in this vicinity.

The Barton Series in the London Area.

The Barton, or Upper Bagshot Series, in Hampshire, is separated from that in the London basin by an interval of no less than about 60 miles. We are of opinion that this break is due to Post-Eocene denudation, and see no reason to doubt that they once formed a practically continuous deposit.

The exact correlation of the sands, or very slightly clayey beds, which alone represent the clayey series of Hampshire in the London basin, is more difficult to determine; but the fauna precludes the idea that the sands of the latter at all correspond to the sandy beds of the Upper Barton of Hampshire. The application of the term Upper Bagshot to them, if implying anything newer than and distinct from the Bartons, is misleading. The clayey green sand, which occurs some 10 or 20 feet below the pebble-bed at their base, is undoubtedly Bracklesham, and probably Lower Bracklesham, for *Nummulites lævigatus* has been found with casts of other Lower Bracklesham forms §. Most of the fauna is of species common to Barton and Bracklesham alike; but a few, such as *Buccinum canaliculatum*, *Volvaria acutiuscula*, *Bulla orbicula*, and *Strigilla Rigaultiana*, are confined to the former, the first three being quite peculiar to the Lower Barton. Taking the fauna as a whole, we find three species, particularly *Dentalium grande*, peculiar to the Upper Bracklesham; thirty-one species common to the Bracklesham and the Barton; nine species peculiar to the Barton, of which three are peculiar to the Lower, and only two, *Nucula similis* and *Strigilla*, to the Upper Barton, the former being perhaps a not very reliable determination, since it might almost equally well be *N. lissa*.

There may thus be room for doubt, remembering the great thickness of these beds in Hampshire, as to whether the beds of the London basin are not partly, or even mainly, of Upper Bracklesham age, but there can be none whatever as to their being Lower Barton, if they are Barton at all. The bulk of the species, being

* Quart. Journ. Geol. Soc. vol. xviii. (1862) p. 79.

† Discovered by Henry Keeping.

‡ Mr. Fisher described the beds as possessing a Barton matrix with Bracklesham fossils; but the latter are actually in the minority in the highest beds.

§ See lists in Quart. Journ. Geol. Soc. vol. iii. p. 390, vol. xxxix. p. 349.

common to both formations, do not help to settle the question, except that some of the species are more distinctive of the latter than of the former. If we take the 12 to 20 feet of green clayey sand of the London basin, with *Nummulites lævigatus*, to represent the 37 feet of green clayey sand with the same fossils, and which is altogether undistinguishable from it, in the Whitecliff-Bay section, we should have the following thickness to account for in the London basin before reaching the base of the Barton series, supposing the two series to be all uniform in thickness:—

	Hampshire Basin.
	93 ft. Huntingbridge Beds, sandy clays, various.
Upper Bracklesham.	5 ft. Sandstone.
	23 ft. Brook Bed, greenish sandy clay. *Pecten-corneus* zone.
	66 ft. clay with belts of lignite.
	187 ft.

Towards this we have in the *London Basin*:—

Between 70 and 80 ft. of loamy sand passing into pure sand up to the horizon at which the determinable fossils have been found.

1 ft. pebble-bed.

10 to 20 ft. of loamy sand and clays overlying the green sand.

So that, even allowing for very considerable thinning, we should have no difficulty in placing the fossiliferous horizon in Tunnel Hill beneath the base of the Barton Series in Hampshire. The palæontological evidence, which has been sifted with care, almost precludes this, however, the list containing nine species which are peculiar to or are not known to pass beneath the Barton in this country. Against this we have to set the four Bracklesham species and two or three undeterminable casts which are more like *Cerithia* of that age than anything else. But, practically, we are bound to take the pebble-bed as a base, since there is nothing above it which would furnish any recognizable dividing line; and to put the whole of the 200 feet of Upper Bagshot sand into the Bracklesham, against the weight of evidence, such as it is, is out of the question.

The area occupied by the formation in the London basin is comprised in sheets 8 and 12 of the Geological Survey Map, and with the exception of a small possible outlier at Highclere, near Newbury, it only exists in the main mass of the Bagshot Beds. Easthampstead Plain, Finchampstead Ridges, Chobham Ridges, Fox Hills, Hartford Bridge Flats are formed of it. The surface is usually barren heath, or is covered with plantations or woods of self-sown Scotch fir, whilst the more clayey Bracklesham supports beech, alder, birch, &c., and is to a far greater extent under cultivation. In our sketch map (fig. 11, p. 616) the shading represents the Upper Bagshot as mapped by the Geological Survey, and the numbers refer to the various localities mentioned in the present paper. The dividing line between the Upper Bagshot and the Middle Bagshot is drawn at a higher level than that fixed on by Professor Prestwich on the ground that the yellow sands contain green grains; but, judging from what occurs in the Hampshire basin, this reason is unsatisfactory, and the difficulty of drawing a line in the middle of a sand-bed has prevented the mapping being executed with consistency *.

It has been recently suggested that a bed of pebbles which occurs very persistently over the whole area, some 10 to 20 feet above the green sand with Bracklesham fossils, should be taken as the base of the Upper Bagshot, and in this opinion we concur †.

Taking the pebble-bed as the base, the greatest proved thickness of the Upper Bagshot is 228½ feet at the Albert Asylum Well (15 on sketch map), and this may be far from the original thickness, as no overlying beds but drift are present.

The various levels at which the pebble-bed is found show that the formation rests in a syncline of the Bracklesham Beds, and, probably, is conformable with them.

The Upper Bagshot Beds consist of whitish-yellow sands, a little loamy in some places. Faint bands of colour denote the original bedding with occasional iron concretions, pipings, and small blotches, the latter having once been fossils. Sometimes, as at Tunnel Hill, between Aldershot and Brookwood, the original forms are preserved as ferruginous casts, either of the interior or retaining the markings of the exterior of the shell. Recognizable fossils have only been found at this locality in beds of sand ranging from 70 or 80 to 118 or 128 feet above the base of the series, so that the overlying beds, nearly 100 feet thick, may represent a higher portion of the Barton Series.

It has recently been suggested that sands at Aldershot, Bearwood, Wokingham, Buckhurst, Bracknell, and Ascot are Upper Bagshot, though mapped as Lower Bagshot (see Q. J. G. S. vol. xli. p. 492, vol. xliii. p. 374); but, after considering the evidence, we have no doubt that the mapping is in these instances correct. Our reasons are stated in the Quart. Journ. Geol. Soc. vol. xlii. p. 402.

The point marked 1, near Ascot, on our sketch map, is the railway-cutting, the section of which is published Quart. Journ. Geol. Soc. vol. xxxix. p. 349, and from which large quantities of Bracklesham fossils have been obtained. The pebble-bed at the base of the Upper Bagshot is well seen about 13 feet above the fossiliferous green sand.

Pebbles derived from this bed are found in great abundance capping Hagthorn Hill, to the north of Tower Hill, also at the point marked 2 on the sketch map, and at Red Lodge, above the 300-feet contour-line. There are good sections in the Bracklesham clays at a brickfield in the northern slope of Tower Hill, (3) on the same contour, and there are good sections in Upper Bagshot yellow sands at the point marked 6, at Gravel Hill, 4, and at Cæsar's Camp, 5, whence we have two casts of shells. In Duke's Hill there is a satis-

* See Mem. Geol Surv. iv. pp. 329, 330, 333.

† See Quart. Journ. Geol. Soc. vol. xxxix. pp. 348, 353, vol. xli. p. 492, vol. xlii. p. 402; Proc. Geol. Assoc. vol. iv. p. 334, vol. viii. p. 149.

factory Upper Bagshot section (7). These sections prove that the base of the Upper Bagshot rises up to the 300-feet contour-line at this northern end of the main mass.

Passing eastwards to Chobham Common the following beds are exposed on a road at the point 8.

1. Capping of pebbles on hill top (remains of Upper Bagshot pebble-bed).
2. Yellow sandy clays, say 10 to 15 feet. } Bracklesham Beds.
3. Green sand, with *Cardita planicosta*, *Corbula gallica*, &c., in abundance. } Bracklesham Beds.

The clays of bed 2 were worked for bricks half a mile north of Chobham Place, and the same clays and underlying green sand are exposed in another disused brickfield near Titlarks Farm (9) (details given Q. J. G. S. vol. xlii. p. 404). The low hill just above this section (10) is capped with pebbles from the Upper Bagshot pebble-bed. These sections prove that the surface of the higher part of the Chobham-Common plain is Middle Bagshot, and the round-topped hills which rise above it are Upper Bagshot. In two of them there are good sections in characteristic Upper Bagshot sand (11, 12). At Long Down there must be over 50 feet of Upper Bagshot, and it appears to extend slightly further than is shown on the map.

A brickfield has quite recently been opened close to Chobham Place (13) and at about the same level. In March 1887 some 3 or 4 feet of stiff grey clay (Bracklesham) was shown, and this together with the former sections leads us to believe that Chobham Place is correctly mapped Bracklesham, so that we cannot confirm Professor Prestwich's section in which 100 feet of Upper Bagshot are represented overlying the Middle Bagshot at that place (Q. J. G. S. vol. iii. p. 384, fig. 4).

Several of the hills east of Chobham Place, at Ottershaw, and towards Chertsey are capped with pebbles, for the most part probably derived from the Upper Bagshot basement-bed; and the great pebble-bed at the top of St. Ann's Hill, Chertsey, in all probability is on the same horizon, though, unfortunately, the fossils which occur in it are not sufficiently perfect for identification.

Chobham Ridges attain a height of over 400 feet, and are composed of Upper Bagshot sand capped with gravel; and if the pebble-bed is taken as its base, it extends much further to the east than is shown on the map.

The well at the Albert Asylum (14), on the top of the ridges, furnishes the greatest recorded thickness of Upper Bagshot, viz., 226 feet of sand and $2\frac{1}{2}$ feet of pebbles. The surface is about 400 feet and the level of the Bracklesham beds $171\frac{1}{2}$ feet above O.D.

A little to the north and west of this well very fine sections were opened on the railway from Bagshot to Camberley (15). They showed sands of different tints of yellow and brown in broad bands of varying shades, and casts of badly preserved shells were very abundant. In our collection there are over 100 specimens from the cutting at Crawley Hill*. Mr. Herries has found similar casts on the Lightwater Road, near Windmill Hill†.

All these fossils are from beds more than 100 feet above the Bracklesham.

There are several good sections in the lower beds of the Upper Bagshot in this district, mapped as Bracklesham. There are two large sand-pits at New England Hill (16) (close to "three Barrows" on the Survey Map), 2½ miles east of the road running along the top of Chobham Ridges, and the pebble-bed crops out at the Gordon Boys' Home, a little below the level of the pits. It again occurs at Bisley (17), and there are two fine Upper Bagshot sections close to Cowshot Manor (18), and several small ones at the Guards' Camp, Pirbright.

We therefore believe that not only the high ground of Chobham Ridges, but also the low hills between Cowshot Manor and New England Hill and the boggy ground covered with heath between them and the Ridges, form part of the main mass of the Upper Bagshot.

There is a small outlier of Upper Bagshot close to Knap-Hill Asylum, and pebbles from the Upper Bagshot basement-bed are found at the top of many of the hills around, possibly, in some instances, they may be *in sitû*.

Professor Prestwich obtained the greater number of his Upper Bagshot fossils from the railway-cutting on the main line of the South-western Railway through the northern end of the Fox Hills (19) (see list, Quart. Journ. Geol. Soc. iii. p. 393), and there are two in Mr. Herries's collection from a pit (20) close to the ruined windmill on the top of the hill. One, a *Tellina*, was in a red, hard sand, just below the gravel which caps the hill.

At about the middle of the Fox Hills there is a fine series of sections on the Woking-Aldershot line. The railway tunnels under the highest part of this ridge, known as Tunnel Hill; but at each end are deep cuttings, giving the following section (21, and fig. 9).

The fossils in beds 1, 2, and 3 can, in many cases, be named with certainty. The list is given on page 616.

The Upper Bagshot extends considerably beyond the limit shown in the map, probably as low as the 200-feet contour on the east of Tunnel Hill. To the west there is a small sand-pit in Upper Bagshot yellow sand, close to Mitchet Lake (23), at the level of about 237 feet above O. D.

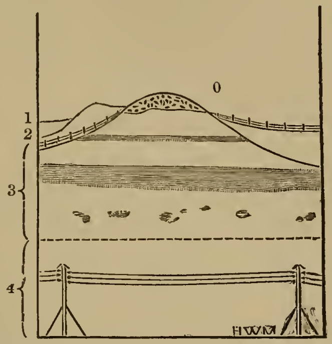
The strata under Tunnel Hill appear to have a slight dip to the north, so that the level of the pebble-bed under the hill must be under 237 feet above ordnance datum, *i. e.* from 70 to 80 feet below the

* Described Mem. Geol. Surv. iv. p. 334. The shells are *Terebellum fusiforme*; *Voluta*, sp.; *Natica*, sp.; *Turritella imbricataria*; *Trochita aperta*; *Xenophora umbilicaris*; and two other species of univalves; *Protocardium*, sp.; *Cardita sulcata?*; *Tellina scalarioides*; *Corbula*, sp.; two other species of bivalves and *Serpula*.

† Geol. Mag. dec. 2, vol. viii. p. 171. Those from the latter are *Turritella imbricataria*, *Ostrea*, sp., and three bivalves.

bottom of the highly fossiliferous beds, and giving a total of 130 feet of Upper Bagshot sand at Tunnel Hill.

Fig. 9.—*Section at Tunnel Hill on the West of Pirbright Common, Surrey, on the east of the railway north of the Tunnel.*



The shaded portions represent dark bands of yellow sand.

0. Angular flint-gravel, containing many pebbles.

Upper Bagshot.

1. Dark yellow, passing down into ochre-sand, numerous casts of fossils, mostly small univalves, in irony concretions, scattered throughout the bed. About 20 feet.
2. A well-defined line of bright yellow sand. 8 inches.
3. Whitish sand. Light yellow sand, passing down into nearly white sand, with a line of irregular patches of more ferruginous yellow sand, with lines and concretions full of casts of shells, many large bivalves, *Cardium porulosum*, *Protocardium parile*, &c. A few flint pebbles. 27 feet.
4. Alternate bands of dark and light brown and yellow sands, many iron sand concretions, but very few fossils. Nearly 40 feet exposed on the north side of the tunnel. Though this is nearly a quarter of a mile long, the bright yellow line 2 and the line of irregular patches in bed 3 are seen at both ends.

The base of the fossiliferous beds is shown by the broken line, and is a little above the tops of the telegraph-poles.

There are several good Upper-Bagshot sections near North Camp Station, S. W. R., one on the railway and others at the rifle-ranges (24), from which Mr. Herries has obtained numerous fossils.

At the southern end of the Fox Hills, near Ash (22), Lieut. Lyons has found the pebble-bed cropping out at a little over the 300-feet contour with the Bracklesham and Lower Bagshot Beds below to the north (Q. J. G. S. vol. xlii. p. 413, vol. xliii. p. 435).

A large outlier of Upper Bagshot is mapped to the north-west of Pirbright, and the northern end of it, on the hills in the cemetery close to Brookwood Station, is correctly mapped; but we doubt whether the Upper Bagshot extends far to the south-east of the station, for at the point marked 25 on our sketch map the pebble-bed crops out, and the Bracklesham greensand comes to the surface a little to the east. There is a pit in nearly white Upper Bagshot sand close to an arch under the railway (26) from which Mr. Herries has also obtained fossils.

At Bakersgate Farm pebbles abound on the surface of the ground, showing that there is no more Upper Bagshot in that direction.

The Bagshot Beds, which are usually fairly horizontal, rise sharply to the south as we approach the Chalk (Mem. Geol. Surv. vol. iv. p. 376, fig. 89), so that the base of the Upper Bagshot, which is but little over 200 feet above ordnance datum at North Camp Station, S. E. R., has risen to 300 feet at Thorn Hill (29) and to more than 560 feet at Cæsar's Camp (Q. J. G. S. vol. xliii. pp. 431, 440).

Near Farnborough Station, S. W. R., there are good sections in the Upper Bagshot yellow sand in a railway-cutting (28) and in road-sections, and the same beds were recently exposed in digging the crypt for the Imperial Mausoleum. Fossils are recorded from these sections (Mem. Geol. Surv. vol. iv. p. 334; Q. J. G. S. vol. xli. p. 500).

In a well at the Farnborough waterworks pebbles were reached at $135\frac{1}{2}$ feet and $153\frac{1}{4}$ feet below the surface, and above the upper pebble-bed were $128\frac{1}{2}$ feet of loamy sand (Q. J. G. S. vol. xli. p. 495).

At Thorn Hill, South Camp, Aldershot, are shallow fortifications and a sandpit at the top of the hill (29). All are in yellow Upper Bagshot sand, and in one Mr. Herries found a cast of a bivalve. The pebble-bed crops out 62 feet below the top of the hill (Q. J. G. S. vol. xlii. p. 410, vol. xliii. p. 431). Its exact limits in the Long Valley have not been worked out; but Lieut. Lyons says that the Brackiesham beds can be traced across the valley, overlain occasionally by the Upper Bagshot with the pebble-bed at its base (Q. J. G. S. vol. xliii. p. 439).

Mr. Herries has found casts of shells in abundance * in yellow Upper Bagshot sand at the steeplechase-course (30) near Long Hill. We have a single valve of a large shell, probably a *Cardium*, and other fossils, from the same bed at Beacon Hill (31).

At Gally Hill, named Curley Hill on the Geological Survey Map, though the whole is mapped Bracklesham, there is the following section in Upper Bagshot in a sandpit (32):—

	ft.	in.
1. Nearly white sand, with a little white clay in very small patches, and numerous green grains	6	0
2. Dark yellow sand, with about as much clay	4	0
3. White and orange-coloured sand	2	0
4. Line of pebbles in yellow sand.		

The beds 1 and 2 contain casts of shells. On the opposite side of the hill and at a rather lower level the Bracklesham clays are worked for bricks. In the Hartford Bridge Flats outlier there are

* 1 specimen of *Dentalium*, 6 of *Xenophora*, and 23 other specimens of univalves, 4 bivalves.

numerous sections in yellow sands of Upper Bagshot age. We have not found fossils in them, but Prof. Prestwich says fossils occur there. There is a good road-section (33) close to Minley Manor Chapel, and on the opposite side of the outlier there is a very good Upper Bagshot section (34) in a sandpit at the rifle-range. It is about 20 feet deep and shows yellow, irregularly-bedded sand, becoming nearly white at the bottom of the pit.

Small roadside sections (35) on the side of the Flats just above Eversley Church show the following series of beds:—

Section 1. Gravel at the top of the Flats.
Section 2. Yellow sand, with numerous green grains, either the bottom of the Upper Bagshot or the top of the Bracklesham.
Section 3. Green sand (Bracklesham) shown in good section some 10 or 15 feet below Section 2.

At Hazley Heath, to the south-west of Hartford Bridge Flats, is a good brickfield-section in Bracklesham clays; and above it, at the top of the heath, there is a pebble-bed in loose yellow sands beneath and distinct from the gravel which caps the heath. If this is the Upper Bagshot basement-bed, as it probably is, Hazley Heath is the most westerly point to which we have traced it.

There are numerous sections in the Upper Bagshot round the Staff College, Sandhurst, and here and there small sections occur on the commons to the north-east. From one (44) we obtained a cast of a bivalve, and from another on Olddean Common a *Xenophora*, another univalve, and a bivalve.

In the neighbourhood of Wellington College the Upper Bagshot extends further than is shown on the Survey Map, so that Finchampstead Ridges is not an outlier but a portion of the "main mass" (they are stated to be mapped Upper Bagshot, with some doubt, Mem. Geol. Surv. iv. p. 335).

At Ambarrow hill there is a small section on the South-Eastern Railway (36), from which we have obtained many fossils, all very badly preserved. *Natica*, *Xenophora*, and *Voluta* are abundant, and we have an impression of *Turritella imbricataria* and many species which are undeterminable.

There are small pits in whitish sand at 37, and a deep cutting has recently been made for a road at 38 in yellow sand, also clearly Upper Bagshot.

The small outlier at Finchampstead Church (39) is also undoubtedly Upper Bagshot. There are two good sections in characteristic yellow sand at the top of the hill, and the Bracklesham green sand is shown in a road section on the northern slope.

The greater part of the Wellington-College estate is mapped Bracklesham, but there is a large extent of Upper Bagshot there, and the pebble-bed can be traced over a large area. It is well seen in the following section (40, and fig. 10):—

Fig. 10.—*Section on the South-Eastern Railway,* $\frac{1}{4}$ *mile to the south of Wellington-College Station at point* 40 *on Sketch Map*, p. 616.

0. Surface earth, 6 inches.
00. Sand, with a line of small angular flints at the base, 9 inches.

	ft.	in.
Upper Bagshot.		
1. Light yellow sand	1	3
2. Pebble-bed in greenish sand, the pebbles in two irregular lines	1	6
Bracklesham.		
3. Yellow sand, with irony concretions; a few casts of a *Turritella*-like univalve	2	6
4. Yellowish, reddish, and light-green sand, with laminæ of nearly white clay	3	0

The Bracklesham green sand and dark clays crop out along the line to the north of the station (see Q. J. G. S. xlii. p. 407, fig. 1).

The well at Wellington College (41) passed through 22 feet of Upper Bagshot sand before reaching the pebble-bed at the base (Mem. Geol. Surv. iv. p. 425; Q. J. G. S. xli. p. 494). There are several good sections in Upper Bagshot near the College, from one of which, at the butts in Edgebarrow hill, we obtained a cast of a bivalve. There is a small Upper Bagshot section at the point marked 42 (Crowthorne), and several good ones in Lodge Hill round the Broadmoor Lunatic Asylum, from one of which Mr. Whitaker informs us casts of shells have been obtained.

There is also a good section at Sandhurst, on the South-Eastern Railway (43), and from it we have several casts of univalves and bivalves.

Attention has been called to a small and very detached Upper Bagshot outlier close to Highclere Station by Mr. Irving, and a sand-pit on the 500-feet contour-line a little to the south-west of the Station furnishes a good section in it. The sand is yellow, irregularly bedded, with little or no clay, and with many irony concretions. Mr. Herries has found several casts of shells in the sand, unfortunately not sufficiently well preserved to be specifically identified, but very like the usual Upper Bagshot casts.

The reasons for believing this sand to be Upper Bagshot and not Lower Bagshot, as mapped, are as follows :—

The chalk is about $\frac{1}{2}$ mile to the north, and there is a high dip to north. Along the railway north of the Highclere Station the following beds are exposed :—

1. Yellow sand, close to the Station. } (Bracklesham.)
2. Greenish, very clayey sand. }
3. Yellow sand, rather clayey, a considerable thickness. (Lower Bagshot.)
4. Judging from wet fields below the level of the line, there appears to be a considerable thickness of clay here. (London Clay.)
5. Yellow and mottled clay. } (Reading Beds.)
6. Yellow sand. }
7. Green-coated flints and *Ostrea*. }
8. Chalk with high dip to north.

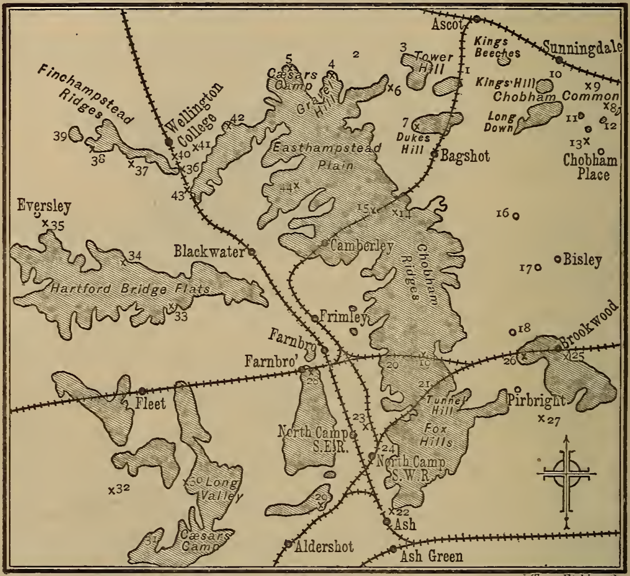
The sands in the pit in question resemble the Upper Bagshot of the chief mass, and they differ from the ordinary Lower Bagshot in the following particulars :—

1. Absence of clay laminæ.
2. Presence of green grains.
3. Absence of current-bedding.
4. Presence of casts of shells in sandy concretions resembling those found in known Upper Bagshot.

We think we have now said enough to show the character of the Upper Bagshot beds, and the persistence of the pebble-bed at their base. As previously stated, they lie in a slight syncline of the Bracklesham, and are probably conformable to them. At Cæsar's Camp, Easthampstead (5), the base of the Upper Bagshot is above the 300-feet contour; at Wellington College (41) it is 264 feet above ordnance datum, at the Albert Asylum (14) about 165 feet, at Tunnel Hill (21) rather under 237 feet, and at Ash (22) it has again risen above the 300-feet contour.

The Upper Bagshot beds are thus distinguished by the elevation they attain and their barren aspect, the chief and almost only vegetation they support being scanty heather, whortleberry, stunted gorse, and Scotch pine; while the lower-lying Middle Bagshots are of a more swampy nature, and support deciduous trees and shrubs. The presence of the dividing pebble-bed can almost always be detected, however overgrown, if carefully searched for. Though now consisting solely of whitish-yellow sands, a little loamy towards the base, faint bands of colour denote the former bedding, while occasional irony concretions, piping, and small blotches testify to the extreme changes induced in their composition by percolating water. Richly fossiliferous and varied as we know the Upper Bartons to be in Hampshire, when covered and protected by impervious beds of clay, we have seen them assume the same monotonous and unfossiliferous condition the moment the outcrop brings them to the surface and permits water to percolate through them. It appears perfectly certain that the Upper Bagshots in the London area were once at least as fossiliferous as those of Hampshire, and the beds and what can still be recognized of their fauna are such as might have been found in an open sea of considerable depth.

Fig. 11.—*Sketch Map showing the Upper Bagshot Sand, of the Bagshot Area.* (Scale $\frac{1}{4}$ inch to 1 mile.)



The numbers refer to localities noticed in the paper.

Fossils from the Upper Bagshot Sand.

(All are from Tunnel Hill, marked 21 on the sketch-map. The * indicates where a species is most abundant.)

	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.
Ancillaria canalifera	—	*	—	
Buccinum canaliculatum	...	*		
Bulla attenuata	—	—	?	*
Bulla elliptica	—	*	—	—
Bulla, sp.				
Bulla orbicula	...	*		
Cancellaria evulsa	—	—	—	—
Cassidaria nodosa	*	—	*	

Fossils from the Upper Bagshot Sand (continued).

	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.
Cerithium, sp.				
Dentalium grande †	*			
Dentalium striatum	—	—	*	—
Dentalium, sp.				
Fusus interruptus	*	—		
Littorina sulcata	—	*	—	
Melanopsis, sp.				
Natica ambulacrum	—	—	—	*
Natica labellata	—	*	*	—
Natica patula	—	—	*	—
Natica venusta?	—			
Natica, sp.				
Pleurotoma biconus	...	*	—	
Rimella rimosa	—	*	*	*
Sigaretus clathratus	—	*	—	
Solarium crenulare	—	—	*	
Terebellum fusiforme	—	*		
Trochita aperta	—	—	—	—
Trochus, sp.				
Turritella imbricataria	*	*	*	*
Serpuloides cancellatus	*	...	—	
Voluta, sp.				
Volvaria acutiuscula	...	*		
Xenophora umbilicaris	—	—	*	—
Cardita sulcata	...	—	*	—
Cardium porulosum	*	—	—	—
Clavagella coronata	—	—	—	—
Corbula gallica	*	—	—	
Corbula Lamarckii	—	—	*	—
Corbula longirostrum	—	—	—	*
Corbula pisum	*	*	*	—
Crassatella sulcata?	...	—	*	—
Cytherea obliqua	—			
Cytherea, sp.				
Lucina elegans	—	...	...	*
Nemocardium turgidum	—	—	*	?
Nucula similis?	...	?	?	*
Nucula, sp.				
Ostrea plicata	—	—	—	*
Pecten carinatus	...	—	—	*
Pecten reconditus	—	...	—	—
Pectunculus deletus	—	—	—	*
Strigilla Rigaultiana	...	...	...	*
Tellina scalarioides	*	—		
Serpula.				
Corals, 2 species of *Turbinolia*.				

† Not Barton, but found in the equivalent Sables Moyens of the Paris basin.

The preceding list contains 52 species of Mollusca †, for the collection of which we are largely indebted to Mr. Herries. Of these, 43 could be determined specifically, 9 generically only, and there was a considerable *residuum* which we were unable to identify. Thirty-one are common to the Upper Bracklesham and Barton, only 3 are absolutely unknown in the Barton, and there are 9 Barton species unknown in the Bracklesham. We must not attach undue importance to these, however, because a considerable distance separates Barton from Tunnel Hill; and we see that as far off as the Paris basin, many of what are our most distinctive Barton shells in Hampshire, such as *Volvaria acutiuscula, Strombus bartonensis, Solarium plicatum*, become distinctive of the Calcaire Grossier, and are quite unknown in the Sables Moyens, where we should expect to find them. On the other hand, we may instance *Dentalium grande* as a purely Bracklesham species in Hampshire, ranging into the Sables Moyens in the Paris area. If we take the * species, which are the most typical and abundant, we find that only 4 of those common to the two formations are more at home in the Bracklesham than in the Barton, while the reverse is the case with no less than 28. Though more of the Barton species belong to the Lower than to either the Middle or Upper divisions of the formation, the Lower Barton facies is not so apparent as we should expect it to be, probably because the sandy bottom favoured species which could not exist in the muddy bottom of the Hampshire basin. Making allowance for this the palæontological evidence agrees with the stratigraphy, the presence of the few Bracklesham forms leading us to place the Tunnel-Hill horizon a little below that of Highcliff.

The Barton Fauna.

The fauna of the Barton Series is the richest in our Eocene, and contains probably more species than have ever before been met with in a single locality. The splendid preservation of the fossils and their striking character attracted attention in very early times, and the work by Brander in 1766 is one of the very earliest in which a large series of fossils was accurately figured and described. They seem to have been collected assiduously ever since, the recurring wash of the waves against the base of the cliffs exposing fresh specimens with every tide, whilst new crops of these delicate fossils seem sprinkled over the dark slopes between Highcliff and Hordwell after every shower.

Prof. Prestwich was able to enumerate 209 species from Barton in his first paper, and in his second the number was increased to 301‡,

† Only 15 forms are given in the Survey list, in the "Geology of the London Basin," p. 600; and of these very few are determined specifically. At least 4 must be different from any in our list.

‡ In 'Geology,' vol. ii. p. 369, Prestwich says "The Barton Clay contains 310 species of Mollusca' and 28 of corals; "*Nautili* have not yet been met with there."

of which 252 were Mollusca. The collection of the Geological Survey, as shown by their catalogue in 1865, comprised 182 species, whilst Morris enumerated 219. Prof. Judd, when writing of "the richly fossiliferous marine deposits of the Barton Clay at the base of the Fluvio-marine series" remarks (Q. J. G. S. vol. xxxvi. p. 151):—"So long ago as 1857 Prof. Prestwich was able to enumerate no less than 300 species of Mollusca from this formation; and when all the known forms contained in the numerous collections in this country come to be described, the number of species from this deposit will probably exceed 1000." A somewhat critical examination of the Edwards collection shows about 527 varieties of Mollusca from the Barton Beds entitled to specific rank, and we are not of opinion that this number will ever be greatly exceeded. Fossils belonging to other groups bring the fauna to a possible total of 600.

The original basis of the tabulated list appended is the catalogue of the Edwards collection in the British Museum. To this we have added as much as possible on the one hand, whilst removing on the other all forms of doubtful specific value. In tabulating the range of the species, we have endeavoured to distinguish their occurrence in each division of the Barton Series; and we believe that the long residence of one and the repeated visits of two of us to the locality, for the purpose of collecting, enable us to deal with the question of the horizons to which species are confined, with a practical experience that it is scarcely probable any other workers have exceeded. Many, especially of the minuter forms identified by Edwards, are almost, if not quite, unique, and we have no means of ascertaining their horizons with certainty. We regard the record of some of the Barton species from other formations as doubtful, but do not suppress them, as we have ourselves discovered several fresh Barton species in Bracklesham Beds whilst preparing this paper. We endeavour to obviate the inconvenience arising from giving extended ranges to species, upon the occurrence of stray and even doubtfully recorded specimens, by placing an asterisk in the columns under which a species is most at home. We have also endeavoured to separate species of the Upper Bracklesham Beds from those of the Lower; and, though necessarily imperfect, this arrangement cannot fail to be of value in showing the passage of the fauna in a truer light than hitherto.

A formidable obstacle was presented by the extensive synonymy in use. No less than 42 species from Barton, out of 182 in the catalogue of the museum at Jermyn Street, cannot be traced under the same names in Edwards's list, whilst in the latest of the lists given by Prestwich 65 additional names of Barton fossils occur which are ignored by Edwards. Similarly we find 60 names in Morris's catalogue unrepresented, and 24 out of the 86 species recorded from the Barton Beds of Alum Bay in the Survey Memoir on the Isle of Wight of 1862. We have taken every precaution that no species should be omitted, but have not thought it necessary to state our reasons for changing or excluding names. Finally, we have not given MS. names of Edwards *in extenso*, but have noted the number of undescribed species under each genus. No doubt many of them have been described on the continent; but to examine each case critically would be equivalent to monographing the entire series of Barton Mollusca. We have contributed to the clearing up of the synonymy by exchanging as many species as possible with M. Cossmann, who is now engaged in revising and supplementing Deshayes's work on the Mollusca of the Paris Basin, and thus assuring ourselves that the correct names are in use. M. Lefèvre, of the Société Malacologique of Brussels, has also kindly certified a number of the species for us, and we believe that the list, if not faultless, will yet be of considerable use to collectors.

We have met with no record of the discovery of any Mammalian remains in the Bartons, though they are far from uncommon in the Lower Headon of Hordwell, except that of *Zeuglodon* by a coastguardsman named Addow, on the shore, in stiff tenacious clay of the Middle Barton. It was purchased by Dr. Wanklyn, and has not been seen since his death some years ago.

Fragmentary remains of Crocodiles and Chelonians are quite abundant in the lowest beds of Highcliff, but have not been determined specifically. For the extensive list of fish-remains we are mainly indebted to Mr. Davies, of the British Museum; most of them are the teeth and spines of Sharks and Rays, and the species, as a rule, have a wide range.

The Molluscous fauna is by far the most important, and may be divided into three great groups. That comprising the largest number of species is peculiar to the Lower Bartons and occurs in the small pockets of fine grey sand known as the Highcliff Sands. Mingled with the fry of larger species is a great number of minute but adult shells, some of which occur in such incredible profusion that an ounce of the sand may contain hundreds of individuals of a species, whilst others are so rare that only solitary examples are known. The relative prevalence of the species varies in samples from different pockets, but by far the most abundant, *Corbula pisum* perhaps excepted, is *Mitra parva*, the next being *Marginella bifido-plicata*. Next come *Bulla elliptica*, *Bayania delibata*, *Volvula lanceolata*, *Strombus bartonensis*, and then, but in rapidly decreasing numbers, several other *Bullæ*, *Volvaria acutiuscula*, *Sigaretus clathratus*, *Actæon Cossmanni*, *Bayania rudis*, *Eulima goniophora*, *Marginella pusilla*, *Teinostoma dubium*, and *Adeorbis elegans**. Most of the remaining minute forms may be considered rare, but the fact that

* The number of shells I have extracted from a single pocket, some $\frac{1}{4}$ peck of sand, is as follows:—of *Mitra parva* 400, *Bayania delibata* 326, *Marginella bifido-plicata* 190, *Volvula lanceolata* 140, *Orthostoma crenatum* 138, *Natica Noæ*, *N. labellata*, and *N. perforata* together 124, *Buccinum Solandri* 90, *Strombus bartonensis* 72, *Bulla elliptica* 70, *Buccinum*, sp., 58, *Cerithium filosum* 50, *Actæon Cossmanni* 41, *Bayania rudis* and *Rissoa bartonensis* each 40, *Bulla conulus* 37, *Bulla pseudo-elliptica* 20, *Sigaretus clathratus* 18, *Actæon simulatus* 16, *Volvula acuminata* 14, *B. angystoma* 13, *Eulima macrostoma* 13, *Nummulites elegans* 12, *Ringicula ringens* 7, *Eulima munda*, *E. goniophora*, *Bulla anomala*, *B. Sowerbyi*, and *Actæon*, sp., 4 each, *Marginella pusilla* and *Nerita inornata* 3, *Bulla ovulata* 2, and the rest 1 each. Corals 35.

they are entirely confined to a special horizon is no doubt due to the absence elsewhere of any similar pockets into which such small shells were drifted and have been preserved. A tiny coral and the fingers of small crabs' claws are mingled with them in equal profusion. Many of the species are exceedingly like living shells from Australia and Japan, and seem to indicate a considerable depth of water with light drifting currents. Many rare freshwater shells are met with in this fauna, the larger of them being almost invariably abraded, as if brought from long distances.

The second fauna is best represented in the Middle Barton, though few of the species are actually confined to it. The shells are of large size, and comprise the bulk of the typical Barton forms figured by Brander. Most of the striking ones are extinct, but others, such as *Ficula nexilis, Cassidaria nodosa*, and the species of *Pleurotoma* and *Natica*, are so nearly identical with living forms, that representatives of them may be said to exist.

The third fauna is that of the *Chama*-beds, comprising a number of exquisite and entirely distinct shells of moderate size, whose sudden appearance is to be attributed less to an interval of time than to a change in the outfall of the river, by which the muddy water and silt of an estuary gave place to clear water and a sandy bottom. An enormous colony of *Chamas* and the ubiquitous *Turritella* took possession of the area; but not the least remarkable circumstance is that the old representative species of several genera were suddenly replaced by others that, though quite distinct, seem closely allied. Thus *Voluta humerosa* replaces *V. maga*, *Murex tripteroides* supersedes *M. asper*, *Typhis fistulosus* displaces *T. pungens*, &c., while nearly the entire tribe of *Pleurotoma* give way to clear-water Cowries, Cones, *Mitræ*, *Murices*, &c. The survival of stray and often water-worn specimens of Middle Barton species does much, however, to rob the *Chama*-beds of the peculiar facies of their fauna when tabulated, and renders the break far less apparent than it actually is in the field.

The fauna from the Long-Mead-End Sands is again very distinct indeed in its general facies from those which precede it. Its most noticeable feature is the large proportion of *Cerithia* and of *Oliva Branderi*. It possesses a peculiar *Natica* and *Marginella*, and species of *Melania* and *Melanopsis* similar to those of the Headon Beds above, while, owing probably to an influx of brackish water, the whole group of *Volutæ*, *Pleurotomæ*, and *Murices* so characteristic of the Lower and Middle Bartons have disappeared. About a dozen of its commonest species are, in fact, indicative of brackish, if not of fresh water, while an equal number of hardly less abundant, truly marine forms pass up from below.

The list of Barton fossils comprises 23 Vertebrates, 47 Invertebrates other than Mollusca, 257 Gasteropods, and 150 Bivalves, exclusive of over 120 undetermined species. Twenty-eight of the Mollusca first appear in the London Clay and range for the most part above the Lower Barton, though 7 of them are absent in the Lower and 3 in the Upper Bracklesham. A further 37 species first appear in the Lower Bracklesham, only 11 of which do not range above the Lower Barton. These are reinforced by no less than 108 additional species in the Upper Bracklesham, 35 of which die out with the Lower and 24 with the Middle Barton. Thus of the 407 species, 175 range below the Barton, against 56 that pass up into the Headon; but of the latter 30 are also Bracklesham and London-Clay species. The upper limits of the Barton formation are thus much more sharply defined, palæontologically, than the lower; but we must remember that in the former case the passage into fluviatile beds is abrupt, and the marine beds next above are separated by a considerable thickness of freshwater deposits, while in the latter the transition lies everywhere in marine deposits. The reason for drawing the line between Oligocene and Eocene in our area, here if anywhere, is quite obvious if our statistics are at all reliable.

The close connexion between the Upper Bracklesham and Lower Barton is rendered very striking by these tables, no less than 35 species being quite peculiar to the two horizons when combined. This contrasts with the 12 which are peculiar to the Lower and Middle Barton combined, and the less than half a dozen peculiar to the combined Middle and Upper Barton. The upper limits of the Bracklesham should obviously, on palæontological data, have been drawn much lower down. Only 16 are peculiar to the Upper Barton and Headon combined, and these are mostly freshwater or brackish-water stragglers.

Of the tabulated Mollusca, 124 are absolutely peculiar to the Barton formation in this country, though we must not lay undue stress upon them, as we have seen that many of those most rigidly limited in range in our area have a more extended or a different range in the Paris area. Of these, 15 range through the three divisions, 12 through the Lower and Middle, 5 are confined to the Lower and Upper, 3 to the Middle and Upper. This somewhat capricious distribution may be partly due to the extra turbidity of the water in the Middle period. There are 51 species absolutely confined to the Lower, 10 to the Middle, 28 to the Upper divisions.

The distribution by genera is equally instructive; but in order to have made an analysis, we must have introduced subgeneric names, which would have lessened the value of the list for general comparison. We have for the same reason retained many familiar generic names which, on the ground of priority, must disappear. The general resemblance between the facies of much of the Barton fauna and that of the London Clay is not apparent in the table, perhaps because species which did not hold their ground during the Bracklesham period, but emigrated, were so considerably modified during the interval that they can be distinguished as new species on their reappearance; while the modifications undergone by those that remained were so slight that in the presence of connecting links they are specifically inseparable.

If we confine our attention to the species whose range is marked by * in the table, we find, excluding a few cosmopolitans, that 7 London-Clay or Lower Bracklesham and 32 Upper Bracklesham species merely straggle up into the Barton formation, only 7 or 8 actually belonging as much to one as to the other. There are 85 distinctively Lower, 39 Middle, and 50 Upper Barton species; only 3 or 4 species distinctive of all 3 stages, without being distinctive of any beds other than Barton; and only 2 distinctively common to the Middle and Upper stages alone. There are 13 characteristic Headon species in the Barton and only 5 that belong equally to Headon and Barton without passing into the Bracklesham.

Vertebrata.

The species which have all the columns left blank are from the Barton Series; but their precise horizon is not known.	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Zeuglodon Wanklyni, *Seeley*	...	...	...	...	—		
Crocodilus, sp.	—	—	—	—			
Chelone, sp.	—	—	—	—	—		
Lamna contortidens, *Ag.*	...	—	—	—	—	—	—
—— elegans, *Ag.*	—	—	—	—	—	—	—
—— (Odontaspis) Hopei, *Ag.*							
Otodus macrotus, *Ag.*	—	—	—	—	—	—	—
—— obliquus, *Ag.*	—	—	—	—	—	—	—
Myliobates †nitidens, *Ag.*	—	...	...	—			
—— goniopleurus, *Ag.*							
—— toliapicus, *Ag.*	...	...	...	...	...	—	
—— punctatus, *Ag.*							
—— marginalis, *Ag.*							
Aëtobatis rectus, *Dixon*							
—— subarcuatus, *Ag.*	—						
Pristis Hastingsiæ, *Ag.*							
—— †acutidens, *Ag.*	...	...	...	...	...	—	
Edaphodon leptognathus, *Ag.*	...	...	...	—	...	*	
—— Bucklandi	...	...	...	...	...	—	
Sphyrænodus, sp. ined.							
Cœlorhynchus rectus, *Eg.*	...	—	—	—	—		
Silurus Egertoni, *Dixon*	...	—	—	—	—		
Notidanus serratissimus, *Ag.*	—	...	...	?	?		

† Recorded by Agassiz, but not since authenticated.

Invertebrata.

The * in the columns denotes where the species is most at home. The † prefixed to a name indicates that the shell is unique. The species which have all the columns left blank are from the Barton Series; but their precise horizon is not known.	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Nautilus, sp.	...	...	...	—	—	?	
†Pedipes glaber, *Edw.*	...	...	...	—			
Cypræa bartonensis, *Edw.*	...	...	...	...	...	*	
Trivia platystoma, *Edw.*	...	...	...	—	—		
Marginella bifido-plicata, *Charlesw.*	—	...	—	*	—		
—— †gracilis, *Edw.*‡	...	...	...	—			
—— pusilla, *Edw.*	...	...	...	*			
—— simplex, *Edw.*	...	...	...	...	...	*	
Voluta luctatrix, *Sol.*	...	...	...	—	*	—	
—— ambigua, *Sol.*	...	...	...	—	*		
—— ——, var. subambigua	...	...	...	...	...	*	
—— nodosa, *Sow.*	*	...	*	—			
—— scalaris, *Sow.*	...	...	...	...	—	*	
—— spinosa, *Linn.*	...	...	*	—	—		
—— ——, var. depauperata, *Sow.*	...	...	...	...	...	...	*
—— scabricula, *Sol.*	...	...	—	—	—	*	
—— Solandri, *Edw.*	...	...	...	—	...	—	
—— athleta, *Sol.*	...	—	—	*	—		
—— maga, *Edw.*	...	...	*	—	—	...	—
—— suspensa, *Sol.*	...	...	...	...	*		
—— decora, *Beyr.*, var. maga, *Edw.*	...	...	...	...	...	—	*
—— humerosa, *Edw.*	...	...	...	...	...	*	
—— costata, *Sol.*	...	...	...	...	—	*	
†Mitra volutiformis, *Edw.*	...	...	...	...	—		
—— scabra, *Sow.*	...	...	...	...	...	*	
—— parva, *Sow.*	—	...	*	*	*	—	?
—— fusellina, *Lam.*	...	...	*	*	—		
—— †obesa, *Edw.*	...	...	...	—			
Conus scabriculus, *Sol.*	...	...	...	...	...	*	
—— lineatus, *Sol.*	...	...	...	...	...	*	
—— dormitor, *Sol.*	...	...	...	...	—	*	—
Pleurotoma rostrata, *Sol.*	...	...	...	—	*		
—— exorta, *Sol.*	...	...	—	—	*		
—— macilenta, *Sol.*	...	...	—	—	*	*	
—— lanceolata, *Edw.*	...	...	...	?	—		
—— lævigata, *Sow.*	...	...	...	—	—	?	
—— microdonta, *Edw.*	...	...	—	*			
—— desmia, *Edw.*	...	...	...	—	*		
—— innexa, *Sol.*	...	...	—	—	*		
—— coarctata, *Edw.*	...	...	...	*			
—— microcheila, *Edw.*	...	...	...	*	?		
—— dissimilis, *Edw.*	—	...	...	*			
—— gomphoidea, *Edw.*	—	...	...	*	—		
—— acuticosta, *Nyst*							
—— biarritziana	...	...	*	—			
—— §hemileia, *Edw.*							
—— §vicina, *Edw.*							
—— §dilinum, *Edw.*							

‡ Apparently a variety of above.
§ These species occur in the Barton Beds at Alum Bay only.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Pleurotoma pupa, *Edw.*	...	...	—	*	—		
—— §turgidula, *Edw.*							
—— §curta, *Edw.*							
—— scabriuscula, *Edw.*	...	...	...	—			
—— verticillum, *Edw.*	...	...	...	—			
—— constricta, *Edw.*	—	...	...	—	—		
—— bracheia, *Edw.*	...	...	—	*			
—— rotella, *Edw.*	...	...	...	—	—		
—— granulata, *Lam.*	...	...	—	*	—		
—— conoides, *Sol.*	...	...	...	—	*		
—— biconus, *Edw.*	...	...	...	*	—		
—— helicoides, *Edw.*	...	...	...	*	—	?	
—— aspera, *Edw.*	...	...	...	?	—		
—— †mixa, *Edw.*	...	...	...	...	—		
—— gentilis, *Sow.*	...	...	*	—			
—— denticula, *Bast.*, var. odontella, *Edw.*	—	...	—	—	—	...	—
—— callifera, *Edw.*	...	..	...	—			
—— monerma, *Edw.*	—	...	...	—			
—— varians, *Edw.*	...	...	...	*			
—— lima, *Edw.*	...	...	...	—	?	—	
—— reticulosa, *Edw.*	...	...	—	—	—		
—— cedilla, *Edw.*	...	...	...	—			
—— †puella, *Edw.*	...	...	...	—			
—— turbida, *Sol.*	...	...	...	*	*	*	
—— zonulata, *Edw.*	...	...	...	*			
—— prisca, *Sol.*	—	—	—	—	*	—	
—— subfilosa, *Edw.*	...	...	...	—	—		
Daphnella sulcata, *Edw.*	...	...	...	...	—	?	*
—— semicostata, *Edw.*							
—— lineata, *Edw.*	...	...	...	—			
—— citharella, *Lam.*	...	...	...	...	*		
Terebra plicatula, *Lam.* (and 5 other species).	...	...	*	—	—		
Strombus bartonensis, *Sow.*	...	...	...	*			
Rostellaria excelsa, *Gieb.*?							
—— ampla, *Sol.*	—	—	—	—	*	—	
Rimella canalis, *Lam.*	...	...	*	—	—		
—— rimosa, *Sol.*	...	...	—	*	*	*	—
Terebellum sopitum, *Sol.*	...	...	...	...	...	*	
—— fusiforme, *Sow.*	...	...	—	*			
Murex asper, *Sol.*	...	?	*	—	*	—	
—— bispinosus, *Sow.*	...	...	—	...	?	*	
—— tripteroides, *Lam.*	...	...	—	...	...	*	
—— defossus, *Pilk.*	...	...	...	...	...	*	
—— crispus, *Lam.*							
—— subrudis, *D'Orb.*	...	...	...	...	...	*	
—— minax, *Sol.*	...	—	*	*	*	—	—
—— obtusus, *Desh.*	...	...	...	...	—	—	—
—— raricostatus, *Desh.*							

§ These species occur in the Barton Beds at Alum Bay only.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Typhis pungens, *Sol.*	...	...	—	—	*	—	—
—— fistulosus, *Sow.*	...	...	...	...	...	*	
Turbinella parisiensis, *Desh.*	...	...	*	...	—	—	
Fusus interruptus, *Sow.*	?	...	*	—			
——, sp. n.	...	...	...	...	...	—	
—— porrectus, *Sol.*	...	...	—	—	*	—	
—— aciculatus ?, *Lam.*	...	...	...	...	—		
—— longævus, *Sol.*	...	—	*	*	*	*	*
—— regularis, *Sow.*	...	—	—	—	*		
—— lima, *Sow.*	...	...	...	...	—		
—— errans, *Sol.*	...	...	—	*			
—— pyrus, *Sol.*	...	...	*	—	*	—	
—— juncea, *Sol.*	...	...	—	—	*	?	
—— turgida, *Sol.*	...	—	*	—	—	*	
(about 12 other species).							
Buccinum lavatum, *Sol.*	...	...	...	...	...	*	—
——, sp. n.	...	...	...	*			
—— desertum, *Sol.*	...	...	...	...	*	*	—
—— canaliculatum, *Sow.* (Fusus)	...	...	...	*			
Oliva Branderi, *Sow.*	...	...	—	—	—	*	
—— Salisburiana, *Sow.*	...	...	—	*	—		
—— aveniformis, *Sow.*	...	...	...	*	—	—	
Ancillaria perita, *Sol.*	...	...	—	—	—	*	*
—— olivula, *Desh.*	...	...	?	—	—	—	
——, sp. n.	...	...	...	...	—	—	
—— canalifera, *Lam.*	...	...	—	*	—		
Cassis ambigua, *Sol.*	...	...	...	*	...	...	—
Cassidaria nodosa, *Sol.*	...	...	*	—	*		
Nassa obtusa, *Edw. MS.*	...	...	—	—			
§Pseudoliva fissurata, *Desh.*	—	...	...	—			
Triton argutus, *Sol.*	...	...	—	—	*		
——, sp. n.	...	...	*	...	...	*	
(and 2 other species).							
Ficula nexilis, *Sol.*	—	—	—	—	*		
Ampullina mutabilis, *Sol.*	...	...	*	—	—		
Natica ambulacrum, *Sow.*	...	...	—	—	—	*	
—— hantoniensis, *Pilk.*	*	...	—	—	*	—	—
—— patula, *Desh.*	...	—	—	—	*	—	
—— grossa, *Desh.*=depressa	...	...	—				
—— Edwardsi, *Desh.*	...	—	*	—	—	—	*
—— sigaretina, *Desh.*	—	—	—	—	—		
—— labellata, *Lam.*	*	—	—	*	*	—	*
—— Noæ, *D'Orb.*	...	...	—	*	...	...	—
—— perforata	...	...	...	*	...	...	—
—— abscondita, *Desh.*	...	...	...	...	...	—	
Sigaretus clathratus, *Récluz*	?	—	—	*	—		
Cancellaria evulsa, *Sol.*	...	...	—	—	—	—	—
——, sp. n.	...	...	...	...	...	*	
—— elongata (?), *Nyst*	...	...	...	—	—	—	—
—— massæformis, *S. Wood*	...	...	—	—	—	*	

§ Only known as a Barton fossil from Alum Bay.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Cancellaria, sp. n.	...	...	...	...	*		
—— quadrata, *Sow*	...	...	—	*	...	—	
—— microstoma, *Charlesw.*	...	...	*	—			
(and 3 other species).							
Mesostoma cancellaroides, *Desh*	...	...	—	—	*		
——, sp. n.	...	...	—	—	—		
Pyramidella (9 species, all from Lower Barton).							
Odostomia miliola, *Lam*	...	...	—	*	—	—	
(and 18 other species from Barton or Highcliff).							
Turbonilla (12 sp.).							
Bayania delibata, *Cossm.*	...	...	...	*			
—— rudis, *Charlesw.*	...	...	...	*			
(and 2 others).							
Syrnola Bernayi, *Cossm.*	...	...	...	*			
Paryphostoma minus, *Desh.*							
Eulima goniophora, *Cossm*	...	...	—	*			
—— munda, *Desh.*	...	...	—	*			
—— macrostoma, *Charlesw.*	...	...	...	*			
(and 4 species from Highcliff).							
Niso, sp.	...	—	*	—			
Solarium Dumonti, *Nyst*	...	...	...	*			
—— plicatum, *Lam.*	...	...	...	*	?	—	
—— crenulare, *Desh.*	...	—	—	—	*		
——, sp. n.	...	...	...	...	...	?	
§ Eumargarita trochiformis, *Desh.*	...	—	*	—			
—— § spiratum, *Lam.*	...	...	—	—			
§ Discohelix patellatus, *Sow.*	...	...	*	—			
Scalaria primula, *Desh.*	...	...	...	*			
—— reticulata, *Sol.*	...	...	—	—	*	—	
—— acuta, *Sow.*	...	...	...	—	—	*	
—— undosa, *Sow.*	...	...	—	—	*		
—— cerithiiformis, *Wat*	...	—	—	*			
—— tenuilamella, *Desh.*	...	...	...	—			
——, sp. n.	...	...	—	—	*		
(and 3 MS. species from Highcliff).							
Cerithium Gardneri, *Cossm.*	...	...	...	—	*		
——, sp. n.	...	...	...	*			
—— lima, *Desh.*	...	...	—	—	...	*	
—— Gravesii, *Desh.*, var.	...	...	...	—			
—— conarium, *Bayan*	...	—	*	—	—		
—— submarginatum, *D'Orb.*	...	...	*	—	...	...	—
——, sp. n.	—	—	*	—			
—— angulatum, *Sol.*	...	...	...	*			
—— variabile, *Desh.*	...	...	...	...	...	—	*
—— pleurotomoides, *Lam*	...	...	...	...	...	*	
—— concavum, *Sow.*	...	...	...	...	...	—	—
—— ventricosum, *Sow.*	...	...	...	...	...	—	*
—— perditum, *Bayan*	...	...	...	...	...	—	

§ Only known as Barton fossils from Alum Bay.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Cerithium filosum, *Charlesw.*	...	...	...	*			
(and 7 MS. species).							
Triforis, sp.	...	...	—	*			
Diastoma costellatum, *Lam.*	...	—	*	—	?		
Pirena rigida, *Sol.*	...	...	...	*	—		
Turritella imbricataria ‡, *Lam.*	—	*	*	*	*	*	
—— granulosa, *Desh.*	...	...	—	*	—	—	
—— concinna, *Edw.*	...	...	—	*			
Strebloceras cornuoides, *Brown*	...	...	...	...	...	—	
Serpulorbis cancellatus, *Desh.*	...	...	*	...	—		
Melania fasciata, *Sow.*	...	...	...	...	...	*	
——, sp. n.	...	...	...	*			
—— hordeacea, *Lam.*	...	...	—	—	...	*	
Melanopsis sigillata, *Edw.*	...	...	...	*			
—— fusiformis, *Sow.*	...	...	...	...	...	—	*
Littorina sulcata, *Pilk.*	...	—	—	*	—		
—— subangulata, *Desh.*	...	—	—	*			
Lacuna, sp. n.	...	...	...	*	—		
(and 8 other rare species).							
Stylifer, sp.	...	...	...	*			
Rissoina, sp. n.	...	...	—	*			
(and 3 other species).							
Rissoa nana, *Lam.*	...	...	...	*			
—— bartonensis, *Charlesw.*	...	...	...	*	—		
—— carinata, *Charlesw.*	...	...	...	*	...	—	
——, sp. n.	...	—	—	*			
(and 4 other rare species).							
Hydrobia anceps, *S. Wood*	...	...	...	*	—	—	*
—— sextonus, *Desh.*	...	...	...	*			
Truncatella, sp.	...	...	...	—			
Trochita aperta, *Sol.*	...	—	—	—	*	—	*
Capulus squamæformis, *Desh.*	...	...	—	—	*		
——, sp. n.	...	...	...	—			
Xenophora discoidea, *Sow.*	...	...	...	*	—		
—— umbilicaris, *Sol.*	...	—	*	—	*	—	
(and 3 MS. species).							
Trochus nodulosus, *Sol.*	...	...	...	...	...	*	
Teinostoma dubium, *Desh.*	...	...	...	—	—		
Delphinula canalifera, *Lam.*	...	—	—	—			
—— callifera, *Desh.*	...	...	—	—	—	?	
Adeorbis elegans, *Charlesw.*	...	—	—	*	—		
—— tricostata, *Desh.*	...	...	...	...	—		
——, sp. n.	...	...	...	...	...	—	
(and 8 other species).							
Neritina concava	...	...	...	...	...	—	*
Nerita, sp. n.	...	...	...	—			
—— hantoniensis, *Pilk.*	...	...	...	*	—		
Nacella, sp.	...	...	...	...	...	—	

‡ Several species are probably comprised in this.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Actæon, sp. n.	...	...	—	*	—		
—— simulatus, *Sol.*	—	—	—	—	?	*	
—— elongatus, *Sow.*	...	...	—	—	?		
—— crenatum, *Sow.*	—	...	...	*	...	—	
Ringicula ringens, *Lam.*	*	*	...	*	...	—	
Volvaria acutiuscula, *Sow.*	...	...	...	*			
Etallonia, sp.	...	...	...	...	...	—	
Bulla attenuata, *Sow.*	—	—	—	—	?	*	*
—— Sowerbyi, *Nyst*	...	—	—	*	*		
—— constricta, *Sow.*	...	...	...	—	*	—	
—— elliptica, *Sow.*	...	...	—	*	—	—	—
—— pseudo-elliptica, *Edw.*	...	...	...	*			
—— producta, *Edw.*	...	...	—	—			
—— angystoma, *Desh.*	...	...	...	*			
—— conulus, *Desh.*	...	...	...	*			
——, sp. n.	...	?	—	*	—		
—— Lamarckii, *Desh.*	...	...	...	...	...	—	—
—— sp. n.	...	...	...	*			
—— coronata, *Lam.*	...	...	...	—	—	?	
Volvula lanceolata, *Sow.*	...	—	—	*	?	—	
—— acuminata, *Charlesw.*	...	...	...	*	?	?	
Acera striatella, *Lam.*	...	...	...	*			
Scaphander Defrancei, *Sow.*	...	...	...	*	...	—	
——, sp. n.	...	...	...	*			
Bullæa, sp. n.	...	...	...	...	...	*	
Dentalium pellucens, *Desh.*	...	—	*	*			
—— striatum, *Sol.*	...	—	—	—	*	—	
Anomia tenuistriata, *Desh.*	*	—	—	—	—	*	—
Ostrea oblongata, *Sol.*	...	—	—	—	*		
—— plicata, *Sol.*	—	—	—	—	—	*	—
—— gigantea, *Sol.*	...	...	—	—	*		
Vulsella deperdita, *Lam.?*	...	...	—	...	...	*	
Pecten corneus, *Sow.*	—	*	*	—	—		
—— carinatus, *Sow.*	...	...	...	—	—	*	
—— reconditus, *Sol.*	...	...	—	...	—	—	
Lima compta, *S. Wood*							
—— soror, *S. Wood*							
Avicula media, *Sow.*	*	—	—	—	—	*	—
Pinna margaritacea, *Lam.*	*	...	—	—	—		
Mytilus strigillatus, *S. Wood*	...	...	...	...	...	—	
—— affinis, *Sow.*	...	...	...	...	...	—	*
Modiola sulcata, *Lam.*							
—— Searlesi							
—— diversa, *S. Wood*							
—— eximia, *S. Wood*							
—— nodulifera, *S. Wood*	...	...	...	...	...	...	—
—— pygmæa, *S. Wood*							
—— bartonensis, *S. Wood*							
—— dimidiata, *S. Wood*	...	...	...	*			
—— seminuda, *Desh.*	...	...	...	*	...	—	

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Modiola hastata, *Desh.*	—	...	*	...	?		
—— elegans, *Sow.*	*	...	—	—	—	—	
—— subcarinata, *Lam.*	*	...	...	...	?	—	
Arca globulosa, *Desh.*	...	—	—	*	—		
—— lissa, *Bayan*	—	—	*	*	...	—	—
—— Lyelli, *Desh.*	...	...	...	—	—		
—— appendiculata, *Sow.*	...	—	—	—	*	—	—
—— biangula, *Lam.*	...	*	—	...	...	—	—
Pectunculus deletus, *Sol.*	...	—	—	—	—	*	
—— proximus, *S. Wood*	...	...	...	...	..	—	
Limopsis scalaris, *Sow.*	...	...	...	—	*	—	
Erinacria curvirostris, *Cossm.*	...	...	...	...	...	—	*
Nucula similis, *Sow.*	...	...	...	?	?	*	
—— tumescens, *Edw.*	...	...	—	...	...	*	
—— lissa, *Edw.*	...	...	—	*	...	...	—
—— prælonga, *Edw.*	...	...	...	...	...	*	
—— bisulcata, *Sow.*	...	—	—	—	*	—	
—— ampla, *Edw.*	...	...	...	...	...	*	
Leda minima, *Sow.*	...	...	—	*	—	...	—
Cardita sulcata, *Sol.*	—	...	...	—	*	—	
—— ——, var. pectinata, *Edw.*	...	...	...	—			
—— Davidsoni, *Desh.*	...	...	...	—			
—— pulchra *Edw.*	...	...	*	—			
—— trapezoidalis, *S. Wood*	...	...	...	—			
—— oblonga, *Sow.*	...	...	—	...	...	*	—
Crassatella sulcata, *Sol.*	...	...	...	—	*	—	
—— tenuisulcata, *Edw.*	...	...	...	...	...	*	
—— plicata, *Sow.*	...	...	...	*			
—— grignonensis, *Desh.*, var. anglica, *S. Wood*	...	...	*	—			
—— sinuosa, *Desh.*	...	...	—	—			
—— subquadrata, *Edw.*	...	...	—				
—— Bronnii, *Merian*	...	...	—	*			
—— pumilis, *S. Wood*	...	...	...	—			
—— bartonensis, *Edw.*	...	...	...	—			
—— dilatata, *Desh.*							
Woodia crenulata, *Desh.*							
Lutetia parisiensis, *Desh.*	...	...	—	*			
Chama squamosa, *Sol.*	...	...	...	...	...	*	
—— selseiensis, *Edw.*	...	...	*	—			
Lucina concentrica, *Lam.*							
——, sp. n.	...	...	...	—	—	*	—
—— gigantea, *Desh.*	...	...	...	...	...	*	
—— gibbosula, *Lam.*	...	...	—	...	...	—	—
—— elegans, *Defr.*	...	—	—	...	...	*	
—— concava, *Defr.*	...	...	...	...	...	—	*
—— § Menardi, *Desh.*							
——, sp. nov.	...	—	—	—	—		
—— § ambigua, *Defr.*							
—— § callosa, *Lam.*	...	...	...	...	...	—	

§ These species occur only in the Barton Beds of Alum Bay.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Strigilla colvellensis, *Edw.*	...	...	...	...	...	*	
—— Rigaultiana, *Desh.* (= Lucina divaricata, *Sow.*)	...	...	...	...	...	*	—
Diplodonta, 9 sp.							
Cardium porulosum, *Sol.*	...	*	*	—	—	—	—
—— obliquum, *Lam.*	...	...	...	*	...	...	*
Nemocardium turgidum, *Sol.* (C. semigranulatum, *Sow.*, P. parile, *Desh.*)	—	—	—	—	*	?	
Erycina tenuicula, *Desh.*	...	...	...	—			
—— breviuscula, *Desh.*	...	...	...	—	?		
—— habilis, *S. Wood*	...	...	—	—			
Scintilla lata, *S. Wood*	...	...	...	—			
—— angusta, *S. Wood*	...	...	...	—			—
Lepton, 3 sp.							
Hindsia inæquilobata, *Desh.*	...	...	...	—			
Kellia delicatula, *S. Wood*	...	...	...	—			
Sportella, 2 sp.							
Levicardium parisiense, *D'Orb.*	...	...	—	...	—		
Anisocardia isocardioides, *Desh.*	...	...	...	...	—		
—— pectinifera, *Sow.*	...	...	...	...	...	—	*
Coralliophaga chartacea, *Bayan*	...	...	...	...	—		
—— vaginoides, *Desh.*							
Cyrena deperdita, *Desh.*	...	...	...	—	—	—	
—— gibbosula, *Morr.*	...	...	...	...	...	—	—
Cytherea sulcataria, *Desh.*	...	...	...	—	...	—	—
—— suberycinoides, *Desh.*							
—— transversa, *Sow.*	...	...	...	...	—	—	
—— Solandri, *Sow.*	...	...	—	*	...	...	—
—— elegans, *Lam.*	...	...	—	*	—		
—— nitidula, *Lam.*							
—— polita, *Lam.*	...	...	*	...	—		
—— cuneata, *Desh.*	...	...	*	—			
—— lævigata, *Lam.*	...	*	—	—	—		
—— parisiensis, *Desh.* (=lucida, *Sow.*).	...	*	—	—			
Psammobia rudis, *Lam.*	...	...	...	...	...	—	*
—— compressa, *Sow.*	...	...	—	*			
—— debilis, *Desh.*	...	...	...	...	—	—	
Donax trigonula, *Desh.*	...	...	...	—			
Tellina ambigua, *Sow.*	...	...	...	...	*	?	
—— ‡ lamellosa, *Desh.*	...	...	—	—			
—— Branderi, *Sow.*	...	...	*	—	—		
—— canaliculata, *Edw.*	...	...	—				
—— hantoniensis, *Edw.*	...	...	...	...	...	—	
—— filosa, *Sow.*	...	...	—	—	...	—	
—— tenuistriata, *Desh.*	...	...	—	—	—	?	
—— donacialis, *Lam.*	...	...	—	—	?		
—— lamellulata, *Edw.*	...	...	...	—	—		
—— squamula, *Edw.*	...	...	...	...	—		

‡ Barton *fide* Deshayes.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Tellina virgo, *Edw.*	...	...	...	—			
—— truncata, *Edw.*	...	...	...	...	?	—	
—— scalaroides, *Lam.*	...	—	*	—			
—— lævis, *Edw.*	...	...	*	...	—	*	—
—— textilis, *Edw.*	...	...	—	...	—		
—— granulosa, *Edw.*, and 4 sp.‡							
Syndosmya, 6 sp.							
Mactra compressa, *Desh.*	...	—	*				
Cardilia radiata	...	...	*				
Solen gracilis, *Sow.* (and 2 sp.)	...	—	—	—	—	—	—
Siliqua ovalis, *Edw. MS.*							
Cultellus bartonensis, *Edw.*	...	...	—	—	—	—	—
—— affinis, *Sow.*	—	*	*	—	—	—	
Solecurtus Deshayesi, *Des Moulins*	...	*	—	—	—		
Mya bartonensis							
Sphenia angulata, *Desh.*	...	...	...	—			
Corbula anatina, *Lam.*							
—— Lamarckii, *Desh.*	...	—	—	—	*	—	
—— gallina (Venus), *Sol.*	...	...	—	—	*	?	
—— longirostrum, *Desh.*	...	—	—	—	—	*	
—— costata, *Sow.*	...	—	—	—	—	—	
—— cuspidata, *Sow.*	...	...	...	...	...	—	*
—— pisum, *Sow.*	...	—	*	*	*	—	—
—— ficus, *Sol.*	...	...	...	*	—	*	
—— gallica, *Lam.*	...	*	*	—	—		
—— Edwardsii, *Tawney*	...	...	...	...	...	*	
—— globosa, *Sow.*	—	—	—	—			
Neæroporomya argentea, *Desh.*	...	...	—				
Neæra serrata, *Edw.*							
Panopæa corrugata, *Sow.*	...	—	—	—			
Thracia, 2 sp.							
Pholadomya margaritacea, *Sow.*	*	—	—	*			
Gastrochæna contorta, *Desh.*	...	...	...	—	—		
—— corallium, *Sow.*	...	...	—	...	—		
Clavagella coronata, *Desh.*	...	—	—	—	—	—	—
Martesia elegans, *Desh.*	...	...	...	—			
—— conoidea, *Desh.*	...	. .	...	—			
Teredo, sp.	...	—	—	—	—		
Teredina personata, *Lam.*	—	—	...	—			
Terebratula bisinuata, *Lam.*	—	—	...	...	...	*	
Palæastacus [robustus, *Carter*, *MS.*]	...	...	...	...	—		
Goniocypoda Edwardsi, *Woodw.*	...	...	...	—			
Balanus unguiformis, *Sow.*	...	...	...	...	—	—	—
Serpula exigua, *Sow.*							
—— extensa, *Sol.*	...	—	—	—	—	—	
—— crassa, *Sow.*							
—— heptagona, *Sow.*	—	—	—				
—— ornata, *Sow.*	...	...	—				

‡ Deshayes gives 4 other species.

Invertebrata (continued).

	London Clay.	Lower Bracklesham.	Upper Bracklesham.	Lower Barton.	Middle Barton.	Upper Barton.	Headon.
Ditrupa incrassata, *Sow.*	—	...	—	—	—	—	—
Schizaster D'Urbani, *Forbes*	...	...	—	—	...	—	
Ophiura Wetherellii, *Forbes*	—	...	...	—			
Cidaris Websteriana, *Forbes*	—						
Echinopsis Edwardsii, *Forbes*	...	...	—				
Echinus Dixonianus, *Forbes*							
Hemiaster Branderianus, *Forbes*	?						
Eupatagus Hastingsiæ, *Forbes*							
Spatangus Omalii, *Forbes*							
Turbinolia humilis, *M.-Edw.*	...	—	—	—	?		
—— Bowerbankii, *M.-Edw.*							
—— Fredericiana, *M.-Edw.*							
—— minor, *M.-Edw.*							
—— firma, *M.-Edw.*							
Holaræa parisiensis, *Mich.*	...	...	...	...	...	—	
Graphularia Wetherelli, *M.-Edw.*	—						
ENTOMOSTRACA (OSTRACODA ‡).							
Cythere striato-punctata, *Röm.*	...	...	—	—	—		
—— consobrina, *Jones*	...	...	...	...	—		
—— plicata, *Münst.*	—	...	—	—	—	...	—
—— Wetherellii, *Jones*	...	...	...	—	—	...	—
—— attenuata, *Jones*	...	...	...	—			
Cythereis horrescens, *Bosq.*	...	...	—	...	—		
Cytheridea Muelleri §, *Münst.*	...	...	...	—	—	...	—
—— perforata, *Röm.*	—	...	...	—	—	...	—
Krithe bartonensis, *Jones*	...	...	...	...	—		
Bairdia subdeltoidea. *Münst.*	...	...	...	—			
—— contracta, *Jones*	...	...	...	...	—		
Cytherella Muensteri, *Röm.*	...	—	—	...	—		
FORAMINIFERA.							
Biloculina ?	...	...	...	...	—		
Quinqueloculina Hauerina, *D'Orb.*	...	...	...	—	—		
Miliola, spp.	...	...	...	—	—		
Cristellaria rotulata, *Lam.*	...	...	...	...	?		
Marginulina Wetherellii, *Jones*	...	...	...	...	—		
Truncatulina lobata, *W. & J.*	...	...	...	...	—		
Planorbulina rosea (?), *D'Orb.*	...	...	...	...	—		
Discorbina trochiformis, *Lam.*	...	...	...	...	—		
Nummulites variolarius, *Lam.*	...	...	*	—			
—— elegans, *Sow.*	...	...	—	*			

‡ Monogr. Tert. Entom. Pal. Soc. 1856, and Geol. Mag. for September and October 1887.

§ Taken in the Woolwich and Reading Beds.

Discussion.

The President referred to the numerous communications to the Society relative to the Eocenes of Hampshire, and complimented Mr. Gardner on being able to say something new.

Mr. Whitaker observed that in point of fact but little had been written about the Barton Beds of Barton Cliff, attention having been mostly drawn to the Headon Series. He spoke of Mr. Trimmer's section, 20 in. to 1 mile, executed in 1849; there was also one at Southampton by Mr. Keeping. The Barton section had hitherto been difficult of access.

Commenting on the cliff-section, he regarded the whole as one great series; there were no great gaps in the succession, the changes being local only. There was some difference of opinion as to the base-line of the Headon Series. The sandy beds below constitute a large portion of the material coloured as Upper Bagshot. In this occurs a clay bed, which he regarded as exceptionally intercalated; do the fossils connect it with the Barton Series? There was no gap of importance between the Barton and Bracklesham Series. The pebble-bed was exceptional in containing some subangular flints and quartz. The oscillations in the area had not been of great importance. He thanked Mr. Gardner for the care he had taken over the lists of fossils.

Mr. Irving recognized a general resemblance to the beds of the London basin, the changes of level being chiefly local. He would like to know if the fauna discovered by Mr. Monckton in the sandy Upper Bagshots occurred in exceptionally argillaceous beds.

Mr. Monckton remarked that this bed was quite as sandy as the others.

Mr. Irving expressed his doubts as to the possibility of specific identification of these fossils. Such a large number of genera were common to the two divisions, that he doubted any great difference in the fauna of the Upper and Middle Bagshots.

Mr. Herries said that the Pebble-bed was a convenient line of separation between the Upper and Middle Bagshots of the London basin, though perhaps at a lower horizon than the division-line in the Hampshire area. He assured Mr. Irving that in the London basin the fossils of the "green earths" (Middle Bagshots) were quite distinct from those in "Tunnel Hill" (Upper Bagshots), in which he believed only one purely Bracklesham form had been found, and of that but a single specimen.

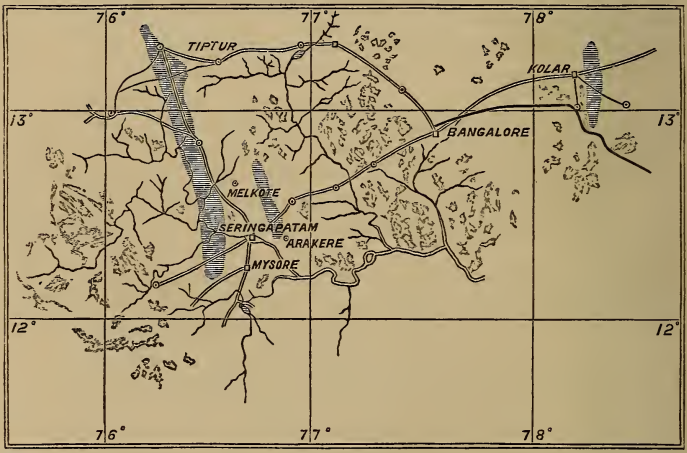
Mr. Gardner had no desire to favour either the Headon or the Barton Series. He placed the upper boundary of the latter where the marine shells cease. The sands, therefore, to which Mr. Whitaker alluded belonged to the Barton Series. The lower boundary of that series was pretty distinct, though at Selsey the beds shade into each other. But the subtropical forms do not occur above the Nummulite-zone. Above this the fauna is of a more temperate character, with a partial recurrence of London-Clay forms. The upper beds in the section were far above the Upper Bagshots of the London basin, and he indicated on the diagram the approximate horizon of Mr. Monckton's "Tunnel-hill" fossils. He assured Mr. Irving that they were not thrown back on genera in regard to these, as the species could be determined. He allowed the whole to be one series, and the changes only local, but he believed the land movements to have been considerable. He thought there were no subangular flints in the Pebble-bed at the base of the Barton.

36. NOTES *on some of the* AURIFEROUS TRACTS *of* MYSORE PROVINCE, SOUTHERN INDIA. By GEORGE ATTWOOD, Esq., F.G.S., Assoc. Memb. Inst. C.E., F.C.S., Memb. Amer. Inst. M.E., &c. *With an* APPENDIX by Prof. T. G. BONNEY, D.Sc., LL.D., F.R.S., F.G.S. (Read June 7, 1888.)

[PLATE XV.]

DURING the end of the winter of the year 1886 and a portion of the spring of 1887 I was employed in Southern India inspecting a large area of mineral lands supposed to be auriferous (see Map, fig. 1), and during my travels by train, bullock-carts, and on foot (the latter

Fig. 1.—*Sketch Map showing the position of some of the Auriferous Lands in Mysore Province, Southern India.*



Hornblende-, mica,- and talc-schists containing auriferous quartz-veins.

about 600 mil s), I collected some rock specimens and made notes and sketches of my observations, which I now submit for the consideration of the Society.

My notes are divided into three parts, namely:—

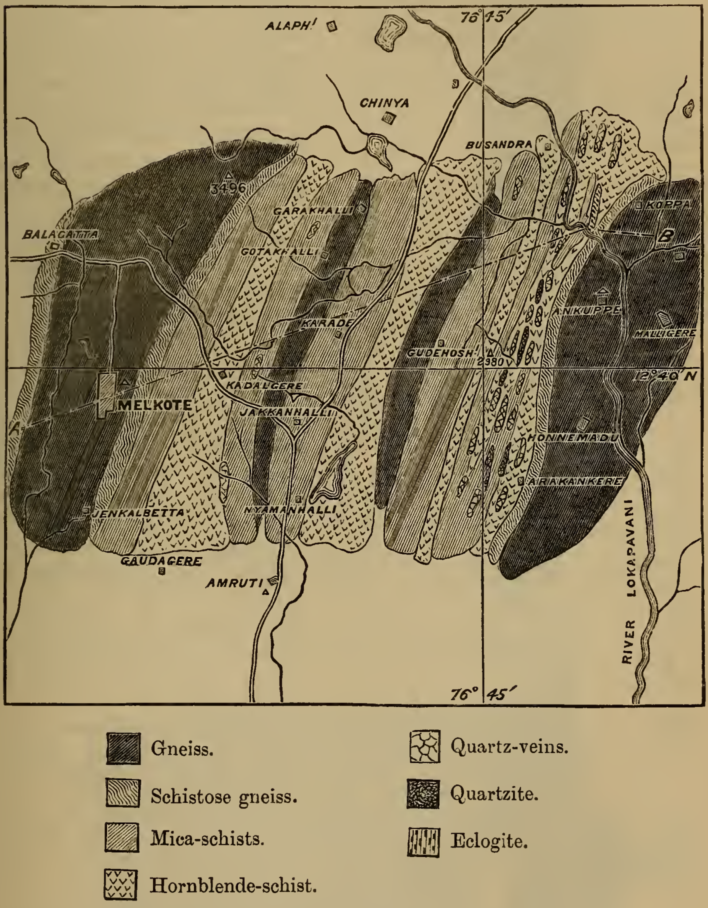
1. The Melkote Area.
2. The Seringapatam Area *.
3. General observations on some of the auriferous tracts of Mysore Province from numerous traverses.

* On the above Areas (Nos. 1 and 2) the author was encamped for about two months.

1. *Melkote Area.*

The first section (see Plan, fig. 2, and Section, fig. 3) which I will describe is in the Hassan District of the Province of Mysore, starting about one mile west of the sacred Hindoo city of Melkote, and ex-

Fig. 2.—*Sketch Plan, extending about 7 miles to the east of Melkote City in the Hassan District of the Mysore Province.*



tending in a north-easterly direction to about half a mile beyond the Lokapavani River.

A gneiss of a highly schistose character was first observed dipping sharply to the west, and in it numerous small bands of flaky mica

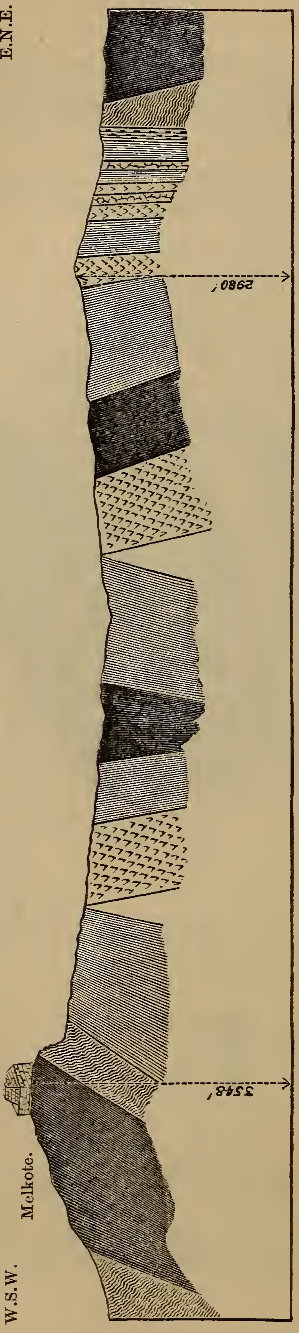


Fig. 3.—*Section of the Melkote Area in the line A–B on Plan, fig. 2.*

For explanation of symbols, see fig. 2.

are found, which, in places, has weathered and decayed, forming a sort of white plastic clay *.

The schistose gneiss is followed by a hard, coarse-grained gneiss, which forms the elevated portions of the Melkote hill- or mountain-range (3550 feet above sea-level at Madras), and has a general strike of north 20° east, dipping at an angle of about 40° to the west.

Large blocks of gneiss, from 10 to 50 feet in length, from 2 to 8 feet in thickness, and from 5 to 20 feet in width, are seen in great numbers on both sides and on the summit of the hill, from which they have become detached in course of time by atmospheric influences and probably by pressure. The ancient temple of Narasimha stands on the summit of the hill, and on the edge of what may be called an escarpment. In places the gneiss has a granitoid appearance; but, owing to the rock in most cases showing foliation, the name of gneiss has been adhered to. Following the gneiss, a band of schistose gneiss comes in, which is replaced by a wide band of mica-schist, dipping at about the same angle as the gneiss. The mica-schist is followed by a band of compact hornblende-schist, dipping the reverse way, at an angle of about 40° to the east, but having the same general strike as the gneiss

* The white clay is called by the natives "náma" and is used by all the Sri Vaishnavas of that region for painting the sectarian mark (Brahman) on their foreheads, and some of it is also sent for the same purpose to Kásí and Benares.

rocks. A band of mica-schists again appears, which gives place to a fine-grained gneiss-rock dipping nearly vertically. Mica-schist dipping to the west is followed by a hard hornblende-schist, which dips to the east, and then fine-grained gneiss accompanied by a broad band of mica-schist comes in, giving place to hornblende-schist, followed by a mixture of narrow bands of mica- and hornblende-schists, quartzites, quartz-veins, a band of eclogite, and some talc- and chloritic schists. The schists are now replaced by schistose gneiss and gneiss similar in some respects to those found at the commencement of the section. The only difference is in the gneiss being much more finely-grained and more regular in its foliation at the east end of the section than at the west.

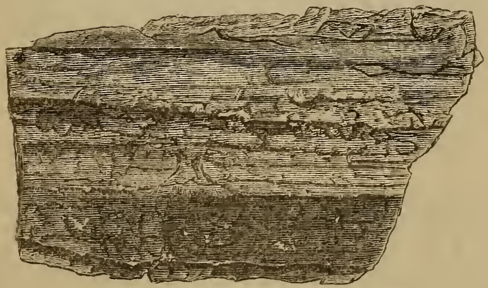
Having briefly named the different rocks met with in the Melkote Area, I will describe in some detail a few of the important ones, referring for the full microscopical description to the Appendix by Prof. Bonney (p. 651).

On the north bank of the Lokapavani River (see Plan, fig. 2) there is a band, some thirty feet in thickness, of a hard, compact, greyish rock, containing numerous reddish-coloured garnets, and with a compact base showing green hornblende. The rock is most difficult to break with the hammer, and the only garnets obtained in a fair state of preservation were those found close to the hornblende-schist which adjoined it. The rock may be called eclogite (Rock-section no. 1, p. 651), and it was found to have a specific gravity of 3·22 and by chemical analysis to contain 59·14 per cent. of silica.

The qualitative analysis showed it to contain only a small quantity of iron as well as of alumina.

The area occupied by the eclogite is limited, so far as the author's observations went, as it could not be found south of the river, and only about one third of a mile to the north of it. Hornblende-schists occur in both wide and narrow bands, and they were examined with considerable care as well as interest on account of the name

Fig. 4.—*Top view of Quartzite, showing Slickensides.*



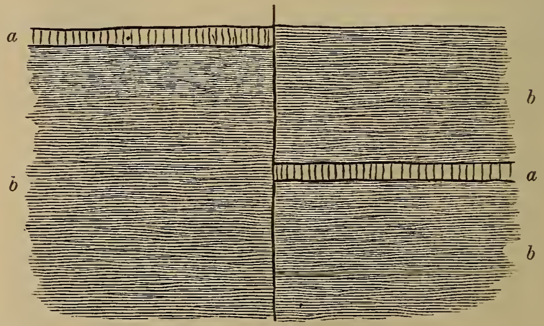
of trap being locally applied to the rocks. The hornblende-schist varies from black to greenish-black and dark grey in colour, very compact (see Rock-sections, nos. 2 and 4, p. 651). The hornblende is green, and the felspar generally plagioclase.

The specific gravity of No. 4 was found to be 3·19, and it contained 49·85 per cent. of silica. The qualitative analysis showed the rock to contain a small quantity of organic matter, a fair percentage of iron-oxides, with a little alumina and a trace of manganese.

Mica-schists having a soft silvery as well as yellowish appearance are abundant in the Melkote Area. The general strike of the mica-schists is about N. 20° E.; but the dip, as will be seen by the section, fig. 3, varies from east to west, and at the east end of the section the dip is nearly vertical; but at the same time the strata are very irregular and much contorted.

Evidences of great crushing-movements are seen by examining the slickensides on the bands of quartzite (fig. 4). The bands of quartzite are narrow, being from 5 to 20 feet thick, running parallel with the schists, and they have also the same dip. Large masses of vein-quartz were also found scored, and with their surfaces showing slickensides. The direction of the crushing-movement appears to be nearly vertical, from the slickensides on the quartzites and quartz *in situ*. However in some parts of the section there are evidences of horizontal as well as lateral movements. In one case in question the lateral throw was found to be about 60 feet (fig. 5).

Fig. 5.—*Plan showing lateral displacement of Quartz-vein.*



a. Quartz-vein. *b.* Schistose rock.

In the mica-schists, especially the soft silvery-looking schist, crushed garnets of different sizes were found, varying from one inch to one tenth of an inch in diameter, and flattened out to a great extent (figs. 6, 7); for instance, a garnet of $\frac{3}{4}$ of an inch in diameter would be only $\frac{3}{8}$ of an inch thick in the centre at its widest part.

Fig. 6.—*Section of Mica-schist, showing flattened Garnets.*

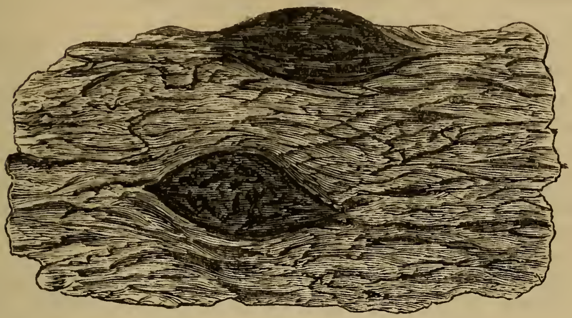


Fig. 7.—*Top view of Mica-schist, showing flattened Garnets.*

To assist in indicating the appearance of the garnets two drawings * (Pl. XV.) were made from the slide (Rock-section no. 3), and the author has also made a chemical analysis of one of the garnets.

	per cent.
Silica	49·50
Iron-protoxide	36·25
Alumina	6·25
Lime	1·43
Magnesia	1·44
Manganese	1·76
Hygroscopic water	0·37
Combined water	3·20
Specific gravity, 3·64.	100·20

From the above analysis, as well as from the microscopic examination, it is an iron-alumina garnet, probably in its original state

* The author is indebted to Mr. Felix Oswald for making the above drawings.

"almandite." The excess of silica in the form of crystalline quartz found by the microscope was confirmed by the chemical analysis.

At the east end of the Melkote Section a very hard, crystalline, gneissic rock is seen, standing, in some places, from 30 to 40 feet above the ground, and above the banks of the Lokapavani River. The rock has a light grey colour, and contains quartz, mica, and felspar (Rock-section no. 5), and has all the appearance of belonging to an ancient series. Small bands of talc- and chloritic schist * are abundant at the east end of the section, as well as small quantities of hæmatite and magnetite. A few pieces of coarse corundum were picked up on the surface.

In traversing the Melkote Area and also most of the schistose bands on the Mysore plateau a deposit is met with which is sometimes found in the nullahs (water-courses) on the side hills on masses of broken quartz (the detritus of ancient alluvial gold washing), and also in excavating below the surface where the ground is more or less soft and covered with alluvium or contains fissures and crevices. The native name for the deposit is "Kunker." The deposit was found to be a calcareous one, generally of a dull and greyish-white colour and of a nodular and botryoidal form.

A piece of the deposit was selected for analysis and afforded the author the following results :—

	Per cent.	Combinations.	
Silica	7·00		
Carbonic acid	40·70		
Lime	48·53	CaO, CO_2	86·66
Magnesia	1·27	MgO, CO_2	2·66
Alumina	0·13		
Iron protoxide	1·38	FeO, CO_2	2·22
Potash	0·13	KO, CO_2	0·19
Soda	0·176	NaO, CO_2	0·30
Chlorine	trace.		
Sulphur	trace.		
Water	0 41		
	99·726		

Specific gravity, 2·81.

It is not unreasonable to suppose that the lime contained in the deposit is derived in a great measure from the hornblende-schists, as the latter contain from 7 to 20 per cent. of lime, whilst the mica-schists are almost devoid of it, and even the gneiss seldom contains more than 2 per cent. of lime.

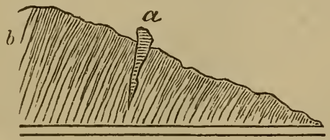
Lime contained in rocks which are exposed to a tropical sun weathers away rapidly. An analysis of a hard diabase rock from South America showed the unaltered rock to contain 9·65 per cent. of lime; a portion of the same stone weathered contained 4·98 per

* The natives call all stones of the magnesian order which have a greasy or soapy feel "Balapam," and they use the stone extensively in the construction of their iron- and steel-furnaces, and also in their dwellings.

cent., and the outer layer of the same stone, which was highly weathered, was found to contain only 2·37 per cent. of lime *.

Quartz-outcrops as well as detached pieces of all sizes are plentiful at the east end of the Section; but a critical examination of most of the outcrops led to disappointment, as the majority of them were found not continuous when examined below the surface. About one outcrop in ten proved, after exploration, to represent a true quartz-vein of strength and permanence. Many of the outcrops are large at the surface, but when intersected 15 to 20 feet below, they are found to diminish in thickness and in some cases disappear altogether (fig. 8).

Fig. 8.—*Section showing downward attenuation of Quartz-vein.*



a. Quartz. *b.* Schistose rock.

Upon an examination of the rocks where the Lokapavani River cuts through the hill, no quartz-veins were visible at the river-level except small stringers; although on the hills above large exposures of quartz, from 4 to 15 feet in width, are observed, which, if continuous, would be intersected by the river. The same feature was observed where precipitous ravines intersected the hill-range.

The schists are bent, contorted, and squeezed to a great extent, and the quartz-veins generally lie between their strata and have the same strike, about north 15° to north 20° east. One quartz-vein of some 4 feet in thickness, lying in hornblende-schist, showed peculiar faulting, having been thrown twice in a height of 30 feet (fig. 9).

Extensive gold-washing (or streaming) has been carried on during ancient times in the ravines and on the hill-sides of these schist-rocks; and from the large heaps of waste stones, consisting chiefly of broken quartz, the workings must at one time have been productive and most likely remunerative.

After washing the alluvium and detritus found in the ravines and nullahs in a miner's cradle (or rocking-machine), also in a Batéa, small grains and nuggets of gold were found in most instances, and they were mixed with particles of magnetite †, hæmatite, fragments of garnet, quartz, &c.

The grains of gold examined under the microscope were found to have a flattened or a somewhat imperfect crystalline form, and when very irregular in shape were found on their surfaces to retain in crevices and hollow places small crystals of magnetite, which appeared to be attached to the gold by a siliceous coating of ferruginous matter. Most of the gold-grains were partially covered with the above

* See Geo. Attwood, "A Contribution to South-American Geology," Quart. Journ. Geol. Soc. vol. xxxv. p. 586 (Nov. 1879).

† Commonly called "black sand" by the miners.

coating, and in that respect they resemble gold nuggets found in the district of Pastora, Venezuela, South America *.

Fig. 9.—*Section showing double faulting of a Quartz-vein.*

a. Quartz. *b.* Hornblende-schist.

The gold has a bright gold-colour with the exception of its outer coating, and appears to be of great purity; by comparing it with other gold grains of a known fineness, it will be about $\frac{940}{1000}$ fine.

From the field-examination, assisted by the microscope and chemical analysis, it is highly probable that the gneissic rocks, as well as the hornblende- and mica-schists, also the quartz-veins which accompany them, belong to the very old series of rocks called Archæan.

2. *Seringapatam Area.*

The second Area is in the neighbourhood of Seringapatam, district of Mysore (see Plan, fig. 10). The line of section takes a south-easterly direction from the 72nd milestone on the Seringapatam and Bangalore road to the north-west side of the village of Arakere.

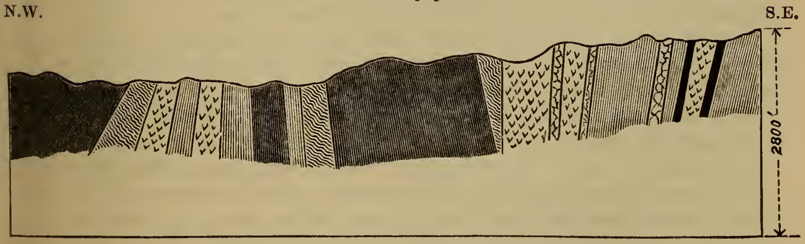
Gneiss-rock, rather coarse-grained, is followed by a schistose gneiss, which gives place to mica- and hornblende-schists. The general strike of the gneiss- and schist-rock is about north 20° east, and the dip various, as seen in the section, fig. 11.

The hornblende- and mica-schists have a sharp dip, nearly vertical, whilst the gneiss-rocks gradually slope away until they recline at an angle of about 35 or 40 degrees.

* See paper "On a Gold Nugget from South America," by Geo. Attwood, Journal of the Chemical Society, July 26, 1879.

Fig. 10.—*Sketch Plan of the Seringapatam Area.*

Fig. 11.—*Section through the Seringapatam Area in the line* A–B *on Plan, fig.* 10.



Gneiss. Hornblende-schist.
Schistose gneiss. Quartz-veins.
Mica-schist. Porphyritic dykes.

At the south-east end of the Section numerous quartz-outcrops are found, varying from 6 inches to 5 or 6 feet in thickness, and the surface is more or less covered with pieces of broken quartz.

Good crystals of schorl were found in some of the detached pieces of quartz. The majority of the outcrops show very hard, white quartz and scarcely any pyritic matter. One promising quartz-vein was opened on and named the Elliot lode. It was proved for about 500 feet in length and over 60 feet in depth; the strike was nearly north and south, and the dip varied four times in 60 feet, and eventually went off to the west, at an angle of about 65 degrees.

Near the surface the wall-rocks of the lode were much decomposed and not well defined; but from 30 to 60 feet below the surface they were found to be hard and compact, well defined, and to consist of mica-schist, highly quartzose. Free gold was found in most of the vein-stone, accompanied by arsenical and iron-pyrites, and occasionally a little copper-pyrites.

The micaceous wall-rocks were found to contain small quantities of gold, whilst the vein-matter itself was rich in gold. The gold was not always found in the quartz itself, but frequently in the cleavages—the latter being more or less filled with iron- and arsenical pyrites. Under the microscope the gold grains obtained from washing the pulverized quartz showed crystalline forms, but not perfect, and the grains were covered in most cases with a coating of siliceous matter, sometimes highly ferruginous, but often almost free from iron-oxides, and frequently quartz-crystals were observed firmly attached to the gold-grains by the siliceous coating, and also in the crevices, or held by claw-like gold protuberances.

In ancient times the Elliot lode was worked extensively, and the old workings were found to extend several hundred feet in length by some 55 feet in depth. With the exception of a few pillars of quartz to keep the walls from closing in, all the vein-stone had been taken away by the ancient miners, and the space filled up with waste rock. The mine was discovered by an accident, as all the workings were filled up close to the surface and that covered with vegetation; a depression on the top of the hill led to work being commenced and to the discovery of the ancient mine.

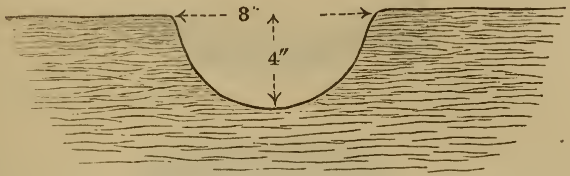
The quartz-rock was very hard in the lower portion of the mine, and the old miners must have had considerable difficulty in breaking it up. Human remains and pieces of charcoal were found in some of the old workings*. It is probable that the old miners used charcoal fires and then water to decompose the rock before breaking it with their tools. Large heaps of waste quartz-fragments were found near the water-springs in the ravines, some hundreds of yards from the mine, and gold was found in most of the ravines by washing the sands and alluvium.

On the hill near the mine, wherever the exposed rock-surfaces were hard and compact, the natives had made holes to act as mortars

* Mr. J. C. Butterfield and Capt. Thos. Kitchen found the bones and charcoal after my departure.

to grind their gold quartz (fig. 12). The holes were about 8 inches in diameter and about 4 inches deep.

Fig. 12.—*Section of Rock-mortar in Schistose Gneiss.*



Some exposed surfaces had as many as twelve or thirteen mortars, while in other places only two or three were observed. The rock in which the mortars were formed is a schistose gneiss (or a gneissic mica-schist), tough and hard. It appears likely that the old miners crushed up the partially calcined quartz in the stone mortars * and then carried the powdered sand to the water below and separated the gold by washing in wooden vessels. The following sketches (figs. 13, 14) represent two forms of gold-washing vessels used by the natives at the present day, and they are not unlikely to be somewhat similar to those employed in past ages, as mechanical appliances in Mysore are not subject to daily improvements as they are in the western countries.

There is no evidence about the after-treatment, but on account of the gold consisting, in many cases, of very fine particles, some means of collecting it beyond washing must have been adopted. Fusion of the concentrated material with lead was probably the method employed in ancient days, and in more recent times amalgamation by means of mercury.

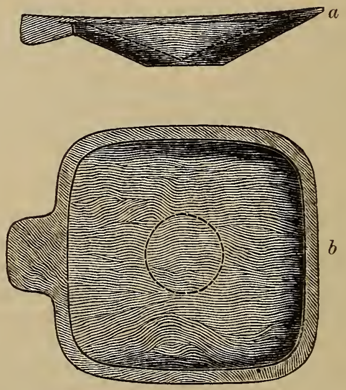
Several other promising quartz-veins were found at the south-east end of the Seringapatam Section, which may lead to further exploration. In the northern part of the section the quartz-veins are composed of hard white quartz showing little or no pyritic matter, and apparently devoid of mineral, whilst at the south-east end a great change in the quartz-veins takes place. Pyrite, chalcopyrite, and arsenical pyrites are found, and the vein-stone contains large quantities of iron-oxides, and is more or less banded or divided by seams, while the quartz is of a finer grain, entirely different from that at the north end of the section.

At the south-east end of the section (see Plan and Section, figs. 10, 11) the schists are much broken up and disturbed by porphyritic dykes. One of the strongest of the dykes was more than 20 feet wide, and had a strike north 80° east (Rock-section no. 8, p. 652). The rock was of a darkish grey colour, very hard and compact, showing felspar-

* Quartz would be very friable if, after being exposed for some time to a charcoal fire, it had water thrown over it whilst heated.

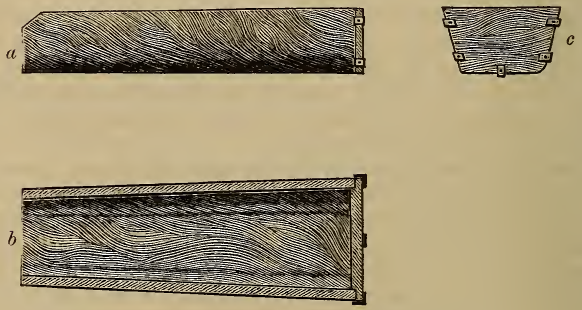
crystals, also pyrite, specific gravity 2·83, and was found to contain silica, 60·71 per cent.

Fig. 13.—*Sketches of a Halagay or Gold-washing dish used by Julgars (Gold-washers) in the Shimoga District, Mysore Province.* (Scale $\frac{1}{9}$ nat. size.)



a. From the side; *b*, from above.

Fig. 14.—*Sketches of Dhone or Sluice-box used by Gold-washers in the Shimoga District.* (Scale $\frac{1}{12}$ nat. size.)



a. From the side; *b*, from above; *c*, end view.

Another porphyritic dyke (see Rock-section no. 6, p. 652) showed considerable signs of weathering; the colour was a light pink, the strike nearly north and south. The specific gravity was found to be 2·83, the same as that of its harder-looking brother. A specimen taken from another porphyrite, having a strike nearly east and west, was found to have a specific gravity of 2·84, and to have a dark-grey base, with the felspar-crystals chiefly pink and glassy.

Another porphyrite (see Rock-section no. 9) had a dark-grey colour, and was very compact and difficult to break, resembling in a great measure Rock-section no. 8.

The porphyritic dykes are of recent origin and most likely of Tertiary age, whilst the gneiss and the mica- and hornblende-schists belong to the older series called Archæan.

At the south-east end of the section a small granitic dyke, having a strike about north 30° east, intersects the Elliot lode diagonally. The dyke is about 10 feet thick, and consists of a coarse-grained granite, with fresh-looking quartz-crystals (in places an inch square), light, pearly, almost transparent mica, in thin folia, and large felspar-crystals of a dark cream-colour. The granitic dyke cuts clean through the Elliot lode, but only throws the lode for a few feet, so far as the underground explorations went. The dyke will therefore be of more recent origin than the porphyrites (and probably Upper Tertiary). Some three miles to the south-east of the above, Mr. Walter Marsh also observed some large exposures of a coarse-grained granite, somewhat similar in structure.

3. *General Observations.*

In the Plan, fig. 1, there will be seen three districts marked as hornblende-, mica-, and calc-schists, containing quartz-veins, which have been visited by the author.

On the west of the plan a large area of land extending from the town of Banavar to the south-east of Honsur Town, a distance of some 45 miles, is marked as being composed of the schistose rocks. Starting from Banavar and travelling south towards Honsur, the schist-band is almost continuous, and on the east and west sides are found the gneiss rocks.

Extensive old gold-mine workings are met with at intervals nearly all the way, although at the time of my visit no active work was being carried forward on any of the mines.

Mr. Bruce Foote, F.G.S., of the Indian Geological Survey, who has lately visited the above district, and has issued a Report on the same to the Mysore government, calls the schistose rock-series "Dharwar Rock," and says: "Two years ago I gave the name of the Dharwar System, from the fact that the rocks forming it occur very largely in the Dharwar country, and that there I first recognized the necessity of separating them from the great gneissic system with which they had till then been grouped" *.

To the east of the Banavar and Honsur schist-bands another band occurs, which has been described at some length in the previous sections, as Messrs. Foote, Lavelle, and Marsh had not examined it fully at the time of my visit.

About 45 miles to the east of the City of Bangalore another schistose series occurs in what is called the Kolar district. In the above series are found some of the best gold-mines in Mysore, viz. Mysore, Nine Reefs, Nundydroog, Gold Fields of Mysore, &c., &c., some being worked and many others still lying idle.

During numerous traverses no quartz-veins carrying gold were found in the gneiss-rocks.

* See Selections from the Records of the Mysore Government, 1887: "Report on Auriferous Tracts in Mysore."

In prospecting for gold in Southern India one feature of especial interest was observed, that is, the general absence of alluvial deposits rich in gold; this and the absence of ancient river-bed gravel containing gold make it evident, after inspecting the auriferous lands of other countries, that the natives have years ago extracted the metal, and they have also tested with care the various outcrops of quartz in their search for gold. The ancients were by no means inferior miners, to judge from the author's experience, as he never found gold in a single place or rock where the old miners had not left indications to show that they had worked before, although several hundred tests were made.

Therefore where the ancient workings now exist will be the most likely places to find gold in paying quantities; and that it will be found by searching, and that the gold-mining industry can and will be carried on profitably, the author has no doubt. The quartz-veins lying in the schists, which are naturally of irregular form, bent and twisted, will require, however, the services of skilled engineers and miners to follow them.

About 10 miles to the east of Gubbi (40 miles east of Tiptur, see Map, fig. 1), in the centre of a large gneissose area, a rock was selected for microscopic examination (see Rock-section no. 10). The rock was fine-grained, with a pink tinge, and consisted of quartz, felspar, and mica, and *in situ* showed distinct foliation and may be called a gneiss. Prof. Bonney remarks that its structure "recalls that of the Archæan gneisses rather than of the normal granites." The author has been much struck with the paucity of granite compared with the immense tracts of gneiss which are found in Southern India; and many rocks called locally granite, upon examination have been found to be undoubtedly gneiss.

A general examination of the strata on the Mysore plateau shows that immense pressure has broken up the gneissose rocks, and also compressed the mica- and hornblende-schists; and it is not unlikely that the above disturbance and breaking-up of the gneissose beds was caused by the gradual rise of the eastern and western ghats, which would create great pressure on the strata forming the Mysore plateau which lies between them.

The Mysore plateau shows evidences of having been subjected to extensive denudation, from the absence of the later formations and the exposures of gneissose and schistose rocks, and from many masses of gneissose rocks (in some cases solitary) standing above the plain at a height of from two to eight hundred feet; also the hardest of the hornblende- and mica-schists often remain in the form of small hills or mountain-ranges above the level of the plain.

Having now come to the end of my notes, I shall conclude with an acknowledgment of the great assistance I have derived in my work from Prof. Bonney's microscopic researches; and I may say, further, that Prof. Bonney, without having been on the ground or seen the results of the chemical analyses or the large collection of rocks brought home, has, with the microscope alone, read the whole story just as well

as if he had been over the ground himself and had had the benefit of the analyses.

Note on Specimens *from* Mysore, *collected by* G. Attwood, Esq., F.G.S. By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.

1. Rock consisting of reddish garnets, very irregular in their outline, in a greenish-grey crystalline matrix, with brown weathering. Apparently a variety of eclogite. *Microsc.*: consists of garnet, quartz, felspar, hornblende, iron-oxide, rutile (?), and a few grains of a honey-yellow mineral. The garnet rarely shows a crystalline form; often it encloses grains of other minerals, chiefly quartz; sometimes it forms with them a kind of granular aggregate. The felspar is to a great extent replaced by secondary products, but some small grains of plagioclase are well preserved. One of the larger (rather decomposed) grains encloses quartz granules. The hornblende is green, sometimes rather dark, showing very characteristic dichroism and cleavage. The yellow mineral mentioned above is not abundant, generally granular in form, but in one case prismatic; here extinction seems to take place at a small angle with the larger edge. The dichroism is not strong, and there is moderate chromatic polarization. It may be a variety of epidote; but I am uncertain. From the general structure of the rock, it appears to me to have formerly undergone mechanical disturbance, but so long since that there has been a practical recrystallization of constituents, *i. e.* very few distinct indications of crushing now remain. The rock rather reminds me of a variety of eclogite which I collected at Wahnapitae, on the Canada Pacific railway.

2. The rock in the hand-specimen appears to be a slightly foliated, dark, hornblende-schist, containing some very small garnets. Under the microscope it is seen to consist of green hornblende, quartz, plagioclase felspar, garnets (very irregular in outline), hæmatite (?), and a little biotite. The rock is now a hornblende-schist, but it is by no means improbable that it may have once been an augitic rock of igneous origin, modified by pressure and consequent mineral changes.

3. A flattened garnet in a fine-grained quartzose mica-schist. Under the microscope more or less granular garnet is curiously associated with clear, crystalline quartz and a little white mica, in a way almost impossible to describe, but which may be understood from the illustration. Parts of the slide are slightly stained with limonite. I have no doubt this is from a garnet-bearing mica-schist, which has been subsequently crushed and has then to a certain extent recrystallized.

4. A rather compact hornblende-schist. Under the microscope it bears a general resemblance to No. 3, except that there is rather more hornblende, less quartz, and the species of the felspar is less determinate. The same remark applies to the following specimen:—

5. A light-grey, crystalline, gneissoid rock. Under the microscope it consists of quartz, felspar slightly decomposed, biotite (sometimes

rather altered), with a little white-mica, epidote, sphene, iron-oxide, and apatite. The rock appears to have suffered from mechanical disturbances, probably at no recent epoch; but its anterior structure is, I think, commonly well preserved and much resembles that which usually occurs in the old gneisses, to some of which this rock has a macroscopic resemblance.

6. A pinkish, somewhat porphyritic felstone. Microscopic examination shows it to be a porphyrite, with devitrified ground-mass, the larger felspar-crystals (plagioclase) being rather decomposed. There is nothing noteworthy in the slide.

7. A rather similar slightly deeper-coloured rock. Also a porphyrite; nothing noteworthy.

8. A darker more mottled felstone. Also a porphyrite, but differing from the others in containing a fair amount of a greenish mineral. This, under the microscope, is seen to occur in irregular patches, sometimes adumbrating the form of a pyroxenic or micaceous mineral. That which dominates in these patches is generally a strongly dichroic, olive-green mineral in small folia, probably a chlorite, associated with viridite and sometimes calcite. Probably all these are of secondary origin, indicating the former presence of a ferro-magnesian silicate.

9. A rock bearing some resemblance to the last named, but with much pyrite in the hand-specimen. This is less abundant in the slide, which shows the rock to be also a porphyrite, bearing some general resemblance to the last described, except that the green patches are yet more indefinite in outline and more indeterminate in structure. So far as I can ascertain, they are largely composed of granules of an impure epidote and belonites of a greenish mineral, probably hornblende.

10. A moderately fine-grained, pinkish, granitoid rock: the microscope shows it to be composed of quartz, felspar (microcline, orthoclase and oligoclase?), hornblende, biotite, and apatite, with probably one or two small zircons. There are some slight indications of mechanical disturbance, but none of marked crushing, and the structure of the rock recalls that of the Archæan gneisses rather than of the normal granites.

So far as I can form an opinion from the slides and specimens alone, I should say that Nos. 1, 3, 5, 10, with possibly 2 and 4, belong to an ancient series of rocks, which, even if wholly or in part of igneous origin, assumed their present mineral structure and condition at an epoch remote from the present. Some of them resemble rocks known to be Archæan, and they do not resemble (so far as my experience goes) any which are indubitably Post-Archæan: 6, 7, 8, 9 are certainly igneous and of more recent date, though I should doubt if they were not at least of early Tertiary age.

EXPLANATION OF PLATE XV.

Fig. 1. Section of flattened garnet, showing mica-schist on right-hand side. ×40.

2. Section of flattened garnet. ×40.

Felix Oswald del.

Mintern Bros Chromo lith.

SECTIONS OF FLATTENED GARNET. MYSORE.

Discussion.

The President remarked that on behalf of the Geological Society, as well as of Indian geologists, he would express his pleasure at hearing a paper on India by an independent observer. He referred to Mr. Foote's view that the auriferous rocks of Mysore differed from the main gneissic group of Southern India. There was no doubt as to the great age of the rocks. The analyses given by Mr. Attwood would be useful. He questioned the Author's use of the word "kunker," which meant a small stone and, in the plural, gravel. As lime is commonly made from calcareous nodules in India, the term "kunker" has gradually but erroneously come into use amongst Europeans for calcareous rocks. There was great interest with regard to the asserted Tertiary age of the porphyrite-dykes, when viewed in connexion with the great volcanic outbursts of the Deccan; but he would like to have some much more positive evidence as regards the age of these intrusions. With regard to the elevation of the Ghats, he doubted its connexion with pressure-effects. The eastern Ghats are more or less imaginary, and the western Ghats simply a ridge left by denudation.

Mr. W. P. Blake observed that the schistose rocks closely resembled the auriferous Archæan rocks of the United States, especially those in Dakota.

The Author, in reply, stated that Prof. Bonney agreed that the porphyritic rocks were much more modern than the Archæan schists through which they broke. He had adopted the word "kunker" as he found it used in the particular area described and generally applied to the calcareous deposits.

37. *The* Stockdale Shales.

By J. E. Marr, M.A., F.G.S., Fellow of St. John's Coll. Camb., and H. A. Nicholson, M.D., D.Sc., F.G.S., Regius Professor of Natural History in the University of Aberdeen. (Read May 9, 1888.)

[Plate XVI.]

§ I. Introduction.

We propose, in a series of papers, to supplement the observations which have been previously published upon the divisions, organic remains, and subdivisions of the Lower Palæozoic Rocks of the Lake-district and adjoining areas. In the investigation of the geological structure of any such complicated region as the Lake-district, the first step necessarily consists in the determination of those rock-divisions which are developed in the area in question to an extent which renders them capable of representation on the one-inch map of the Ordnance Survey. When the first step has been satisfactorily accomplished, the *general* structure of the region may be said to be determined; but there may, nevertheless, remain many points of great geological interest and importance which still require solution. Thus, it is now generally recognized that in any region a set of deposits may have been formed so slowly that a thickness of only a few feet of such may mark a lapse of time represented elsewhere by many hundreds of feet of sediment. In such cases a more minute subdivision of the strata than can be represented upon an ordinary geological map becomes necessary, and it is also essential to enter into a detailed examination and comparison of the organic remains of the different beds. By this method of investigation very important results have already been obtained in other regions, and we see no reason to doubt that the application of the same method to the study of the Palæozoic Rocks of the Lake-district will result in the eventual filling up of many of the gaps which at present exist in the geological history of this area.

Under ordinary circumstances it would, no doubt, have been more convenient to commence our investigations with an examination of the oldest rocks of the district, and in selecting the Stockdale Shales as a starting-point we were influenced by several considerations. In the first place, the Stockdale Shales form a well-marked series, readily separable from the rocks lying below and above them, while they present at the same time considerable variations in the character of their sediments and included fossils.

Secondly, the outcrop along their whole range in the Lake-district proper has been marked in the published maps of the Geological Survey. Thirdly, the equivalent and similar rocks in other areas have been described with a minuteness which is wanting in the case of the other series of the Lower Palæozoic rocks of this region; we are therefore likely, by selecting this series, to test the value of these minute subdivisions for purposes of comparison.

The general features of the district have been so frequently described, and its structure is so universally known, that it is sufficient to remark here that the Stockdale Shales occur on the south side of a great anticlinal, and that they do not appear on the north, as the newer rocks of the northern limb are concealed by the unconformable overlap of the Upper Palæozoic rocks. In the southern limb the beds first appear on the eastern side of the Lake-district proper, a few miles to the west of Shap Wells, after which they are traceable with a general E.N.E.–W.S.W. strike over the valleys of Long Sleddale, Kentmere, and Troutbeck, and across the head of Windermere to Coniston Waterhead. In this region they dip, usually at a high angle, to the S.S.E., and their course is interrupted by several large north and south faults, the position of which will be seen by reference to the maps of the Geological Survey. (We would here notice that we do not give a map of the outcrop of the beds, as one on a smaller scale than that of the published geological maps would be insufficient for our purpose.) On the western side of Coniston Lake the strike of the beds changes, trending generally in a N.E.–S.W. direction, and continues thus to Broughton Mills, to the south of which we have seen no trace of the Stockdale Shales, on the western side of the Duddon estuary. On the eastern side of that estuary the beds are brought to the surface by a great anticlinal fold, and appear in the neighbourhood of Dalton-in-Furness, where the exposures are poor. In addition to this the Stockdale Shales are also seen in two areas lying on the eastern margin of the Lake-district,—first in the exposure of Lower Palæozoic which is found between the Pennine fault of the Cross-Fell chain and the New Red Sandstones of the Eden valley, where the beds crop out in the neighbourhood of the village of Knock, in the course of Swindale Beck and its tributary, Rundale Beck. Secondly, in the anticlinal which runs along the Rawthey valley, in the neighbourhood of Sedbergh, where the shales are seen in the bed of the river at Rawthey Bridge, and in several of the tributary streams, as Hebblethwaite Gill, Cross Haw Beck, and Taith's Gill, on the south side of the Rawthey, and in the stream which runs from Spengill Head, on the north side. Representatives of these beds also occur in the neighbourhood of Ingleton in Austwick Beck, and in Teesdale possible equivalents have been described by Messrs. Gunn and Clough.

In most places, owing to the small thickness of the series and the high angle of dip, the outcrop is very narrow. This outcrop is nearly at right angles to the direction of the principal streams, so that there are frequent opportunities of seeing the relations of the

Stockdale Shales to the beds above and below. Against this advantage must be placed the paucity of sections, but especially the constant occurrence of a strike-fault, which frequently cuts out a great part of the series, and, as we shall eventually show, in every case causes a portion to be missing. Nevertheless the number of exposures is sufficient to allow us to piece together the whole of the succession, save, possibly, at one point only, where we shall give reasons for believing that if any portion of the deposit is now entirely unseen in this district, it is only a very insignificant one.

We would record our debt of gratitude to Professor Lapworth for invaluable assistance, and to Professor Hughes for information about the rocks of the Sedbergh district.

§ II. Notice of Previous Writings.

The first attempt at a subdivision of the rocks of the Lake-district was made by Mr. Jonathan Otley, whose paper appeared originally in the 'Lonsdale Magazine,' vol. i. p. 433, and subsequently in the 'Philosophical Magazine' for 1820 (Phil. Mag. vol. lvi. p. 257). Mr. Otley adopted that threefold subdivision of the slates of this area which was afterward supported by Professor Sedgwick, and which forms the basis of all subsequent classifications. The well-known narrow band of Coniston Limestone was shown to form a natural separation between the slates of the second and third divisions. This Coniston-Limestone band was proved by Sedgwick to contain a fauna similar to that of his Bala rocks of North Wales, whilst the true slates of the third division undoubtedly contained, in their higher portions, fossils similar to those of the typical Silurian rocks of the area explored by Sir Roderick Murchison. At this time the beds which form the subject of this communication were not separated off from that division of the Upper Slates to which Prof. Sedgwick, in 1845, applied the term "Coniston Flags;" so that all that was written previous to the period when that separation was effected, concerning the relationship of the Coniston Flags to the Coniston-Limestone series, applies also to the relationship between the latter and the Stockdale Shales. In Professor Sedgwick's writings we find the Coniston Flagstones or Flags at one time connected with the Coniston-Limestone series, at another separated from these and united to the rocks above them; and he finally adopts this arrangement, and, to quote the words used in his 'Letters' to Wordsworth, places the Coniston Flags "at the base of the Upper Silurian series of the Lake District."

The beds now known as the Stockdale Shales were originally distinguished by Professors Harkness and Nicholson in the year 1868, in a paper "On the Coniston Group" (Quart. Journ. Geol. Soc. vol. xxiv. p. 296).

These authors describe the lower portion of the Stockdale Shales under the name of "Graptolitiferous Mudstones," and give a list of fossils found in these beds at Skelgill and in Long Sleddale. They refer to the beds now included in the upper part of the Stockdale Shales under the term "Grey Grits." Both these sets of deposits are included as a subdivision of the Coniston Flags, and the Mudstones are considered to rest conformably upon the Coniston Limestone, and are referred by the authors to the Bala.

We append a brief abstract of the views expressed in various papers which have appeared subsequently to the one above referred to, and which treat specially of the Stockdale Shales.

1868. "On the Graptolites of the Coniston Flags," by H. A. Nicholson (Q. J. G. S. vol. xxiv. p. 521).

Alters the term "Graptolitiferous Mudstones" to "Graptolitic Mudstones," and describes many Graptolites from these beds.

1868. 'An Essay on the Geology of Cumberland and Westmoreland,' by H. A. Nicholson.

The Stockdale Shales included as a member of the Coniston Flags. Fossil lists given. Age considered as between that of Bala Limestone and that of Lower Llandovery.

1872. "Migrations of the Graptolites," by H. A. Nicholson (Q. J. G. S. vol. xxviii. p. 217).

Gives list of species from the "Graptolitic Mudstones."

1872. "Memoirs of the Geological Survey." Explanation of Quarter Sheet 98, N.E., by Messrs. W. T. Aveline and T. McK. Hughes.

First use the term "Stockdale Shales," and separate them from the Coniston Flags: divide them into a lower portion, "Graptolitic Mudstones," and an upper, "Pale Slates." Give the lithological characters of each, and a list of fossils from the "Graptolitic Mudstones" of Holbeck Gill (= Skelgill), near Ambleside. Refer them to Upper Silurian.

1872. "On the Silurian Rocks of the English Lake District," by Prof. H. A. Nicholson (Proc. Geol. Assoc. 1872, p. 105).

Discusses age of "Graptolitic Mudstones"; abandons view that they belong to Coniston Flags, and refers them to Lower Silurian, and considers them conformable with beds above and below.

1872. "On the Continuity and Breaks between the various divisions of the Silurian Strata of the Lake District," by W. T. Aveline (Geol. Mag. vol. ix. p. 441).

Considers slight unconformity to exist between Coniston Limestone and Stockdale Shales: refers latter to Upper Silurian, and correlates them with Tarannon Shales of North Wales.

1875. "On the central group of the Silurian series of the North of England," by H. A. Nicholson and C. Lapworth (Rep. Brit. Assoc. 1875, p. 78).

Use the term "Coniston Mudstone series" for the Stockdale Shales, and suggest the term "Skelgill Beds" for the "Graptolitic Mudstones," and that of "Knock Beds" for the Pale Slates, and correlate the entire "Coniston Mudstone Series" with the Lower and Upper Llandovery and Tarannon Shales of North Wales.

1876. "Absence of Llandovery Rocks in the Lake District," by W. T. Aveline (Geol. Mag. dec. ii. vol. iii. p. 282).

Again correlates Stockdale Shales with Tarannon Shales.

1876. "Llandovery Rocks in the Lake District," by H. Hicks (Geol. Mag. dec. ii. vol. iii. pp. 335 and 429).

Considers Stockdale Shales of Llandovery age.

1876. "On the Vertical Range of the Graptolitic types in Sweden," by G. Linnarsson (Geol. Mag. dec. ii. vol. iii. p. 241).

Correlates Stockdale Shales with Upper Graptolitic Schists of that country.

1876. "Llandovery Rocks in the Lake District," by C. Lapworth (Geol. Mag. dec. ii. vol. iii. p. 447).

Assigns Skelgill beds to Lower Llandovery.

1877. "On the Strata and their Fossil contents between the Borrowdale Series of the North of England and the Coniston Flags," by Profs. R. Harkness and H. A. Nicholson" (Q. J. G. S. xxxiii. p. 461).

Describe "Graptolitic Mudstones" or "Skelgill Beds," and give lists of Graptolites and of more highly organized fossils from these beds; correlate them with highest beds of Bala series or with lower portion of Llandovery group.

Describe "Knock Beds," and incline to regard them as base of (Upper) Silurian.

1878. "Discovery of Silurian Beds in Teesdale," by Messrs. Gunn and Clough (Q. J. G. S. xxxiv. p. 27).

Describe beds at Cronkley Pencil Mill resembling Pale Slates.

1878. "The Moffat Series," by C. Lapworth (Q. J. G. S. xxxiv. p. 240).

Correlates Skelgill beds with Birkhill Shales, which he refers to Lower Llandovery.

1878. "On some well-defined Life-zones in the . . . Lake District," by J. E. Marr (Q. J. G. S. xxxiv. p. 871).

Refers Skelgill beds to May Hill, and supposes unconformity between them and Ashgill Shales.

1879. "On the Geological Distribution of the Rhabdophora," by C. Lapworth (Ann. & Mag. Nat. Hist. ser. 5, vol. iii.).

Assigns a Llandovery May-Hill age to the Skelgill beds; divides them into a lower (*tenuis*) and upper (*argenteus*) zone, and gives lists of fossils from each.

Besides the above, many papers have appeared which contain incidental references to the Stockdale Shales, or which describe fossils contained therein. These will be alluded to in the body of the paper.

§ III. Description of the Typical Sections of Skelgill and Stockdale.

The most convenient course for us to adopt in describing the succession of the different subdivisions of the Stockdale Shales is to commence with an account of the typical sections of the two stages of the series, and afterwards to supplement this by an account of the resemblances and variations exhibited in the other sections.

The typical section of the beds of the lower stage is that displayed in the course of the stream near Ambleside, which is termed Holbeck Gill on the maps of the Ordnance Survey, but which has been so often alluded to in geological writings under the name of Skelgill (derived from the farm of High Skelgill, situated near its banks), that it would be highly inconvenient to adopt any other name. It is on account of the strong development of the beds of this stage, in this locality, that one of us, in conjunction with Professor Lapworth, has proposed for the beds the title of "Skelgill Beds," a term which we propose to employ here instead of the more ancient term "Graptolitic Mudstones," because there are other Graptolitic beds in the district, and the term "Mudstone" is hardly so applicable to the true Shales in which the Graptolites are found, as to the bluish-grey clayey beds, devoid of stratification, which occur between the different bands of Graptolitic Shale, and which do not contain Graptolites.

The upper stage of the series is well seen in the course of Stockdale Beck, which also contains a fair development of the lower stage, so that the name of this beck is particularly applicable to the whole series. In a tributary of Stockdale, which is called Browgill on the maps of the Ordnance Survey, there is an excellent development of fossiliferous beds of the upper stage, and those beds of this stage which are not seen here are seen in the larger beck close by; so we propose to adopt the section at Browgill, supplemented by that in the adjoining Stockdale stream, as our type section, and, for the sake of uniformity, as well as in order to have the type sections along the main line of outcrop of the Stockdale Shales, to substitute the term "Browgill Beds" for "Knock Beds" in describing this upper stage of the series. We do this with the consent of Professor Lapworth, who, with one of us, originally proposed the term "Knock Beds" for this series. Our classification, then, is as follows:—

Stockdale-Shale series.	Upper	Browgill stage.
	Lower	Skelgill stage.

A. *The Skelgill Beds of Skelgill.*

The stream of Skelgill Beck well deserves to be considered as furnishing the type section of the lower stage of the Stockdale Shales, not only on account of the magnificent section exposed along its banks, but also on account of its accessibility, and the unrivalled views of the Lake-district hills as seen from its neighbourhood. The stream rises in the moorland immediately to the east of Wansfell Pike, and enters Windermere a few yards south of the Low Wood Hotel, after a course of about two miles. For the first half-mile it runs in a shallow valley through volcanic rocks and the beds of the Coniston-Limestone series, and then reaches a bridge over which passes a cart-track from Troutbeck village, known as Hundreds Road. This bridge we may speak of as the Upper Bridge. At this point the stream, which has been flowing due south, assumes a south-westerly direction, and enters a ravine which is in a straight line with a shallow depression marking the position of the outcrop of the Skelgill Beds, which are concealed for some distance to the north-east of this point. The beds are seen in the stream immediately after turning the corner below the bridge, and a more or less continuous section of the several members of the stage is traceable along the left bank for about half a mile down the stream to a point about 10 chains east of the farm of High Skelgill. The right bank is mainly composed of Ashgill Shales, with a few exceptions to be noted subsequently. At the point near High Skelgill the stream once more turns due south, and soon flows over the beds of the Browgill stage, so that at present our description will be limited to the exposures in that part of the stream which runs between the Upper Bridge and the point at which the stream again turns due south near High Skelgill Farm. Along this portion the direction of the stream is parallel with that of the strike of the beds, which is here nearly due N.E.–S.W., and the beds are dipping at a comparatively low angle, averaging about 35° to the S.E.

Below the Upper Bridge the stream runs for a distance of about 15 chains through a ravine cut in the moorland, and we may speak of this as the "moorland" portion of the gill. From this point until a wall is reached, about 5 chains east of the spot near the farm where the stream once more turns due south, it flows through a wooded ravine, and this we shall refer to as the "wooded" portion of the gill. About 5 chains below the point where the stream enters this wood is a foot-bridge, over which a footpath, slanting obliquely up the steep left bank of the stream, is carried; this is the Lower Bridge. Some 15 chains further down the first important tributary from the north enters the main stream, and a few yards further down a second tributary from the north joins the main beck at the point where the latter quits the wood. The remaining few chains over which the stream preserves its S.W. direction are on swampy ground, with no sections; and at the point where the flow changes to the southward, a third tributary enters the main stream from the north.

After these preliminary remarks, we may proceed to describe the section in greater detail.

The most continuous vertical exposure which is readily accessible is seen at the Lower Bridge, which one of us, in a paper printed in the Society's Journal for 1878, has spoken of as the Lower Footbridge. The section there inserted is, in the main, correct, but some of the thicknesses have to be modified as a result of numerous subsequent measurements (fig. 1).

Aa. Lower Skelgill Beds.

(1) A few yards below the Lower Bridge a cliff, some 10 feet in height, is seen, standing immediately above the stream on the left bank. Here the stream is seen to be flowing over the highest beds of the Ashgill Shales, containing the characteristic Brachiopods of the deposit, and having a discontinuous line of calcareous nodules

at the summit. Immediately above this is a very tough bed, one foot thick, consisting of an impure, compact limestone, containing flocculent dark-grey patches, giving it a mottled appearance, and holding a considerable quantity of iron-pyrites. There are no subsidiary planes of deposition in this bed, which breaks with extreme

Fig. 1.—*Section across Skelgill.* (Scale 15 feet to 1 inch.)

difficulty, with a somewhat hackly fracture. At this point we have obtained no fossils, but a few yards above the Lower Bridge, at a spot presently to be described, there are a fair number of fossils, which are obtainable with difficulty, the most abundant being a new species of *Atrypa*, on which account we propose to term this bed the Zone of *Atrypa flexuosa*.

(2) Immediately over this hard limestone band are bluish-black, rather flaggy and somewhat calcareous shales, resting with perfect

conformity upon the limestone. One foot above the limestone is a permanent divisional plane, which is markedly slickensided, and along which some movement has taken place. A little more than a foot above this is another prominent, slickensided, divisional plane, against which the laminæ are seen to die out at the S.W. end of the cliff, whilst at the N.E. end a little fault-breccia occurs, showing that there has certainly been some disturbance here. About one foot above this is a marked, pale-green band, and above this six feet six inches of blackish shales occur, passing to the top of the cliff, where a great mass of fault-breccia marks the position of a considerable strike-fault. The Graptolites preserved in these black shales, which here have a thickness of at least 9 feet 9 inches, are difficult to extract from this cliff; but fortunately at this point the shales are also developed on the right bank of the stream, where the black calcareous shales are seen dipping immediately at those on the cliff, and an examination of the rocks in the bed of the stream forbids the existence of any fault. The identity of the beds is proved by the fact that the Graptolites, which are beautifully preserved in the shales seen in an excavation in the bank, a few feet above the stream, are identical with those obtainable with some difficulty in the shales of the cliff. These species are:—

Monograptus leptotheca, *Lapw.*
—— Sandersoni, *Lapw.*
—— revolutus, *Kurck.*
—— tenuis, *Portl.*
—— attenuatus, *Hopk.*
Dimorphograptus confertus, *Nich.*
—— elongatus, *Lapw.*
Diplograptus sinuatus, *Nich.*
—— longissimus, *Kurck.*
—— vesiculosus, *Nich.*
Climacograptus normalis, *Lapw.*
—— minutus, *Carr.*

Of these forms the most noticeable are the remarkable *Dimorphograptus confertus*, Nich., which occurs in swarms, especially along one bedding-plane, where it is found to the almost complete exclusion of any other species, and *Monograptus revolutus*, which is also very abundant. One example of *Dimorphograptus elongatus* occurred.

We shall speak of this zone as the *Dimorphograptus-confertus Zone*; and this and the underlying zone, we regard as constituting the *Lower Skelgill Beds*.

It will be convenient to consider the development of these beds in other parts of the gill before proceeding to describe the higher subdivisions.

Although the Lower Bridge crosses the gill in the wooded portion, nevertheless the wood mainly occupies the left bank of the stream until we attain a point a few yards below the Lower Bridge, where the right bank also becomes wooded, to the south-west of a wall which runs down this bank to the top of the small cliff overhanging the stream. Here the fault described as occurring at the top of the small cliff in which the beds of the *Dimorphograptus-confertus Zone* are developed has come down to the stream, and the Ashgill Shales are immediately succeeded by higher beds, which are much crushed at the base, the Lower Skelgill Beds being entirely faulted out; but some distance below this wall the *Dimorphograptus-confertus* Beds are again exposed on the right bank of the stream, which here forms a dip-slope from which the shales of this zone may be broken off in slabs of considerable size. Most of the fossils obtained at the Lower Bridge are found here, and where the shales are unweathered the Graptolites have been replaced by white calcite, though in the weathered state they occur as yellow-brown impressions, as is the case for the most part with those found at the Lower Bridge. On the opposite side of the stream at this point the section is very similar to that at the Lower Bridge on the same bank, though there is a smaller thickness of shales of the *Dimorphograptus-confertus* Zone below the fault. The portion seen is disturbed, a slight disturbance having probably crushed out a portion of the *Atrypa-flexuosa* Limestone, which is here only three inches thick. Above this we find ten inches of calcareous bluish flags, with the usual Graptolites of the *Dimorphograptus*-zone, above which is a calcareous pyritous band, apparently in the position of the slickensided divisional plane noticed in the section at the Lower Bridge. This band contains badly preserved Graptolites along with numereous Ostracods and small Brachiopods, whose identification it would be too hazardous to attempt. Isolated plates of a species of *Turrilepas* are also tolerably abundant.

Lower down the strike-fault is more pronounced, and where there are exposures the Lower Skelgill Beds are again entirely cut out, until we reach the second tributary from the north, on the west bank of which is seen the *Atrypa-flexuosa* band halfway up in a cliff, separating the *Dimorphograptus-confertus* Beds above, with the usual fossils, from the Ashgill Shales below.

Returning now to the Lower Bridge, and tracing the Lower Skelgill Beds up stream, we find the *Atrypa-flexuosa* Limestone resting on the Ashgill Shales immediately above the bridge; but the beds above it are here covered with talus. A few yards higher up the stream a dip-fault with a downthrow of a few feet to the north runs in a general E.-W. direction, bringing the Ashgill Shales against the *Dimorphograptus-confertus* Beds on the right bank of the stream, and the strike-fault, which has here reached the bed of the stream, has caused the disappearance of a much greater thickness of beds on its north side, so that at the foot of a high precipice, which will be hereafter noticed as containing a magnificent exposure of some of the Middle Skelgill Beds, not only are the *Dimorphograptus-confertus* Beds faulted out, but also the lower part of the Middle Skelgill Beds, which latter rest against the *Atrypa-flexuosa* Bed. This limestone is here seen in the stream, and after being somewhat displaced again by another dip-fault (which runs up a deep gash on the north-east side of the high cliff, in the same way as the first-named dip-fault runs up a similar gash on the south-west side of the clift), it is well seen resting on the uppermost beds of the Ashgill Shales, at a point where the stream turns a corner and runs down a steep dip-slope. Here the highest Ashgill Shales again contain the calcareous nodules noticed before, and the *Atrypa-flexuosa* band, which is one foot thick, contains a number of fossils, including:—

Climacograptus normalis, *Lapw.*	Strophomena.
Atrypa flexuosa, n. sp.	Homalonotus?

The breccia of the strike-fault is here seen immediately above the limestone, nor do we meet with any exposure of the *Dimorphograptus-confertus* Beds on the left bank of the stream above this point, the strike-fault usually occurring in the bed of the stream and bringing the Middle Skelgill Beds against the *Atrypa-flexuosa* Zone or even the Ashgill Shales.

At one point however, in the moorland portion of the stream, a very good exposure of the *Dimorphograptus-confertus* Beds occurs on the right bank. This is about a hundred yards below the Upper Bridge. Below the Upper Bridge the stream makes a bend, leaving a promontory mainly composed of the Middle Skelgill Beds in a greatly shattered condition, and at the south-west corner of the promontory the *Dimorphograptus-confertus* Beds are seen dipping so as to pass beneath the Middle Skelgill Beds, though a short interval occurs between them, certainly occupied by the usual strike-fault, the breccia of which is seen in places.

The *Dimorphograptus*-beds consist of blue mudstones, here breaking into rectangular fragments, and resting on the Ashgill Beds, against which they are crushed, as shown by the absence of the *Atrypa-flexuosa* band, and the disturbed character of the *Dimorphograptus*-beds, where brought against the Ashgill Shales. The fossils here are somewhat different from those seen at the Lower Bridge. We have found:—

Monograptus revolutus, *Kurck.*	Dimorphograptus confertus, *Nich.*
—— Sandersoni, *Lapw.*	—— Swanstoni, *Lapw.*
—— attenuatus, *Hopk.*	Diplograptus vesiculosus, *Nich.*
—— tenuis, *Portl.*	—— modestus, *Lapw.* ?

Of these, *Diplograptus vesiculosus*, Nich., *Dimorphograptus Swanstoni*, Lapw., and *Monograptus tenuis*, Portl., are abundant, whilst *Dimorphograptus confertus*, Nich., is rarer. We consider that these beds are somewhat higher in the series than those occurring at the Lower Bridge:—first, because the *D.-confertus* Beds at the Lower Bridge immediately succeed the *Atrypa-flexuosa* Limestone; and secondly, because *Monograptus tenuis* is comparatively abundant in the shales immediately below the strike-fault in the cliff just below the Lower Bridge, whilst it is much rarer lower down the cliff, where *Dimorphograptus confertus*, Nich., becomes so abundant. Nevertheless we are not prepared to divide the *Dimorphograptus-confertus* Zone into a lower band characterized by the abundance of *D. confertus*, Nich., and an upper band characterized by the comparative scarcity of *D. confertus*, Nich., and the abundance of *D. Swanstoni*, Lapw., and of *Diplograptus vesiculosus*, Nich., and *Monograptus tenuis*, Portl., though we think it is highly probable that this might be done.

Before passing on to describe the Middle Skelgill Beds, we may sum up the results we have arrived at:—

(i) The uppermost Ashgill Shales are marked by a band of calcareous nodules. These shales pass up conformably into the overlying beds (Lower Skelgill Beds).

(ii) The Lower Skelgill Beds are divisible into two zones :—

(1) A limestone, one foot in thickness, containing *Atrypa flexuosa* and other fossils : = *Atrypa-flexuosa* Zone.

(2) A set of hard, calcareous shales, of which at least 9 feet 6 inches, are seen, to which we must add three or four feet more if the beds with *Dimorphograptus Swanstoni*, Lapw., are different from those with numerous *D. confertus*, Nich. These shales contain abundance of *Dimorphograptus confertus*, Nich., along with *Monograptus revolutus*, Kurck, *Diplograptus vesiculosus*, Nich. &c. : = *Dimorphograptus-confertus* Zone.

(iii) A strike-fault occurs everywhere in the gill between this zone and the overlying Middle Skelgill Beds, so that the thickness of the *Dimorphograptus-confertus* Beds and of the lowest member of the Middle Skelgill Beds can never be ascertained in this stream.

(iv) The Lower Skelgill Beds, which are harder and more calcareous than the succeeding Graptolitic bands, are always continuous with the underlying Ashgill Shales, and are therefore usually found on the right bank of the stream, whilst the succeeding beds are almost entirely confined to the left bank, as the stream has naturally worked its way along the strike-fault for the greater part of this portion of its course.

Ab. Middle Skelgill Beds.

(1) Starting again at the Lower Bridge, and examining the discontinuous rock-exposures in the wooded bank of the stream above the breccia of the strike-fault (which, it will be remembered, occurred above the *D.-confertus* Beds of the cliff immediately below the bridge, and on the left bank of the stream), we find black shales, with a considerable quantity of pyrites, and containing many Graptolites in high relief. Just above the bridge, a thickness of four feet of these beds used to be visible, below some blue mudstones from which Graptolites are absent. The beds are better displayed in the small cliffs which occur on the left bank of the stream at various points in the wood, commencing about halfway between the Lower Bridge and the first tributary from the north, and continuing to the junction of the main beck with this feeder. The blue mudstones devoid of Graptolites are seen here, and below them, and between them and the strike-fault so frequently alluded to, we get the following section in descending order :—

	ft.	in.	
Black Graptolitic shales	3	6	
Pale green band		$\frac{1}{4}$	
Black Graptolitic shales	1	3	
Non-Graptolitic striped bed		6	
Black Graptolitic shale	2		seen above the fault.
Total	7	$3\frac{1}{4}$	seen.

This is the greatest thickness of these beds which we have measured between the strike-fault and the overlying blue mudstones. In other parts of the stream the strike-fault approaches nearer to the mudstones and, indeed, frequently cuts out these black Graptolitic shales altogether. The passage from the Graptolite-bearing beds into the blue mudstones above is complete. The Graptolites become much scarcer about two inches from the summit of the black beds, and at the same time the blackness of the rock diminishes, until, when the last Graptolites are seen, the rock has assumed a greyish-blue colour, and its hardness has increased considerably.

The group of Graptolitic shales we are now considering may be seen at several points in the wood above the bridge, and in most cases the passage can be traced into the blue mudstones above. At the great cliff just above the foot-bridge the strike-fault has cut out these beds and brought the overlying blue mudstones against the *Atrypa-flexuosa* Bed, but on the other side of the dip-fault which bounds the N.E. side of this cliff the shales are again seen, though greatly crushed at the base. Many fossils, in an admirable state, may be obtained near an adit which has been driven into the shales, a little below the top of the wood; and at the end of the wood, where we emerge upon the moorland, the strike-fault is seen on the left bank of the stream, where the shales are crushed into a mass of black mud with ferruginous stains, immediately above which the blue mudstones are seen in the cliff. Higher up the stream, the Graptolitic shales below these mudstones are cut out, except at the promontory on the right bank of the stream just below the Upper Bridge. Here the shales are seen in a very crushed state on the north-east side of the promontory, succeeded, as usual, by the blue mudstones.

The group of shales we have above described is distinguished from those we have already considered, and from others which yet remain to be described, by lithological and palæontological characters.

The beds are extremely dark, generally almost or quite black, and though earthy are yet hard, and break into rather massive pieces. They are more cleaved than the shales below, and as the Graptolites are chiefly found along bedding-planes separated from one another by an inch or two of rock in which fossils are scarce, they do not break into quite such thin slabs as do the shales of the *D.-confertus Zone.* Several narrow lines of pale green mudstone occur here and there, and in these Graptolites are very seldom found, though they are not entirely absent. Pyrites occurs abundantly both in nodules and in irregular patches along the bedding-planes, and, as a result, the joints and cleavage-planes are usually stained a very deep brown.

The fossils usually occur in a state of high relief, and are mostly pyritous and of a golden colour, though sometimes they are graphitic and silvery when first obtained. Most of the following fossils are readily found wherever these shales occur in the stream :—

Monograptus fimbriatus, *Nich.*	Diplograptus sinuatus, *Nich.*
—— gregarius, *Lapw.*	—— Hughesii, *Nich.*
—— tenuis, *Portl.*	—— modestus, *Lapw.* ?
—— attenuatus, *Hopk.*	—— vesiculosus, *Nich.*
—— Sandersoni, *Lapw.*	Petalograptus ovatus, *Barr.*
—— leptotheca, *Lapw.*	—— ovato-elongatus, *Kurck.*
—— triangulatus, *Harkn.*	Climacograptus normalis, *Lapw.*
—— cyphus, *Lapw.*	Dawsonia campanulata, *Nich.*
Rastrites peregrinus, *Barr.*	Discinocaris, n. sp.
Diplograptus tamariscus, *Nich.*	Orthoceras araneosum, *Barr.*

The above is a complete list of all the fossils found in these shales in the gill. The first-named occurs everywhere in the zone in great abundance, and usually in a beautiful state of preservation, and we have met with it in no other beds either above or beneath. We shall therefore speak of these shales as composing the Zone of *Monograptus fimbriatus.*

Monograptus gregarius, Lapw., *Rastrites peregrinus*, Barr., *Petalograptus ovatus*, Barr., and *P. ovato-elongatus*, Kurck, are all abundant, and we frequently find beds covered with a confused mass of *Monograptus attenuatus,* Hopk. *Dawsonia campanulata,* Nich., is often found in groups. We have only seen one or two doubtful examples of *Diplograptus vesiculosus*, Nich. It is to be noted that the genus *Rastrites,* which appears so abundantly in this horizon, has never been found by us in any of the Lower Skelgill Beds.

(2) Above the Zone of *Monograptus fimbriatus* we find a more or less continuous section of the Middle Skelgill Beds all the way between the two bridges ; and the observations made at the Lower Bridge may be frequently checked by an examination elsewhere. The sections below the Lower Bridge are less continuous, but here and there high cliffs occur, showing a good development of the various subdivisions. The blue mudstones succeeding the *fimbriatus*-zone are seen at the bottom of the path which crosses the Lower Bridge. They are five feet in thickness, and pass downward in the manner described into the *M.-fimbriatus* beds. At the summit a similar passage is traceable into a thin black Graptolitic band.

The blue mudstones are hard, somewhat cleaved, grey-blue beds, with prominent bedding-planes some distance apart. The rock is somewhat calcareous, but the carbonate of lime has been mostly collected into a series of extremely tough nodules, which have weathered out along the cliff-faces, and show as a series of rust-stained holes. The following measurements were taken at the Lower Bridge, and show the variations in the band, the section being a descending one:—

	ft.	in.
Blue mudstones passing into Graptolite-shales above ...	1	0
Nodule-band.		
Blue mudstones		10
Nodule-band.		
Blue mudstones	1	0
Nodule-band.		
Blue mudstones		7
Nodule-band.		
Blue mudstones		7
White streak.		
Blue mudstones, passing into *M.-fimbriatus* beds	1	0
Total	5	0

The nodules are again well exhibited in the cliff at the bottom of the moorland portion of the gill, just before the stream enters the wood, and in many places between this and the Upper Bridge. At one point, however, where the cliff attains a great height, and has a concave curve produced by a loop of the stream, these beds are faulted out, and a higher set of mudstones is brought down against the strike-fault, which here runs in the bed of the stream.

The fossils of the mudstones which we have been describing are procurable with some difficulty, owing to the hardness of the rock. They are not often found on the bedding-planes, which usually present wrinkled surfaces, so that the rock must be broken across in order to obtain the well-preserved fossils. We have found:—

Encrinurus punctatus, *Wahl.*, var. arenaceus, *Salt.*
Acidaspis.
Leptæna quinquecostata, *M'Coy.*
Orthoceras araneosum, *Barr.*

The *Encrinurus* is a tolerably common fossil, and we have not hitherto met with it in any of the other deposits in this gill, so we use it to mark this zone, which we consequently name the *Zone of Encrinurus punctatus*, Wahl.

(3) Above this zone comes a band of small thickness, but of great interest, owing to the varied assortment of fossils which it contains. It occurs right in the centre of the Middle Skelgill beds, and is succeeded by mudstones of a similar lithological character to those which lie below it, and passes up into them in the same manner. The lower portion of these upper mudstones, similarly to the upper portion of the lower group, consists of light-coloured, shaly layers, and between these two we find eight inches of extremely black shales, somewhat similar to those of the *M.-fimbriatus* Zone, but even harder, and containing Graptolites in an exquisite state of relief. About three inches from the summit of this bed is a pale-green streak in which Graptolites are extremely rare, and which is remarkable for its extraordinary persistence. The bed is seen by the path which crosses the Lower Bridge, and may be traced passing along the face of the cliff to the dip-fault which occurs a few yards above the bridge. It is here thrown down, and occurs in the great precipice between the two dip-faults, at a height of a foot or two above the stream. It is marked all the way from the path to the north-east end of this cliff by a furrow caused by our removal of the shales, so that it is now extremely difficult to get satisfactory specimens at this spot. The same bed may be found at one or two points below the Lower Bridge, but in many places, both here and above the bridge, the deposit is inaccessible. Along a great part of the cliff below the Upper Bridge the band is found to be crushed out, and the mudstones above are brought into contact with those below; but on tracing the line of junction the thin band gradually appears, at first much crushed, but further away from the point of maximum disturbance it is in its normal condition. At the point of maximum throw of the principal strike-fault of the stream the beds are absent

from the base to this zone inclusive, and the succeeding mudstone bed is brought against the Ashgill Shales.

The fossils enumerated in the ensuing list have been discovered by us in this black band:—

Monograptus argenteus, *Nich.*
—— gregarius, *Lapw.*
—— leptotheca, *Lapw.*
—— Nicoli, *Harkn.*
—— Clingani, *Carr.*
—— crenularis, *Lapw.*
—— cyphus, *Lapw.*
—— convolutus, *His.*
—— involutus, *Lapw.*
—— attenuatus, *Hopk.*
—— argutus, *Lapw.*
—— Hisingeri, *Carr.*
—— tenuis, *Portl.*
Rastrites peregrinus, *Barr.*
Rastrites hybridus, *Lapw.*
—— urceolus, *Richter.*
—— gemmatus, *Barr.*
Diplograptus sinuatus, *Nich.*
—— tamariscus, *Nich.*
—— Hughesii, *Nich.*
—— modestus, *Lapw.*?
Petalograptus ovatus, *Barr.*
Climacograptus normalis, *Lapw.*
Discinocaris Browniana, *Woodw.*
—— gigas, *Woodw.*
Dawsonia campanulata, *Nich.*
Orthoceras araneosum, *Barr.*

The beautiful *M. argenteus*, Nich., which used to be readily procurable from this band, appears to be entirely confined to it, and although the bed is so thin, its fauna is so rich, and the bed such a remarkable one in every particular, that we consider it worthy of being ranked as a distinct zone, which we term the *Zone of Monograptus argenteus.*

(4) Once more we return to the Lower Bridge, and proceed to examine there the mudstones into which the *M.-argenteus* Zone passes upward.

What we have said of the lithological characters of the *Encrinurus-punctatus* Zone is applicable here, except that the calcareous nodules, instead of being spread at nearly equal distances throughout the deposit, are chiefly collected towards its centre. Otherwise, we meet with the same blue mudstones, with bedding-planes tolerably far apart, and the intervening rock breaking with the same difficulty as that of the *Encrinurus*-zone. The calcareous nodules weather out leaving a brown or chocolate-coloured earth, which is also frequently found along the bedding-planes. The following details of these mudstones, given in descending order, and measured at this foot-bridge, are generally applicable to the horizon at other parts of the gill:—

	ft.	in.
Blue mudstones (passing up into Graptolitic shales) ...	4	0
Nodule-band.		
Blue mudstones		6
Nodule-band.		
Blue mudstones		6
Nodule-band.		
Blue mudstones		10
Nodule-band.		
Blue mudstones		3
Nodule-band.		
Blue mudstones	6	0
Total...........	12	1

This is one of the most prominent bands in the gill, as the lines of nodules present a very striking appearance, and as the whole deposit is traversed by a series of strike-joints, along which it breaks off in massive blocks, sometimes four or five feet in length each way; the overlying shales usually present a projecting cornice of jagged appearance above the smooth face of the portion of the cliff which is composed of these mudstones. For these reasons, there is not the slightest difficulty in tracing this band wherever exposed, and there are few places where this hard blocky deposit is concealed by detritus. Where the band comes down to the stream, at the point of maximum disturbance produced by the strike-fault, namely in the very high precipice in the moorland part of the gill, a number of flat elliptical concretions, with a reticulated surface and a black earthy appearance, were found by us in it. These concretions are apparently formed of oxide of manganese, and they probably occur in other parts of the gill, though we have not come across them.

The fossils of this band are admirably preserved, like those of the *Encrinurus*-zone. They are:—

Favosites mullochensis, *Nich. & Eth., jun.*
Phacops elegans, *Bœck & Sars.*
—— ——, var. glaber.
Cheirurus bimucronatus, *Murch.*, var. acanthodes, var. nov.
Cheirurus moroides, n. sp.
Harpes angustus, n. sp.
—— judex, n. sp.
Calymene Blumenbachii, *Brongn.?*
Whitfieldia tumida, *Dalm.?*

The new variety of *Phacops* is the most prominent fossil, and, although not confined to this band, occurs more abundantly here than elsewhere; hence the name we have adopted for this band, viz. the *Zone of Phacops glaber*.

(5) The Graptolitic shales which have been alluded to as forming a cornice above the *P.-glaber* zone in the precipices are seen about halfway up the path which crosses the Lower Bridge, where the usual gradual passage from the mudstones to the Graptolite-bearing shales may be observed. This passage always takes place in the vertical distance of two or three inches, and is due to the gradual development of lamination-planes in the mudstones, which at the same time begin to contain a few Graptolites, assume a darker hue, and are not calcareous. These Graptolitic shales above the *glaber*-zone are very finely laminated, so that they break into thin pieces, thus differing from the mudstones of the *M.-argenteus* and *M.-fimbriatus* zones and of the Lower Skelgill Beds. When much jointed and cleaved, they break up into small rectangular pieces, but when the divisional planes produced subsequently to deposition are less marked, they afford tolerably large but thin slabs. The shales are also less dark than those of the underlying Graptolitic zones, the usual tint being a somewhat dark greyish blue instead of black, though here and there black shales do occur. One of the most noticeable features is the light olive-brown staining of the joint surfaces; by this peculiarity, and by their fissile character, they are

readily distinguishable from any of the preceding Graptolite-zones, even at a distance of some yards.

The entire thickness of this subdivision is seven feet nine inches, and the subjoined details are given, as usual, in descending order:—

	ft.	in.
Richly Graptolitic black shales, passing into mudstones above...		4
Blue mudstones, with few Graptolites.....................................		11
Graptolitic shales	3	8
Green mudstones...	1	6
Graptolitic shales		2
Green streak.		
Graptolitic shales, passing into *glaber*-zone below	1	2
Total	7	9

The lowest part, one foot four inches in thickness, lying below the green mudstones, is distinguished by the great abundance of *Diplograptus tamariscus*, Nich., preserved in a state of semi-relief. As this species is tolerably abundant elsewhere, including the upper part of the zone under consideration, we do not intend to separate this lowest portion as a distinct subzone, especially as all the fossils found in it occur in the rest of the zone; but we call attention to it, as a similar abundance of *D. tamariscus* is found on the same horizon in other sections.

As the shales of this zone are easily distinguished in other parts of the gill, and present no particular variations, we need not give a detailed description. Most of our fossils have been obtained from the immediate neighbourhood of the Lower Bridge, from the angle of the stream just above the high precipice a few yards above this bridge, and from the bank just N.E. of the high precipice in the moorland portion of the stream. These fossils are:—

Monograptus convolutus, *His.*
—— gregarius, *Lapw.*
—— Clingani, *Carr.*
—— crenularis, *Lapw.*
—— communis, *Lapw.*
—— Nicoli, *Harkn.*
—— attenuatus, *Hopk.*
—— argutus, *Lapw.*
—— cyphus, *Lapw.*
—— involutus, *Lapw.*
Rastrites hybridus, *Lapw.*
—— peregrinus, *Barr.*
Rastrites urceolus, *Richter.*
—— gemmatus, *Barr.*
Petalograptus cometa, *Gein.*
—— folium, *His.*
—— ovatus, *Barr.*
Retiolites perlatus, *Nich.*
Diplograptus Hughesii, *Nich.*
—— tamariscus, *Nich.*
—— modestus, *Lapw.*
Climacograptus normalis, *Lapw.*
Dawsonia campanulata, *Nich.*
Leptæna quinquecostata, *M'Coy.*

Of these *M. convolutus*, His., is the most prominent form. It does occur in the *M.-argenteus* zone in considerable abundance, but it is found here in a beautiful state of preservation and in great abundance; only one specimen of *P. cometa* has been found in this gill. We name this zone the *Zone of Monograptus convolutus.*

(6) The succeeding blue mudstones, which we take as marking the summit of the Middle Skelgill Beds, are seen on the footpath at the Lower Bridge, near its summit. They are four feet in thickness, and similar in lithological characters to the mudstones of the *Phacops-glaber* zone, but do not contain any band of calcareous nodules.

They are seen in many parts of the gill, immediately succeeding the shales of the *M.-convolutus* zone. Fossils are rare, and the mudstones are of little interest. They have yielded :—

Phyllopod spine.
Whitfieldia tumida, *Dalm.* ?
Leptæna quinquecostata, *M'Coy.*

We shall speak of this band as the *Barren Band.*

To sum up the results obtained in our examination of the Middle Skelgill beds :—

(i) The base is nowhere seen, owing to the strike-fault.

(ii) The beds form the chief portion of the great cliff-section which occurs on the left bank of the gill from the Upper Bridge to the bottom of the wood.

(iii) The beds are divisible into three zones of Graptolitic shales, each topped by a zone of blue mudstones :—

(1) A zone of black, pyritous, earthy, somewhat hard mudstones, at least 7 feet thick, with *Monograptus fimbriatus*, Nich., *M. gregarius*, Lapw., *Rastrites peregrinus*, Barr., *Petalograptus ovato-elongatus*, Kurck, and *Dawsonia campanulata*, Nich., &c. : =*Monograptus-fimbriatus* zone.

(2) A zone of hard, blue, bedded mudstones, 5 feet thick, with bands of calcareous nodules, containing *Encrinurus punctatus*, Wahl., &c. := *Encrinurus-punctatus* zone.

(3) A thin band of black mudstones, only 8 inches, with *Monograptus argenteus*, Nich., *M. gregarius*, Lapw., and a host of other fossils : =*Monograptus-argenteus* zone.

(4.) A zone of hard, blue, bedded mudstones, 12 feet in thickness, with many calcareous nodules towards the centre, and containing many Trilobites, including *Phacops elegans*, var. nov. *glaber* : =*Phacops-glaber* zone.

(5) A thick zone of laminated, dark, greyish-blue Graptolitic shales, with olive-brown stains on the joint-faces, having several green streaks throughout and thick deposits of mudstones near the top and base, the whole attaining a thickness of 7 feet 9 inches, and containing *Monograptus convolutus*, His., *Monograptus gregarius*, Lapw., and many other Graptolites : =*Monograptus-convolutus* zone.

(6) A zone of blue mudstones, 4 feet thick, and containing few fossils : =*Barren Band.*

Ac. *Upper Skelgill Beds.*

(1) The Graptolite-shales which succeed the highest beds of the Middle Skelgill group are only one foot thick. They consist of very fissile laminated shales, sometimes black and very ferruginous, and at other times of a lighter colour. They are seen near the Lower Bridge near the summit of the footpath, where they contain a considerable number of fossils. Other and more highly fossiliferous exposures of this band occur at several points above the Lower Bridge, on the moorland portion of the stream. The fossils serve to connect them with a succeeding band of Graptolitic shales, and they themselves contain no characteristic form. Their fossils are :—

Monograptus Clingani, *Carr.*
—— gregarius, *Lapw.*
—— Nicoli, *Harkn.*
—— crenularis, *Lapw.*
—— spinigerus, *Nich.*
—— distans, *Portl.*
—— jaculum, *Lapw.*
Rastrites urceolus, *Richter.*
—— hybridus, *Lapw.*
Diplograptus tamariscus, *Nich.*
—— sinuatus, *Nich.*
Petalograptus ovatus, *Barr.*
—— folium, *His.*
Climacograptus normalis, *Lapw.*
Favosites mullochensis, *Nich. & Eth., jun.*
Peltocaris aptychoides, *Salt.*
Aptychopsis Lapworthi, *Woodw.*

From the abundance of *Monograptus Clingani*, Carr., which usually occurs in an immature condition, this band may be termed the *M.-Clingani Band*; it is not worthy to rank as a distinct zone. Only one specimen of *Monograptus gregarius* has been hitherto discovered in it.

(2) The *Clingani*-band passes up in the usual manner into yet another band of blue mudstones, four feet six inches thick, and containing a line of calcareous nodules close to the summit, and another about two thirds of the way up. This is clearly seen on the path at the Lower Bridge, and at many points higher up the stream. Fossils are tolerably abundant, especially between the two lines of calcareous nodules. We have collected:—

Ampyx aloniensis, n. sp.
Harpes angustus, n. sp.
—— judex, n. sp.
Proëtus brachypygus, n. sp.
Phacops elegans, var. glaber.
Cheirurus bimucronatus, *Murch.*, var. acanthodes.

From the occurrence upon this horizon only, and in tolerable abundance, of the very interesting form of *Ampyx*, we name this the *Zone of Ampyx aloniensis.*

(3) The *Ampyx*-zone passes up into an extremely well-marked zone of Graptolitic shales, 3 feet 6 inches in thickness. These beds consist of alternating thin laminæ of black, grey, dirty white, buff, orange, and green shales, with some coarser bands, the surface of which is marked by lozenge-shaped reticulations; they are well seen on the path at the Lower Bridge, and at one or two places along the cliff at the moorland portion of the stream, especially in the bend, opposite the north-eastern end of the promontory, just below the Upper Bridge. They swarm with Graptolites, and we have collected from them:—

Monograptus spinigerus, *Nich.*
—— discretus, *Nich.*
—— jaculum, *Lapw.*
—— distans, *Portl.*
—— leptotheca, *Lapw.*
Petalograptus palmeus, *Barr.*
Diplograptus tamariscus, *Nich.*
—— Hughesii, *Nich.*
—— modestus, *Lapw.*
Climacograptus normalis, *Lapw.*
Orthoceras araneosum, *Barr.*

Monograptus spinigerus, Nich., is very abundant throughout, and occurs in vast abundance in the upper portion of the zone, whilst *Monograptus discretus,* Nich., thickly covers whole slabs of the lower portion of the deposit. There is no doubt that the only suitable name for this band is the *Zone of Monograptus spinigerus.*

(4) The *M.-spinigerus* zone is seen to pass up into the highest beds

of the Upper Skelgill group exposed at the Lower Bridge. We find here 10 feet of blue mudstones, in which we have obtained at this point only a few badly preserved Ostracods. The Browgill Beds occur on the moorland at the Lower Bridge, just above these mudstones, but the actual junction is not seen. The junction is observable, however, at two or three points along the moorland portion of the gill, and the beds are seen to pass with considerable rapidity into the Browgill Beds. Their thickness there is also 10 feet, so that it is evident that the whole thickness is seen at the Lower Bridge. We have searched in vain for other fossils, but found none in this section; but as a remarkable *Acidaspis* occurs upon this horizon in another locality, we term these beds the *Zone of Acidaspis erinaceus.*

To sum up the results obtained from an examination of the Upper Skelgill Beds :—

(i) They are conformable to the Middle Skelgill Beds below, and pass up into the Browgill Beds above without the intervention of any Graptolitic shales.

(ii) They are divisible into two Graptolitic bands, each succeeded by a band of blue mudstones, viz. :—

(1) A band of black and blue thinly laminated shales, one foot thick, with abundance of *Monograptus Clingani*, Carr.: =*M.-Clingani Band.*

(2) A deposit of blue mudstones, 4 feet 6 inches thick, with many Trilobites, including *Ampyx aloniensis*, n. sp.: =*Ampyx-aloniensis Zone.*

(3) A set of Graptolitic shales of various colours from black to deep orange, 3 feet 6 inches thick, and from the abundance of *Monograptus spinigerus*, Nich., therein, termed the *Zone of Monograptus spinigerus.*

(4) A thick group of bedded blue mudstones (10 feet thick) containing few fossils, and passing up into the Browgill Beds above: =*Acidaspis-erinaceus Zone.*

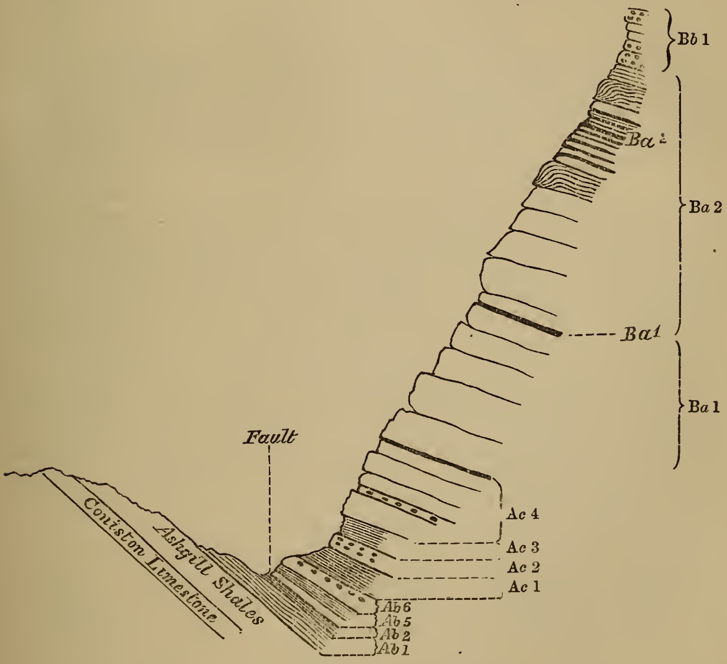
The section (fig. 1, p. 661) shows the succession of the Skelgill Beds at Skelgill, and may be taken as representing the section at the Lower Bridge, some feet being added to the top of the *D.-confertus* zone and to the base of the *M.-fimbriatus* zone to show the maximum thicknesses of these beds, as far as seen in the gill.

B. *The Browgill Beds of Browgill and Stockdale.*

Some ten miles north of Kendal the river flowing from the north through the little valley of Stockdale joins the main valley of Long Sleddale on the east side of the latter. About fifteen chains above the junction of the two streams, the cluster of houses forming the little hamlet of Stockdale is grouped on the right bank of the Stockdale Beck. Close to the stream, and on its north bank, a quarry is excavated in the Lower Coniston (Brathay) Flags, close to the base of the latter, which here as elsewhere contains Graptolites in an excellent state of preservation. Among these are *Monograptus priodon*, Bronn, *M. vomerinus*, Nich., *Cyrtograptus*

Murchisoni, Carr., and *Retiolites Geinitzianus*, Barr. Above this the stream-course is cut for a distance of two chains through the Browgill Beds, and as the passage of these into the Skelgill Beds below is seen beneath a small cascade, the whole of the Browgill Beds are developed in this section, and a nearly continuous section is displayed, the beds dipping quite regularly to the S.S.E. at an angle of about 60°. Just above the cascade which falls over the Coniston Limestone, a tributary enters Stockdale Beck from the north-east; this is Browgill, and the same stream is referred to by Professor Sedgwick under the name of Iron Crow Gill, and by Profs. Harkness and Nicholson under that of Arncoside Beck. The lowest twenty chains of the gill are hollowed in the beds of the Coniston-Limestone series; but at a point a short distance above the 1000-foot contour-line a fault runs diagonally across the stream with a downthrow to the east, which brings the Stockdale Shales against the

Fig. 2.—*Section at "Rake," Browgill.* (Scale 24 feet to 1 inch.)



Coniston-Limestone Series, and the former beds are traceable for some distance up the stream, which here runs along the strike. As at Skelgill, the Coniston-Limestone Series is seen on the north-west bank, which is a dip-slope, and a steep scarp sometimes rising into precipitous cliffs forms the south-east (left) bank. The lower portion of this is occupied by the Skelgill Beds, whilst the upper portion shows the green grits and shales of the Browgill Beds. The cliff attains its maximum height near the point where the 1250 feet contour-line crosses the stream, and here a cleft occurs in the cliff which is spoken of in the dialect of the country as a " rake "*. We shall speak of this cleft as " The Rake." In its walls there is an admirable exposure of the lower part of the Browgill Beds, which are slightly displaced by a small fault which has determined the formation of the rake.

The section seen in this " rake " is represented in figure 2, where the slope of the cliff is exaggerated in order to save space. The bed *Ac* 4, which corresponds with the *Acidaspis-erinaceus* zone of Skelgill as will be hereafter shown, is the highest band of the Skelgill Beds. This passes up in the same way as at Skelgill into the pale-green beds of the Browgill group, without the intervention of Graptolitic shales. Two distinct zones of Graptolitic shales occur in the cliff, and it will be convenient to connect with each of them the mass of non-Graptolitic green beds which occurs beneath them.

B*a*. *Lower Browgill Beds.*

B*a* 1. The pale shales passing into the blue mudstones of the uppermost Skelgill Beds are 21 feet in thickness without the intervention of any black shales in which we have found Graptolites. There is a thin band (under an inch in thickness) at a height of 11 feet 6 inches above the top of *Ac* 4, but we found no Graptolites therein. The shales are pale green, slightly gritty in places, and well laminated. They frequently contain cubic crystals of iron-pyrites, and dendritic efflorescences of oxide of manganese, and are quite similar to the bulk of the Browgill Beds, which present a great uniformity of character wherever developed. 21 feet above the uppermost Skelgill Beds occurs a thin black band, B*a* 1′, weathering to a buff-yellow colour, and crowded along one bedding-plane with tolerably large specimens of *Monograptus turriculatus*, Barr., which are seen as dark-brown stains upon the rock, but are sufficiently well preserved to show the long spines of the cells in many specimens. The only other Graptolite found here is *Monograptus rectus*, Lapw. From the great abundance of *Monograptus turriculatus*, we shall speak of this band with its underlying 21 feet of pale shales as the *Zone of Monograptus turriculatus*, Barr.

B*a* 2. Above this Graptolitic band is another mass of pale shales similar in every respect to those of the *turriculatus*-zone. They are disturbed at one point by a small monoclinal fold; but this seems to be unaccompanied by any fracture, so that no shales are apparently faulted out here, and there is a thickness of 19 feet between the black band of the *M.-turriculatus* zone and the group of Graptolitic shales about to be described.

These shales, B*a* 2′, consist of olive-green and grey shales, with a

* A " rake " is, on a small scale, the same as a " couloir," and is often formed along a prominent joint-plane or line of fault, or by the weathering-out of a dyke.

number of interstratified greyish-black Graptolitic shales, the whole attaining a thickness of about 15 feet. There are two important Graptolitic bands 2 feet 8 inches apart, and each about 3 inches thick, and a number of minor ones. Many of the species are limited to one or two bands; but it would be difficult to subdivide this group, though it may be noted that *Retiolites Geinitzianus* occurs chiefly in the higher bands. The Graptolitic beds are usually weathered to a buff colour, on which, as in the *M.-turriculatus* zone, the Graptolites occur as brown stains. The fossils are:—

Monograptus crispus, *Lapw.*
—— exiguus, *Nich.*
—— pandus, *Lapw.*
—— discus, *Törnq.*
—— griestonensis, *Nicol.*
Monograptus Hisingeri, *Carr.*
Cyrtograptus Grayæ, *Lapw.*
—— ? spiralis, *Gein.*
Petalograptus palmeus, *Barr.*
Retiolites Geinitzianus, *Barr.*

The four species at the top of the list and the *Retiolites* are extremely abundant. For a long time we were disposed to adopt *M. exiguus*, Nich., as the type-fossil of the zone; but as *M. crispus*, Lapw., appears to be more abundant, we have decided to speak of it as the *Zone of Monograptus crispus*, including with it the 19 feet of pale shales which occur below it, and also the succeeding 10 feet of pale shales devoid of Graptolites which occur between these black shales and the band next to be described. These pale shales contain another monoclinal fold, also apparently unaccompanied by any fault.

B*b*. *Upper Browgill Beds.*

The deposit which we take as the base of the Upper Browgill Beds occurs at the extreme summit of the rake, and above it the moorland is reached with few exposures; but the deficiency of sections can be easily made up by an examination of the beds of the main stream of Stockdale.

The base of these Upper Beds, B*b* 1, consists of a calcareous development of the pale shales seven feet six inches in thickness. We find a lower blue calcareous band with weathered calcareous nodules like those of the *glaber-* and *punctatus*-zones of Skelgill, 2 feet 6 inches thick, separated from an upper band of similar rock, one foot thick, by about four feet of pale shales. We have discovered no fossils in these beds, and indeed, with the exception of a few undeterminable Brachiopods, have obtained no fossils in any locality from the Upper Browgill Beds, though we have searched for them carefully. We feel convinced, however, that some will eventually be found. Before quitting this section it may be noted that we have measured 65 feet of shales and subordinate grits belonging to the Lower Browgill Beds.

Returning to the Stockdale Beck, we can complete the section, which, indeed, is here so much more perfect than that of Browgill that we should certainly have adopted the name Stockdale Shales for the upper group, if it had not been previously used for the whole series. The two zones we have described as forming the Lower Browgill Beds of the rake are also seen in the main beck, where the Graptolitic shales are unweathered and of a greyish black. It is more difficult to obtain exact measurements in this stream than in the cliffs of the rake, but the thickness given above seems to hold good here also. The calcareous band which we have taken as marking the base of the Upper Browgill Beds is seen in the stream about halfway between the cascade over the Coniston Limestone and the quarry in the Coniston Flags by the stream, north of the hamlet. Above it is a thickness of pale green and reddish-purple grits and shales, passing gradually up by the intercalation of grey bands into the blue-grey Coniston Flags. An approximate measurement shows the occurrence of about sixty feet of these shales between the calcareous band and the base of the Coniston Flags, which gives a thickness of about 130 feet for the whole of the Browgill Beds in this locality.

The chief features which distinguish the Upper Browgill Beds from the Lower ones are:—

(i) The absence of Graptolitic shales;
(ii) The occurrence of more massive grits;
(iii) The reddish-purple colour of some of the beds.

The latter distinction appears to be due to the staining of the beds subsequently to deposition, and it is therefore of little value for classificatory purposes. In some sections along the outcrop of the Stockdale Shales the staining is absent; in other places it penetrates even to the Lower Browgill Beds, and usually takes place among the softer and more shaly deposits. The colouring material seems, however, to have been introduced from above, so that when staining does occur, it affects the Upper Browgill Beds far more than the Lower Beds, which are, indeed, usually entirely unaffected by it.

To sum up the results of the examination of this section:—

B*a*. The Lower Browgill Beds are divisible into:—

B*a* 1. Twenty-one feet of pale shale with a band, one inch in thickness at the summit, marked by the occurrence of *M. turriculatus*, Barr.: =*Zone of M. turriculatus.*

B*a* 2. A set of pale shales 15 feet thick with many Graptolitic bands, having 19 feet of pale shales below and 10 above, total 44 feet, containing *Monograptus crispus*, Lapw., *M. exiguus*, Nich., &c., in abundance: =*Zone of M. crispus.*

B*b*. The Upper Browgill Beds are divisible into:—

B*b* 1. A mass of calcareous blue mudstones with some paler beds, marked by the occurrence of calcareous nodules, and 7 feet 6 inches thick.

B*b* 2. A series of pale green and reddish-purple shales with massive grit beds, the whole attaining a thickness of about 60 feet.

It will be noticed that the calcareous band occurs about the centre of the Browgill Beds, and therefore forms a convenient line of division between the Lower and Upper Beds.

It should be mentioned that the Graptolites of the Browgill Beds of Stockdale and of Browgill are very rarely preserved in relief, and this is true of the Graptolites of the same beds in all parts of the district.

§ IV. Description of Confirmatory Sections.

In confirming the observations made upon the Skelgill Beds of Skelgill and the Browgill Beds of Browgill, by an examination of other sections, we propose first to describe the sections along the main line of outcrop of the Stockdale Shales, beginning at the E.N.E. end and proceeding to the W.S.W., and afterwards to allude to those in the outlying districts.

Although the outcrop of the Stockdale Shales is parallel with that of the Coniston-Limestone series, the latter are seen further eastward than the former. At Shap Wells the Coniston-Limestone series comes out from under the Carboniferous beds in Blea Gill, and the first beds seen above it are in Wasdale Beck, and belong to the Lower Coniston Flags, here considerably altered by the Shap granite, but nevertheless containing the usual vomerine Graptolites. Between these beds there is perhaps room for the Stockdale Shales; but as the highest beds of the Coniston-Limestone series seen in Blea Beck are by no means its uppermost beds, there is almost certainly a strike-fault here, and the Stockdale Shales may be wholly or in part faulted out. As the ground is drift-covered here, and for many miles further east, the presence or absence of the Stockdale Shales cannot be determined. The first satisfactory section of the Stockdale Shales which we have discovered is that seen in Browgill, of which a portion has been already described, and it remains for us therefore to complete the description by the addition of the details of the Skelgill Beds of this beck.

Browgill.

Referring to the section across the beck in fig. 2, it will be seen that an important strike-fault occurs a little above the stream at the rake. This is traceable all along the outcrop of the beds in Browgill, as well as in Stockdale Beck, and separates the Middle Skelgill from the Lower Skelgill Beds, or (in Stockdale Beck) cuts the Lower Beds out altogether. The dip of the beds is different on opposites sides of the fault, being at a much higher angle (about 60°) on the north-west bank of the stream than on the south-east, where it is usually below 30°. The steep dip-slope of the north-west bank is occupied by ordinary Coniston Limestone where it joins the moorland above, and the parts nearer the stream show a development of the Ashgill Shales. These seem to pass up with perfect conformity into the lowest beds of the Skelgill group, which are different from those of the Skelgill Beck.

A*a* 1. We find about 2 feet 6 inches of mottled, light-grey, flaggy, pyritous shale, somewhat calcareous in places, forming the right bank of the stream a little above water-level, and occurring in the bed of the stream itself. Graptolites are not uncommon in it, but we have only succeeded in finding two species, both of which are fairly abundant; they are:—

Diplograptus acuminatus, *Nich.*	Climacograptus normalis, *Lapw.*

There is no doubt, both from the position of this bed and its resemblance to the calcareous *Atrypa-flexuosa* band of Skelgill, that this deposit represents that zone, in which, it will be remembered, *Climacograptus normalis* occurred. The peculiar mottled appearance of the two deposits is strikingly similar. We propose, however, to speak of this deposit in Browgill as the *Zone of Diplograptus acuminatus*.

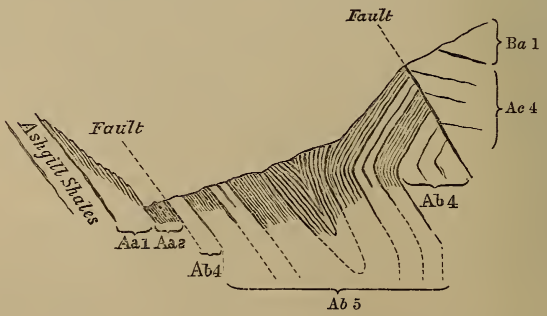
A*a* 2. Above this zone we find one or two feet of greatly disturbed, hard, black, mudstones, which we have little hesitation in referring to the *Dimorphograptus-confertus* zone; but the fossils are so badly preserved that we have not succeeded in extracting any which are capable of exact determination.

The disturbed character of the beds is due to their proximity to the strike-fault, the fissure of which comes immediately against them, and separates them from the overlying shales of the Middle Skelgill series. In this stream also we are therefore unable to estimate the thickness of the *Dimorphograptus-confertus* zone, or of the lowest subdivision of the Middle Skelgill beds.

At the rake itself a considerable thickness of the Middle Skelgill beds is missing, and the shales of the *convolutus*-zone are the lowest beds of this group which are seen. Some yards above the rake, the beds A*a* 3 of the *M.-fimbriatus* zone are seen, much broken, but with specimens of *Monograptus fimbriatus*, Nich., beautifully preserved in relief. The character of the beds is that of the representatives in the typical section; but as they are faulted above and below (the main strike-fault passing below them), they present little of interest.

The lowest beds of the Middle Skelgill series, with the exception just noted, occur at a point some distance below the rake, and not far above where the cross-fault brings the Coniston-Limestone series against the Stockdale Shales. The section here is represented in fig. 3.

Fig. 3.—*Section of Isoclinal, Browgill.* (Scale 12 feet to 1 inch.)



The Lower Skelgill beds are seen occupying the same position as at the rake, but only one foot of the shales which we refer to the *Dimorphograptus*-zone is found below the strike-fault. Another fault, which dies out before we reach the rake, brings the Browgill Beds against the Middle Skelgill Beds, and between the two faults these latter occur in an overfolded synclinal, as shown in the figure. The lowest beds seen belong to *Ab* 4, the *glaber*-zone, of which a few inches are seen in contact with the Lower Skelgill Beds, whilst two feet are visible resting against the second fault. These beds are blue mudstones, of the same character as those we have had frequent occasion to describe, but we have found no fossils therein at this spot. Their identification is rendered certain by their position, for they pass into the newer beds of the synclinal.

It is evident that the strike-fault between the Lower and Middle Skelgill Beds is more important here than at Skelgill, and the result is that the zones of *Encrinurus punctatus* and *Monograptus argenteus* are unrepresented in this section.

Ab 5. Continuing the description of the beds in the isocline, we observe the *glaber*-mudstones passing up into 1 foot 6 inches of black shales, in which the Graptolites are well preserved in relief.

Succeeding these are some pale-greenish mudstones apparently devoid of fossils, and above them we meet with about four feet of blackish shales, with olive-brown staining along the joint-surfaces, and containing *Monograptus convolutus* with its usual associates. The list of fossils found in these shales in Browgill will be enumerated after describing the shales of this zone seen at the rake; but in the meantime we would mention that we found one specimen of *Petalograptus cometa* a few inches below the pale-green mudstones in the inverted limb of the syncline, and therefore in newer beds.

The band of black shales between the pale-green mudstones and the *glaber*-zone is, as at Skelgill, marked by the occurrence of great quantities of *Diplograptus tamariscus*, Nich.

We have called particular attention to this isoclinal fold, because such are most exceptional in the Stockdale Shales between Browgill and Coniston Waterhead, and it is the rule along that country to find members of the series faulted out, and not reduplicated.

To return to the section at the rake:—

A thickness of one foot four inches of the *convolutus*-shales is seen immediately above the strike-fault, these forming the extreme summit of the zone, and passing up into the mudstones of the succeeding zone. These shales are quite like those of the *convolutus*-zone in Skelgill, viz. greyish-blue shales, with olive-brown stains along the joint-surfaces.

We have obtained from the *M.-convolutus* zone of Browgill:—

Monograptus convolutus, *His.*	Rastrites hybridus, *Lapw.*
—— gregarius, *Lapw.*	Retiolites perlatus, *Nich.*
—— Nicoli, *Harkn.*	Diplograptus Hughesii, *Nich.*
—— proteus, *Barr.*	—— tamariscus, *Nich.*
—— attenuatus, *Hopk.*	Petalograptus cometa, *Gein.*

Ab 5. The beds into which the shales of the preceding zone pass up consist here of pale-green mudstones, having a very ferruginous, calcareous, nodular band near the summit; the whole has a thickness of only two feet, and we have obtained no fossils from it, but it is shown by its position to be the representative of the "Barren Band" of Skelgill.

Ac 1. The preceding beds pass into three feet of Graptolitic shales of a leaden colour, except near the centre, where they are blacker. This is the *Clingani*-band, and, like the corresponding band at Skelgill, it contains a great abundance of *Climacograptus normalis* along certain lines, along with :—

Monograptus Clingani, *Carr.*	Monograptus crenularis, *Lapw.*
—— Nicoli, *Harkn.*	

M. Clingani is the prevailing form.

Ac 2. The overlying mudstones, which present the usual passage into the shales above and below, are only one foot five inches in thickness. They consist of pale-green, calcareous shale, with numerous dendritic markings, and containing few fossils except along one bedding-plane, where they are very numerous, indeed far more so than in any one of the non-Graptolitic bands of the Stockdale Shales of any other locality whatsoever. Two nodular, calcareous bands are seen near the centre of the zone, with the usual chocolate-coloured earthy residue left where the nodules are weathered out, and between these bands occurs the bedding-plane alluded to above. Besides this, a few fossils are found in the lower calcareous band. Fossils :—

Ampyx aloniensis, n. sp.	Phacops elegans, var. glaber.
Harpes judex, n. sp.	—— elegans, *Bœck & Sars.*
Calymene Blumenbachii, *Brongn.*	Acidaspis.
Proëtus brachypygus ?	Leptæna quinquecostata, *M'Coy.*
Encrinurus punctatus, *Wahl.*	—— *cf.* sericea, *Sow.*
Phacops mucronatus, *Brongn.*	

Also occasional plates of a Cystidean.

Very many heads of the *Ampyx* are seen, and all the fossils of the *A.-aloniensis* zone of Skelgill appear to occur here, with a few others, so that there would be no difficulty in fixing the horizon of the zone, even if it were not seen in the same position as at Skelgill, viz. between the *Clingani*-band and the *spinigerus*-zone.

Ac 3. The *spinigerus*-zone of Browgill is about two feet thick; but the passage into the mudstones above is so gradual that it is difficult to fix upon the exact line of demarcation. The lower part of the zone consists of black shales, weathering olive-brown, and with many Graptolites along certain bands, whilst the upper part is composed of shales of many colours, some showing the lozenge-pattern also found in the beds of this zone at Skelgill and, indeed, in all places where it is well developed throughout the district, so that we need not call attention to this feature in our future descriptions of the sections.

Monograptus spinigerus occurs as usual in countless multitudes, with its customary associates, which we did not trouble to collect ; but one specimen of *Rastrites hybridus* was obtained, and we call attention to it, as it has not turned up in the *spinigerus*-zone elsewhere.

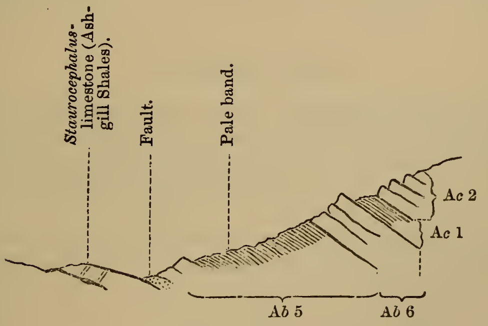
Ac 4. The highest beds consist of the blue mudstones, which occur between the *spinigerus*-zone and the Browgill Beds; these are here ten feet in thickness, and contain a calcareous nodular band of the usual description, ten inches thick, and at a distance of three feet from the base. No fossils have been found here in these mudstones of the *erinaceus*-zone, and their passage up into the Browgill Beds has been already described.

The section in Stockdale Beck below the cascade over the Coniston Limestone is, so far as the Skelgill Beds are concerned, quite like that occurring at the rake in Browgill; for we get the *convolutus*-beds as the lowest zone developed, and above it the remaining zones of the Middle Skelgill, and all the zones of the Upper Skelgill Beds occur just as there, so that further description is unnecessary. The strike-fault below the shales of the *convolutus*-zone is marked by a depression down which a rivulet trickles from a swamp in the field above, and this fault appears to bring the *convolutus*-beds actually against the Coniston Limestone, though there is a short interspace, marked by the above hollow, in which no rock is seen.

Stile End.

The Stockdale Shales are apparently shifted to a slight extent by a dip-fault, or probably a complex of such faults, running down the Long Sleddale valley; but as the lower parts of the valley are here occupied by alluvium and drift, no section of the beds is seen until after mounting the hill on the west side of the valley for a considerable distance. About halfway up the Stile End Pass, shales

Fig. 4.—*Section near Stile End.* (Scale 12 feet to 1 inch.)



belonging to the *Dimorphograptus*-zone are seen cropping up on the moorland; but the exposure is a small one and of little interest. Still higher up, and a very short distance below the summit of the pass, on the Long Sleddale side, a section of the Skelgill Beds is found on the right bank of a small stream to the south of the path (see fig. 4).

The base of the Ashgill-Shales series occupies the left bank of the stream, down which the usual strike-fault runs, and the lowest beds seen on the right bank are mudstones, of which a thickness of 1 foot 6 inches occurs. Above this are 5 feet 8 inches of Graptolitic shales, having the ordinary lithological characters of the *convolutus*-zone, and containing its fossils. A pale-green band, two inches thick, occurs a foot above the base of these shales, and at first sight it appeared as though the shales, with many specimens of *D. tamariscus*, would occur beneath this; but this was found not to be the case, and we believe that the mudstones at the bottom of the section belong to the *convolutus*-zone, and that the shales with many specimens of *D. tamariscus* should occur beneath this, and are not here exposed. Fossils :—

Monograptus convolutus, *His.*
—— leptotheca, *Lapw.*
—— gregarius, *Lapw.*
—— Nicoli, *Harkn.*
Rastrites urceolus, *Richter.*
Rastrites hybridus, *Lapw.*
Diplograptus tamariscus, *Nich.*
Climacograptus normalis, *Lapw.*
Aptychopsis.

A*b* 6. The Barren Band here consists of two feet ten inches of blue mudstones, passing down into the beds below. (It will be convenient if we remark that a passage is understood unless otherwise intimated.) It yielded *Leptæna quinquecostata*, M'Coy, and *Whitfieldia tumida*, Dalm. ?

A*c* 1. The *Clingani*-band is represented by one foot of grey-blue Graptolitic shale, with the usual fossils accompanying the characteristic small *M. Clingani,* and above it is A*c* 2, the *Ampyx-aloniensis* zone, of which only two feet are seen, and which yielded no fossils.

The Browgill Beds occur in isolated outcrops on the moorland, at several places between Long Sleddale and Kentmere, but they present little of interest.

Kentmere Sections.

No section of any importance occurs on the east side of the Kentmere valley, the hill-sides being largely occupied with turbary. A number of dip-faults run down the valley, shifting the beds to some extent, and the first good section of the Stockdale Shales is seen in the bed of the Kent, just east of the church. Only the upper portion of the Browgill Beds occurs here, with the usual fine, hard, greenish-grey grit interstratified with shales ; but the passage into the Coniston Flags is admirably displayed, the Browgill Beds having interstratified bands of blue mudstones towards the summit, until at last these preponderate, and the pale bands become rarer, and finally disappear altogether, the complete passage taking place in the course of twenty or thirty feet.

On the west side of the valley the dip-faults become very numerous, and the beds are greatly shifted laterally, as shown by the outcrop of the Coniston Limestone ; but we meet with no exposures of the Stockdale Shales until arriving at a point some distance above the bottom of the Kentmere valley. Here two small streamlets unite at the 900-feet contour-line to form a tributary of Hallgill, and the southernmost of these displays the Stockdale Shales dipping to the S.S.E., and striking transversely across the beck.

The lowest bed seen belongs to the zone of *Ampyx aloniensis*, and one of the calcareous nodular bands is seen in it, and above it is the base of the *spinigerus*-zone, composed of black earthy shales crowded with *Monograptus discretus*, Nich., and containing also *M. jaculum*, Lapw., and other fossils. Above this is a short interval, and then the upper part of the *spinigerus*-zone comes on, exhibiting the usual variegated shales, with :—

Monograptus spinigerus, *Nich.*	Diplograptus modestus, *Lapw.*?
—— jaculum, *Lapw.*	Petalograptus palmeus, *Barr.*
—— distans, *Portl.*	Climacograptus normalis, *Lapw.*
—— crassus, *Lapw.*	Retiolites perlatus, *Nich.*
Rastrites urceolus, *Richter.*	Peltocaris.
Diplograptus tamariscus, *Nich.*	

These shales are succeeded by 10 feet of blue mudstone, belonging to the *A.-erinaceus* zone, in which no fossils have been found here.

These pass into the Browgill Beds, some feet of which are seen in the stream, after which is a gap in the place where the *turriculatus*-bearing black band should occur. No signs of it are visible. Above this are more pale-green shales, with a few black bands containing badly preserved Graptolites. Some of the bands are probably covered up, for in the stream immediately below this are loose fragments containing the Graptolites characteristic of the *M.-crispus* zone, including :—

Monograptus crispus, *Lapw.*	Monograptus jaculum, *Lapw.*
—— exiguus, *Nich.*	Petalograptus palmeus, *Barr.*
—— discus, *Törnq.*	Retiolites Geinitzianus, *Barr.*
—— pandus, *Lapw.*	

Troutbeck Valley.

A marked depression indicates the position of the Skelgill Beds above the section just described, and an isolated exposure on the moorland just south of the summit of the Garbourn Pass furnishes the following fossils of the *fimbriatus*-zone :—

Monograptus fimbriatus, *Nich.*	Climacograptus normalis, *Lapw.*
Diplograptus tamariscus, *Nich.*	Orthoceras araneosum, *Barr.*
—— sinuatus, *Nich.*	

Proceeding to the Troutbeck side of the pass, the depression marked by the mudstones or, rather, more probably by a fault which cuts them out entirely, is seen running diagonally down the hillside towards Troutbeck church, shifted laterally by some small dip-faults, and crossing the Garbourn road just below the large flag-quarries. On the hillside above this depression are several exposures of and quarries in the Browgill Beds, but no continuous section. On reaching the bottom of the valley the beds are shifted half a mile to the north by the great dip-fault, and the next section in the Stockdale Shales is met with in Scot Beck. A dip-fault runs down this stream, bringing the Stockdale Shales of the left bank against the Ashgill Shales on the right. The hard mottled pyritous limestone of the *Atrypa-flexuosa* zone is seen on the left of the stream, containing no fossils here. Above it are two or three inches of hard, bluish-black, unfossiliferous shales, apparently belonging to the *Dimorphograptus*-zone, and above these is a smashed mass of shales with a few badly preserved Graptolites, including *Monograptus fimbriatus*, Nich., *M. concinnus*, Lapw., and *Petalograptus ovato-elongatus*, Kurck, belonging to the *fimbriatus*-zone. The usual strike-fault evidently occurs at the base of these, and accounts for their crushed condition. Lower down the stream the Browgill Beds are seen, with many black bands, which are greatly hardened, and no fossils were seen in them. Immediately to the west of this a drain was cut in 1886 in the field, and exposed the *spinigerus*-beds with beautifully preserved specimens of *Monograptus spinigerus*; and at the summit of these were a few inches of the mudstones of the *erinaceus*-zone. After crossing a mass of Coniston Limestone brought against the Stockdale Shales by trough-faults, the depression marking the position of the (probably) faulted-out Skelgill Beds may be traced westward across Nanny Lane, after which it bends to the south-west, and so is continued into Skelgill at the Upper Bridge, as previously described. On the moorland to the south of this depression are many small quarries in the Browgill Beds, which contain numerous minute and indeterminable Brachiopods. These beds are traceable on the high ground to the south-east of the beck to near High Skelgill Farm.

Skelgill.

It will be remembered that the Skelgill Beds were last seen where the stream left the wood and ran for a few yards over a swampy tract. It here turns due south, and is presently crossed by the bridge leading to High Skelgill Farm. The Browgill Beds first appear in the stream just above this bridge, and consist of pale green shales, interstratified with which are a number of indurated grey bands, the lamination-planes of which are marked with minute wrinklings, which render the contained Graptolites undeterminable. They are almost certainly the *crispus*-beds, the *turriculatus*-beds being concealed under the alluvial material higher up the stream. About 30 yards below the bridge the calcareous nodular bands forming the base of the Upper Browgill Beds are found, and are succeeded by the usual pale shales with interstratified grit bands, with which no Graptolite-shales were seen; and these pass up, in the way described when dealing with the Kentmere section, into the Lower Coniston Flags, which contain well-preserved fragments of vomerine Graptolites. Beyond this the beds strike through Dove-nest Wood to the eastern shore of Windermere.

Pull Beck.

The extensive bay of Pull Wyke, on the west side of Windermere and close to the head of the lake, is due to the soft rock of the Stockdale Shales, which are masked to the westward by the existence of an alluvial flat, through which the stream called Pull Beck runs. Crossing over this stream by the bridge over which the Coniston road runs, we may follow the latter road past the great Brathay Flag-quarries to a cart-track which turns to the right through a gate immediately beyond the quarries. If we follow this cart-track we are presently brought down to the stream near some cottages. The Skelgill Beds are exposed in numerous more or less isolated outcrops in the bed and banks of the stream and in the lane north of the cottages; but they are so cut up by numerous minor dip-faults as to assume the character of a fault-breccia on a large scale, and any attempt to make out a succession is futile. The *Atrypa-flexuosa* limestone is seen in the lane north of the cottages, and has the same character as at Skelgill; but no fossils were found here. The *Dimorphograptus-confertus* Beds occur in the stream by the bridge at the cottages, and contain numerous well-preserved specimens of *Monograptus revolutus*, Murch. The Middle Skelgill Beds are seen in many places, and the fossils of most of the zones can be collected in an admirable state of preservation, as the beds in this faulted tract have escaped to a great extent the effects of cleavage. In the wood west of the cottages a small exposure of the *aloniensis*-zone occurred and yielded an excellent specimen of *Proëtus brachypygus*, n. sp. Beyond the wood the stream runs through a few fields to a small spinney called Redding Coppice, and there receives a tributary from the west, whilst the main stream flows from the south-west. In the main stream, just above the point of junction with the tributary, the black bands of the *crispus*-zone occur, and the fossils at this point are in a better state of preservation than in any other exposure of this zone which we have met with. They include:—

Monograptus crispus, *Lapw.*
—— exiguus, *Lapw.*
—— pandus, *Lapw.*
—— discus, *Törnq.*
—— Hisingeri, *Carr.*
Cyrtograptus? spiralis, *Gein.*
Retiolites Geinitzianus, *Barr.*
—— perlatus, *Nich.*, var.
Petalograptus palmeus, *Barr.*
—— ——, var. tenuis.
Peltocaris.

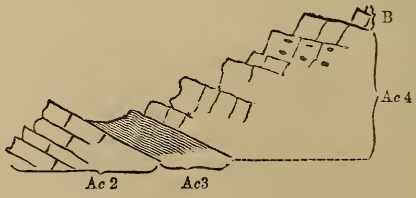
Higher Browgill Beds occur further up the stream. Just west of this point a great dip-fault shifts the beds five sixths of a mile to the south, and the pale shales of the Browgill Beds are seen in a beck coming down the hill from the west, just south of Sunny Brow. Here they are of no great interest, and although several exposures of Browgill Beds and occasional patches of the Skelgill Beds are seen between here and the Coniston Valley, no section of particular interest is found till Coniston Waterhead is reached. There are some exposures of Skelgill Beds in a stream near the Waterhead Hotel; but the best sections occur further west.

Yewdale Beck.

Just east of the Waterhead Hotel another great north-and-south fault, ranging down Coniston Lake, shifts the beds to the north a distance of nearly a mile, and accordingly we again meet with the Stockdale Shales in Yewdale Beck, which flows through the Yewdale Valley west of Tarn Hows Wood, in a south-westerly direction, and consequently parallel with the strike of the beds, which between Sunny Brow and Broughton Mills is north-east and south-west instead of east-north-east to west-south-west. At this point are some saw-mills, which are about half a mile north of Coniston church; and above the weir belonging to these mills the *Dimorphograptus-confertus* beds are seen striking slightly obliquely across the stream, and are again met with some yards higher up after crossing a meadow. There is an apparent thickness here of at least 50 feet; but an examination of the beds suggests much repetition. They occur in a series of lenticular masses, so as to produce a simulation of false-bedding, and the beds are extremely indurated, the lamination-planes being marked with minute wrinklings, which render the fossils, abundant enough, generally undeterminable. We recognized *Monograptus revolutus*, Kurck, and *M. tenuis*, Portl. A strike-fault ranges along the south-east bank of the stream and brings the Middle Skelgill Beds against the *Dimorphograptus*-beds, cutting out the lower portion of the middle group, so that the zones of *Monograptus fimbriatus*, *Encrinurus punctatus*, *Monograptus argenteus*, and part of the zone of *Phacops glaber* are absent. The upper part of the *Phacops-glaber* zone is seen passing into the *convolutus*-beds, of the usual appearance, and containing the usual fossils; but the summit of this bed is not seen at any accessible point, and, indeed, the next beds we were able to examine were those belonging to the zone of *Acidaspis erinaceus*, which were seen passing up into the Browgill Beds.

Following the beck to the cluster of houses known as the Far End another exposure is reached where the beck turns sharply to the south-south-east, and the Stockdale Shales leave the beck and

Fig. 5.—*Section at Far End, Yewdale Beck.*
(Scale 12 feet to 1 inch.)



strike across the drift-covered country in the direction of the railway-station. At this turn of the stream the above section is met with (fig. 5). The *Ampyx*-zone (4 feet seen) is succeeded by the *spinigerus*-zone (2 feet thick, but somewhat crushed), which yielded, to a brief search,

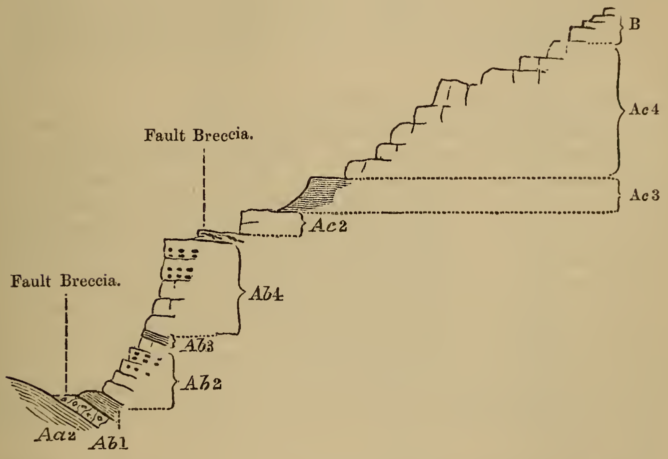
Monograptus spinigerus, *Nich.*	Diplograptus Hughesii, *Nich.*
—— distans, *Portl.*	

Two calcareous nodular bands of the ordinary kind occurred near the top of the *erinaceus*-zone, which shows the usual passage into the Browgill Beds, and is here 10 feet thick.

Mealy Gill.

Half a mile after leaving Yewdale Beck the Stockdale Shales are again met with in Church Beck, where this stream is joined by a tributary coming from the south-west known as Mealy Gill, and a good section of the shales is exhibited in a wooded gully through which the latter runs, and is found just above the bridge over which a siding from the railway-station is carried.

Fig. 6.—*Section in Mealy Gill.* (Scale 12 feet to 1 inch.)



The lowest beds seen are on the north-west bank of the stream, as seen in fig. 6, which shows a restored section taken from different parts of the gill, so as to exhibit all the zones which we have detected here in the Skelgill Beds. The Lower Skelgill Beds occupy a great part of this bank, but in one place a fragment of the *fimbriatus*-zone occurs in which the fossils are beautifully preserved. They include:—

Monograptus fimbriatus, *Nich.*	Petalograptus ovato-elongatus, *Kurck.*
—— leptotheca, *Lapw.*	Climacograptus normalis, *Lapw.*
Rastrites peregrinus, *Barr.*	
Diplograptus sinuatus, *Nich.*	

In most cases, however, the usual strike-fault runs up the bed of the stream, and the Middle Skelgill Beds are developed only on the right bank. About halfway between the railway-bridge and a waterfall which flows over the smashed Lower Skelgill Beds is a precipitous cliff-section on the right bank, and at the base of this a few feet of much-broken shale of the *fimbriatus*-zone occur above the fault, having a gentler dip than the Lower Skelgill Beds of the opposite side of the stream.

A*b* 2. Above these *fimbriatus*-shales about 4 feet of mudstone of the *Encrinurus-punctatus* zone can be measured; but the junction with the *fimbriatus*-shales is not seen.

A*b* 3. The most interesting feature of this gill is the occurrence therein of the *argenteus*-zone, as this is the only section other than the typical one in which we have found it. It is a little thinner than at Skelgill, being only 6 inches thick, and is more strongly cleaved than at that place; but in the centre runs the remarkable pale green streak, one quarter of an inch thick, which is also found at Skelgill at a distance of 7 miles in a direct line.

Owing to the cleaved nature of the rock fossils are difficult to procure; but we found

Monograptus argenteus, *Nich.*
—— leptotheca, *Lapw.*
—— cyphus, *Lapw.*
Diplograptus sinuatus, *Nich.*
Petalograptus ovatus, *Barr.*

The first-named occurs in considerable quantity.

A*b* 4. Six feet of the zone of *Phacops glaber* is seen above the *argenteus*-zone. It has the usual calcareous nodular bands, as has the *punctatus*-zone in this section. A fault is seen above this with what are apparently some of the *convolutus*-shales crushed in the fissure in one place; but the next zone which is well developed is

A*c* 2, the zone of *Ampyx aloniensis*, so that the *convolutus*-zone, the Barren Band, and the *Clingani*-band are here cut out.

At the waterfall the section is similar, the very top of the *Encrinurus-punctatus* zone only is found above the fault, and this is succeeded by the *argenteus*-zone, which is close to the stream at the head of the fall, and is succeeded by some *Phacops-glaber* mudstones, after which the second fault brings the zone of *Ampyx aloniensis* against these.

A*c* 3. The *spinigerus*-shales of normal character, but somewhat crushed, 2 feet thick, but possibly some crushed out altogether. They contain abundance of *Monograptus spinigerus*, Nich., along with *M. lobiferus*, M'Coy, *M. distans*, Portl., *Diplograptus tamariscus*, Nich., &c.

A*c* 4. The zone of *Acidaspis erinaceus* is from 8 to 10 feet thick so far as can be seen, and the mudstones pass up into the Browgill Shales.

The beds of the last two zones are seen on the moorland on the right bank and a turn in the stream causes the beds of the *erinaceus*-zone to strike into the stream, where the Browgill Beds overlie them. Twenty-one feet of pale green shales are succeeded by a black band

1 inch thick, which is greatly hardened, and is probably the band containing *Monograptus turriculatus*, Barr.; but we could obtain no fossils therefrom. About 8 feet of pale green shales overlie this, and then several black bands like those of the *crispus*-zone are interstratified with the pale shales; but they too have had their fossils obliterated.

A little to the south-west of the section just described the beds are shifted somewhat to the north by a dip-fault, and the line of outcrop of the Skelgill Beds may be followed by a line of depression, along which runs Braidy Beck, a tributary of Mealy Gill, to a pool of water known as Boo Tarn, and then onward alongside the Walney Scar road, and over a peat-moss to Torver Beck, which is a mile and a quarter to the south-west of the section last described. Along the whole of this distance frequent exposures of the Browgill Beds are seen on the moorland; but there is no feature of any interest to record.

Torver Beck.

This stream runs from Goat's Water at right angles to the strike of the beds. West of the large flag-quarry of Tranearth the depression above mentioned crosses the beck, and there is certainly a strike-fault across the stream here, as there is little space in which no rock is exposed, and a considerable amount of the Coniston-Limestone series and nearly all the beds of the Skelgill group are unseen.

To the east of the fault the section shown in fig. 7 is seen.

Ac 3. The *spinigerus*-zone is the lowest band visible. The beds are much broken against a minor fault which crosses the stream transversely, and a dip-fault also runs on the north-east side of the beck, displacing the beds of the *erinaceus*-zone. Above the small transverse fault are two or three feet of the *spinigerus*-shales, which are here blacker than is usually the case, and contain fossils preserved in relief,

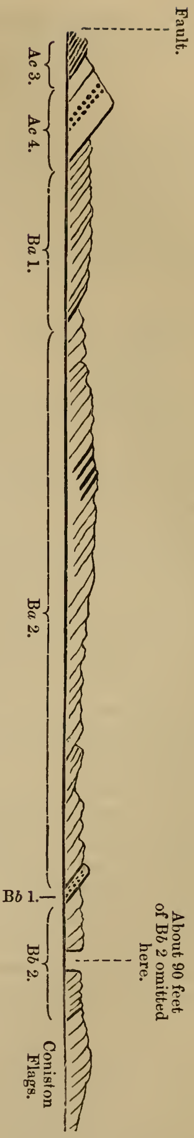


Fig. 7.—*Section in Torver Beck.* (Scale 48 feet to 1 inch.)

a mode of occurrence somewhat unusual among the shales of this zone. The fossils are:—

Monograptus spinigerus, *Nich.*	Monograptus lobiferus, *M'Coy.*
—— crassus, *Lapw.*	Diplograptus tamariscus, *Nich.*
—— jaculum, *Lapw.*	Petalograptus palmeus, *Barr.*

Ac 4. These shales pass up into the mudstones of the *Acidaspis-erinaceus* zone. These are seen on the right bank of the beck, just above a wall, and bend round so as to occur with a slightly different strike on the left bank. They are 10 feet thick, and contain two bands of calcareous nodules near the centre, separated by about a foot of mudstone. Fossils are common between these nodular bands, and we have obtained here

Lindstrœmia, sp.	Phacops elegans, *Boeck & Sars.*
Acidaspis erinaceus, n. sp.	Leptæna quinquecostata, *M'Coy.*

All these forms are found abundantly, the *Acidaspis* usually in fragments, and perfect specimens are rare. These *erinaceus*-beds are shifted to the north-west for a distance of about ten paces by the dip-fault, and there come down to the stream, as the fault has now entered the bed of the stream.

The beds of the last zone pass up into the pale shales of the Browgill group, and there is a tolerably complete section of this group to the base of the Coniston Flags; but as the beds are much disturbed exact measurement is impossible. We find the following development of these beds:—

B*a* 1. Fifteen or twenty feet of ordinary pale shale, surmounted by a thin seam of hard grey shale one inch thick, in which we obtained *Monograptus turriculatus*, Barr., in a bad state of preservation; but this is sufficient to show that these beds belong to the *turriculatus*-zone.

B*a* 2. About 10 feet of pale shale, surmounted by 20 feet of black shales interstratified with pale bands, as is usual in the *crispus*-zone, and specimens of *Monograptus crispus* occurred here. About 20 feet of pale shale come on above this. These are the beds of the *crispus*-zone.

B*b* 1. A pale band with calcareous nodules 2 or 3 feet thick, forming as usual the base of the Upper Browgill Beds.

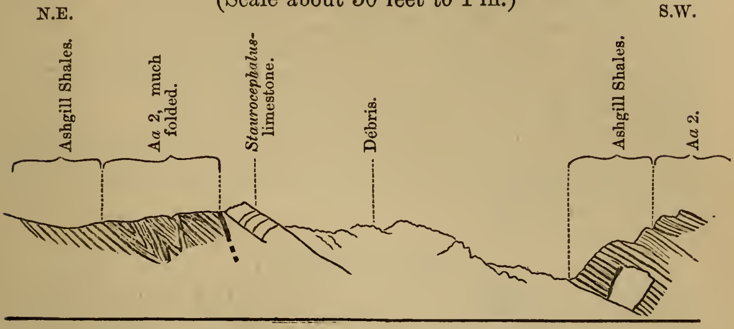
B*b* 2. These uppermost beds of the Browgill group are less stained than usual, being mostly green, and contain the hard fine-grained grit-beds. Over 100 feet of these beds seem to be developed, so that the Browgill Beds in this section are about 200 feet in thickness. They pass up in the ordinary way into the Brathay Flags, below a waterfall. This and the section at Stockdale are the only two sections along the main line of outcrop which afford a fairly complete exhibition of the whole of the Browgill Beds.

Ashgill.

The usual depression is continued from Torver Beck to Ashgill Quarry, about two thirds of a mile to the south-west.

The section in the quarry is shown in fig. 8.

Fig. 8.—*Section across Ashgill Quarry.*
(Scale about 50 feet to 1 in.)



The *Dimorphograptus*-beds are seen in the face of the quarry resting on the Ashgill Beds, the *Atrypa-flexuosa* limestone being here crushed out. They are hard, ferruginous, well-laminated, grey-black shales, of glossy appearance, and with Graptolites, including *Monograptus revolutus*, Kurck, in a very indifferent state of preservation. *Dimorphograptus confertus* seems to occur here, but the shales are strongly cleaved, and sufficiently large pieces cannot be obtained to show the whole of any individual Graptolite. No higher beds of the Skelgill series occur.

In the south-west corner of the quarry a fault, which runs slightly obliquely to the strike, brings the *Dimorphograptus*-beds once more against the lowest part of the Ashgill Shales—the *Staurocephalus*-limestone. They are here seen to be affected by a series of folds, which causes reduplication of the shale. This is the clearest section we have seen exhibiting this feature; but we feel convinced that these shales are repeated often many times upon themselves all the way from Yewdale Beck to Appletreeworth Beck. Below the quarry no rock is seen for a considerable distance; but at the tail of what was once an island (though the south-western branch of the stream is now dry), about halfway between the quarry and Ashgill Bridge, the black shales of the *crispus*-zone crop out in the stream, associated with the usual pale shales. The fossils here are in a very tolerable state of preservation and include:—

Monograptus crispus, *Lapw.*
—— exiguus, *Nich.*
—— pandus, *Lapw.*
—— discus, *Törnq.*

Monograptus griestonensis, *Nicol.*
—— Hisingeri, *Carr.*
Retiolites Geinitzianus, *Barr.*
Petalograptus palmeus, *Barr.*

The *Retiolites* occurred only in the highest band visible. The whole thickness is about 20 feet. Just above Ashgill Bridge the calcareous nodular band forming the base of the Upper Browgill Beds is seen, the intervening ground being covered with drift. A few feet above the calcareous band and on the other side of the bridge are some light shaly beds, stained pink, with a thin pebbly seam a quarter of an inch thick, about 7 inches from the summit. The pebbles are only about the size of a pea and are well rounded; and we mention this band as it is the only one which we have found in the whole Stockdale-Shale series which has any coarse material in it. Above this is a considerable thickness of pale shale with hard grits belonging to the Upper Browgill Beds; but the junction with the Lower Coniston Flags is not seen.

The depression caused by the Skelgill Beds or by the strike-fault runs in a south-westerly direction from this over a low col to the head of Appletreeworth Beck, which is reached in about one sixth of a mile from Ashgill.

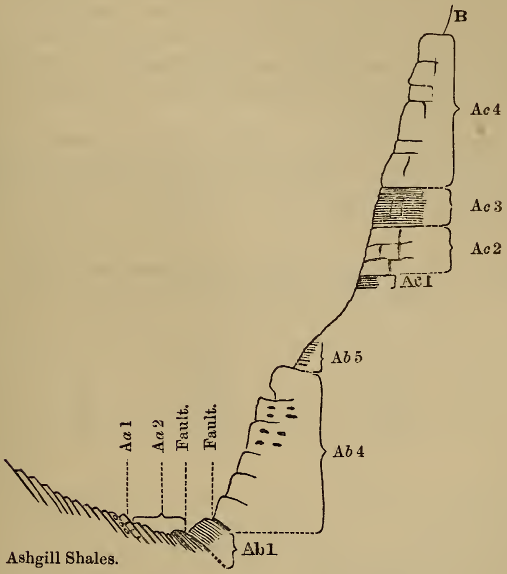
Appletreeworth Beck.

Sections in the Stockdale Shales are exhibited at intervals for over a mile between the head of the beck and Appletreeworth Farm. The stream runs in a south-westerly direction and along the strike of the beds, and we find the Lower Skelgill Beds as usual continuous with the Ashgill Shales and occurring generally on the north-west (right) bank of the stream, whilst the middle and upper beds and the Browgill group are developed on the left bank. No section of any importance need detain us until we reach a precipitous cliff a few hundred yards above the farm on the left bank of the stream. The section across the stream at this point is shown in fig. 9. The dip-slope is composed of the usual Ashgill Shales, at the summit of which is a band of large calcareous nodules, as at Skelgill. Immediately above this is a very thin, dark grey, calcareous band crowded with Ostracods and inseparable both from the Ashgill Shales below and the *Atrypa-flexuosa* beds above. We do not know whether to refer this Ostracod-bearing band to the lower or upper group; but it is a matter of no importance, as there is not the slightest doubt that a passage exists here. The *Atrypa-flexuosa* band is only 3 inches thick and consists of the usual light grey, mottled, pyritous limestone. The usual strike-fault runs down the stream; but at the upper end of the cliff it occurs some way off the stream on the left bank, and allows of the occurrence of about 15 feet of *Dimorphograptus*-shales with *Monograptus revolutus*, &c., in a small cliff. These beds are probably folded on themselves, as they exhibit a simulated false-bedded structure. At the point where our section is taken, lower down the stream, the fault has come to the bed of the stream, and below the line of section the thickness of beds rendered invisible by the fault increases, and higher and higher beds are brought against the Lower Skelgill Beds, until at last all the zones of the Middle and Upper Skelgill Beds are faulted out and the Browgill Beds rest against the Lower Skelgill Beds.

A little above the *Atrypa-flexuosa* band a thin bed occurs in the *Dimorphograptus*-shales, with small Brachiopods and *Turrilepas*, as at Skelgill.

A*b* 1. The shales of the *fimbriatus*-zone are seen on the line of our section at the base of the left bank of the stream; they contain

Fig. 9.—*Section across "Cliff" Appletreeworth Beck.*
(Scale 12 feet to 1 inch.)



Monograptus fimbriatus, Nich., *Petalograptus ovato-elongatus*, Kurck, *Rastrites peregrinus*, &c. A subsidiary disturbance is seen above them, removing the *Encrinurus-punctatus* zone, the *argenteus*-zone, and part of the zone of *Phacops glaber*; but about 10 feet of the latter remains with its nodular bands.

A*b* 5. The *convolutus*-beds are seen, but the exposure is not a very good one. We obtained *Monograptus convolutus*, His., *Rastrites hybridus*, Lapw., *Diplograptus tamariscus*, Nich., &c. A gap occurs here with no rock visible.

A*c* 1. The next rock above this gap belongs to the *Clingani*-band, a few inches of shale occurring with *Monograptus Clingani*, Carr., &c.

A*c* 2. The *aloniensis*-zone consists of blue mudstones about 2 feet 6 inches thick.

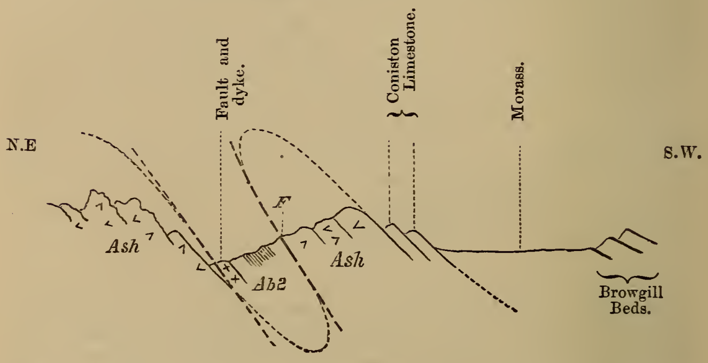
A*c* 3. The *spinigerus*-zone consists of many-coloured shales 2 feet 6 inches thick, with abundance of *Monograptus spinigerus*, Nich., *Monograptus distans*, Portl., and the accompanying fossils, and is succeeded by

Ac 4. The *Acidaspis-erinaceus* mudstones, 10 feet thick, and passing up into the Browgill Beds above. The latter are difficult of access, and we were unable to work them in detail.

We have not collected carefully from the beds of this section, as they are much cleaved, and the fossils are very indifferent; we merely obtained sufficient to satisfy ourselves of the identity of the beds, and did not work the Trilobite-bearing mudstones at all for fossils; indeed, with the exception of one or two cases, we have left these latter untouched, knowing the time required, as a general rule, to extract any fossil remains from these comparatively barren bands, and knowing also that the identification of the Graptolitic zones above and below each mudstone band is sufficient to fix the position of the mudstone.

It has been stated that the strike-fault increases in intensity towards the south-west; and just below Appletreeworth Farm the disturbance has been so great as to produce the remarkable section seen in fig. 10.

Fig. 10.—*Section of Farm, Appletreeworth Beck.*
(Scale about 200 feet to 1 inch.)



We have here a faulted synclinal of Skelgill Beds brought beneath the Coniston Limestone by a fault which is shown, by the way in which it crosses the beck, to have a reversed hade. We would suggest that the fold which here brings up the Coniston Limestone has decreased to such an extent higher up the gill that there it only affects the Lower Skelgill Beds, repeating them upon themselves, a supposition for which we have given other evidence. If this is really the case, and the facts favour it strongly, the great apparent thickness of the Lower Skelgill Beds in Yewdale Beck and other sections is illusory.

The syncline of Skelgill Beds rapidly dies out to the south, as does the Coniston-Limestone anticline to the north, and the main outcrop of the Skelgill Beds proceeds to the south-west in a line continuous with the morass represented at the right-hand side of our section. Though the depression can be followed to Broughton Mills, no exposure of the Skelgill Beds occurs, and only a few isolated patches of the Browgill Beds are seen.

Before leaving this section at the farm, we would add some further particulars.

The ashes seen in the extreme left of the section belong to a massive volcanic series, probably at this point below the whole of the Coniston-Limestone series, though, as is well known, similar beds are elsewhere intercalated between different members of the Coniston Limestone.

Along the fault between the volcanic rocks and the Skelgill Beds a felsite-dyke has burst, and this has baked the Graptolitic shales to a deep crimson colour. Specimens of this crimson shale can be obtained with the usual fossils of the *Dimorphograptus*-zone, viz.:—*Dimorphograptus confertus*, Nich., *Monograptus revolutus*, Kurck, and *M. tenuis*, Portl. The crimson shales appear to be included in the felsite; and on the hillside south-east of the stream the normal black *Dimorphograptus*-shales are seen dipping to the south-east, and containing the same fossils as the altered portions. Above this is a gap with no rock seen, and further up the hill we meet with volcanic rocks like those at the extreme north-west of the section, succeeded on the brow of the hill by normal Coniston Limestone. This dips towards the morass seen in the right-hand portion of the section, and under this either the Skelgill Beds are concealed or the strike-fault which so frequently affects them runs, for on the other side of the morass the ordinary Browgill Beds are found passing into the normal Coniston Flags of the district without any further disturbance.

It has been observed that no section of any importance in the Stockdale Shales occurs between this point and Broughton Mills. Below the Mills an alluvial tract occupies the position of the Stockdale Shales; and although the underlying Coniston-Limestone series is traceable at intervals along this line of strike as far as Millom, no further exposure in the Stockdale Shales is found on the west side of the Duddon estuary, though there is room in some places for the beds of this series between the Coniston Limestone and the Coniston Flags; but in such cases the rock is concealed by alluvium.

Poaka Beck.

On the east side of the Duddon estuary an anticlinal fold brings up the Stockdale Shales in the neighbourhood of Dalton-in-Furness. In a paper in the 'Quarterly Journal' for 1878 one of us refers to two specimens of *Stricklandinia lirata* as coming from the Browgill Beds of Rebecca Hill. The shale in which they occur is certainly like that of the Browgill Beds, but we have never met with any Brachiopods other than extremely minute ones in these beds, and we think it possible that the specimens preserved in the Woodwardian Museum have really been derived from one of the mudstone-bands of the Skelgill Beds.

The only section in the Skelgill Beds of the east side of Duddon which is known to us occurs in Poaka Beck, just above Bridge End, 3 miles to the north of Dalton-in-Furness. The section seen there is shown in fig. 11.

Fig. 11.—*Section at Poaka Beck.* (Scale 12 feet to 1 inch.)

A*a* 2?. The lowest beds seen are greatly disturbed, rusty-brown, weathered shales, with many ill-preserved Graptolites, of which the only one which we could determine was *Climacograptus normalis*, Lapw.; but from the general appearance of the shales we believe them to belong to the zone of *Dimorphograptus confertus*.

Above these shales is a considerable fault-breccia and then a space in which no rock is seen.

A*b* 6?. Two feet four inches of blue mudstone, the Barren Band or the summit of the *Ampyx-aloniensis* zone.

A*c* 1?. Very dark ferruginous mudstones, 8 inches thick, with few Graptolites. We obtained *Monograptus distans*, Portl., *M. Nicoli*, Harkn., and *Climacograptus normalis*, Lapw. We believe this to represent the *M.-Clingani* band, but did not see that fossil therein.

A*c* 2?. Pale green mudstone 1 foot thick. Either the *Ampyx-aloniensis* zone or a pale band interstratified with the *M.-spinigerus* shales.

A*c* 3. Banded black, grey, and pale mudstones, 2 feet 2 inches in thickness, with abundance of *Monograptus spinigerus*, Nich., and undoubtedly representing the *M.-spinigerus* zone.

A*c* 4. Blue mudstones of the *Acidaspis-erinaceus* zone, of which only the lowermost 6 feet are visible. At some distance above this on the hillside is a quarry in B, the pale shales of the Browgill Beds, which here contain unusually large cubic crystals of pyrites and many small undeterminable Brachiopods. There is little doubt that the bed we have marked A*c* 1 is really the *M.-Clingani* band, otherwise the *spinigerus*-zone would be of unusual thickness here, and we shall eventually point out that the beds tend to thin out in this direction.

The whole section is of little interest, and we call attention to it as it is the most southerly exposure of the Stockdale Shales in the Lake-district proper.

Having now traced the beds along their line of outcrop in the Lake-district, we may proceed to a description of the beds in those outlying districts to which we have previously referred.

Swindale Beck, Knock.

If we continue the line of strike of the Stockdale Shales in an east-north-easterly direction from Shap Wells it would pass near the village of Knock, under the Pennine Chain, and close to this village the Stockdale Shales actually do occur in Swindale Beck, and in a tributary which enters it from the north-east. In this tributary (Rundale Beck) some very black shales are seen, evidently separated from the surrounding rocks by a series of faults, and having a strike discordant with that of the adjacent rocks.

The beds are lithologically like those of the *fimbriatus*-zone, and though we have not found the characteristic fossil of that zone, there is no doubt from an examination of the appended list that the beds really do appertain to it.

Monograptus leptotheca, *Lapw.*
—— cyphus, *Lapw.*
—— tenuis, *Portl.*
—— triangulatus, *Harkn.* ?
Rastrites peregrinus, *Barr.*
Petalograptus ovatus, *Barr.*
Diplograptus sinuatus, *Nich.*
—— Hughesii, *Nich.*
Climacograptus normalis, *Lapw.*

In Swindale Beck itself the highest Lower Palæozoic beds seen belong to the Lower Coniston Flags, and between these and the Coniston-Limestone series is a tolerable section of the Browgill Beds, though the section is by no means complete. The Upper Browgill Beds do not appear prominently, but the two Graptolitic zones of the Lower Browgill Beds are well represented. We could find no representatives of the Skelgill Beds in the main beck, and the lowest Graptolitic zone which is in the pale shales is only 1 inch thick; but it has yielded a great number of beautifully preserved specimens of *Monograptus turriculatus*, Barr., along with *Monograptus lobiferus*, M'Coy, and *Rastrites distans*, Lapw., showing that we have here the *turriculatus*-zone. This band occurred just above the level of the water, and is now almost entirely worked out, though the stream will doubtless cut a new exposure in time. A few feet above it are a series of black shales interstratified with pale shales and yielding the fossils of the *crispus*-zone. We have obtained from them:—

Monograptus broughtonensis, *Nich.*
—— pandus, *Lapw.*
Cyrtograptus Grayæ, *Lapw.*
Cyrtograptus ? spiralis, *Gein.*
Retiolites Geinitzianus, *Barr.*
—— cf. macilentus, *Törnq.*

The Browgill Beds are here traversed by some mica-trap dykes, and the pink staining has affected the Lower Browgill Beds, a circumstance of unusual occurrence.

Spengill.

The existence of an anticlinal in the neighbourhood of Sedbergh was long ago described by Professor Sedgwick, and as a result of this fold we meet with beds of the Stockdale-Shale series in many of the streams in the valley of the Rawthey, on the north side of the anticlinal. By far the most complete of these sections is exhibited in a stream which runs down from Spengill Head in a southerly direction towards the farm of High Haygarth, about 5 miles east of Sedbergh, on the road to Kirkby Stephen. We shall speak of this stream as Spengill, a name which is more euphonious than that by which the stream is designated on the map of the Ordnance Survey. About 2 miles north of High Haygarth the main stream coming from the north is joined by a feeder from the north-west, and at the point of junction of the two streams a cart-track crosses a little ford. Above this an admirable exposure of the Stockdale Shales is afforded by a deep gully, and still further up in the bed of a shallower valley. A few yards below the ford a hard calcareous grit, one foot in thickness, was first pointed out to one of us by Professor Hughes; it occurs in a weathered exposure on the heathery right bank of the stream, by the side of the cart-track, and here fossils can readily be procured from it. In the Woodwardian Museum

Cornulites.
Orthis protensa, *Sow.*
—— biforata, *Schloth.*
Strophomena siluriana, *Dav.*
Meristella crassa, *Sow.* ?

are preserved from this bed. The first four of these are found in the Ashgill Shales. This grit-band is succeeded by several feet of leaden-blue, cleaved, non-laminated mudstones, with abundance of *Phyllopora Hisingeri*, M'Coy, and *Myelodactylus*, sp. They are quite similar to the Ashgill Shales of other areas, and we believe that both these shales and the grit are referable to that horizon.

Some little distance above the ford a very hard limestone band, 6 inches thick, is exposed on the right bank of the stream just above water-level. It contains a few Crinoids, and we would take this as the base of the Stockdale Shales and as the equivalent of the *Atrypa-flexuosa* band. The section of the Stockdale Shales of Spengill is given in fig. 12, where this bed is marked A*a* 1.

A*a* 2. Immediately above this limestone are black, crushed shales with *Climacograptus normalis*, Lapw., and *Monograptus revolutus*, Kurck, and they pass into a series of greyish-black, very fissile shales, much stained with ferruginous matter, and crowded with Graptolites. These shales are seen on both sides of the stream. These beds dip at an angle of about 60° to the north, and the direction of dip is maintained by the overlying beds, though its amount becomes less in the upper portions of the Stockdale-Shale series. There is a thickness of at least 25 feet of the blackish shales, and as the dip is fairly constant it does not appear that the beds have been repeated. The fossils in these shales are :—

Monograptus revolutus, *Kurck.*
—— tenuis, *Portl.*
—— attenuatus, *Hopk.*
—— Sandersoni, *Lapw.*
Dimorphograptus confertus, *Nich.*
—— Swanstoni, *Lapw.*
Diplograptus vesiculosus, *Nich.*
—— modestus, *Lapw.* ?

It will be seen that this list is identical with that of the Graptolites from an exposure of the *confertus*-shales a little below the Upper Bridge, Skelgill. As at that place, *Dimorphograptus confertus* is rare and *D. Swanstoni* abundant. We think it highly probable that the seams containing the abundance of *D. confertus* are crushed out from between these shales and the underlying calcareous band; but it is just possible that they may be on a higher horizon. Whatever be the relative position of the shales in which *D. confertus* is abundant and *D. Swanstoni* apparently absent, and those in which the latter is abundant and the former rare, there can be no question that the two belong to one Graptolitic zone, occurring always between the zone of *Atrypa flexuosa* or of its equivalent, that of *Diplograptus acuminatus*, and the zone of *Monograptus fimbriatus*.

Ab 1. The actual passage between the *confertus*-shales and the succeeding Graptolitic shales is not seen; but we are disposed to believe that the junction is here an unfaulted one. If so, this is the only locality we have met with where such is the case.

There is no great gap between the *confertus*-shales and the overlying beds, and the two are dipping with perfect conformity. Moreover if a strike-fault did occur here, we believe we should find traces of it, as it is usual to get a considerable breccia developed at that point, and this breccia would almost certainly be exhibited. Be that as it may, the measured thickness of the

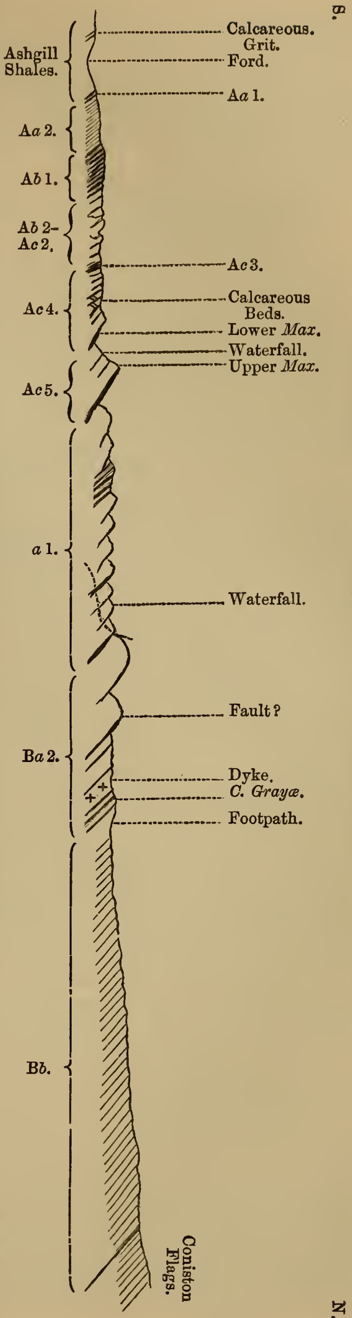


Fig. 12.—*Section in Spengill.* (Scale about 75 feet to 1 inch.)

confertus-beds is greater here than in any other section except where we have indications of repetition.

The shales above the *confertus*-beds are also Graptolitic and are very similar to the *confertus*-shales in lithological characters, being fissile and having a ferruginous staining due to weathering. The fossils are different:—

Monograptus fimbriatus, *Nich.*
—— gregarius, *Lapw.*
—— attenuatus, *Hopk.*
—— triangulatus, *Harkn.*

Rastrites peregrinus, *Barr.*
Diplograptus sinuatus, *Nich.*
Climacograptus normalis, *Lapw.*

There is no doubt that these are the shales of the *fimbriatus*-zone, and another argument of the succession being here complete is furnished by the fact that *Monograptus triangulatus* is here very abundant, while elsewhere it is rare. It will be eventually seen that this form marks the lowest horizon of the representatives of the Middle Skelgill Beds in other areas.

The beds of the Middle Skelgill group above the *fimbriatus*-shales are extremely disturbed in this section. They are best exposed on the left bank of the stream. A crush occurs between the *fimbriatus*-shales and the succeeding beds, which are blue mudstones, probably forming the top of the zone of *Phacops glaber*, as the succeeding shales appear to belong to the *convolutus*-zone. In this case the zones of *Encrinurus punctatus* and *Monograptus argenteus* are entirely faulted out. As our time for examining this section was limited, and the Middle Skelgill Beds seemed to be of normal character, we did not work them out in detail, a task of some difficulty owing to their extremely folded condition. The beds which we refer to the *convolutus*-zone have the ordinary appearance of the shales of that horizon, and exhibit the very marked olive-brown staining which distinguishes its deposits. Above them are some blue mudstones; but a considerable fault occurs between the Middle Skelgill Beds and the lowest exposed beds of the Upper Skelgill group. The section of the representatives of this group is one of considerable importance, and we worked it carefully.

Ac 3. Returning to the right bank, an angle of the bank is seen jutting out into the stream at some little distance below a waterfall. In this angle some very black shales, interbedded with lighter bands, appear for about 2 feet below the overlying mudstones. The uppermost black shales have well-preserved Graptolites, including:—

Monograptus spinigerus, *Nich.*
—— distans, *Portl.*
—— leptotheca, *Lapw.*
—— lobiferus, *M'Coy.*

Rastrites urceolus, *Richter.*
Diplograptus Hughesii, *Nich.*
Climacograptus normalis, *Lapw.*

Monograptus spinigerus occurs in the usual numbers, and indicates that this is undoubtedly the zone characterized by that species.

The succeeding beds of the Upper Skelgill group offer interesting differences from those of other sections.

Ac 4. No less than 30 feet of blue mudstones overlie the shales of the *spinigerus*-zone, without the intervention of any Graptolitic shales. They contain many calcareous, nodular bands towards the summit, forming an impure limestone some 10 feet in thickness. Our attention was first called to this calcareous band by Prof. Hughes, and a number of fossils occur in it. We have found:—

Lindstrœmia, sp.	Cheirurus bimucronatus, *Murch.*
Favosites.	Illænus Bowmanni, *Salt.*
Phacops elegans, *Bœck & Sars.*	Leptæna quinquecostata, *M'Coy.*

The band strongly resembles that of the zone of *Acidaspis erina ceus* as seen at Torver Beck, and there is no doubt as to the identity of the two deposits, though the characteristic *Acidaspis* has not yet turned up in the Spengill section.

Ac 5. The zone about to be described has been found in no other section in the district, and indeed there is no doubt that it is absent all along the line of outcrop of the Stockdale Shales in the central district, as we have frequent opportunity of seeing a passage from the underlying beds into the Browgill group.

A waterfall in the Spengill section here separates the lower ravine which we have described from an upper one, and this waterfall is found to be determined by a mass of hard blue mudstones, which also form cliffs on each side. The cliff on the right bank is seen to form a projecting cornice, and immediately under this cornice 4 inches of very hard black Graptolitic shale occur. From this band we extracted a number of specimens of *Rastrites maximus*, Carr., and one example of *Monograptus jaculum*, Lapw. No doubt other fossils also occur; but the spot is a dangerous one, on account of the broken nature of the rock forming the cornice. These beds strike across the stream at the foot of the waterfall, and are again seen at the foot of the cliff on the left bank; but pieces of the shale are difficult to extract here. The characteristic *Rastrites maximus* was found here also. The blue mudstones above this band are 24 feet thick, and at the summit of them and forming the top of the cliff over which the water falls is another band, also 4 inches thick, very similar to the former, though lighter in colour, and likewise containing numerous examples of *Rastrites maximus*. We speak of these black shales with the intervening mudstones as constituting the *Zone of Rastrites maximus*.

The upper black band of the *R.-maximus* zone is at once succeeded conformably by the lowermost Browgill Beds.

B*a* 1. The Browgill Beds occupy the upper ravine, which runs obliquely to the strike, so that we meet with a generally ascending succession, until we reach a second waterfall, which marks the upper end of this ravine. Above the *R.-maximus* beds are nineteen feet of ordinary pale green shale, after which we meet with four feet of pale green and bluish-grey bands with some thin dark seams. These are well seen on the right bank of the stream a little above water-level, and a few yards above the waterfall, where they are extremely conspicuous, owing to the stripes of the different-coloured bands. Above them are three feet of unstriped bluish-grey beds, on the top of which rests a thickness of four inches of dark-grey, rather ferruginous shales, with *Monograptus turriculatus*, Barr., and *Rastrites distans*, Lapw., the former abundant and the latter rare. This bed is seen on both sides of the stream. Above it one foot two inches of pale shale separate it from another greyish-black band, four inches thick, with :—

Monograptus turriculatus, *Barr.*	Rastrites distans, *Lapw.*
—— Hisingeri, *Barr.*	

One foot six inches of pale shale intervenes between this and a third black band, also four inches thick, in which we saw no *M. turriculatus*, but *Rastrites distans* was procured therefrom.

These two upper zones are well seen at the top of a buttress of rock on the left bank of the stream, and also higher up, to the east of the waterfall. Fourteen feet of pale shale ensue, and then a concretionary grey bed about three inches thick, in which are no fossils, is met with, forming the extreme summit of the cliff over which the water falls at the head of the second ravine. This band may be traced along the lateral cliff on the right bank of the stream, and below the waterfall, and the ascending section followed from it. The beds below it are inaccessible on this side, until near the bottom of the dip where the banded rock already noticed occurs. Above the concretionary band we find in this cliff:—Green beds with fine shaly bands, many of them stained pink, and in some of which Graptolites are seen, but are poorly preserved, seventeen feet.

This shaly bed, five inches thick, and stained pink, crowded with *Monograptus turriculatus*, Barr., contains also :—

Monograptus rectus ?	Retiolites obesus, *Lapw.*

A total thickness of 61 feet 4 inches has been measured between the top of the zone of *Rastrites maximus* and this point, and we refer these beds to the zone of *Monograptus turriculatus*.

B*a* 2. Above the waterfall, the stream runs through a shallow valley, with exposures on each bank, but mainly on the left one. Above the uppermost *turriculatus*-band, we get thirteen feet of green beds with fine shaly bands, at the top of which there is reason to suppose the existence of a fault.

A thin blue-black band, sometimes stained pink, is next met with, and this yielded :—

Monograptus pandus, *Lapw.*	Cyrtograptus ? spiralis, *Gein.*
—— griestonensis, *Nicol.*	

This band is much baked by a dyke, and fossils are difficult to extract. It is two or three inches thick.

Two or three feet of pale shale lie between this Graptolitic shale and a felsite sheet breaking along the bedding and having a thickness of about twenty feet, and above it are twelve feet of ordinary pale shales somewhat baked; the next band seen is very fine, grey, gritty shale three inches thick, one bedding-plane of which is covered with the beautiful little *Cyrtograptus Grayæ*, Lapw., and the bed yielded also *Monograptus pandus*, Lapw., and a specimen of *Retiolites Geinitzianus*, Barr. The band is seen on the grass- and heath-covered left bank, and is succeeded by sixteen feet of ordinary pale shales, after which is a gap crossed by a footpath, in which there is room for about ten feet of rock.

We refer the beds between the uppermost *M.-turriculatus* band and this point to the zone of *Monograptus crispus*. There is little doubt that some of the beds are faulted out, either along the line of the dyke or below it, or both, and the shales which are seen are so baked that delicate forms like *Monograptus crispus*, if they originally occurred there, would be obliterated. The other species found all belong to the *crispus*-zone, and the zone is found in the immediate vicinity of this gill. About forty-four feet of rock has been measured belonging to this zone.

At the same time we would refer to the grey gritty shale as the *Cyrtograptus-Grayæ* band, believing it to form the very uppermost part of the *crispus*-zone. Above the footpath the section is less continuous.

B*b*. We believe that the footpath marks the line of separation between the Lower and Upper Browgill beds.

Above the footpath are fourteen feet of green shales, passing up into a great mass of red shales, with interstratified grits, which become greenish grey towards the summit, the whole having a thickness of about 160 feet. We have obtained no fossils from this portion, which is quite similar to the Upper Browgill group as developed elsewhere.

It will be seen that the Browgill Beds of this locality have a total thickness little short of 300 feet, and for diversity of character and richness of fossils they are unexcelled in any other part of the district.

River Rawthey.

The following Graptolites from black shales interstratified with pale green shales are preserved in the Woodwardian Museum; they were collected by Prof. Hughes at Rawthey Bridge and undoubtedly belong to the *crispus* zone:—

Monograptus exiguus, *Nich.*	Cyrtograptus spiralis, *Gein.*
—— pandus, *Lapw.*	Petalograptus palmeus, *Barr.*

The Browgill Beds are all well seen in Hebblethwaite Gill, on the south side of the Rawthey valley, and nearer Sedbergh than the last locality.

Professor Hughes has obtained *Monograptus turriculatus* from this stream, and we found bands with:—

Monograptus pandus, *Lapw.*	Petalograptus palmeus, *Barr.*
Cyrtograptus ? spiralis, *Gein.*	Retiolites Geinitzianus, *Barr.*

So that the two Graptolitic zones of the Browgill Beds appear to be here present.

Austwick Beck, near Settle.

The section here is described by Prof. Hughes in the 'Geological Magazine,' vol. iv., and one of us has given additional notes in the 'Geological Magazine,' dec. iii. vol. iv. The Bala Beds are succeeded here by a conglomerate of variable thickness, passing up into a limestone which contains Trilobites found in different zones in the Stockdale Shales; this limestone is immediately followed by the Lower Coniston Flags. Either the Skelgill Beds are absent, and the representatives of the Browgill Beds rest unconformably on the Bala Beds, or the conglomerate and succeeding limestone represent the whole Stockdale-Shale series. We shall revert to this question in the sequel.

Ribble Valley.

At Crag Hill, near Horton, Prof. Hughes describes a breccia-like limestone overlying the Coniston Limestone, in which he records the occurrence of *Favosites*. One of us has examined this.

There certainly is a strong resemblance between this limestone-conglomerate and the conglomerate of the valley, and the former like the latter occurs between the ordinary Coniston Limestone and the Lower Coniston Flags. We agree with Prof. Hughes therefore in referring the Crag-Hill calcareous conglomerate to the Stockdale-Shale series.

Teesdale.

We complete our description of the Stockdale Shales of the north of England by referring to the probable existence of Browgill Beds at Cronkley Mill, as described by Messrs. Gunn and Clough.

The accompanying figure (fig. 13) gives a general section through the Stockdale Shales, showing the full development of the zones. The thickness of the whole series varies from two hundred and fifty feet to over four hundred feet, the latter thickness being that of the beds in the Sedbergh district.

We append a table (pp. 726–729) showing the distribution of the fossils in the different zones of the Stockdale Shales.

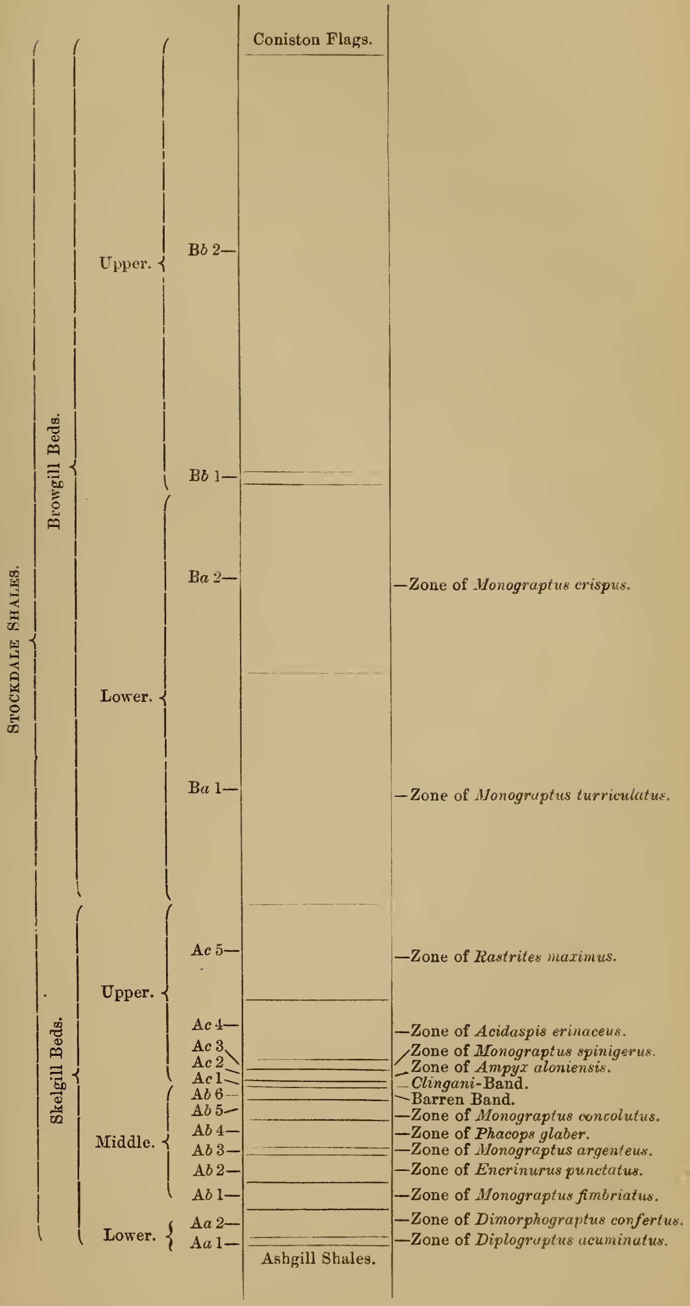
§ V. Comparison with corresponding Beds in other Areas.

One noticeable feature about the Stockdale Shales is the intercalation of non-Graptolitic beds containing more highly organized fossils with the Graptolite-bearing shales. We are thus enabled to compare the series with the corresponding Graptolitic beds of other areas as well as with non-Graptolitic ones.

We will commence with a comparison of our beds with the corresponding Graptolitic shales of the other areas, and we naturally start with those of the South of Scotland, which have been so admirably and clearly worked out by Professor Lapworth.

It is hardly necessary to insist on the similarity between the Skelgill Beds and the Birkhill Shales, and between the Browgill Beds

Fig. 13.—*Vertical Section of Stockdale Shales.*
(Scale about 1 inch to 50 feet.)



and those of the Gala group; indeed, Prof. Lapworth has himself shown the relationship of these in his papers on "The Moffat Series"* and "On the Geological Distribution of the Rhabdophora"†; but a most remarkable similarity between the Scotch and North of England beds becomes apparent when we come to compare the zones of each, for not only are the fossil contents of the zones of the two areas remarkably similar, but a decided resemblance can be traced when we compare the lithological characters.

The Lower Skelgill Beds are flaggy beds like those of the zones of *Diplograptus acuminatus* and *Diplograptus vesiculosus* at the base of the Birkhill Shales.

The Middle Skelgill Beds resemble the *Monograptus-gregarius* zone, not only in the blackness of the shales, but also in the development of interstratified mudstones containing calcareous nodules.

The Upper Skelgill Beds resemble the zones of *Monograptus spinigerus* and *Rastrites maximus* in that the beds are generally of a lighter colour than those of the underlying zones.

The Grits and pale Shales of the Browgill Beds are comparable with similar rocks in the Gala group.

Comparing the zones in detail:—

1. The zone of *Diplograptus acuminatus* at the base of the Birkhill Shales is like the same zone at the base of the Skelgill Beds. Both are slightly calcareous flaggy shales, and the two fossils found in the *acuminatus*-zone at Browgill, viz. *Diplograptus acuminatus*, Nich., and *Climacograptus normalis*, Lapw., both occur in the Birkhill zone. The two other species found in the Birkhill zone, *Dimorphograptus elongatus*, Lapw., and *Diplograptus vesiculosus*, Nich., have not yet turned up in the Lake-district; but possibly a further search will result in their discovery.

2. The zone of *Diplograptus vesiculosus*, Nich., is represented by the zone of *Dimorphograptus confertus*, Nich. In both areas the beds consist of black flagstones.

Of the fossils found in this zone in the Lake-district, *Monograptus tenuis*, Portl., *M. attenuatus*, Hopk., *Dimorphograptus elongatus*, Lapw., *Diplograptus vesiculosus*, Nich., and *Climacograptus normalis*, Lapw., are also found in the corresponding Birkhill zone.

Monograptus revolutus, Kurck, *M. Sandersoni*, Lapw., *M. leptotheca*, Lapw., *Dimorphograptus confertus*, Nich., *D. Swanstoni*, Lapw., and *Diplograptus longissimus*, Kurck, have not been recorded from the Birkhill Shales, but they are mainly found on one horizon in the Lake-district, and may eventually turn up in the Scotch area.

3. The zone of *Monograptus gregarius*, Lapw., is undoubtedly represented by the zones of *Monograptus fimbriatus*, *M. argenteus* and *M. convolutus*, with their interstratified mudstones. In all these zones *Monograptus gregarius* is abundant, and it is practically limited to them, only one specimen having been discovered in the *Clingani*-band.

Of the thirty-three species of Graptolites found in these zones in

* Q. J. G. S. xxxiv. p. 337.
† Ann. & Mag. Nat. Hist. ser. 5, vol. iii. p. 39.

the Lake-district, at least twenty-one also occur in the *gregarius*-zone of Scotland, whilst only four species found in the latter aefa are absent from the representative zones in the Lakes. The lithological resemblances have been already commented upon, and there can be no hesitation in correlating the Middle Skelgill Beds of the Lake-district with the zone of *Monograptus gregarius* of Scotland.

4. The succeeding subzone of *Petalograptus cometa* is not differentiated in our area. It appears to have thinned out; it is partly replaced by a mudstone band, or was formed contemporaneously with the uppermost portion of the *convolutus*-beds of the Lake-district; the latter contain *cometa* rarely, and all the forms found in the *cometa*-zone are also found in our *convolutus*-zone, with the exception of *Rastrites capillaris*, Carr., which is recorded in Prof. Lapworth's list at page 323 of his paper on the Moffat Series, but not in the general list at page 328.

5. The *Clingani*-band, which occurs at the base of the *spinigerus*-zone in Scotland, may be compared with our *Clingani*-band. Three of the four forms mentioned by Prof. Lapworth are found also in our band.

The Birkhill zone of *Monograptus spinigerus*, on the whole, bears a very striking resemblance to the zone containing this form in abundance in the Lake-district. The *Clingani*-band at Eldinhope Ruin is succeeded by 6 feet of soft greenish-grey shales without Graptolites. At Skelgill it has above it the 4 feet 6 inches of blue mudstones constituting the zone of *Ampyx aloniensis*. The many-coloured shales above are quite comparable to those of the upper part of the *spinigerus*-zone in Scotland, even to the occurrence of the lozenge-shaped patches on the rough surfaces of the harder beds. Of the Graptolites from the *spinigerus*-zone of the Lake-district, ten out of sixteen are found in the Birkhill Shales, or more than this if we count also those of the *Clingani*-band in our area, whilst three which occur in Scotland have not yet been found in our zone.

6. The abundance of *Rastrites maximus* in our uppermost zone of the Skelgill Beds shows its relationship to the highest zone of the Birkhill Shales. A fuller examination of the beds in the Spengill section would almost certainly result in the discovery of a more abundant fauna.

It is noticeable that the *maximus*-beds occur in pairs in Scotland; and Prof. Lapworth states that at Craigmichan only one pair is visible. We also have a pair of these beds separated by many feet of mudstone.

In this comparison we have not yet insisted upon what we consider of far more importance than the occurrence of a certain percentage of fossils common to the corresponding zones (for the percentages would certainly be considerably increased after further work), namely, the great abundance of the characteristic forms of the different zones in the corresponding order, We find:—

In the Lake-district:—	In the Moffat area:—
1. *Diplograptus acuminatus*, common.	*D. acuminatus*, common.
2. *D. vesiculosus*, common. *D. acuminatus* has disappeared.	*D. vesiculosus*, common. *D. acuminatus* has disappeared.
3. *Monograptus gregarius*, common. *Diplograptus vesiculosus*, very rare.	*M. gregarius*, common. *D. vesiculosus*, very rare.
4. Lack of abundance of *Petalograptus cometa*.	Abundance of *P. cometa*.
5. Abundance of *Monograptus spinigerus*. 1 sdecimen of *M. gregarius*.	Abundance of *M. spinigerus*. Absence of *M. gregarius*.
6. Abundance of *Rastrites maximus*.	Abundance of *R. maximus*.

Furthermore, our divisions of the Middle Skelgill Beds are, at any rate partially, suggested by an examination of the mode of occurrence of the Graptolites in the *gregarius*-zone of Scotland. Prof. Lapworth states that in his district "*Monograptus Sandersoni* (Lapw.) and *M. fimbriatus* (Nich.) are unknown above the central line" of the *gregarius*-zone. In our country they are found in the *fimbriatus*-zone, but not above it. Again, "*Monograptus triangularis* (Harkn.) occurs only in the neighbourhood of the nodule-band" which is near the centre; with us it is only found in the *fimbriatus*-zone. Lastly, "neither *Rastrites peregrinus* nor *Diplograptus vesiculosus* reach the summit of the group." We find the former confined to the *fimbriatus*-zone, and the latter rarely occurring in it, and not higher.

Passing now to the Browgill Beds, we find at first sight less striking resemblances in the more minute subdivisions; but this is partly due to the reference of the peculiar *Monograptus discus* to *M. turriculatus*, Barr., and the inclusion of *Monograptus pandus* with *M. priodon* in the published lists. Prof. Lapworth, in his paper on the "Geological Distribution of the Rhabdophora," p. 41, gives a list of fossils from the Gala group. Twenty-one species are there enumerated, of which twelve have been discovered by us in the Browgill Beds, and of these twelve only two pass down into the Skelgill Beds, and these only occur in the upper group. We cannot find any record of the separation of the *turriculatus*-beds as a distinct zone; they undoubtedly form such in the Lake-district, and the two forms *Monograptus turriculatus*, Barr., and *Rastrites distans*, Lapw., appear to be strictly limited to it in that area.

The fossils of the zone of *Monograptus crispus* are mostly found in the Gala group, and *M. exiguus* is a very common form in the two areas. In Prof. Lapworth's paper on "The Girvan succession" * the equivalents of the Gala group, the "*Crossopodia*-group," are divided into Lower Penhill Shales with *Monograptus exiguus* &c., Middle Penhill flags and greywackes, in which the Graptolites of the preceding beds recur, and Upper Penhill mudstones, or *Grayœ*-beds, with *Cyrtograptus Grayœ* and *Retiolites Geinitzianus*. It has already been pointed out that although we are unable to separate the *Grayœ*-beds and the beds with *Retiolites Geinitzianus* from the beds of our *crispus*-zone, we have found that they are limited to the upper

* Q. J. G. S. vol. xxxviii. p. 652.

part of it, and *Cyrtograptus Grayæ*, especially, occurs in such vast abundance in one seam at the very top of the *crispus*-beds, that we have thought fit to allude to this seam especially as the *Grayæ*-band.

Our comparison of the Stockdale Shales with the Birkhill and Gala groups renders unnecessary a minute comparison with the similar Graptolitic deposits in other areas. Such a comparison has already been successfuly instituted by Prof. Lapworth in his papers on the " Geological Distribution of the Rhabdophora " and on " The Moffat Series."

We merely proceed to add a few supplementary remarks, and in the first place call attention to some researches of the late Dr. Tullberg, published since the appearance of the above-mentioned papers of Prof. Lapworth. By Dr. Tullberg's early death science has been deprived of a most promising Graptolithologist and stratigraphical geologist, and his co-workers have lost a genial companion. In a paper " Om Lagerföljden i de Kambriska och Siluriska Aflagringarne vid Röstånga " * he suggests the following correlation of the beds of Scania and Scotland :—

Brachiopod-skiffer with *Phacops mucronatus*, Brongn.	= Lower Birkhill ?
Lobiferus-skiffer.	= Upper Birkhill ;

and divides the latter as follows :—

Shales with *Monograptus spinigerus*, Nich., *Diplograptus* (*Petalo.*) *cometa*, Gein., *M. gregarius*, Lapw., *M. cyphus*, Lapw., *M. Sandersoni*, Lapw., *Rastrites peregrinus*, Lapw., *Climacograptus normalis*, Lapw., &c.	=	Zone of *M. gregarius.* „ „ *D. cometa.* „ „ *M. spinigerus.*
Shales with *Rastrites maximus*, not found in Scania.	=	Zone of *Rastr. maximus.*
Retiolites-skiffer.		
Shales with *Monograptus crispus* &c.	=	Gala and Grieston.
The latter succeeded by		
Shales with *Cyrtograptus Murchisoni* &c.	=	Wenlock.

A fuller comparison is made by the same author † in a paper published in 1882. At the summit of the beds which he describes as appertaining to the Lower Silurian group or Ordovician, he places a dark-grey shale with *Diplograptus*, n. sp., and *Climacograptus scalaris*, Lapw., and an absence of *Monograptus*. This succeeds the zone of *Phacops mucronatus*, Ang., and most probably represents our zone of *Diplograptus acuminatus*. The *Rastrites*-beds are placed at the base of the (Upper) Silurian and are divided as follows :—

At the base is the zone of *Monograptus cyphus*, containing also a *Dimorphograptus*. We shall presently give reasons for concluding that this represents our zone of *Dimorphograptus confertus*.

* Geol. Föreningens i Stockholm Förhandl. 1880, No. 59, Bd. v. No. 2.

† " Skånes Graptoliter : Part I.," Sveriges Geologiska Undersökning, Ser. C, no. 50.

His succeeding zone of *Monograptus gregarius*, containing also *Monograptus fimbriatus* and *Rastrites peregrinus*, is in the position of our zone of *M. fimbriatus*, which contains the same forms.

Above this is Tullberg's zone of *Monograptus convolutus*. It also contains *M. lobiferus*, *M. leptotheca*, *M. communis*, *Rastrites peregrinus*, and *Petalograptus folium*. All these forms occur in the *convolutus*-zone of the Lakes, except *R. peregrinus*, which is replaced by *R. hybridus*; there seems therefore to be no representative of the thin *argenteus*-zone in Scania.

The zones of *Petalograptus cometa* and *Monograptus spinigerus* are united together in Scania. Tullberg finds in this zone *M. spinigerus*, *M. intermedius* (=*discretus*, Nich.?), *M. Clingani*, *M. argutus*, *Diplograptus Hughesii*, and *Petalograptus cometa*.

The zone of *Rastrites maximus* is doubtfully represented. He refers certain shales seen at Tosterup with *Monograptus turriculatus* and *M. crispus* to this horizon; but we believe that this and the succeeding zone of *Monograptus uncinatus* are really referable to the Browgill Beds. The beds which Tullberg compares with the Gala Group of Scotland, and which are therefore comparable with the Browgill Beds, are (in ascending order):—The zones of *Cyrtograptus Grayæ*, Lapw., *Cyrtograptus? spiralis*, Gein., *Cyrtograptus Lapworthi*, Tullb., forming the base of his *Cyrtograptus*-beds. We feel doubt as to whether these are all separable from the two upper zones of his *Rastrites*-beds.

In our district *Cyrtograptus? spiralis* occurs abundantly below the band with *Cyrtograptus Grayæ*; but as the former species apparently ranges into the Wenlock Beds of Britain, it probably occurs in the representatives of the Gala Group, both above and below the band with *Cyrtograptus Grayæ*.

We just now alluded to the zone of *Monograptus cyphus* as being probably referable to our zone of *Dimorphograptus confertus*. In 1881, Baron Kurck described a section at the quarry of Bollerup which exhibits the zone of *Monograptus cyphus* and the base of the zone of *Monograptus gregarius*. From the *cyphus*-beds he records:—

Monograptus cyphus, *Lapw.*	Diplograptus tamariscus, *Nich.*
—— revolutus, *Kurck.*	—— longissimus, *Kurck.*
—— attenuatus, *Hopk.*	Climacograptus undulatus, *Kurck.*
Dimorphograptus Swanstoni, *Lapw.*	Discinocaris Brouniana, *Woodw.*
—— cf. Swanstoni, *Lapw.*	

The second *Dimorphograptus* is described and figured, and agrees in every particular with a species described and figured by one of us in the Society's Journal for 1868*, under the name of *Diplograptus confertus*, Nich. The discovery of more perfect specimens has shown us that this is in reality a *Dimorphograptus*, and we have named the zone in which it occurs after it. In the *cyphus*-zone at Bollerup five species of Graptolites out of the eight recorded are found also in our zone, and we have no hesitation in asserting that the *Dimorpho-*

* "On the Graptolites of the Coniston Flags," Q. J. G. S. vol. xxiv. p. 526.

graptus-confertus zone of the Skelgill Beds is the British representative of the *cyphus*-zone of Bollerup. The lowest band of the *gregarius*-zone which is seen in the quarry at Bollerup contains *Monograptus triangulatus*, Harkn., and this is a reason for supposing that the section at Spengill, where beds with *Monograptus triangulatus* occur immediately above the *confertus*-zone, is complete.

In a former paper read before the Society in 1880*, one of the writers in describing the shales at the base of Barrande's band E. e. 1. in Bohemia, expressed the opinion that "not only does this zone represent the Birkhill Shales, but it can, like them, be divided into a series of subzones characterized by various species of Graptolites," though the actual succession of the zones was not determined. This opinion is justified by the researches of Dr. Tullberg who, in his 'Skånes Graptoliter,' when discussing the theory of "Colonies," gives the results of his examination of a series of specimens from these colonies, and from the corresponding beds at the base of E. e. 1. He recognizes the following zones:—

1. Zone of *Monograptus gregarius*, 2. Zone with *M. leptotheca* and *M. lobiferus*, 3. Zone with *M. turriculatus*, and 4. Zone with *Cyrtograptus? spiralis*, besides others of Wenlock and Ludlow age.

From Colonie Krejči he recognizes *Rastrites peregrinus*, *Monograptus gregarius*, *M. fimbriatus*, *M. triangulatus*, *M. lobiferus*, *M. leptotheca*, and *Climacograptus scalaris*.

This corresponds with the fauna of his *gregarius*-zone in Scania and of our *fimbriatus*-zone.

In Colonie Haidinger he finds *Monograptus lobiferus*, *M. triangulatus*, *M. convolutus*, *M. communis*, *Climacograptus scalaris*, *Diplograptus*, cfr. *folium*, *D. tamariscus*, and *Rastrites peregrinus*. He compares this with the fauna of his zone of *Monograptus leptotheca*, corresponding with ours of *M. convolutus*.

In Colonie D'Archiac he has recognized *Monograptus lobiferus* and *M. triangulatus* in one bed, *M. proteus* in another, and *Cyrtograptus? spiralis* in a third, and supposes that here are representatives of his zones of *M. leptotheca*, *M. runcinatus*, and *Cyrtograptus? spiralis*.

To these we would add the occurrence of the zones of *Monograptus spinigerus* and either *Rastrites maximus* or *Monograptus turriculatus* in the Colony of Hodkoviček, and of the former zone in the colonies D'Archiac and Haidinger.

Two specimens of shale from the Lower Palæozoic Beds of Hof, Bavaria, are mounted on a tablet in the Woodwardian Museum. These pieces contain the fossils of our zone of *Monograptus fimbriatus*, viz:—

Monograptus fimbriatus, *Nich.*	Rastrites peregrinus, *Barr.*
—— attenuatus, *Hofth.*	Diplograptus modestus, *Lapw.*
—— tenuis, *Portl.*	—— vesiculosus, *Nich.*
—— gregarius, *Lapw.*	Climacograptus normalis, *Lapw.*

A comparison of the non-Graptolitic fauna of the Stockdale Shales

* Q. J. G. S. vol. xxxvi. p. 604.

with that of similar beds is more difficult, but fully confirms the conclusions come to after examining the Graptolites.

The different forms of Phyllocarida might have been considered along with the Graptolites, as they occur in Graptolitic rocks.

Of these *Discinocaris* is found in the Birkhill Shales and their Bohemian equivalents; whilst *Peltocaris aptychoides* and *Aptychopsis Lapworthi* are also found in the Birkhill Shales.

Of the other fossils, *Encrinurus punctatus*, *Calymene Blumenbachii*, and *Leptæna quinquecostata* are found both in Llandovery Beds and in beds above and below them, whilst *Favosites mullochensis* occurs in the Llandovery Beds of the Girvan area.

Phacops elegans has been recognized in the Mulloch-Hill Sandstones (a specimen from this locality being preserved in the Woodwardian Museum) and in the corresponding beds at the Gasworks, Haverfordwest. It also occurs in the Gala Beds of Devil's Bridge, Aberystwith, where it was found some years ago by one of the authors.

In Norway it is common in the sandstones of stage 5β of Kjerulf, which correspond in lithological characters and fossil contents with the Mulloch-Hill Beds and the beds at the Gasworks, Haverfordwest. Dr. Schmidt records it from the Raiküll Beds of Russia, where it is found along with other fossils occurring in Kjerulf's 5β, and *Diplograptus esthonus* *. All these beds are admitted to be of Llandovery age, with the exception of the Devil's-Bridge deposit, which is compared with the Gala Group, and therefore indirectly with the Tarannon Shales. That some of the Trilobites occurring in our Skelgill Beds do pass up into the Browgill Beds seems clear from the occurrence of many of them in the calcareous band immediately below the Coniston Flags in Austwick Beck, and we have one specimen of *Phacops elegans* var. *glaber* from the Browgill Beds of Browgill, though its exact positiou was not ascertained. More Trilobites would probably be found in the Browgill Beds of the central area if the calcareous bands were further examined; for the carbonate of lime of these beds was probably derived from Trilobites, as in the case of the Trilobitic mudstones of the Skelgill group.

The examination of the occurrence of *Phacops elegans* shows that it is a Llandovery-Tarannon form, and it has not been recorded from earlier or later formations.

Phacops mucronatus, Brongn., occurs in the Llandovery Beds of Haverfordwest, and in the Upper Brachiopod Schists of Westrogothia. It is different from the form which occurs in the Ashgill Shales, and which seems to correspond with the form from the Lower Brachiopod Schists.

Orthoceras araneosum, Barr., is found in the Wenlock and Ludlow rocks of Britain, and in the beds of Barrande's Stage E, in Bohemia †.

The other fossils are new. Of these, *Ampyx aloniensis* belongs to

* Schmidt, 'Revision der ostbaltischen silurischen Trilobiten,' p. 43; and Q. J. G. S. vol. xxxviii. p. 526.

† Blake, 'British Fossil Cephalopoda,' p. 124.

a genus which is common in Ordovician rocks. Two species are, however, found in the Silurian, viz.:—*Ampyx parvulus*, Forbes, from the Lower Ludlow rocks of Ludlow, and *Ampyx Roualti*, Barr., from the corresponding beds of Bohemia. It is interesting to find another form which reduces the gap between the newest *Ampyx* of the Ordovician rocks and these diminutive forms of the Ludlow series.

The fauna that most nearly approaches our Trilobite fauna of the Stockdale Shales is found in the Tarannon Shales of the Onny River. A number of Trilobites from these beds are preserved in the Museum of Practical Geology, and we have examined the specimens; they are:—

Phacops glaber, n. var.	Calymene Blumenbachii, *Brongn.*
Cheirurus bimucronatus, *Murch.*	Illænus Thompsoni, *var.*
Encrinurus punctatus, *var.* arenaceus.	Proëtus nasiger, *Edgell*, MSS.
	Acidaspis dama, *Fl. & Salt.*?

The first form occurs also in the Stockdale Shales; of the two latter, *Proëtus nasiger* is very near our *P. brachypygus*. It appears to possess a narrower tail, and larger basal lobes to the glabella. The specimen doubtfully referred to *Acidaspis dama* is near to our *A. erinaceus*. The glabella and free cheek only are seen in the specimens of the Museum of Practical Geology. The former is smooth, and the lobes are slightly different from our forms. The discovery of more specimens may prove that these distinctions are merely varietal in the case both of the *Proëtus* and of the *Acidaspis*.

VI. Remarks on the Bearings of the Results.

The Stockdale Shales have been shown to consist of from two-hundred and fifty to four hundred feet of alternating black and green shales, blue mudstones, often calcareous, and greenish-grey grits.

They are divisible into a Lower group, the Skelgill Beds, consisting mainly of dark Graptolite-bearing shales alternating with lighter mudstones, which are entirely devoid of Graptolites except where they pass into the adjacent Graptolitic shales, and an Upper group having from twice to three times the thickness of the Lower one (but probably formed much more rapidly, and therefore not of anything like the actual importance of the Lower group), consisting chiefly of green and purple shales with interstratified grit-bands, and a few insignificant seams of dark Graptolite-bearing shales.

The Stockdale Shales are furthermore capable of being divided into a series of zones, recognizable by their lithological characters and also by their contained fossils, these zones undergoing only a slight alteration in thickness and character when traced across the country.

The lowest zone has been shown to be entirely conformable to the Ashgill Shales below, there being no discordance of strike, and the same bed of the Ashgill Shales being seen, in several remote sections, with the lowest band of the Stockdale Shales resting directly upon it.

The apparent unconformity by which one of us was formerly deceived turns out, on examination, to be due to the existence of strike-faults. Although there is absolute conformity between the lowest beds of the Stockdale Shales and the highest beds of the Ashgill Shales, the palæontological break is complete, and it is at this point that we draw the line of division between the Ordovician and Silurian systems.

Similar conformity is seen between the top of the Stockdale-Shale series and the base of the succeeding Coniston Flags, the passage being rather a gradual one, however, instead of very sudden, as in the case of the junction at the base.

In all the sections described, with the possible exception of that at Spengill, the Lower Skelgill Beds are seen to be separated from the higher beds of the group by a strike-fault; and minor faults of a similar nature are seen at higher levels. That this fault does not remove any great thickness of rock is shown :—

(1) By the frequent juxtaposition of the zones of *Dimorphograptus confertus*, and *Monograptus fimbriatus*, which contain several species in common.

(2) More particularly by the resemblances between the above-named zones and two similar zones in the Moffat area, the zones of *Diplograptus vesiculosus*, Nich., and *Monograptus gregarius*, Lapw., and the relationship of the *M.-fimbriatus* zone to the lower portion of the latter. As the succession is complete in the Scotch region, no important zone of rock can be concealed in that of the Lake-district.

The occurrence of a fault of such wide extent exerting so little effect is remarkable, and we can offer proofs that the fault itself is not an ordinary one, but that it runs generally with the bedding, and that it is rather of the nature of a crush. The soft Skelgill Beds lie between the harder rocks at the summit of the Ordovician series and those of the Browgill group, and they must have given way during a process of stretching, which caused the upper beds adhering to the Browgill rocks to move over the lower beds, which have been shown to adhere to the Ashgill Shales. That such stretching has taken place is proved by the following facts :—

(1) The behaviour of the strike-fault with the beds. The outcrop of the Skelgill Beds is a sinuous one, being bent into V's in crossing the valleys, the apex of the V's always pointing down the valleys, as the dip of the beds is always greater than the slopes of the valley-bottoms. Moreover, these valleys are usually occupied by great dip-faults, which displace the beds laterally. In such cases the strike-fault would be found to affect different beds when crossing these valleys and shifted by the dip-faults, whereas it is always found to run along the narrow band between the Ashgill Shales and the Browgill Beds.

(2) The Skelgill Beds are often entirely, or almost entirely, removed. When developed in force, there is usually a section cut through them, and the narrow depressions occurring between the different sections and marked by a line of swamp, are bounded by

the Ashgill Shales or Coniston Limestone on one side and by the Browgill Beds on the other. The Ordovician and Silurian rocks usually approach so near to each other that it may readily be seen that there is no room for more than a small portion of the whole thickness of the Skelgill Beds in the interval. The beds are therefore now preserved as a series of lenticular patches, the main portion of the line of outcrop being occupied by little or none of them.

(3) Smaller crushes of a similar nature can often be traced in a single section, as, for instance, in the case already described of the crushing-out of the shales of the *argenteus*-zone below the Upper Bridge at Skelgill.

(4) The hade of the fault may frequently be actually seen coinciding with the dip of the beds; and the line of fracture is often marked by broken shale frequently further crushed into a black mud. Where the dip of the beds is different on the two sides of the fault, this is probably a local phenomenon produced by the rucking up of the lower beds during the process of sliding.

(5) The occurrence of a quartz-vein along the line of movement just below the promontory near the Upper Bridge at Skelgill, which coincides with the dip of the beds there, and the upper surface of which is completely polished by the shales which rest on it, shows that these shales have been moved over the nearly horizontal vein at this point.

(6) At the Lower Bridge at Skelgill it can be shown that some 15 feet more rock has been removed by the fault in the great cliff just above the bridge than in the section just below it. Between these two sections is the small dip-fault already described, which has a downthrow to the E.N.E. on the S.S.W. side of the stream, and one to the W.S.W. on the N.N.E. side. This looks as if the tearing away of the additional 15 feet of rock had been limited by a pre-existing joint-plane, and that on this side of the joint the lower and upper rocks had moved towards each other to fill up the gap so produced.

(7) It is probably due to the same process of stretching that the great dip-faults, which frequently cause a lateral shift of the Coniston Limestone to an extent of over half a mile, rapidly die out to the south, so that beds some two miles south of the Coniston-Limestone outcrop are scarcely affected.

It has been stated above that the beds of the Stockdale-Shale series undergo little alteration in character and thickness when traced laterally. This is well shown by the remarkably exact correspondence between the shales of the zone of *Monograptus argenteus*, as seen in Skelgill and Mealy Gill. There is, however, a certain amount of lateral change, as shown clearly by the great thickening of the Browgill Beds between Stockdale Beck and Spengill. The variations of thickness, so far as we have been able to ascertain them by measurement, are indicated in the following table:—

	Poaka Beck.	Appletree-worth Beck.	Torver Beck.	Mealy Gill.	Yewdale Beck.	Skelgill.	Stile End.	Browgill.	Spengill.
Crispus-zone to *Turriculatus*-band	...	...	30′ (about)	...	...	...	...	21′ 8″	15′ seen
Turriculatus-bands and included mudstones	...	...	1″	1″?	...	...	...	1″	35′ 4″
Pale shale below lowest *Turriculatus*-band	...	...	15′–20′	21′?	...	...	...	21′	26′
Maximus-zone	...	...	0	...	0	0	...	0	24′ 8″
Erinaceus-zone	6′ seen	...	10′	8′ seen	10′	10′	...	10′	30′ (about)
Spinigerus-zone	2′ 2″	2′ 6″ (about)	2′ 3″	3′ (about)	2′	3′ 6″	...	2″ (about)	2′ seen
Aloniensis-zone	1′	2′ 6″ (about)	...	...	4′ seen	4′ 6″	...	1′ 5″	
Clingani-band	8″	...	...	...	...	1′	1′	3′	
Barren band	2′ 4″ seen	...	...	...	...	3′ 6″	2′ 10″	2′	
Convolutus-zone	...	...	...	...	...	7′ 9″	7′ 4″ seen	4′ seen	
Glaber-zone	...	10′ (about)	...	...	...	12′	...	...	4′–5′ seen
Argenteus-zone	...	...	...	6″	...	8″	...	...	
Punctatus-zone	...	...	...	4′ seen	...	5′	...	...	
Fimbriatus-zone	...	...	...	7′ 6″ seen	...	7′ 3″ seen	...	...	many feet
Confertus-zone	...	...	...	...	...	7′–8′ seen	...	1′ seen	about 25′ seen
Acuminatus-zone	...	3″	...	...	...	9″	...	2′ 6″	6″

An examination of this table shows a general thickening-out of the beds eastward. There are doubtless some errors in it, owing to difficulties of measurement; for instance, we feel that the thickening of the *Clingani*-band from one to three feet in crossing the valley of Long Sleddale is unlikely, and the apparent increase may be due to our having included shaly mudstones in this bed at Browgill.

Some of the variations may also be due to a greater compression of beds in one locality than in another, and to portions having been torn away without our detecting it, which is very possibly the case in some instances where the section is not very clean-cut. But with these allowances, the fact of a general thickening to the east remains apparent, and is especially marked in those beds which must have accumulated with considerable rapidity. The great increase in thickness of the zones of *Acidaspis erinaceus* and of *Monograptus turriculatus*, the appearance of new Graptolitic seams in the latter, and the incoming of the zone of *Rastrites maximus* in Spengill, illustrate this clearly. To what is this thickening eastward due?

It seems to suggest the existence of land in that direction; and we are inclined to connect this with the apparent unconformity in the Settle area, which possibly indicates the occurrence of land in that region during the formation of the Skelgill Beds, and during a portion of the period when the Browgill Beds were forming, though the *elegans*-limestone of Austwick Beck shows that that area was submerged, at any rate during the later portion of the Browgill times; but the calcareous conglomerate of Crag Hill may be actually at the base of the Coniston Flags, as the *elegans*-limestone has not been detected here.

We make this suggestion with diffidence at present; after a more detailed examination of other beds of this area, which we hope soon to accomplish, we shall be able to express an opinion upon this subject with greater confidence.

Another point to which any one who works in a series of beds like those which we have examined must have his attention called is the remarkable alternation of the Graptolitic Shales with other non-Graptolitic beds. To what is this due? to recurrent climatic change, or to difference in the character of the sea-floor? One of us has discussed this question in a paper which appeared in the 'Proceedings of the Cambridge Philosophical Society' (Proc. Camb. Phil. Soc. vol. vi. pt. ii.), and gives reasons which induce him to consider it as due to climatic change. Without entering into this question here, we would call attention to another difficulty. Is the apparent absence of Graptolites in the Trilobite-bearing mudstones, and of Trilobites in the Graptolitic shales, due to the migration of the latter organisms from the area during the formation of these shales, and to the disappearance of Graptolites from the area during the formation of the mudstones? or did the forms linger on in the area in diminished numbers during the period that was unfavourable to their existence? We cannot offer any satisfactory evidence on this point, but we believe that both events went to produce the observed results. We do find Graptolites rarely preserved in the mudstones, and though we have hitherto found no Trilobites in the Graptolite-shales, occasional Brachiopods and corals have turned up. In Dalecarlia one of us has seen Trilobites preserved in some of the Graptolite-bearing representatives of the Stockdale Shales. Such a lingering-on under unfavourable conditions would be admirably qualified to bring about that variation in the creatures which would account for the marked contrast between the fossil contents of beds separated only by a few feet of intervening rock.

On the other hand, the occurrence of a zone in Scania with an intermixture of the forms of the zones of *Petalograptus cometa* and *Monograptus spinigerus* tends to indicate that there may have been also migration from one region to another during a time unfavourable to the existence of a group of organisms in the former, and that in this way an intermixture of two faunas elsewhere separated would result, but our present experience tends to show that this is somewhat rare.

With regard to the age of the Stockdale Shales, we shall say little, as we consider the question fully settled. They are conformable to the Ordovician beds below and to the Wenlock beds above; and this indicates that they represent the two Llandovery subdivisions and the Tarannon shales, in other words that they belong to the series for which Professor Lapworth has suggested the name Valentian.

Our comparison of the beds with those of other areas entirely supports this view. The Birkhill Shales have been referred by Professor Lapworth to the Lower Llandovery, in his paper on "The Moffat Series." But the same author has also shown that the Gala Beds, the equivalents of our Browgill Beds, represent the Tarannon Shales; in which case, the Birkhill Shales and the corresponding Skelgill Beds must include representatives of both Lower and Upper Llandovery; and this is the view taken by Professor Lapworth, in his subsequently published paper on "The Geological Distribution of the Rhabdophora," where he describes the Birkhill Shales and Gala Group under the title "Valentian or Llandovery-Tarannon Formation."

The fossils of the Stockdale Shales support this to the fullest extent. Many of the Graptolites and of the higher organisms are exclusively limited to representatives of the Valentian formation in other areas, and there are very few which transgress the limits of this group.

The most important result of our researches is the additional evidence which we have furnished of the value of Graptolitic zones as a means of comparison of Lower Palæozoic rocks of distant areas. We have long looked with admiration on the remarkable results of Professor Lapworth's detailed researches upon these rocks, and have for many years been convinced of the importance of his results. We have watched with pleasure the adoption of his views and of his methods of working by the enthusiastic geologists of Scandinavia. We must confess, with disappointment, that we have frequently heard British geologists express themselves in words of hesitation concerning the importance of the Graptolitoidea as a means of advancing the comparative study of the stratified deposits, and we sometimes feel that Dr. William Smith's dictum as to strata identified by their organized fossils is little heeded in Britain, so far, at any rate, as the Lower Palæozoic rocks are concerned. If we have added a grain to the weight of evidence that has been accumulating in ecent years, as to the widespread uniformity of fossil-zones among these rocks, we have not laboured in vain.

§ VII. Description of Fossils.

The Graptolitic fauna of the Stockdale Shales is one which is sufficiently well known by the researches of Prof. Lapworth; and we have not added any new forms during our recent researches.

The other fossils are chiefly Trilobites, though a few Corals and Brachiopods also occur.

We append notes upon the new forms and those which have not hitherto been described from British deposits. The Trilobites are difficult to obtain in a good state of preservation, and it would probably require many years' patient collecting to obtain perfect specimens of all the forms. Under these circumstances we have refrained at present from minute descriptions, and have drawn up brief diagnoses, which will, we believe, be sufficient to enable others readily to recognize those forms which it was necessary for us to notice on account of their importance as indices to the various non-Graptolitic zones.

The Coral-fauna of the Stockdale Series is a very limited one, as regards both the variety of species represented and the number of individuals. The Upper Skelgill Beds have yielded an undeterminable species of *Lindstrœmia*, and a Monticuliporoid has been found in the *acuminatus*-zone in Skelgill. With these exceptions the known corals of the Stockdale Series are referable to the genus *Favosites*, and, mainly if not exclusively, to one species of the same, viz. *F. mullochensis*, Nich. and Eth. jun. This species occurs abundantly in the Silurian rocks of Ayrshire, at Mulloch Hill and at Woodland Point; and it is of not very uncommon occurrence in the zone of *Phacops glaber* in Skelgill.

Phacops (proper) elegans, Boeck & Sars. (Pl. XVI. figs. 1, 1 *a*, 2, 3, 3 *a*, 3 *b*.)

Trilobites elliptifrons, Esmark, "Om Nogle nye Arter af Trilobiter," Mag. for Naturv. Anden Række, Bd. i. p. 269.

Trilobites elegans, Sars & Boeck, Gæa Norvegica, p. 139.

Phacops quadrilineata, Ang. Pal. Suec. p. 12.

Phacops Stokesii, Nieszk. " Mon. Tril. d'Ostsee prov.," im Arch. für Nat. Liv- Ehst- und Kurl. ser. 1, Bd. i. p. 530.

Phacops latifrons, Eichw. Leth. Ross. vol. i. p. 1428.

Phacops elegans, Kjerulf, Veiviser, p. 20.

Phacops elegans, F. Schmidt, Rev. d. ostb. Tril. Mém. Acad. St. Petersb. sér. 7, Tome xxx. No. 1. p. 72.

Phacops elliptifrons, Törnq. "Undersökn. öfv. Siljans. Tril.," Sver. Geol. Unders. ser. C, no. 66.

We have compared the forms discovered in the Stockdale Shales with the figures of the Russian specimens, and with actual examples collected by one of us from the Llandovery rocks of Christiania, and they agree in every particular.

The species has frequently been confused with *Phacops Stokesii*, Milne-Edw., a form common in the Wenlock rocks. From this the present species differs in the shape and smoothness of the glabella, the possession of smaller eyes, and the convexity of the axis of the tail.

The incurved lower margin of the cheek possesses six cavities for the reception of the ends of the pleuræ (Pl. XVI. fig. 3 *b*). The interspaces between these increase in size anteriorly, as the posterior pleuræ, the ends of which are received by these, do not overlap one another so much as the anterior pleuræ, when the animal is rolled up. Indications of similar cavities are seen in a specimen of *Phacops Stokesii* from the Wenlock Limestone of Dudley, preserved in the Woodwardian Museum, and numbered $\frac{a}{887}$.

Hor. & Loc. Heads and tails of this species are common in the *Phacops-glaber* and *Ampyx-aloniensis* zones of Skelgill, the latter zone of Browgill, the *Acidaspis-erinaceus* zone of Torver Beck and Spengill, and the calcareous bed of Austwick Beck. It is a common Llandovery fossil in many parts of Britain and the continent.

Phacops (proper) elegans, var. nov. glaber. (Pl. XVI. fig. 4.)

Tail $\frac{1}{2}$ inch broad, $\frac{1}{4}$ inch long. Axis one fifth the width of the whole tail, tapering gradually, and extending about two thirds the length of the tail; marked with two very deep prominent furrows anteriorly, and four or five obscure ones posteriorly. Limb marked by two slight furrows on either side, the under surface exhibiting a thick recurved margin.

These broad tails are very abundant in one horizon of the Skelgill Beds, and less common in others. They are easily distinguishable, by their great breadth and extreme smoothness, from the tails of the typical *P. elegans*; but one or two intermediate forms would indicate that the present Trilobite is but a variety of the normal form.

A single head, apparently belonging to this variety, and differing from the ordinary form in the size of the eye and some details of the shape of the glabella, is too imperfect to figure.

The specimens indicate a Trilobite which, when complete, must have measured an inch and a half in length, thus greatly exceeding that of *Phacops elegans* proper.

Hor. & Loc. Common in the *glaber*-zone of Skelgill; rare in the *aloniensis*-zone of Skelgill and Browgill.

Phacops (Dalmannites) mucronatus, Brongn. (Pl. XVI. figs. 5, 6.)

Entomostracites caudatus, Wahl. Nov. Act. Soc. Upsal. vol. viii. p. 25.
Asaphus mucronatus, Brongn. Crust. Foss. p. 24.
Asaphus mucronatus, Dalm. Vet. Akad. Handl. 1826.
Asaphus mucronatus, Hisinger, Lethæa Suecica, p. 13.
Phacops mucronata, Ang. Pal. Scand. p. 10.
Phacops mucronata, Emmr. Neues Jahrb. 1845.

The Lake-district form, so far as we can make out from the somewhat scanty material we possess, corresponds in every particular with specimens of *P. mucronatus* obtained by one of us from the upper part of the Brachiopod-schists of Westrogothia, which occupy a corresponding position to that of the Stockdale Shales. It seems to differ from the poorly preserved form described by Salter (Mon. Brit. Tril. p. 46).

Hor. & Loc. Heads and tails of this Trilobite are not rare in the zone of *Ampyx aloniensis* at Browgill. A fragment of tail, possibly referable to the same species, has been discovered in the Barren Band at Skelgill.

CHEIRURUS BIMUCRONATUS, Murch., var. nov. ACANTHODES. (Pl. XVI. figs. 7, 8.)

Head less than $\frac{1}{4}$ inch long. Glabella with basal lobe circumscribed, the furrow well marked in front, shallower behind. Middle and upper furrows as in the normal form. Eye opposite the upper lobe. Facial suture cutting the posterior margin far forward. Posterior angle of the cheek produced into a curved spine at least as long as the glabella. Tail, with a short axis possessing two well-marked furrows. Limb slightly furrowed, the border produced into three prominent spines on each side.

This form differs from the Wenlock species not only in possessing the elongated spines to the cheek and tail, but also in the forward position of the eye, and the point where the facial suture cuts the lateral margin. In these respects it agrees with a specimen from the Llandovery rocks of Llandovery, figured by Salter (Mon. Brit. Tril. pl. v. fig. 4), the original of which is in the Woodwardian Museum, which also may have possessed the elongated spines. We suspect that several forms which have been referred to Murchison's species are really distinct, but in the meantime prefer to keep the well-marked little Trilobite from the Stockdale Shales (which must have attained a length not much exceeding one inch) under this specific name, merely giving it a varietal distinction.

Hor. & Loc. Zone of *Phacops glaber*, Skelgill; zone of *Ampyx aloniensis*, Skelgill and Browgill; zone of *Acidaspis erinaceus*, Spengill; Calcareous band, Austwick Beck.

CHEIRURUS (PSEUDOSPHÆREXOCHUS) MOROIDES, n. sp. (Pl. XVI. figs. 9, 10, 10 *a*.)

Glabella, length 5 lines, width 4 lines, widest in the centre. Neck-lobe not preserved. Basal lobe circumscribed, elliptical, rather broader than long, occupying more than one third the entire width of the glabella, basal furrows very deep and defined: middle furrow moderately deep, extending about $\frac{1}{3}$ of the way across the glabella; upper furrow much shorter and not so strongly defined. Middle lobe shorter than basal, and slightly larger than upper. Frontal lobe short.

The whole glabella very convex, and uniformly marked with very large granules, between which are smaller ones and a third series yet smaller.

Only two imperfect specimens, displaying portions of the glabella, have, so far, been discovered, but they are sufficient to show that the species is clearly distinct from *C. granulatus*, Ang., *C. conformis*, Ang., and *C. Rœmeri*, Schmidt (the forms which it most nearly resembles), in the characters of the basal lobe and the details of the ornamentation.

Hor. & Loc. Rare in the *Phacops-glaber* zone of Skelgill.

ACIDASPIS ERINACEUS, n. sp. (Pl. XVI. figs. 11, 12.)

Length $\frac{1}{5}$ inch. Head twice as broad as long, front produced, smooth; sides ornamented with several short spines. Glabella tumid, the central portion broadest in the centre, flanked on either side by two circumscribed lobes, of elliptical shape, the posterior one being the larger. Eyes and course of facial suture not clearly defined in the specimens. Posterior angles produced into long spines curving outward and backward. Neck-lobe large, with lateral tubercles, each giving off a stout short spine, and having a large granule in its centre. Entire head ornamented with coarse granules.

Body-rings 8 in one of the two nearly complete specimens discovered, and 6 in the other less mature one. Axis with marked tubercles at the extremities of the rings; pleuræ (omitting spines) nearly twice as wide as axis, consisting of an anterior smooth portion, and a posterior ridge ornamented with two granules on each pleura. The ridge is bent back at the outer margin to form a long slender spine at least as long as the body of the Trilobite.

Tail having a short axis of two rings with prominent tubercles. Limb ornamented with ten spines as follows:—two very short anterior ones on each side, succeeded by a very long pair connected with the axis by raised ridges. Each marked with a tubercle. Behind this is a short pair and, lastly, a larger pair, all of these being directed backwards.

This species resembles *A. centrina*, Dalm. (=*A. granulata*, Ang.), from the same horizon in Sweden, but it differs from the latter, as shown in Angelin's figure, in the following particulars:—

The head has a produced front and a strongly granulated surface.

The rings of the axis have large lateral tubercles instead of a row of granules.

The tail differs in the disposition of the spines and the presence of a connecting-ridge between the large spine and the axis. It is true that Barrande has shown that the disposition of the tail-spines varies in the same species; but we possess a large number of tails of our form in which the arrangement is constant.

One of us has collected an *Acidaspis* from the Upper Brachiopod-schists of Olleberg, in which the spines appear to be disposed as in the present species.

Hor. & Loc. Very abundant in the zone of *Acidaspis erinaceus* at Torver Beck.

HARPES JUDEX, n. sp. (Pl. XVI. figs. 13, 14, 14 *a*.)

Length probably $\frac{3}{4}$–1 inch.

Head semicircular, surrounded by a broad, very convex limb, of horse-shoe shape, prolonged backward into a blunt point.

Glabella almost circular, marked by a small pair of basal lobes extending over the fixed cheek as shallow depressions, which are stated by Barrande to characterize the genus. Eyes minute; no visible trace of an ocular ridge. The cheeks and limb are marked by a venose arrangement of narrow ridges, seen enlarged in fig. 14 *a*. Axis of body wide, pleuræ straight for the greater part, but slightly recurved at the extremities, marked by shallow, straight grooves.

This differs from all the Bohemian forms. It is near to *H. Wegelini*, Ang., but the glabella is broader, and the venose structure of the cheeks and limb is not shown in the figure of the Swedish species.

Our specimens have been subjected to so much pressure that the original structure is much obscured.

Hor. & Loc. Zones of *Phacops glaber* and *Ampyx aloniensis*, Skelgill, and in the latter zone at Browgill.

HARPES ANGUSTUS, n. sp. (Pl. XVI. figs. 15, 16, 16 *a*.)

Head semioval, surrounded by a broad convex fringe, somewhat squared in front, extending backward towards the extremity of the body, where it terminates in a tolerably sharp point.

Glabella semicylindrical, reaching two thirds of the distance between the neck-furrow and the fringe, the space in front of it being occupied by a prominent tubercle. A furrow appears to occur on each side of the glabella, separating off a small basal lobe, which is not visible from above, being situate entirely upon the nearly perpendicular side. No depression is seen to extend from this on to the cheek. Eye small, situate near the anterior end of the glabella. Ocular ridge not shown. Cheeks and limb punctate, the puncta sometimes occurring in tolerably regular lines, and thus originating a venose structure, which is less prominent than in the last-described species.

About fifteen body-rings preserved in one specimen; axis very narrow and convex. Pleuræ nearly four times the width of the axis, almost straight throughout, and with a shallow groove. Tail unknown.

This is a much narrower form than the last, from which it differs in other particulars, so that it seems improbable that we have here merely differences of sex.

Hor. & Loc. Zones of *Phacops glaber* and *Ampyx aloniensis*, Skelgill.

AMPYX (RHAPHIOPHORUS) ALONIENSIS, n. sp. (Pl. XVI. fig. 17.)

Length, exclusive of spines, $\frac{1}{8}$ inch.

Head broader than long; glabella trapeziform, produced in front into a slender spine. Neck-segment very narrow. A pair of basal furrows, nearly parallel with the neck-furrow, produce a pair of well-defined though small basal lobes. Indications of a second pair of furrows running obliquely downward may be accidental. Posterior angle produced into a long spine, about $\frac{1}{4}$ inch long.

Body-rings badly preserved, four only seen; the pleuræ twice the width of the rings of the axis, marked by straight furrows

Tail very short and wide, apparently with two rings to the short conical axis.

This species is allied to *A. setirostris*, Ang., and *A. Rouaulti*, Barr. From the former it differs in its greater width and smaller size; from the latter in the character of the glabella-furrows and its broader axis. *Ampyx parvulus*, Forbes, has many differences from our form.

Hor. & Loc. Zone of *Ampyx aloniensis*, Skelgill and Browgill.

PROËTUS BRACHYPYGUS, n. sp. (Pl. XVI. figs. 18, 19.)

Length $\frac{1}{4}$ inch, width $\frac{1}{5}$ inch.

Head $\frac{1}{3}$ length of the whole creature. Glabella parabolic, with two small circumscribed basal lobes.

Body $\frac{1}{2}$ length of the animal, 8 segments. Axis wide, rather flat, with tuberculate extremities to the rings. Pleuræ slender, strongly grooved.

Tail three times as broad as long. Axis tapering rapidly, and extending two thirds the length of the tail, with 2–3 conspicuous rings. Limb gently rounded, marked with three or four prominent furrows.

We have found two nearly complete specimens of this minute form, which, though indifferently preserved, are quite unlike any other form of *Proëtus* which we know. The breadth of the whole creature, the width of the axis, and the short broad tail are very distinctive features. Isolated tails, apparently referable to this species, are tolerably abundant.

Hor. & Loc. Not uncommon in the *Ampyx-aloniensis* zone of Skelgill; one specimen in the same zone of Pull Beck, near Ambleside.

ATRYPA FLEXUOSA, n. sp. (Pl. XVI. figs. 20, 20 *a*, 20 *b*.)

Shell heart-shaped, with a fairly deep sinus.

Ventral valve with a small, prominent, pointed beak; sinus deep, with a short tongue-shaped extension, and marked by eight prominent, longitudinal ribs. Ribs less strongly marked on the convex portions of the valve. About 14 rather prominent, transverse laminæ of growth.

Dorsal valve with a very elevated mesial fold, the longitudinal ribs and transverse laminæ well developed over the whole of the surface.

Length $\frac{3}{4}$ inch, width $\frac{3}{4}$ inch, depth $\frac{1}{2}$ inch.

This species is intermediate in character between *A. imbricata*, Sow., and *A. altijugata*, Lindstr. The sinus is narrower and deeper than in the former species, but wider and shallower than in the latter, from which it also differs by the possession of more strongly developed transverse laminæ of growth.

Hor. & Loc. Tolerably abundant in the *Atrypa-flexuosa* zone of the Lower Skelgill Beds, at Skelgill.

List of Species.

	Rastrites distans, *Lapw.*	— gemmatus, *Barr.*	— hybridus, *Lapw.*	— maximus, *Carr.*	— peregrinus, *Barr.*	— urceolus, *Richter*	Cyrtograptus Grayæ, *Lapw.*	— ? spiralis, *Gein.*	Monograptus argenteus, *Nich.*	— argutus, *Lapw.*	— attenuatus, *Hopk.*	— broughtonensis, *Nich.*	— Clingani, *Carr.*	— communis, *Lapw.*	— convolutus, *His.*	— crenularis, *Lapw.*	— cyphus, *Lapw.*	— crassus, *Lapw.*	— crispus, *Lapw.*	— distans, *Portl.*
Zone of *Monograptus crispus.*							*	*				*							*	
Zone of *Monograptus turriculatus.*	*						...	...				...							...	
Zone of *Rastrites maximus.*	...			*			...	...				...							...	
Zone of *Acidaspis erinaceus.*	...			...			...	...				...							...	
Zone of *Monograptus spinigerus.*	...		*	...		*	...	...				...						*	...	*
Zone of *Ampyx aloniensis.*	...		...	...		...	...	...				...						...	...	...
Band with *Monograptus Clingani.*	...		*	...		*	...	...				...	*			*		...	...	*
Barren Band.	...		...	...		...	...	...				...	...			...		...	...	...
Zone of *Monograptus convolutus.*	...	*	*	...	*	*	...	...		*	*	...	*	*	*	*	*	...	...	...
Zone of *Phacops glaber.*	...	...	...	...	...	...	...	...		...	...	...	...	...	...	...	...	...	...	...
Zone of *Monograptus argenteus.*	...	*	*	...	*	*	...	...	*	*	*	...	*	...	*	*	*	...	...	...
Zone of *Encrinurus punctatus.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Zone of *Monograptus fimbriatus.*	...	...	...	...	*	...	...	...	...	...	*	...	...	...	...	...	*	...	...	...
Zone of *Dimorphograptus confertus.*	...	...	...	...	...	...	...	...	...	...	*	...	...	...	...	...	...	...	...	...
Zone of *Diplograptus acuminatus.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

—— discretus, *Nich.*	...	...	...	...	...	...	...	...	*	...	*				
—— exiguus, *Lapw.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*
—— fimbriatus, *Nich.*	...	...	*												
—— gregarius, *Lapw.*	...	...	*	...	*	...	*	...	*						
—— griestonensis, *Nicol.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*
—— Hisingeri, *Carr.*	...	...	...	...	*?	...	...	...	...	...	...	...	...	...	*
—— involutus, *Lapw.*	...	...	...	...	*	...	*								
—— jaculum, *Lapw.*	...	...	...	...	...	...	...	...	*	...	*	...	*		
—— lobiferus, *M'Coy*	...	...	...	...	...	...	...	...	...	...	*	...	...	*	
—— leptotheca, *Lapw.*	...	*	*	...	*	...	*	...	...	...	*				
—— Nicoli, *Harkn.*	...	...	...	...	*	...	*	...	*						
—— pandus, *Lapw.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*
—— proteus, *Barr.*	...	...	...	...	...	...	*								
—— rectus?	...	...	...	...	...	...	...	...	...	...	...	...	...	*	
—— revolutus, *Kurck*	...	*													
—— Sandersoni, *Lapw.*	...	*	*												
—— spinigerus, *Nich.*	...	...	...	...	...	...	...	...	*	...	*				
—— tenuis, *Portl.*	...	*	*	...	*										
—— triangulatus, *Harkn.*	...	...	*												
—— turriculatus, *Barr.*	...	...	...	...	...	...	...	...	...	...	...	...	...	*	
—— discus, *Törnq.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*
—— concinnus, *Lapw.*	...	...	*												
Dimorphograptus confertus, *Nich.*	...	*													
—— elongatus, *Lapw.*	...	*													
—— Swanstoni, *Lapw.*	...	*													
Petalograptus cometa, *Gein.*	...	...	...	...	...	...	*								
—— folium, *His.*	...	...	...	...	...	...	*	...	*						
—— ovatus, *Barr.*	...	...	*	...	*	...	*	...	*						
—— ovato-elongatus, *Kurck*	...	...	*												
—— palmeus, *Barr.*	...	...	...	...	...	...	...	...	...	...	*	...	...	...	*
—— var. tenuis, *Barr.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*

List of Species (continued).

	Zone of *Monograptus crispus.*	Zone of *Monograptus turriculatus.*	Zone of *Rastrites maximus.*	Zone of *Acidaspis erinaceus.*	Zone of *Monograptus spinigerus.*	Zone of *Ampyx aloniensis.*	Band with *Monograptus Clingani.*	Barren Band.	Zone of *Monograptus convolutus.*	Zone of *Phacops glaber.*	Zone of *Monograptus argenteus.*	Zone of *Encrinurus punctatus.*	Zone of *Monograptus fimbriatus.*	Zone of *Dimorphograptus confertus.*	Zone of *Diplograptus acuminatus.*
Diplograptus acuminatus, *Nich.*															*
— Hughesii, *Nich.*					*	...	...	...	*	...	*	...	*	...	...
— longissimus, *Kurck.*														*	...
— modestus, *Lapw.*?					*	...	...	...	*	...	*	...	*	*	...
— sinuatus, *Nich.*							*	...	*	...	*	...	*	*	...
— tamariscus, *Nich.*					*	...	*	...	*	...	*	...	*	...	...
— vesiculosus, *Nich.*													*	*	...
Climacograptus minutus, *Carr.*														*	...
— normalis, *Lapw.*					*	...	*	...	*	...	*	...	*	*	*
Retiolites Geinitzianus, *Barr.*	*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
— perlatus, *Nich.*					*	...	...	...	*	...	...	...	...	...	...
— —, var. obesus, *Lapw.*		*	...	...	...	...	...	...	...	...	...	...	...	...	...
—, *cf.* macilentus, *Törnq.*	*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Monticuliporoid?															*
Lindstrœmia, sp.				*	...	...	...	...	...	*	...	...	...	...	...
Favosites mullochensis, *Nich. & Eth. jun.*										*	...	...	...	...	...
— sp.							*	...	...	...	...	...	...	...	...
Dawsonia campanulata, *Nich.*									*	...	*	...	*	...	...
Discinocaris Brouniana, *Woodw.*											*	...	...	...	...

——, sp.	...	...	*												
—— gigas, *Woodw.*	...	...	...	...	*										
Peltocaris aptychoides, *Salt*	...	...	...	...	...	...	...	...	*						
——, sp.	...	...	...	...	...	...	...	...	...	...	*				
Aptychopsis Lapworthi, *Woodw.*	...	...	...	...	...	...	...	...	*						
Turrilepas	...	*													
Homalonotus?	*														
Encrinurus punctatus, *Wahl.*	...	...	...	*	...	...	...	...	...	*					
Acidaspis erinaceus, n. sp.	...	...	...	...	...	...	...	...	...	...		*			
—— sp.	...	...	...	...	...	...	...	...	...	*	...				
—— sp.	...	...	...	*	...	...	...	...	...	*					
Phacops elegans, *Boeck & Sars*	...	...	...	...	...	*	...	...	...	*		*			
—— ——, var. glaber	...	...	...	...	...	*	...	...	...	*	...				
—— mucronatus, *Brongn.*	...	...	...	...	...	...	...	...	...	*					
Cheirurus acanthodes, var. nov.	...	...	...	...	...	*	...	...	...	*		*			
—— moroides, n. sp.	...	...	...	...	...	*					...				
Calymene Blumenbachii, *Brongn.*	...	...	...	...	...	?	...	...	...	*					
Harpes judex, n. sp.	...	...	...	...	...	*	...	...	...	*					
—— angustus, n. sp.	...	...	...	...	...	*	...	...	...	*					
Ampyx aloniensis, n. sp.	...	...	...	...	...	...	...	...	...	*					
Proëtus brachypygus, n. sp.	...	...	...	...	...	...	...	...	...	*					
Illænus Bowmanni, *Salt*	...	...	...	...	...	...	...	...	...	...		*			
											...				
Atrypa flexuosa, n. sp.	*														
Leptæna quinquecostata, *M'Coy*	...	...	...	*	...	...	*	*	...	*					
——, *cf.* sericea, *Sow.*	...	...	...	...	...	...	...	..	...	*					
Whitfieldia tumida, *Dalm.*?	...	...	...	...	...	*	...	*							
Orthoceras araneosum, *Barr.*	...	...	*	*	*	...	...	...	...	...	*				

EXPLANATION OF PLATE XVI.

Unless otherwise stated, the figures are of the natural size.

Fig. 1. *Phacops elegans*, Boeck & Sars: internal cast of glabella, *Glaber*-zone, Skelgill, × 2.
1 *a*. Ditto: a small tail, × 2.
2. Ditto: from a wax impression of intaglio of head and anterior body-rings, *Erinaceus*-zone, Torver Beck.
3. Ditto: internal cast of a nearly complete specimen, *Glaber*-zone, Skelgill.
3 *a*. Ditto: glabella and cheek of the same specimen, from a wax impression of internal cast.
3 *b*. Ditto: diagrammatic sketch of incurved lower margin of cheek of the same specimen, showing cavities for the reception of the extremities of the pleuræ, × 4.
4. Ditto, var. nov. *glaber*: internal cast of tail, *Glaber*-zone, Skelgill.
5. *Phacops mucronatus*, Brong.: internal cast of glabella, *Aloniensis*-zone, Browgill.
6. Ditto: tail from same zone and locality.
7. *Cheirurus bimucronatus*, var. nov. *acanthodes*: glabella and cheek, *Glaber*-zone, Skelgill, × 2.
8. Ditto: tail, restored, from a second specimen, same zone and locality.
9. *Cheirurus moroides*, n. sp.: from a wax impression of an external mould of the glabella, *Glaber*-zone, Skelgill, × 2.
10. Ditto: from a wax impression of an external mould of the glabella, *Glaber*-zone, Skelgill.
10 *a*. Ditto: details of ornamentation of the same, highly magnified.
11. *Acidaspis erinaceus*, n. sp.: *Erinaceus*-zone, Torver Beck, × 2.
12. Ditto: a younger specimen, same zone and locality, × 2.
13. *Harpes judex*, n. sp.: slightly distorted, the wrinkles on the centre of the glabella being apparently due to this, *Aloniensis*-zone, Skelgill.
14. Ditto: a crushed head, showing the venose structure, *Glaber*-zone, Skelgill.
14 *a*. Ditto: a portion of the same specimen, highly magnified.
15. *Harpes angustus*, n. sp.: head, and cast of portion of body, *Aloniensis*-zone, Skelgill, × 2.
16. Ditto; internal mould of head, *Glaber*-zone, Skelgill.
16 *a*. Ditto: a portion of the same, highly magnified, showing punctations.
17. *Ampyx aloniensis*, n. sp.: from a wax impression of intaglio, *Aloniensis*-zone, Skelgill, × 3.
18. *Proëtus brachypygus*, n. sp.; from a wax impression of intaglio, *Aloniensis*-zone, Skelgill, × 2.
19. Ditto: *Aloniensis*-zone, Pull Beck, × 2.
20. *Atrypa flexuosa*, n. sp.: ventral valve, *Flexuosa*-zone, Skelgill.
20 *a*. Ditto: the same specimen, dorsal valve.
20 *b*. Ditto: ditto, anterior view.

Note.—In fig. 2 the axis should be extended through the lowest (imperfect) body-ring. In fig. 19 the glabella-lobes are made too wide.

Discussion.

The President observed that the more minute details of stratigraphical geology were as important as divisions of wider range, especially in the Palæozoic rocks. He referred in illustration to the work done in Bohemia by one of the Authors.

Prof. Lapworth looked forward to the day when the existence of these Graptolite-zones in Lower Palæozoic rocks would be generally acknowledged, and they would be employed as a basis for classification and mapping. He remarked that the thin Moffat series of South Scotland represented the whole of the Llandeilo, Bala, and Llandovery formations in other regions. There was never any doubt as to the general age of the beds above and below these Stockdale Shales, but there had been a great controversy as to the age of the shales themselves, which the Authors had now settled. The zones they had detected in the Lake-district agree with zones already established in South Scotland, Wales, Scandinavia, &c., and it is clear that the ideas of correlation by means of such zones are destined to be generally accepted.

He commented on the small thickness of these Stockdale beds, but pointed out that they were represented by very great thicknesses of deposit elsewhere; thus the Browgills were represented by thousands of feet in the Gala group and the Tarannon, and the Skelgills by enormous thicknesses in Girvan and Central Wales. The Authors had accomplished a piece of work of the highest systematic importance. Further zone-work was required, and it would be followed by a remapping of many areas.

Prof. Hughes alluded to the enormous changes in the classification of the older Palæozoic rocks which resulted from Prof. Lapworth's researches in the Moffat area. He referred to the apparent absence of reappearances of fossils in the beds described, but pointed out an instance of such a reappearance of a group of fossils elsewhere. He noticed the absence of fossils in the upper Browgill Beds of Spengill, and speculated on the possible connexion of this with the red coloration of the rocks. He thought that we must not overlook the important question whether the application of the Graptolitic and Trilobitic *verniers* would give the same results. He contrasted our present knowledge with the state of things when he mapped that country.

Dr. Woodward noted the fact that in the case of these thin beds a fauna limited to a small thickness of them was found to extend through a much greater thickness of rock elsewhere. With regard to the relative value of fossils, he pointed out that we must make the most of what we can get.

Mr. Hopkinson had examined the beds many years ago, and, although he had not worked out the zones, his recollections of the general succession coincided with the views of the Authors.

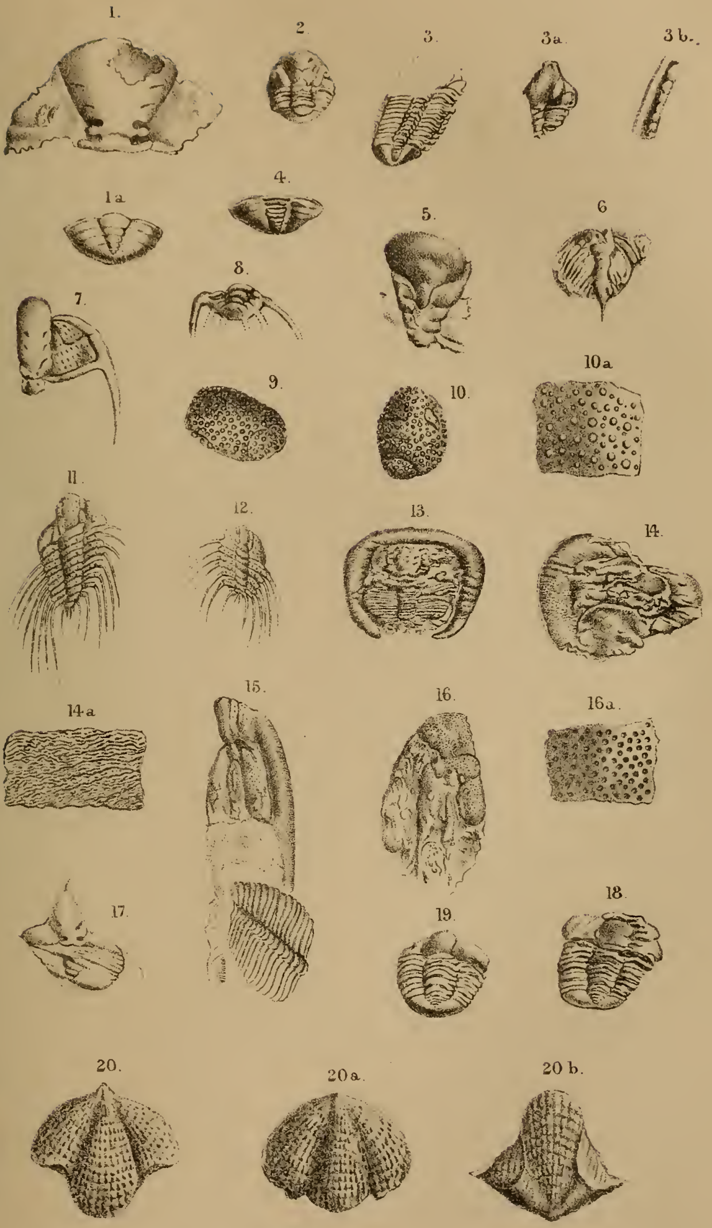
Mr. Etheridge commented on the value of zones, and specially referred to Prof. Keeping's work in Central Wales, and that of Prof. Blake on the Kimmeridge beds of the north of France and the Yorkshire Lias.

Dr. Hinde referred to the value of the large series of specimens exhibited in showing the characters of the rocks and fossils described.

Mr. Rutley pointed out the difficulty of restoring the physical geography of these early times.

Mr. Marr, in reply, pointed out that one peculiarity connected with Graptolites was the extremely slow accumulation of the deposits which usually contained them, as might be inferred from the remarks of previous speakers on their mode of swelling out laterally into normal deposits of great thickness. Hence, although the forms had undoubtedly migrated from region to region, the time taken for migration was so short, as compared with the time taken for the accumulation of an appreciable thickness of sediment, that the film formed during the time of migration might be practically neglected.

He thanked the Society, on Prof. Nicholson's behalf as well as his own, for the way in which the paper had been received.



F. H. Michael del. et lith.

Mintern Bros. imp.

FOSSILS OF THE STOCKDALE SHALES

38. *On the* Law *that governs the* Action *of* Flowing Streams. By R. D. Oldham, Esq., A.R.S.M., F.G.S., Deputy Superintendent, Geological Survey of India. (Read January 11, 1888.)

Of all the agents which Nature employs in her great and ceaseless work of change, of destruction and construction, of removal and renewal, probably none have been less studied, few are less understood, by geologists, than water in the form of streams and rivers.

In a general way it is known that, with sufficient velocity, a stream will erode its bed, and that if the velocity be reduced sufficiently it will deposit part or all of what solid material it may be carrying down its course. But, while mathematicians and engineers have been investigating, in all their details, the laws which govern the flow of water, geologists have done little to investigate the laws under which it acts in shaping the surface of the world we live in.

Rain, glaciers, and the sea; these seem almost to have limited the horizon of the geological view, and, without forgetting the researches of Prof. Hull, the essay of the late Mr. Greenwood, or the application of the principles enunciated by him to a special case by the late Mr. Fergusson, we may almost say that the intermediate link in the chain—the flowing stream—has either been regarded as unworthy of notice, or the vague general ideas and statements of the textbooks have been regarded as a complete and satisfactory account of the problem.

Yet in the whole range of physical geology there is no subject which will better repay a detailed investigation or open a wider field of intricate and interesting problems than this: and it is with the hope of being able to contribute something to our knowledge of this almost unexplored region that this paper is laid before you.

My attention was first drawn to this subject when at Hardwár in December 1883. In course of the operations for constructing new head-works to the Ganges Canal a small driblet of water began to eat into sand, over which it had flowed previous to the removal of a block of masonry. I noticed that only in certain parts of its course did it erode its channel and that there were intermediate reaches where there was no erosion, or, when it had assumed a nearly permanent condition, even deposition. The areas of no erosion, or deposition, gradually encroached upon the channels of erosion above them and were themselves encroached upon by the channels of erosion below.

Acting on the hints obtained, I commenced an inductive investigation into what should be the action of a stream flowing over a uniform deposit, whether of its own formation or not. This, with my subsequent inquiries into the truth of the deductions arrived at, will be presented in the following pages.

The fundamental principle on which all such investigations must be based is one of great simplicity, though its application leads to conditions and combinations of no little complexity. Mr. Greenwood has explained how the tendency of a river to preserve a uniform velocity throughout its course leads to the parabolic section presented by the channel from source to mouth; but, owing to his having overlooked the very different nature of the solid burden carried by the river in different parts of its course, his explanation lacks completeness. As it seems to me, the law is not that the river tends to preserve or obtain a constant velocity, but that at any point of its course the velocity of current will tend to become such that the stream can just carry its solid burden. With regard to the application of this law, it is necessary to observe that it is the coarsest débris borne by the stream which will determine its velocity; thus, in a stream carrying shingle, sand, and mud, the velocity will be controlled by the shingle, after that has been deposited, by the sand, and finally by the mud.

But this must not be taken to mean that the current is directly governed by the nature of the burden cast upon the stream. Gradient and shape of channel are of course the two principal factors which govern the velocity of current, and in a subsidiary degree the nature of the sides of the channel; of these the two former frequently, the last generally, are to a greater or less degree the product of the stream itself, and by deposition or erosion they tend to become such that, when equilibrium has been established, the stream is just able to transport its solid burden.

The law, as stated above, I hold to be obeyed by every stream throughout its length, though its action is often controlled and obscured by interfering causes, such as unequal hardness of the bed where the stream flows over rock. Where a stream enters on an alluvial plain, the law can be seen to prevail, and is moreover, on slight consideration, seen to be almost axiomatic in its nature; for, suppose the velocity of current to be greater than that due to the law propounded, the immediate consequence would be erosion of the channel and transport of débris: when the stream reached the sea, if not sooner, the velocity would be checked and the transported débris would be deposited. In this way the lower end of the reach would be raised, the upper lowered, and the gradient diminished; this, leaving out of consideration the effect of the shape of the channel, would result in a diminished velocity and equilibrium when the stream could just transport its solid burden. Similarly, if the velocity were less than that demanded, deposition would commence, and the gradient below the deposit would increase until the velocity of the stream reached the required limit.

But it is not only by an alteration of gradients that the stream can adjust its velocity, for, with the same slope and sectional area of channel, the velocity varies with the square root of the hydraulic mean depth, or of the sectional area divided by the wetted perimeter. From this it follows that the gradient required to produce a given velocity will vary with the shape of the channel, being greater where this is broad and shallow, and less where it is narrow and deep.

Turning now to the application of these principles, let us take the case of a stream flowing in a restricted rocky channel and debouching on to a gently sloping plain whose gradient is too gentle to admit of the stream carrying on its burden of débris. This is consequently deposited as a " fan " whose surface has a steeper slope than that of the plain and on which the stream is broken up into several broad and shallow channels, in which it has such a velocity as just suffices to transport its burden.

In course of time, as the fan increases in size, some of these separate portions of the stream will reunite, and, by the mere fact of uniting, their velocity will be increased; since the same body of water flowing over the same gradient has a more rapid current when flowing in a single channel than when flowing in two separate channels. But this increase of velocity will cause the stream to erode the surface of the fan over which it flows, and by forming a defined channel, to increase its hydraulic depth. The velocity and consequently erosion will thus be still further increased.

But this channel of erosion must at its lower end come out to the surface either of the fan or the plain, while its upper end is depressed below the surface of the fan ; its gradient is therefore less than that of the fan and consequently, in spite of the greater hydraulic mean depth, a limit will be reached where the velocity of current will again be only just sufficient to enable it to transport its burden of débris.

Where this eroded channel passes out to the general surface of the ground, and its waters are no longer confined within a defined channel, the débris will be deposited in a second "fan." I am aware that the word fan has never been used in this sense ; but the form of deposit is essentially so similar to that of the fan, as ordinarily known, that I am loth to invent a new word, and prefer to define the lower region of deposition as a " secondary fan."

At the base of the secondary fan an eroded channel will be formed, and at its lower end another fan, till we have a series of stretches in which the stream has alternately a higher gradient with shallow ill-defined channel and a lesser gradient with deeper well-defined channel, the velocity in each case being such as will just enable the stream to transport its burden of débris. I shall define the former of these conditions as a "fan," the latter as a "reach."

Where a fan passes into a reach the gradient will be steeper than that of the fan, for the upper end of the reach has been excavated out of the latter ; over this steeper gradient the stream will flow under the same conditions as over the surface of the fan, the velocity will be higher than on the fan, and erosion will take place. We may consequently expect that the reach will be constantly cutting back into the fan, and must consider whether there will not be an equal encroachment by the fan on the lower end of the reach.

I have already explained that the fan below the reach will commence where the lesser gradient of the latter brings it out to the surface, and the waters are scattered abroad instead of being confined to a defined channel. But this spreading of the waters will cause a sudden check in the velocity of the current, and a large portion of the débris will be deposited as a bar across the reach. This bar, both by the actual resistance it offers and by its influence in causing the waters to spread out at a point higher up stream than before, will continually increase by the deposit of débris on its up-stream side; the lower fan will consequently encroach on the reach above it, and we have the compensation required for the encroachment of the reach on the fan.

These encroachments of fan on reach and reach on fan necessitate some modification of what has gone before. Both reach and fan have been regarded as regions of transport pure and simple, without either erosion or deposition, but it is evident that the gradual growth of the bar at the foot of the reach must react upwards and induce a certain amount of deposition in the reach, while the erosion at the foot of the fan must similarly react upwards and cause a certain amount of erosion on the surface of the fan.

These considerations lead us to the following definition of the normal condition of equilibrium which a stream tends to assume:—that it will consist of alternate fans and reaches in which the stream is respectively split up into several shallow ill-defined channels, and collected into a single deep well-defined channel; that the former will be a region mainly of transport, but subsidiarily of erosion, while the latter will be a region, mainly of transport, but subsidiarily of deposition; that fan will pass into reach by a short stretch of maximum gradient where erosion is at its maximum, and reach into fan by a short stretch of minimum gradient where deposition is at its maximum; and that the sum total of erosion will equal that of deposition.

Probably no stream is a purely transporting agent, but, unless the deposition or erosion are excessive, the above definition will apply with the exception of the last clause; there will be an excess of erosion or deposition according as the stream is on the whole eroding or depositing.

The only actual levels, taken under circumstances that will test the above hypothesis, which are accessible to me are those taken in connexion with the Ganges Canal and recorded in the late Sir P. B. Cautley's account of that work; but before referring to them there are some general considerations bearing on the hypothesis.

Since framing the definition given above I have travelled largely, to a great extent in country where the streams flow at the general level of the surface and where, owing to their drying up completely for half the year, the form of their channels can be very favourably studied; and in every case where the stream does not flow in an excavated channel, but at the general surface-level of the alluvial deposits, wherever, in fact, there are no interfering influences, I have found that the stream-bed exhibits those features which it should according to my hypothesis. The stream-bed alternately spreads out into a broad ill-defined stretch of sand or gravel, and contracts into a narrow well-defined channel; moreover the broad stretches always rise up to the general surface, often the gravel spreads over it, while the narrow channels are distinctly depressed below the general surface. Taking the slope of the latter to represent the average slope of the stream, this alternate elevation and depression of the stream-bed with reference to it accords perfectly with my hypothesis.

Besides my own observations, I have studied the maps produced by the Survey of India, and find that wherever the circumstances are favourable this alternate expansion and contraction of the stream-bed is very noticeable; nor does it seem to be confined to small streams only, but may also be detected, though, as might be expected, obscurely, in such large rivers as the Ganges and the Jumna.

Turning now to the Ganges-canal levels, if the maps in the Ganges-canal atlas are examined and the position of contour lines, drawn at a vertical distance of five feet apart on the Patthri and Rani Raos, be represented by dots, the crowding of these together where the channel broadens is palpable, but the original map does not indicate where the channel is well and where ill defined. Fortunately the text comes to our assistance and we are informed that in the case of the Patthri Rao the canal crosses it where it had no defined channel; in the case of Rani Rao the canal was taken across a well-defined channel, but we are informed that 2000 feet below the canal this stream ceased to have a defined channel and was spread abroad over the country; and it is evident at a glance that the gradient is there higher than where the channel is well defined, precisely as should be the case if my hypothesis were true.

These two torrents are carried over the canal by "superpassages," that is bridges built so as to form a continuous channel for the torrents. In the case of the Patthri Rao the course of the stream was diverted, and it is consequently of no use for our present purpose. But for the Rani Rao, the superpassage was built so as to replace that part of the defined channel which was removed in excavating the canal. Within a few years of its completion, it is recorded that the region where the channel was no longer well defined, instead of commencing 2000 feet below the superpassage, had extended right up to it, and presently sand began to accumulate on the bridge. This accumulation of sand for many years gave much trouble to the engineers in charge, but it has now ceased. Whether this is, as the engineers believe, altogether due to their works, or whether it is due to the defined channel below the fan having worked up to the bridge, or whether, as is most probable, it is due to a combination of the two, the records are not sufficient to determine.

Thus the surveys for and records of the Ganges Canal show the alternation of reach and fan, the greater gradient of the latter and the gradual progress of both up stream as demanded by the hypothesis formulated above. The small stretches of high and low gradient are not shown in these records, being probably of too small extent and too difficult to detect without special search, but they are indicated by the later records of the Patthri Rao. Here the stream, after crossing the superpassage, is artificially confined in a channel of 150 feet broad, in which the slope of deposit is 14·5 feet per mile; but, where the stream is allowed to spread, the slope immediately falls to 3·04 feet per mile, and increases after 1 furlong to 20·3 feet per mile on the fan.

From this it will be seen that the hypothesis above propounded leads to conclusions which are strongly supported by the surveys and levels of topographers and engineers, whose object was a mere delineation and record of observed facts without any consideration of their possible bearing on an unmooted hypothesis; and this agreement appears to be as strong a confirmation as could be desired.

These considerations lead us to regard a flowing stream as another instance of the automatic adjustments of Nature by which cause is proportioned to effect, and the energy exerted to the work to be done. They moreover show that the ordinary text-book statement, that the size of the débris transported depends on the velocity of the current, is but a partial account of the case; that though the velocity of the current is directly due to the slope and shape of the channel, these are largely controlled by the nature of the burden cast on to the stream; and that, where equilibrium has been established, where, to borrow a phrase, the stream is in unison with its environment, the velocity of the current may be said to depend on the size of the débris it carries.

It will be no answer to this to point out that the actual velocity of a stream is often in excess or defect of what the hypothesis demands; for, in such cases, the stream is either eroding or depositing, and the mere fact of erosion or deposition of itself proves that equilibrium has not been, but is being, attained. Where the velocity is too great, erosion tends to diminish the average gradient, and hence the velocity; and if, owing to a defect of velocity, deposition takes place, the stream deposits its burden in such a manner as to increase the general gradient to the limit at which the velocity will be sufficient for the transport of its burden.

These local exceptions cannot be held of importance in the face of the broad fact that on the whole it is in the upper reaches of a river, where the burden cast upon it consists of coarse débris, that high velocity is found, while in the lower reaches, where the burden consists of fine mud, a low velocity prevails. And this fact, even in the absence of the special considerations detailed above, might by itself be fairly held to show that the velocity of the stream is ultimately regulated by the work it has to do, and not its work by the velocity it possesses.

Discussion.

Mr. Drew hoped that Mr. Oldham would continue his observations. The paper was difficult to discuss without being read, but Mr. Drew did not understand there being greater velocity on a "fan," the origin of which implied loss of velocity. Mr. Oldham used the word "fan" in a rather different sense from that in which it was originally proposed by the speaker.

Rev. E. Hill was glad to hear a paper on physical geology. The two parts of the paper appeared to be separate. The dependence of the velocity of the stream upon the coarseness of its burden appeared to be a paradox, and perhaps was put forward as such. The alternation of "fan" and "canal," or, as Mr. Oldham called it, "reach," is well illustrated in the Alps, and must be produced whenever a succession of steps is traversed.

Prof. Blake suggested that Mr. Oldham might mean that it depended on the coarseness or fineness of the material introduced into the stream, whether it was retarded or not in its lower reaches and so made to alter its velocity.

Dr. Blanford said that he understood Mr. Oldham to express the view that the velocity of a stream was dependent upon the coarseness or fineness of the solid materials transported, a view in favour of which the speaker did not think Mr. Oldham had brought forward valid evidence. The observations on the alternation of "fans" and "reaches" were interesting, and alternations of a similar nature, of faster and slower areas, occurred in all parts of rivers. It was, however, unfortunate that Mr. Oldham's critical illustrations were taken from localities where the course of the rivers had been affected by the Ganges canal-works.

The President regretted that Mr. Oldham's paper was heard at a disadvantage, as the Author was not present to reply to the remarks made.

39. *On* Perlitic Felsites, *probably of* Archæan Age, *from the* Flanks *of the* Herefordshire Beacon; *and on the possible* Origin *of some* Epidosites. By Frank Rutley, Esq., F.G.S., Lecturer on Mineralogy in the Royal School of Mines. (Read June 20, 1888.)

[Plate XVII.]

In a previous communication to this Society * a rock was described (No. 20) in which faint indications of a perlitic structure were discernible. It occurred on the side of the Herefordshire Beacon, overlooking Castle-Morton Common, and a short distance in rear of the well-known cave.

The specimens now under consideration were derived from the Rabbit Warren near the above-mentioned locality; No. 1 from a point about thirty yards above the path, where it touches a small beck which runs between the higher portion of the Beacon and the Warren; while No. 2 was procured a little above and to the east of this spot, and about halfway up the steep bank of the Warren.

The first is a rather deep greenish-grey to brownish-grey rock, which, on a smoothly-cut surface, shows a meshwork of very delicate veins, darker than the material of which the rock is mainly composed.

The second specimen is of paler colour, a yellowish-green or buff tint predominating.

It was difficult at the time to procure better samples, and both of these must be regarded as in a considerably advanced stage of alteration. They were, however, kept, as they seemed to show faint indications of perlitic structure, and although, in sections cut from them, the structure is somewhat obscure, there is nevertheless sufficient proof that it is present.

A section taken from specimen No. 1 appears by reflected light, under a low power, to consist of greenish-white to greyish-white matter, broken by small dark specks and curved lines, which unmistakably denote perlitic structure, although this is, at first sight, somewhat difficult to recognize, owing to the extensive alteration which the rock has undergone.

The section is seen to be traversed by a network of delicate fissures filled with quartz.

From this it is evident that the rock has been subjected to great pressure and crushed into a mass of angular fragments, ranging from very small dimensions up to about a quarter of an inch in diameter; but, beyond the actual gape of the veins, which seldom attain $\frac{1}{50}$ inch in breadth, there has been no appreciable displacement of the fragments.

* "On the Rocks of the Malvern Hills," Quart. Journ. Geol. Soc. vol. xliii. p. 499.

By transmitted light the decomposition-product appears to be chiefly epidote with possibly a little kaolin. The latter would naturally have resulted from the alteration of the felspathic portion of the felsite; while the epidote seems, in great part, to have been formed within the minute fissures and perlitic cracks by which the rock is penetrated. Specks of hæmatite are also present.

The prevailing greenish colour of the rock is due to the epidote, of which the largest crystals occur chiefly in the quartz-veins. The crystals are too small and, as a rule, too imperfectly developed for the measurement of the oblique extinction-angle in clinopinacoidal sections; but in one case it was found to be about 28° to the edge 001 : 010, or trace of the basal plane, the angle between the faces 001 and 100 in this instance being 113° to 114°. If the section were truly parallel to the clinopinacoid this angle should be 115° 24′. Sections in the orthodiagonal zone give parallel extinction. The close massing of the epidote renders the perlitic structure somewhat obscure in transmitted light. The structure, however, appears more distinct when surface-illumination is resorted to; but, even in transmitted light and between crossed nicols, the most decomposed portions of the section may be seen to have a perlitic structure.

Under these conditions of illumination this may be recognized by any one or more of the following characters:—1st, by the segregation of epidote along the perlitic cracks being denoted by the interference-colours; 2ndly, by feeble translucence verging on opacity along the cracks due mainly to the close massing of very small grains of epidote; 3rdly, by delicate rings or curved lines of felsitic or simply siliceous matter, the continuity of which is apparently broken by the extinction in any given position of certain of the minute crystalline grains which constitute these delicate strings, so that an ever-shifting succession of bright points may be traced along the perlitic cracks during rotation of the section; and 4thly, by oval or irregularly-shaped nuclear residues of felsitic matter lying within the perlitic areas, and free, or comparatively free, from epidote.

In section No. 2, from which the accompanying drawings (Pl. XVII.), were made, the decomposition-products are not so abundant as in No. 1. They are, however, present to a considerable extent and also consist mainly of epidote, which, by its segregation along irregular, wavy, and anastomosing lines, indicates that a banded structure may also have existed in the rock.

The specimens do not disintegrate at all readily when scraped on a smoothly cut surface with the point of a penknife, and, indeed, there is more knife than rock abraded during the process. It does not therefore appear that kaolin is present in any appreciable quantity, if at all, or the rock would be less coherent. We may consequently assume that most, if not all, of the greenish-white matter in the rock is epidote. It is, however, probable that kaolin represented the first stage of decomposition of the felspathic constituent of the felsite, and that the epidote has resulted from the alteration of this first decomposition-product by the action of water charged with bicarbonate of lime and more or less carbonate of iron in solution, substances readily taken up by water filtering through overlying rocks.

If beneath the calculated percentage composition of kaolin we place an analysis of epidote, and subtract from the kaolin the amount of silica, alumina, and water present in the epidote, we see that the kaolin would require to have 31 per cent. of its constituents replaced by ferric oxide, lime, and magnesia.

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	H_2O.
Kaolin	46·40	39·68	...	...	...	13·92=100
Epidote (Bourg d'Oisans), (Rammelsberg)............	38·37	21·13	16·85	23·58	0·17	... =100·10
Epidote (Val Maigels, Grisons), (Vom Rath)	39·07	28·90	7·43	24·30	0·10	0·63=100·43

That such a change may take place seems very probable, since water which has filtered through rocks moderately rich in lime and iron would suffice to bring about a conversion of this kind.

It is difficult to say whether, in a felsitic rock, the conversion of the felspathic constituent into epidote would take place *directly* from the alteration of the felspar, or indirectly from it, by the alteration of kaolin; but the alkalies present in the felspar would not be involved in the fabrication of epidote, and it seems highly probable that the conditions requisite to effect the alteration of felspars would entail the early removal of their alkalies and the consequent formation of kaolin. Such changes may occur in felsitic rocks, especially in those which, by reason of their perlitic structure, offer exceptional facilities for the percolation of water.

As regards the blowpipe characters of the rocks which form the subject of this paper, thin splinters fuse on the edges to a white frothy glass in some spots and to a brown or greenish-black in others, the latter being evidently due to the fusion of parts more strongly charged with epidote.

By ordinary transmitted light the epidote ranges from almost colourless to yellowish-green, and where the granules are closely massed together, the green colour is deeper, becoming brownish-green, and in such spots the section transmits very little light. Between crossed nicols some of the sections of the larger crystals show oblique extinction and the interference-colours are strong. The majority of the sections, however, give parallel extinction. The pleochroism is not strongly marked. In sections parallel to 100, $\mathfrak{b}$=nearly colourless, $\mathfrak{c}$=pale yellowish-green.

That the two specimens here described show perlitic structure there can be no doubt; but, owing to the prevalence of epidote, it is rendered unusually obscure, and I have therefore given a more detailed description of the microscopic characters, in the hope that it may encourage search for this structure in felsitic rocks, even when alteration is far advanced. In the cases here given very slight additional change would have obliterated all traces of perlitic structure. *It is possible that some epidosites result from alterations of this kind.*

The mass in which these rocks occur forms a buttress, faulted against the eastern flank of the Herefordshire Beacon, and has been described as "altered Primordial" by the late Dr. Harvey B. Holl. That they are of later Archæan or Cambrian age is probable.

With regard to another specimen derived from this mass *, which was described and figured in the paper which I last read before this Society, mention was made of numerous minute granules which were massed most closely along lines of perlitic fission in the rock, and as to the nature of which I expressed considerable doubt at the time. On re-examining the section and comparing it with those now described, I am inclined to regard these small granules as epidote.

Dr. W. S. Bayley, in a recent publication †, appears to have misinterpreted my statement on this subject, indicating that I considered these granules to be topaz, whereas I "very doubtfully" referred a few isolatad crystals to the latter mineral. It is quite possible that these crystals are also epidote, as they give extinctions parallel and at right angles to the length of the prism, which would occur in orthodiagonal sections of epidote.

From the foregoing observations it seems reasonable to think that felsites resulting from the devitrification of obsidian, quartz-felsites, aplite, arkose, and felspathic grits may, by the decomposition of the felspathic constituent, pass, in the first instance, into rocks composed essentially of quartz and kaolin, and that by subsequent alteration of the kaolin in the manner already indicated, they may eventually be converted into epidosite. This, however, I put forward as a suggestion, not as a conclusion. According to the relative percentages of quartz and felspar originally present in rocks, so, by alteration, they may eventually become more or less epidositic, and, in cases where the original percentage of quartz was low, a true epidote may result. The three sections now exhibited show three different grades of epidosition, although their original characters were probably identical.

Concerning the origin of epidosite, Kalkowsky says:—"One frequently meets with rocks consisting of epidote and quartz, which are generally termed epidosite; in many cases these are, however, nothing else than the last decomposition- and alteration-products of basic anogenic and katagenic rocks. There are probably also original epidote-rocks which belong to the quartzite family, and may be called epidote quartzites" ‡.

In the theory which I have here proposed it seems needless to demand that the rock should have been originally of a basic character, although I would in no way question the truth of Dr. Kalkowsky's statement, for there may be more ways than one in which epidosites are formed. In the case of the felsites from the Herefordshire Beacon it is evident that the epidote was not an original constituent

* "On the Rocks of the Malvern Hills," Quart. Journ. Geol. Soc. vol. xliii. p. 499.

† "Summary of Progress in Mineralogy and Petrography in 1887," published from monthly notes in the 'American Naturalist,' p. 1112.

‡ 'Elemente der Lithologie,' p. 272 (Heidelberg, 1886).

of the rock, since it has been chiefly developed along fissures and perlitic cracks, and the latter are known to have been formed during or subsequently to the solidification of the rocks which they traverse. It is also clear that in these instances the rock was originally vitreous, and unaltered vitreous rocks never contain epidote, so far as I am aware, although it is by no means uncommon in their devitrified condition.

EXPLANATION OF PLATE XVII.

Fig. 1. Epidositic felsite (The Rabbit Warren, Herefordshire Beacon), showing perlitic structure, marked by the development of epidote along the perlitic cracks. ×25 linear, ordinary transmitted light.

2. Another portion of the same section, ×120 linear, showing traces of perlitic structure.

Discussion.

The President wished to hear the opinion of chemists as to whether any solution acting on so inert a substance as kaolin could convert it into epidote.

Mr. Teall congratulated the Author on having carried the history of the vitreous rocks a stage further. He could confirm his observations as to the frequency of epidote in perlitic rocks, and believed it had been largely developed during the alterations of the old vitreous rocks; but he would not venture to express an opinion on the process by which the epidote was formed.

Mr. W. P. Blake noted the frequent occurrence of epidote in the Triassic rocks of North America, where it is sometimes extensively interstratified with and formed in sandstones, as in the Sierra Nevada.

Mr. Bauerman commented on the way in which epidote was formed throughout the mass of the rock, and suggested the bearing of the matter of this paper on the question of the formation of such masses of epidote as that of Lake Superior, which may also have been formed, though on a large scale, in fissures. Epidote also occurs in the same way in Cyprus.

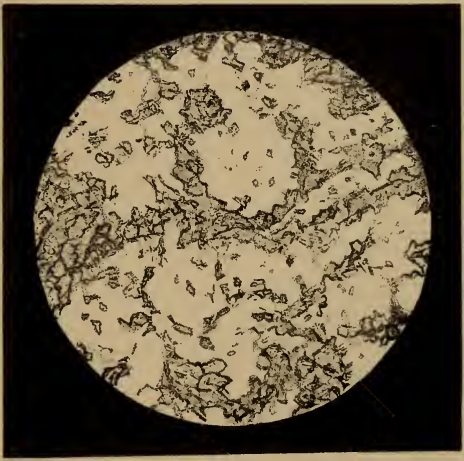
Mr. Cole asked whether, seeing that even pyroxenes occur in many trachytes, it was not possible that the original rock contained sufficient lime to account for the formation of the epidote by secondary decomposition. He referred to the observations of M. Lévy on variolite of the Durance, where the perlitic cracks are marked out by crystalline granules.

The Author admitted the uncertainty connected with the precise mode of formation of epidote, and stated that, so far as he knew, epidote had never yet been produced artificially; he was, however, puzzled to imagine the extensive percolation of water through the rocks without conversion of the felspar into kaolin. With regard to Mr. Cole's question, he was inclined to think that the rocks were practically devitrified obsidians, and he did not think there was any evidence of the original existence of pyroxene in them, although it was abundant in other rocks in their immediate vicinity.

Fig. 1.

x 25.

Fig. 2.



x 120.

F H Michael lith. Mintern Bros imp.

PERLITIC FELSITE (EPIDOSITIC)
FROM THE HEREFORDSHIRE BEACON.

40. *On a* Hornblende-biotite Rock *from* Dusky Sound, New Zealand. By Captain F. W. Hutton, F.G.S. (Read May 23, 1888.)

This rock was collected in Dusky Sound by Mr. W. Docherty, and given to the late Sir J. von Haast, who gave it to me. I do not know its field relations, but undoubtedly it is of eruptive origin and is associated with the Archæan gneisses and schists of that district. As I am not aware of any similar rock having been described, I think that some account of it may be interesting.

The rock is compact, crystalline, of a dark green colour, weathering reddish brown, and the specific gravity varies between 3·00 and 3·07. With a lens it is seen to be composed of two minerals in nearly equal proportions. One is a black mica, the plates of which are sometimes collected into masses 0·1 to 0·2 inch in diameter, but generally scattered through the other mineral. Cleavage-flakes of this mica can be easily detached, and, under the polariscope, prove to be biotite, in which the two optic axes nearly coincide. When thin, these cleavage-laminæ have a greenish tinge by transmitted light.

Under the microscope, in thin sections of the rock, the biotite has the usual brown colour and strong dichroism. It often contains crystals of apatite, which is, I think, not usual.

The other mineral, in thin sections, is of a pale bluish-green colour and dichroic, but not strongly so, passing from a pale brownish green to a pale bluish green, some portions being more strongly dichroic than others. With ordinary light very little structure is apparent, but with crossed nicols the general mass shows an aggregate polarization of rather coarse grains, almost a mosaic; but here and there distinct crystals of considerable size can be recognized, without, however, retaining any of their crystalline faces. These crystals seldom show cleavage, and in the few cases where it is developed there is only one set of lines, the position of which I could not determine; but certainly it does not lie in the orthopinacoid. Most of the crystals show twinning, often of a polysynthetic character, very similar to that so commonly seen in augite. A common case is for one side of a crystal to show a single twin, while the other side is polysynthetic. Or a band of twin laminæ may occupy the centre of the crystal only. In a section taken nearly parallel to the brachypinacoid one set of laminæ extinguished at an angle of 17° 30′ from the twinning plane, while the alternate set extinguished at an angle of 16° 45′ on the other side of that plane. Another crystal, somewhat similarly cut, gave 12° and 16° as the two angles. This proves the crystals to belong to the monoclinic system and to be probably hornblende. I was fortunately enabled to test this determination further by finding a crystal in which the twins extinguished simultaneously when the twinning plane was parallel to one of the diagonals of the polarizer. This proved that the crystal was cut parallel to the base. The crystal consisted of a single twin on one half, and several twin laminæ on the other half, and the boundaries of the laminæ were so sharp, although the section was not very thin, that it was evident they had been cut nearly at right angles, or, in other words, that the section was nearly parallel to the basal pinacoid. I therefore tried the simple half with convergent polarized light, and found a very distinct optic axis, with revolving band, on the circumference of the field, thus confirming the previous determination of the green crystals as hornblende.

Some of these crystals show traces of schillerization in one direction, which I take to be a face of the prism. I saw no inclusions in them. There are no other essential constituents of the rock but hornblende and biotite. Occasionally an actinolitic structure is seen, but not commonly. The mineral which shows aggregate polarization is either crushed hornblende or some altered form of it; it is identical in colour with, and shows the same dichroism as, the hornblende crystals. In one case I saw a small quantity of calcite in a crack.

I suppose that this rock will come under Dana's name of hornblendite; but I think it objectionable to take the name of a mineral and apply it to a rock, especially when that rock consists of two minerals in nearly equal proportions. There is in the Canterbury Museum a very similar-looking rock from Wet-Jacket Arm, Breaksea Sound; but I have not been able to examine it microscopically.

Discussion.

The President remarked upon the rare occurrence of such rocks as the one described, and regretted that no specimen of the rock could be exhibited to the meeting.

41. *On the* Occurrence *of* Marine Fossils *in the* Coal-measures *of* Fife. By James W. Kirkby, Esq. (Read June 20, 1888.)

(Communicated by Prof. T. Rupert Jones, F.R.S., F.G.S.)

This paper records the discovery of fossils of good marine types in the Fifeshire Coal-measures. Reference is also made to the occurrence of similar fossils in the same formation elsewhere.

The Fifeshire Coal-measures* form a comparatively small field on the north shore of the Firth of Forth, where they abut on the coast-line from Dysart eastward to Largo. They extend only two or three miles inland where the field is widest. On the west they are bounded by outcropping beds equivalent to Millstone-Grit; on the north by faulted strata of the Carboniferous-Limestone series. On the east and south they are bounded by the sea, beneath which they dip. Including an upper set of red beds ($d^{5'}$ of the Geological Survey maps), there is a thickness of over 2000 feet of these measures; but all the workable coals are in the lower portion (d^5 of the Geological Survey maps): see vertical section at p. 748.

The prevailing fossils of this coal-field are those always characteristic of the formation in other districts. The flora is essentially the same as in the North of England. Among the animal fossils usually met with are *Anthracosia acuta*, *Anthracomya modiolaris*, *Anthracoptera carinata*, and other Lamellibranchs of this family. *Spirorbis carbonarius* is the common Annelid. The Ostracods consist of various species of *Carbonia*, with *Beyrichia arcuata*; with them also occurs the phyllopod *Leaia Leidyi*. Among the fish are *Megalichthys Hibberti*, *Strepsodus sauroides*, *Diplodus gibbosus*, and well-known species of *Ctenodus*, *Cœlacanthus*, *Rhizodopsis*, *Acanthodus*, *Palæoniscus*, &c. The Amphibians *Loxomma Allmanni* and *Anthracosaurus Russelli* are the highest forms of animal life represented.

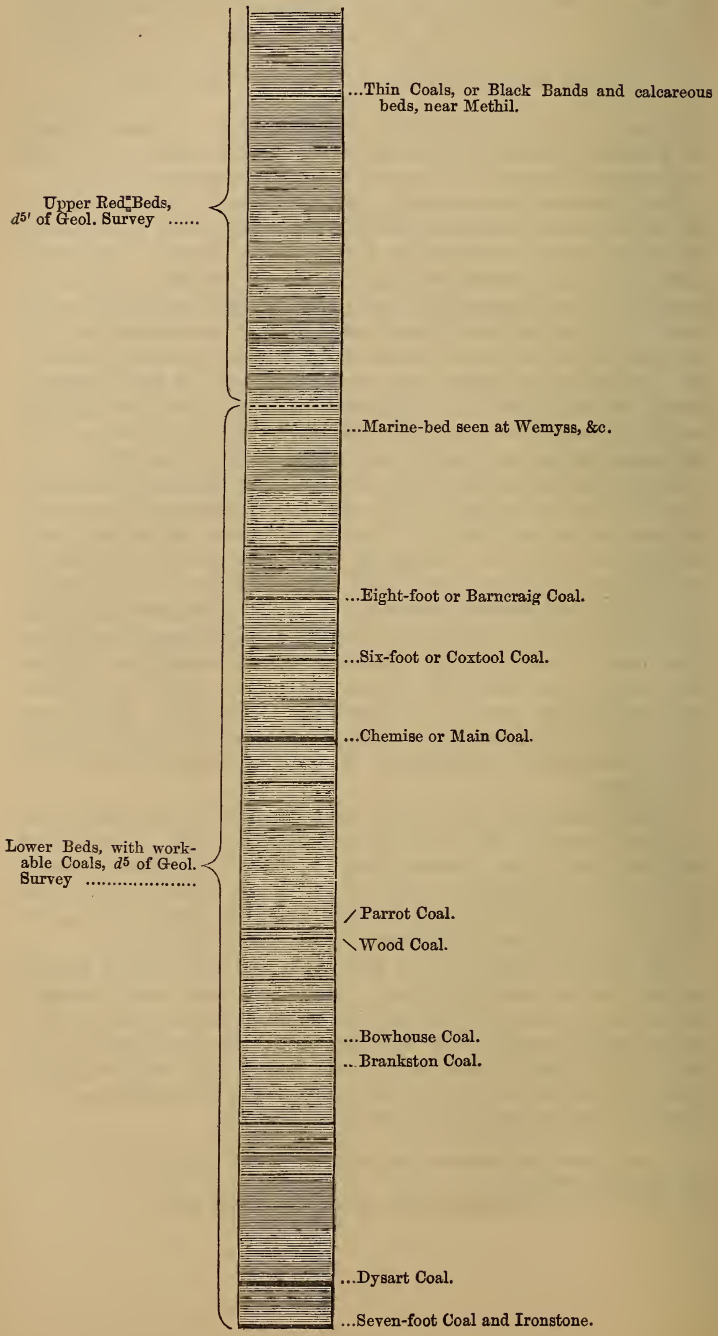
Of late years pits have been sunk further on the dip for the purpose of winning the deeper-lying coal of the field. One of these was put down to the Chemise Seam in 1884–5 by Messrs. Bowman & Co.†, of the Muiredge Collieries. This pit, which is now known as the Denbeath Colliery, is situated near the shore, between the villages of Methil and Buckhaven, in the parish of Wemyss.

The sinking commenced in the upper red beds, which are well exposed on the shore adjoining. These beds were sunk through to the extent of nearly 70 fathoms, and then the underlying portion of the series was reached. A few fathoms in this lower division, and above a thin band of poor coal, a thick bed of dark shale was passed through, the material from it being tipped over the waste-heap along with the other excavated rock from the sinking.

* The Upper Coal-measures were treated of in the Quart. Journ. Geol. Soc. vol. xxxviii. p. 245, &c.

† Whom I have to thank for information very readily given.

Vertical Section of the Coal-measures in Fifeshire (300 feet at the top omitted.) (Scale 1 inch to 300 feet.)



In this shale, a few months afterwards, I found the remains of a *Lingula* in great abundance. Further search led to the discovery of other Mollusca, two of which are easily determinable as *Murchisonia striatula* and *Bellerophon Urei*. Other specimens probably belong to *Bellerophon decussatus*: and imperfect examples of a Lamellibranch are not unlike a *Sanguinolites*.

The *Lingula* differs in no way from Lower-Carboniferous examples of *L. mytiloides*, or from Permian examples of *L. Credneri*, which names Mr. Davidson has shown refer to one and the same species. On some planes of the shale it is very thickly strewed, in many cases with the valves together, in others as single valves or in fragments.

The *Murchisonia* only occurred twice. One specimen shows from twelve to fourteen individuals within a few square inches of surface. These shells are well preserved.

Several specimens of *Bellerophon Urei* were found, all more or less in bad condition.

Along with the Mollusca are some scales, plates, and teeth of fishes, some of the scales resembling those of *Rhizodopsis*. Also stray patches of coprolitic matter, and very rarely there are fragments of plants. No Microzoa have been detected, though the shale has been carefully examined for Ostracods.

The shale is black, brown, or rather purple, in colour. Part of the bed is laminated; but much of it splits irregularly with a curious roughly granulated surface. Here and there in it are flattish concretions or cakes of soft red ironstone, which contain good examples of the *Lingula*.

The position of the bed is about 35 fathoms above the "Eight-Foot Coal," and thus considerably higher than all the workable coals of the series.

As the measures lying above the "Eight Foot" are exposed on the shore to the eastward of West Wemyss, I afterwards looked for this *Lingula*-bed there, and soon found it to the east of Wemyss Castle. It is here seen as a thick black shale, more or less laminated, and associated with a thin coal. Being a soft bed it is denuded to a lower level than the sandstones above and below it, and is thus covered by the tide before high water. The coal is the highest that is marked on the six-inch Geol. Survey Map (Sheet 32). The base of the upper red beds is seen a short distance to the dip; so that the stratigraphical position is about the same as at the first locality.

The *Lingulæ* are here scarcely so numerous as at Denbeath Pit, though not at all rare. *Bellerophon Urei* occurs with them. Likewise the teeth (or dermal spines) of that common Coal-measure fish *Diplodus gibbosus*. A few other fish-teeth, some Palæoniscid scales, and coprolites (filled with scales), along with traces of plants are the other fossils found.

Quite recently, in company with Mr. J. S. Grant-Wilson, of the Geological Survey, I came upon another outcrop of this bed, in a little den or ravine at East Wemyss, about a mile to the east of the last-described locality. This outcrop is seen in the den a short distance above the Parochial Office, and not far below the curling-pond. The coal is again present, resting on fireclay. The fossils are found in the shale above the coal. The upper group of beds ($d^{5'}$), in the form of red sandstone and shale, comes into section a few yards further down the den.

Other marine fossils appear in the shale of this locality. The remains of a small Crinoid are common; and besides *Lingula mytiloides* there occur *L. squamiformis*, *Discina nitida*, *Productus semireticulatus* var. *Martini*, *Discites rotifer*, an *Orthoceras*, some Hybodont teeth, and other things.

Perhaps the most characteristic form among the fossils at East Wemyss is the *Discites* identified with the *D. rotifer* described by Mr. Salter from a marine deposit near the top of the middle measures of the Lancashire coal-field (see p. 752). It is two inches or more in diameter, and has the same style of whorls, with sigmoidal ribs. as represented in that species. *Discites rotifer*, however, is evidently nearly akin to the *D. falcatus* of Sowerby, as pointed out by Mr. Salter, and it is possible that they may ultimately be found to be one and the same species.

The *Orthoceras* always occurs flattened by pressure, and nothing like a perfect example has been found. So far as they go, the specimens, some of which are over seven inches long, seem nearest to *O. attenuatum*, Fleming.

Some of the Hybodont teeth resemble those of *Orodus*, and are beautifully sculptured. Dr. Henry Woodward, who very kindly examined one of the specimens, informs me that they come near to the genus *Mesodomodus* as figured by Messrs. St. John and A. H. Worthen, from the Lower Carboniferous "Kinderhook Beds" of Burlington, Iowa*. Others of the teeth belong to a species of *Petalodus*.

From the three foregoing localities there have been obtained the following species:—

Strepsodus sauroides ?, *Ag.*, teeth and scales.
Rhizodopsis ? sp., scales.
Palæoniscid scales.
Diplodus gibbosus, *Ag.*
Mesodomodus, sp. nov.
Petalodus, sp.
Discites rotifer, *Salt.*
—— sp., with longitudinal ribs.
—— sp., smooth.
Orthoceras attenuatum ?, *Flem.*
Bellerophon Urei, *Flem.*
Bellerophon decussatus, *Flem.*
Murchisonia (Aclisma) striatula, *De Kon.*
Sanguinolites ? sp.
Productus semireticulatus, *var.* Martini, *Sow.*
Discina nitida, *Phillips.*
Lingula mytiloides, *Sow.*
—— squamiformis. *Phillips.*
Crinoid stems=*Actinocrinus* ? sp.
Plant remains, obscure.

West of Scotland.—These are the only marine beds known in the Fifeshire Coal-measures. But in the West of Scotland marine fossils are recorded from different horizons of the formation: these

* Geol. Surv. Illinois, 1875, vol. vi. p. 291, pl. v. figs. 18–22.

it may be useful to mention, for the sake of including here all that is as yet known on the subject.

In Lanarkshire the following species have been found by the Geological Survey in the Slaty-band Ironstone (or in strata connected therewith) at the base of the Coal-measures*:—*Conularia quadrisulcata*, *Bellerophon Urei*, *B. decussatus*, *Loxonema* or *Murchisonia* sp., *Schizodus* sp., *Productus longispinus*, *Discina nitida*, *Lingula mytiloides*, *L. squamiformis*, *Serpulites carbonarius.*

Lingula squamiformis is also recorded by the same observers as occurring higher in the series, in the Airdrie or Quarter Blackband Ironstone†.

The same authorities found *Aviculopecten papyraceus* and *Posidonomya*, sp., still higher, in a shale some distance above the Ell Coal ‡.

Probably from near the same horizon Mr. Dunlop has recently discovered, in the Airdrie Coal-field, *Aviculopecten papyraceus* and *Orthoceras attenuatum*, along with fish-remains, and the common Coal-measure Ostracod, *Beyrichia arcuata* §.

Higher still, near the top of the Coal-measures (d^5 of Geol. Surv., or workable portion), and thus probably at about the same horizon as the Fifeshire bed, Mr. Skipsey discovered, in 1865, the following marine fossils at the sinking of a pit at Drumpark, to the east of Glasgow ||:—*Conularia quadrisulcata*, *Schizodus deltoideus*, *Productus scabriculus*, *Discina nitida*, and the pentagonal stems of a crinoid. These fossils were imbedded in shale and ironstone nodules, the *Productus* being the most common.

There are, thus, not less than four horizons at which marine fossils are found in the Coal-measures of the West of Scotland.

England.—In England the occurrence of marine fossils in Coal-measures has been recorded from various districts.

Among the earliest notices is that by Prof. John Phillips, who described the finding of *Aviculopecten*, *Posidonomya*, *Goniatites*, and *Orthoceras* in the roof of one of the Lower or Gannister coals near Leeds, Bradford, Halifax, and other places in Yorkshire ¶.

Mr. E. W. Binney afterwards described similar marine bands in the Gannister coals of Lancashire, where they are found overlying several coal-seams of that series. *Aviculopecten*, *Goniatites*, *Orthoceras*, and other species are found in these beds **.

It was pointed out by Mr. Binney that such fossils are seen at more than one horizon in Yorkshire, and that they are also met with in the same series of strata in Derbyshire, Staffordshire, Cheshire, and Flint ††.

* Memoirs of Geol. Surv. Scotl., Explanation of Sheet 23, p. 23; Expl. Sheet 31, pp. 74, 75, 80.

† *Ibid.*, Explan Sheet 23, p. 91.

‡ *Ibid.*, Explan. Sheet 23, p. 92.

§ From information supplied by my friend Mr. John Young, of Glasgow.

|| Trans. Geol. Soc. Glasgow, 1865, vol. ii. p. 52.

¶ Manual of Geology, 1855, p. 183.

** Trans. Manchester Geol. Soc. 1860, vol. ii. pp. 72–83.

†† *Loc. cit.* pp. 79, 83.

These *Aviculopecten*-bands of the Lower Coal-measures are described in the Memoirs of the Geological Survey for Lancashire, and the following is the list of fossils from them, after Mr. Salter:—

Orthoceras, sp.	Posidonomya Gibsoni, *Brown.*
Discites, sp.	—— lævigata, *Brown.*
Goniatites Listeri, *Martin.*	Monotis lævis, *Brown.*
—— paucilobus, *Phill.*	—— ? (Gervillia) obtusa, *Brown.*
—— sp., near truncatus.	Lingula mytiloides, *Sow.*
Aviculopecten papyraceus, *Goldf.*	Beyrichia arcuata, *Bean.*

Another marine bed of the Lancashire Coal-field appears near the top of the Middle Coal-measures, the middle measures of Lancashire being the same as the Coal-measures proper of the North of England and Scotland (d^5 of the Geol. Survey). Attention was first drawn to it by Prof. A. H. Green, who noticed its outcrop on the banks of the river Tame, at Ashton-under-Lyne, in 1864, and where I saw it in 1866 in company with my old friend Mr. Binney. The fossils occur in a thick stratum of grey shale; and they were considered by Mr. Salter to be wholly distinct, *A. papyraceus* excepted, from the species of the Lower Coal-measures and Carboniferous Limestone. Mr. Salter quoted the following species*.—

Orthoceras, sp.	Ctenodonta, sp.
Discites rotifer, *Salter.*	Aviculopecten papyraceus, *Goldf.*
—— sp.	—— fibrillosus, *Salt.*
—— sp.	Serpulites, sp.
Nautilus præcox, *Salt.*	Megalichthys Hibberti, *Ag.*
Goniatites, sp.	Calamites, sp.

In 1860 (Quart. Journ. Geol. Soc. vol. xvi. p. 412) I gave a short account of the discovery of *Lingula Credneri*, Geinitz, a Permian species since shown by Mr. Davidson to be the same as *L. mytiloides*, in the Durham Coal-measures. The specimens were found during the sinking of the shafts at Ryhope Colliery, near Sunderland, in shale about 590 feet below the base of the Permian strata. All the workable coals were below this *Lingula*-bed, though twelve thin seams were passed through above it. The remains of Fishes, *Anthracosiæ*, and Ostracoda occurred in the same bed with or near the *Lingula*.

In the "Descriptive Programme of Excursions" for the Birmingham Meeting of the British Association, 1866, it is stated, at page 46, that three beds of black shale, containing marine fossils, were passed through at the Sandwell Park sinking (Hamstead Colliery), sixty-one yards above the Thick Coal of the South Staffordshire coal-field. Among these fossils are mentioned species of *Lingula*, *Productus*, *Spirifera*, *Ortheous* (*Orthoceras*?), and *Euomphalus*.

Conclusion.—All these occurrences of marine fossils show that the Coal-measures, as a formation, contain many exceptions to their ordinary fauna and flora. If the amphibian and fish remains, the

* Mem. Geol. Survey: Geol. of Country around Oldham, pp. 20, 64–66.

Mollusca, Cypridæ, and plants of the latter indicate freshwater conditions, it is evident that such conditions were occasionally overborne by inroads of the sea, bringing back species of shells and crinoids that had existed in the Carboniferous-Limestone ocean of an earlier period. This appears to have taken place in the areas of most coal-fields, and repeatedly in some. It is thus reasonable to assume that the open sea was not far off when the British Coal-measures were being formed, and that a slight increase in the rate of depression of the area sufficed to bring back the sea and marine life.

There is undoubtedly something peculiar about the ordinary fauna of the Coal-measures, though the peculiarity is, perhaps, just as great, whether it is viewed as of freshwater or of marine origin. And though it cannot have been marine in the same sense as the fauna of the Carboniferous Limestone or any open-sea deposit, it can scarcely be understood on the view of its being of lacustrine origin, as some geologists still hold. Certainly these intercalated marine beds seem easier of explanation when the formation is looked upon as the deltaic or, in some way, marginal accumulations of a large land-area. Under such conditions everything observed in the palæontology of the strata can be accounted for, whether the indications be of dense vegetable growth, vegetable drift, or of freshwater, brackish-water, or open-sea animal life.

Anyone who has studied the Carboniferous series of Fife stratigraphically, from the base of the Calciferous Sandstone* upward, will only see in these marine beds the last and final instances of what has come under his notice times out of number before, the coming in of marine deposits in succession to shales, sandstones, fire-clays, and coals containing plant remains or estuarine fossils. The whole formation indicates a long series of depressions with intervening siltings up during periods of rest, the former often bringing in marine conditions, the latter as often resulting in an approach to land-surfaces and subterrestrial conditions. This is true of the Calciferous Sandstones, where there are more coals (only poor and thin) than in the Coal-measures proper, but where thin limestones and other marine strata are comparatively common. In the lower portion of the Carboniferous-Limestone series marine beds are thicker and the remains of marine life more abundant, though coals and plant-bearing beds come in among them. The same is the case, though less pronounced, in the upper portion of the Carboniferous Limestone; while between the upper and lower portions there is a thick group of carbonaceous strata containing as good workable coals, and as many of them, as exist in the true Coal-measures one thousand feet or so higher up. And so in the group of strata classed as Millstone Grit, marine beds alternate with others containing vegetable remains and poor coals. Then follow the Coal-measures with the second great series of thick coals, with here and there marine beds, without the least indications of unconformity or physical break. In fact there is no such break anywhere in the Carboniferous series of Fife. The whole succession is one of regular

* Quart. Journ. Geol. Soc. vol. xxxvi. p. 559 &c.

order from the lowest beds seen at Anstruther to the highest at the mouth of the River Leven; and the lines of division used in their systematic arrangement are arbitrary, though convenient. The Coal-measures of this county are thus part and parcel of the underlying portion of the series, and they have evidently originated under much the same physical conditions as prevailed here during the whole of the Carboniferous period. I believe that the same regular sequence of Carboniferous strata obtains in other parts of Scotland, and it is the same in the North of England.

In conclusion, it may be remarked that no marine deposits have been observed as yet in the upper red beds ($d^{5\prime}$) of the Coal-measures in Fife, or in other parts of Scotland. These latter beds contain the ordinary coal fossils, except that in Fife there have been found on one horizon the remains of species of *Eurypterus*, some Limuloid Crustacea, and a cockroach. The next appearance of undoubted marine life in palæozoic strata is in the Lower-Permian Limestone of Durham and Northumberland, where two of the species* found at Wemyss, along with two or three other Carboniferous forms, are found among what is essentially a new fauna. These recurrent species, however, form a connecting-link between Carboniferous and Permian life; while, on the other hand, the fewness of the surviving species of the great Carboniferous-Limestone fauna shows how extensive and long-lasting must have been the physical changes that took place in the period intervening.

* *Lingula mytiloides* and *Discina nitida*.

42. *The* Greensand Bed *at the* Base *of the* Thanet Sand. By Miss Margaret I. Gardiner, Bathurst Student, Newnham College, Cambridge. (Read June 20, 1888.)

(Communicated by J. J. H. Teall, Esq., M.A., F.G.S.)

This bed may be seen at various points from Pegwell Bay in the east to Chislehurst in the west of Kent, and there is a bed at Sudbury, in the N.W. corner of Suffolk, which Mr. Whitaker considers to be the same*. At Lewisham and Croydon, to the west of Chislehurst, it is missing, and the light buff micaceous sand which usually succeeds it in West Kent rests directly on the flint bed above the chalk; so that, unless either the 9 inches of greensand and flint or the 2 feet of grey sand last seen in 1830 at Epsom by Prof. Prestwich are the same, the succeeding beds of the Thanet Sand overlap it westwards.

Specimens have been obtained from Pegwell Bay, Chislet near Herne Bay, Upnor, Chislehurst, and Sudbury. Leaving for the present the Sudbury sand out of consideration, this basement bed is a very fine sand formed of about equal quantities of dark and light grains mixed with more or less clayey matter. Its appearance in a section varies considerably with the weather, for it is the dark greenish grey of the darker grains which gives the colour when it is wet; but when it is dry the clayey matter becomes a white powder, and is a much more conspicuous constituent. A microscopic inspection shows the sand to consist of quartz, flint, glauconite, and small quantities of felspar and various rarer minerals, with a few casts of microscopic organisms.

Quartz.—The quartz is in not much rounded grains of average largest dimension about ·1 millim. One of the striking points about the sand is the small proportion of quartz-grains, namely, only about 45 per cent.

Glauconite.—The glauconite-grains are small as compared with those of most greensands. The majority are of rounded outline, and consist of an aggregation of smaller grains, often wedge-shaped in form and fitted together in a convolute manner. The cracks between the parts of the grain are marked by a yellow line, probably of iron-oxide. This kind of aggregate seems to be the commonest form of glauconite-grain, and occurs in those of the Cambridge Greensand, Lower Greensand (Folkestone), Upper Greensand (Highclere), and the basement bed of the Woolwich Sands. Other green grains are subangular. Some of these are only pieces of the round grains, but others are probably coated grains of flint or quartz, since some may be seen to give a distinct quartz-reaction. When mounted in balsam the glauconite is opaque except just at the edge, but in water or glycerine by

* Geol. Surv. Mem. to Sheet 47.

transmitted light, and always by reflected light, it is a bright yellow green. That of some other sands, *e.g.* the Cambridge Greensand and the basement Woolwich beds, is a very blue green. Between crossed nicols it gives either no reaction or a speckled look, somewhat like that of flint. The glauconite-percentage is only 15.

Flint.—On first looking at a slide of this sand one is struck by the large number of very sharply angular chips. These may be roughly divided into two sets, the one transparent, the other almost or entirely opaque. The transparent ones have a rough pitted surface, which gives them a slightly greyish tint, and are often marked by small black dots, which, when present in any number, give the grains a darker colour. Between crossed nicols they have a minutely tesselated appearance, the lighter parts being of a bluish neutral tint. Their close resemblance to chips obtained by crushing a flint seemed to leave little doubt as to their nature; but, since the glauconite gives a somewhat similar reaction, it seemed possible that at least some of the more rounded grains, or those which gave a less distinct reaction, might be weathered glauconite. As a test, glauconite grains were bleached by boiling in hydrochloric acid, and it was found that these could be distinguished from the flint by their different surface, clearer colour, and less distinct outline. The Upper Greensand (Highclere) was then examined for comparison. It is a very similar sand of quartz and glauconite. Though the glauconite-grains are in all respects like those of the Thanet Sand, yet there are no grains which could be mistaken for flint. There seems no reason why the glauconite-grains in the one should be supposed to have lost their colour by weathering when they have not done so in the other. Finally the sand was placed in a borotungstate solution of sp. gr. just below that of flint; although a few green grains fell through, all those floated out, with the exception of a very few grains of both quartz and flint which had probably adhered to the side of the funnel, were green. Therefore, unless the glauconite increased in sp. gr. by weathering, these grey grains cannot be glauconite. A consideration of this evidence seems to leave no doubt that these lighter grey grains are flint, although they form the abnormally large proportion of 20 per cent.

The more opaque grains are in general form like the clear ones. In both, forms which resemble microscopic spear- and arrow-heads are not uncommon. There is a more or less distinct transition from the clear to the opaque, and some are opaque in parts and clear in others. By reflected light many show the same greyish colour as the clear grains, though many are almost black. In fact, by reflected light one often cannot tell whether a particular grain is transparent or opaque, though both are easily distinguished from the quartz- or the green glauconite-grains. Crushed fragments of the weathered white coating of a flint are very like some of the more opaque and transitional forms by transmitted light, though these differ by being white in reflected light. The slightly weathered surface of a black flint is such a mere film that it has not been found possible to get pieces of it to compare; but some of these grains look by reflected light very like small, black flint pebbles, and the double thickness of weathered coating even, though thin, might be sufficient to make them opaque. In the boro-tungstate solution these opaque grains fall with the clear ones. Altogether there seems to be no reason for considering these grains to be glauconite, as their comparative opacity and the faint reaction which they sometimes give in parts between crossed nicols at first inclines one to do. The evidence there is seems to be in favour of the supposition, suggested by their form, that these grains are also flint. Counting these in with the others, the flint-percentage rises to 40. This and the other percentages have been obtained by counting between 3000 and 4000 grains. The flint-grains are of about the same size as the quartz-grains, *i.e.* about 1 millim. in their longest dimension.

It is these opaque grains quite as much as the glauconite which give the dark colour to the sand; for when the clay is washed out, what remains is dark grey, quite black when wet; but when the clay is washed out of the Upper Greensand, which is a sand very like this without the flint, the residue is of a light green colour.

Besides these flint-grains, larger ones which might almost be called small pebbles, about $\frac{1}{16}$ inch in diameter, are often found, and at Pegwell Bay much larger flints, some slightly rounded like those just above the chalk, and others which are regular pebbles. Six were picked out of a piece of cliff about 2 feet square, but in most parts they were not quite so numerous.

Twinned Felspar occurs in no great quantity. What there is is very generally twinned in two directions.

Magnetite and Spinel.—Amongst the grains which come down in a boro-tungstate solution of sp. gr. 2·9 black opaque grains are the commonest. Amongst these some are very perfect octahedra. Only some seem to be magnetic, so that probably both magnetite and a dark spinel are present.

Zircon also forms a large proportion of the heavier minerals. It occurs in very perfect crystals and in grains. The crystals differ considerably in size and form. Two from amongst the larger and smaller respectively measured ·116 millim. × ·036 millim. and ·06 millim. × ·02 millim. Often only the (100) and (101) planes are developed, but sometimes also the (110) and (111) and other pyramid planes. Very frequently one pair of the (101) planes is developed at the expense of the other, so that the crystal has a truncated appearance. There are often needle-like inclusions parallel to some of the pyramid faces.

Garnet (?).—In about the same quantity is present a mineral of which only broken fragments of fairly large size have been seen. It is very clear, colourless, highly refracting and isotropic. The fragments are often very sharply broken, and sometimes the fracture has a conchoidal look. Inclusions of black and green grains are not uncommon.

Rutile is not present in such quantity as the minerals already described, though there is always some in any slide of the heavier minerals separated from this sand. It is in long narrow prisms and grains.

Tourmaline is present in about the same quantity. It is dark brown, purplish grey or very light and almost colourless. The light variety is in small and very perfect crystals, often as broad as they are long, so that they have the outline of a hexagon. They are terminated at both ends by the rhombohedron-planes, but the darker varieties are generally broken, or if not, the rhombohedral planes are only at one end, and the basal plane is developed at the other.

Anatase has been looked for, but not found.

The description so far applies to specimens from all the places mentioned except Sudbury, that is to say, since these places are distributed along the whole length of the southern outcrop, it may be taken as a general description of the basement sand of the Thanet Sands in the South of England from a mineralogical point of view. The following minerals occur in very small quantities, and so are not in any way characteristic.

Garnet.—A few minute colourless dodecahedra have been noticed. One measured ·02 millim. from one dodecahedron-face to the parallel one. One has grown round a smaller red crystal of the same form—a fact which seems to point to their being garnets.

Actinolite.—A few fragments of a fibrous-looking green mineral strongly pleochroic, or yellow-green, with vibrations parallel to the length, and blue-green with those in the opposite direction are probably actinolite.

Epidote.—One somewhat rounded crystal of the outline of an oblique parallelogram with the corners rounded off, strongly pleochroic and with very distinct cleavages, has been referred for me by Mr. Davies to this mineral. Judging by the colour and pleochroism other grains may be of the same mineral.

Chalcedony.—There are a few grains of a mineral polarizing in grey and having a spherulitic structure. Such grains are common in the residue of chalk dissolved in hydrochloric acid.

Organic Remains.—A few microscopic organisms have been met with, and are sufficiently numerous to render it probable that with careful searching many genera might be found. The commonest are siliceous, spherical bodies with a pitted surface, with a more or less distinct dark centre, apparently not casts. These may be either Radiolarians or Diatoms. Casts of Foraminifera, probably of the genera *Planorbulina* and *Textularia* in a clear, colourless mineral, perhaps chalcedony, have been noticed.

The Greensand bed at Sudbury.—This bed has apparently been classified with the Thanet Sand on account of its position and colour. The great point of difference from the southern greensand already described is in the much larger glauconite-percentage, which gives the bed a greener, less grey colour. Glauconite constitutes about 75 per cent. of the grains, and the proportion by bulk is still greater, since the glauconite grains are larger and the other grains smaller than those of the southern bed. Under these circumstances it is difficult to compare the flint-percentage. The flint forms about 10 per cent. of the quartz and flint grains, leaving the glauconite out of consideration. This, though much lower than in the south, is still high. The quantity of sand other than glauconite in the specimen brought away was so small that it did not seem worth while to try to make a separation; but in slides of the sand left when the glauconite was washed off zircon, rutile, tourmaline, black mica, and fragments of the isotropic mineral described as garnet have been found. The points of resemblance to the southern basement-bed of the Thanet Sand are the facts that both are glauconitic, and contain a larger proportion of flint than is common, as well as fragments of a colourless garnet, which do not seem to be of such universal distribution as the other heavy minerals common to both. The basement Woolwich bed, though almost as largely glauconitic where it rests on the chalk in Hampshire, differs in several respects. Its glauconite is of a blue and not a yellow green; and though search has been made, no flint grains have been found.

The statement has been made in the Survey Memoirs that there seems to be no proof of unconformity between the Chalk and the Tertiaries. Prof. Prestwich, in his new volume, assumes such an unconformity, since he says, "as the area of the Chalk-sea at the close of the Cretaceous period gradually became more and more restricted during emergence, so the early Eocene strata during the first period of the following submergence were of very limited extent" *. Although a small flint-percentage might be due to an unconformity at a distance, so large a percentage could hardly have occurred in a sand formed far from the source of the flint; because the further the flint was carried, the greater would be the chance that, when deposited, it would be mixed with sand from other coasts. If such a sand could only be formed close to a chalk-shore, its existence at the base of the Tertiaries forms an additional piece of evidence in favour of the gradual extension of the early Tertiary sea described by Prof. Prestwich.

One at once wonders how so large a flint-percentage could have been formed in early Tertiary times, whilst the sand now being formed along a very similarly situated shore contains little or no flint. The difference may, perhaps, be due to a difference in the nature of the coast. Our coast consists of chalk-cliffs with the two long breaks of the Tertiary and the Wealden sands and clays. Is it not probable that currents drift the débris of these coasts as well as the material brought down by the Thames to mix with the débris of the chalk, and so *bring down* the flint percentage? If the early Thanet-sea stretched from the borders of Belgium as far north as Sudbury it would almost certainly have had something like 200 miles of unbroken chalk-cliff along its western shore, for the Tertiaries were not there, and even Prof. Prestwich, who seems to date the Wealden and Boulonnais anticlinal earlier than any one

* 'Geology: Chemical, Physical, and Stratigraphical,' vol. ii. p. 337.

else, does not give any reason for thinking that the chalk was quite cut through in the middle of the Wealden area before the deposition of the Tertiary beds. If there were no strong currents to bring material from the other coasts, such a shore would be just the place for the accumulation of sand largely consisting of flint. It is true that the succeeding beds have a flint-percentage of about 5, and cannot have been formed in a sea with very different shores; but it is possible that they are really contemporaneous beds formed further out to sea, which crept westwards after the flint-sand, the flint-sand always being formed against the cliffs.

Discussion.

Dr. Hinde considered the paper important as showing the great amount of minute particles of flint present in these sands. It was a matter for regret that the Authoress could not be present when the paper was read.

43. *On the* Durham Salt-District.

By E. Wilson, Esq., F.G.S. (Read June 6, 1888.)

The new salt-field in the North of England occupies the low-lying country bordering the estuary of the Tees, situate partly in Yorkshire, partly in Durham, and bounded by the Magnesian Limestone district of Durham on the north, by the Jurassic hills of Cleveland on the south, and by the German Ocean on the east*.

At the present time this salt-field has a proved or fairly indicated area of at least twelve square miles. Of this area, however, more than half lies beneath the sea, and is therefore inaccessible by the only system of working at present in operation in the district. Beyond these limits, however, the Durham salt-field has probably a wide extension. Evidences of a limitation of the field in a northerly and also in a westerly direction have, indeed, been obtained; but what are its boundaries on the south and on the east we have not as yet, and perhaps never shall have, any means of determining.

Discovery of the Rock-salt at Middlesborough and Origin and Progress of the Salt Industry in South Durham †.

In the year 1859, Messrs Bolckow and Vaughan, the celebrated ironmasters of Middlesborough-on-Tees, being in want of water at their Middlesborough Ironworks, had a borehole, 18 inches in diameter, put down to a depth of 1200 feet ‡. Although large supplies of water were yielded by the more pervious strata passed through in this boring, this water was so highly charged with sulphate of lime as to be quite unfit for the purposes for which it was required. After passing through 70 feet of superficial deposits, which in this district consist of marine warp, river-alluvium, and Boulder-clay, and 1136 feet of red sandstone and red and blue marls with gypsum, a bed of rock-salt, 100 feet in thickness, was struck at 1206 feet from the surface, the boring leaving off (in August 1863) in rock described as "limestone and conglomerate containing much salt" at a total depth of 1313 feet 4 inches.

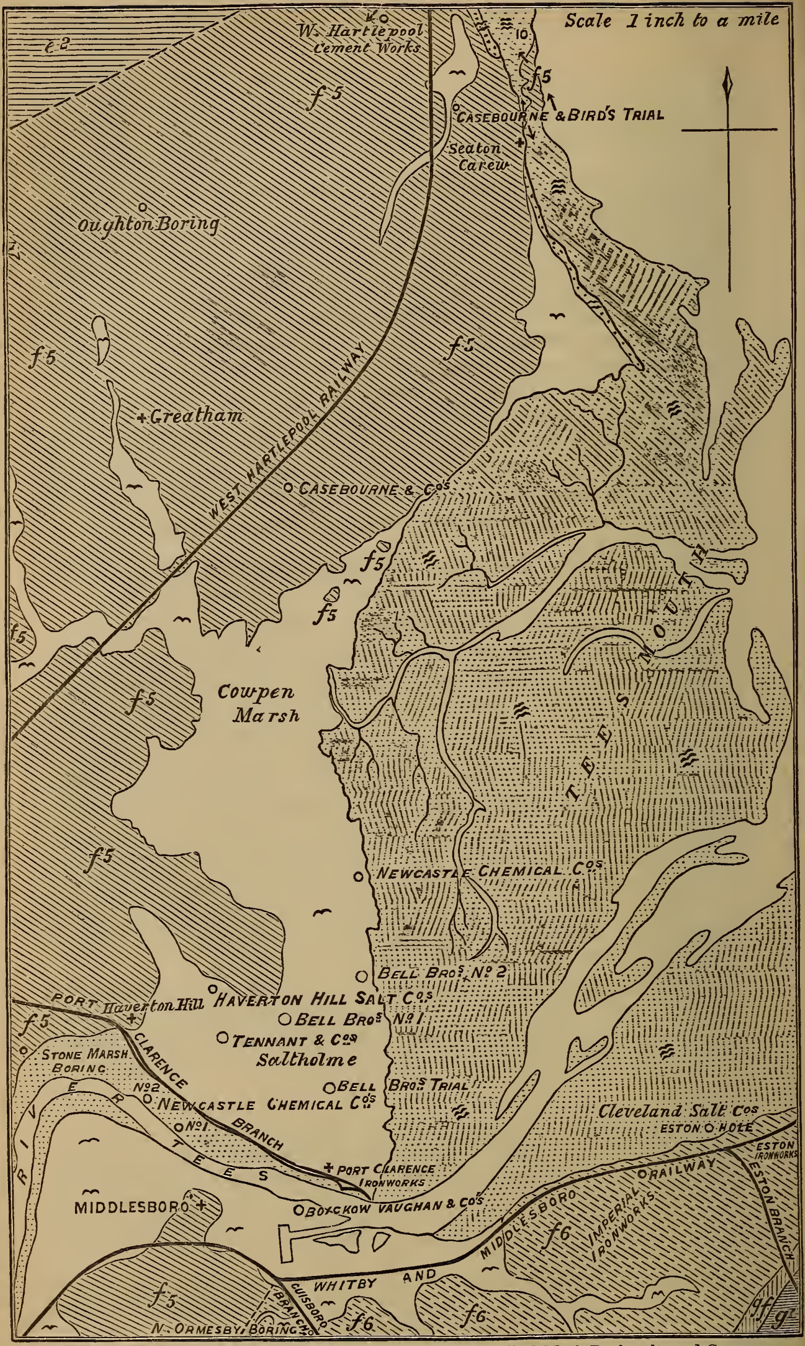
The discovery of rock-salt in the Tees Valley was thus a fortuitous piece of good luck. It may be remarked that this was also the case in Cheshire and in Antrim; but in those instances the discovery of the salt-beds was made in searching for coal. Shortly after its

* See map, p. 762.

† The discovery of rock-salt in the Tees Valley may be said to have been forecast so far back as 1816. In that year Mr. N. J. Winch, in his "Observations on the Eastern part of Yorkshire," read before the Geological Society, referring to the mineral springs of Dinsdale and Croft-on-Tees, said, "I have never heard that any brine spring had its source in this series of strata, though red sandstone in which gypsum abounds seems a likely locality for rock-salt" (Trans. Geol. Soc. vol. v. 1821, p. 543).

‡ For details of this section see Mr. John Marley "On the discovery of rock-salt in the New Red Sandstone at Middlesborough," Rep. Brit. Assoc. 1863, Trans. of Sections, p. 82, and 'Geologist,' 1863, p. 387.

Map of the Durham Salt-District, 1888.



e^2. Magnesian Limestone. f^5. Red and white Sandstone, with Red Marl, Rock-salt, and Gypsum; f^6. Red and green marls with Gypsum. *gf*. Black Shales (Rhætic). g^1. Dark Shales and Limestones (Lower Lias). o Salt-wells and trial-borings.

Alluvium. Blown sand. Tidal flats.

discovery at Middlesborough an attempt was made to sink a shaft in order to mine the rock-salt, but the influx of water was so considerable that the undertaking was for the time abandoned, and for nearly twelve years nothing further was heard about Middlesborough salt *.

In the year 1874 Messrs. Bell Bros. engaged the "Diamond Rock Boring Company" to put down an exploring hole †, close to their ironworks at Port Clarence on the north bank of the Tees, about three quarters of a mile (1314 yards) nearly due north of the Middlesborough boring, and after nearly two years' work, the bed of rock-salt, 65 feet in thickness, was reached at a depth of 1127 feet. In order to prove the character of the strata beneath the rock-salt, this borehole was continued for 150 feet below the thick bed of rock-salt, or to 1342 feet ‡ from the surface, and at this depth strata were met with which were identified (erroneously, I believe, see p. 770) as the Magnesian Limestone of Durham §.

Having proved the salt-bed, Messrs. Bell sank a well at the Clarence Ironworks, nearly a mile (1680 yards) due north of the place where it was first discovered at Middlesborough, and at this point found it at a depth of 1043 feet, having a thickness of 65 feet. Subsequently they put down a second hole about half a mile (830 yards) E.N.E. from their first well, and again found the salt-bed, rather thicker than before, at a depth of 1129 feet. Messrs. Bell Bros. were the first who succeeded in working the salt-bed in the Durham district, by a process which will be hereafter referred to.

The success of this enterprising firm soon led other competitors into the field. Most of the subsequent explorations have proved the rock-salt to be present in good thickness; but in two or three

* "On the Manufacture of Salt near Middlesbrough," by Sir Lowthian Bell, Bart., F.R.S., M.Inst.C.E., 'Proc. Inst. Civil Engineers,' vol. xc. 1886–87, part iv. p. 131 *et seq.*

† *Loc. cit.* See Appendix, p. 779, for details of this boring.

‡ Two analyses of this limestone given by Sir Lowthian Bell, in his valuable paper already quoted, yielded the following results:—

	feet.	feet.
"Depth from under-surface of the salt......	154	193
Carbonate of lime	54·71	94·48
" magnesia	41·18	2·98
" iron	0·81	0·78
Silica	2·00	1·20
Bitumen	0·22	0·36
Moisture	1·08	0·20
	100·00	100·00"

There are some slight discrepancies here. In the sections to Sir L. Bell's paper (pl. 3. fig. 3) the total depth of the boring is given as 1355 feet, and the beds of "limestone and much gas" and "grey limestone and gypsum" described in that section, and from which the above analyses appear to have been taken, lie at depths of from 56 to 133 below the *under* surface of the rock-salt, and therefore could not have come from depths of 154 and 193 feet below that bed. Probably "depth from *upper* surface of the salt" is here meant.

§ *Loc. cit.* p. 133.

notable cases it was either very poorly developed or entirely wanting. The Newcastle Chemical Works Company put down two boreholes on the north bank of the Tees, opposite Middlesborough and about 1400 yards W.N.W. of Messrs. Bolckow, Vaughan and Co.'s Middlesborough well. Although the sinking at this point was carried to a depth of 1260 feet, including upwards of 200 feet of Magnesian Limestone underlying the New Red Sandstone, not a trace of the rock-salt was found *. Again at a boring which was made at Stone Marsh, Haverton Hill, on the Tees, one mile W.N.W. of the last-mentioned exploration, to a depth of 1000 feet, including about 180 feet of Magnesian Limestone, a bed of rock-salt only 9 feet in thickness was found near the base of the New Red Sandstone. About three quarters of a mile (1300 yards) north of the Newcastle Chemical Co.'s unsuccessful sinking, the Haverton Hill Company have sunk several wells, and here the rock-salt was met with in full development (93 to 123 feet) at a depth of about 900 feet. The Newcastle Chemical Company having secured a district on the Tees-mouth shore, north of the area leased to Messrs. Bell, and 1235 yards nearly due north of the No. 2 well of that firm, sank seven wells within a limited area, and in all of these found the salt-bed in full thickness (90 to 117 feet) at a depth of 1100 feet. A company, promoted by Mr. Casebourne of Hartlepool, has put down a hole on property belonging to the Greatham Hospital, at a point two miles a little west of north of the last-mentioned wells, and found the salt 82 feet thick at a depth of 889 feet. This is the most northerly point at which the salt-bed has yet been proved. Last year the same firm (Messrs. Casebourne and Bird) commenced a boring † for salt at Seaton Carew, two miles N.N.E. of their Greatham well, and about the same distance south of Hartlepool. The New Red Sandstone was penetrated to a depth of 522 feet, without any traces of rock-salt being found. The Magnesian Limestone was then entered, and at the time of writing had been proved to a depth of 838 feet, or 1360 feet from the surface, without being passed through.

So long ago as the year 1827 a boring was put down to a depth of 529 feet at Oughton, 1½ mile west of Seaton Carew. The greater portion, if not the whole, of this boring was in Triassic sandstones and marls, but no salt-beds were met with. In 1887 Messrs. Casebourne and Co. put down a boring at the Cement Works near West Hartlepool, half a mile N.W. of the Seaton Carew boring, to a depth of 770 feet. The upper 715 feet of this section consisted of New Red Sandstone (Keuper Waterstones), the lower 55 feet of Magnesian Limestone. No rock-salt was found here either, but considerable deposits of anhydrite occurred at the base of the Trias ‡.

* See Appendix, p. 779, for details of this section.

† See Appendix, p. 781, for details of this section.

‡ The presence of from 500 to 700 feet or so of Triassic strata near Seaton Carew, within a mile of the probable boundary of the Magnesian Limestone, would seem to indicate the existence of a fault, with a downthrow on the south, between this place and West Hartlepool.

It is intended to carry the Seaton Carew boring to a total depth of 2000 feet, in order to determine whether or not productive measures of the Durham Coal-field extend beneath the Permian and Triassic rocks in this direction. Whatever be the result, this trial-boring will always be one of very great geological interest, not only from the light it will throw upon this important question, but also from its furnishing us for the first time, in one complete vertical section, with the entire series of the Magnesian Limestone of Durham *.

Further successful explorations for rock-salt have also been recently conducted south of the estuary of the Tees. The Middlesborough Estate Co., Limited, have proved the salt-bed 90 feet in thickness at a depth of 1341 feet from the surface at North Ormesby, three quarters of a mile (1200 yards) due south of Messrs. Bolckow and Co.'s Middlesborough boring. The Cleveland Salt Company (formerly Messrs. Bolckow and Vaughan) have sunk a well on the Tees foreshore, near the Eston Ironworks, about $2\frac{1}{4}$ miles east of their Middlesborough well, and found the salt-bed 81 feet in thickness at a depth of 1570 feet from the surface †. The salt-bed (86 feet) has also been proved at the Imperial Ironworks, half a mile nearer Middlesborough, at about the same depth. In the year 1887 there were, according to Sir Lowthian Bell, no less than twenty wells in the Durham district from which salt in the form of brine had been raised, although seven of these were then disabled through accident. The annual production of salt from these wells in that year has been estimated at 150,000 tons, and for the present year at 200,000 tons or thereabouts. Seeing that the demand for this substance at the soda-works of the neighbouring district is at the present time very considerably in excess of this amount, there can be very little doubt that, the natural supplies being ample, the above output is capable of very considerable expansion in the future.

Stratigraphical Position of the Saliferous Rocks of the Durham district.

As in other cases where our knowledge of the stratigraphy of a district mainly depends upon the evidence afforded by deep borings, the determination of the geological age of the saliferous rocks of the Durham district is by no means free from difficulty. We must not therefore be surprised to find that very diverse and conflicting opinions have already been expressed, and that at the present time a good deal of confusion exists on the subject. I propose in the first place to briefly review these opinions, and afterwards to consider in a little more detail the particular view which I believe to be the correct one.

In a paper read before the British Association in 1863, Mr. John Marley described the discovery of rock-salt at Middlesborough by

* Since this paper was read the boring at Seaton Carew has been continued and is still proceeding. The Magnesian Limestone has been proved to have a total thickness of 878 feet at this point. At a depth of 1400 feet from the surface Carboniferous rocks were entered, and on Sept. 29th, 1888, had been proved to a depth of 400 feet, or a total depth of 1800 feet from the surface. These rocks consist of grey and red sandstones with dark bituminous shales with two thin coal-seams, and evidently belong to the Coal-measures of Durham; but, so far, no workable coal has been reached.

† See Appendix, p. 778.

Messrs. Bolckow and Co., and gave a detailed section of that boring, and the analysis of the salt here quoted *. The author refers "the strata in which the salt occurs to the Upper New Red Sandstone, or the same as those in which the rock-salt of Cheshire occurs."

In a paper "On the parts of England and Wales in which Coal may and may not be looked for beyond the known Coalfields," read before the British Association in 1866 †, Sir Roderick Murchison referred to the (then) recent discovery at Middlesborough, "by the spirited ironmaster Mr. Vaughan, of a body of rock-salt subordinate to the New Red Sandstone at a depth of 1800 ‡ feet without reaching even the surface of the Magnesian Limestone." In the Presidential Address to the British Association in the year 1880, Sir Andrew C. Ramsay, LL.D., F.R.S., referring to the earlier salt-explorations of Messrs. Bolckow and Messrs. Bell, said (p. 11), "in the North of England at and near Middlesb'rough, two deep boreholes were made some years ago in the hope of reaching the coal-measures of the Durham Coalfield§. One of them, at Saltholme, was sunk to a depth of 1355 feet. First they passed through 74 feet of superficial clay and gravel, and next through about 1175 feet of red sandstones and marls with beds of rock-salt and gypsum. The whole of these strata (excepting the clay and gravel) evidently belong to the Keuper marls and sandstones of the upper part of our New Red Series. Beneath these they passed through 67 feet *of dolomitic limestone, which in this neighbourhood forms the upper part of the Permian series*, and beneath the limestone the strata consist of 27 feet of gypsum and rock-salt and marls, one of the beds of rock-salt having a thickness of 14 feet. This bed of *Permian Salt* is of some importance, since I have been convinced for long that the British Permian strata were deposited, not in the sea, but in salt lakes comparable in some respects with the great salt lake of Utah, and in its restricted fauna to the far greater salt lake of the Caspian Sea" ‖.

In the geological article by Messrs. W. Y. Veitch and G. Barrow, F.G.S., appended to the 'Guide to Middlesborough and the District,' for the use of Members of the British Association visiting Cleveland, Sept. 8th, 1881, the authors give three detailed sections of the salt-measures of the district, viz., Messrs. Bolckow, Vaughan & Co.'s Middlesborough well, and Messrs. Bell Brothers' Saltholme Test-boring and No. 1 well, and speak of the salt-deposits as occurring in the New Red Sandstone.

In the Sixth Report of the Committee of the British Association "On the Circulation of Underground Waters in the Permeable Formations of England and Wales" ¶, Mr. C. E. de Rance, F.G.S.,

* Rep. Brit. Assoc. 1863, Trans. of Sections, p. 82. 'Geologist,' 1863, p. 387. Appendix, *infrà*, p. 782.

† Rep. Brit. Assoc. 1867, Trans. of Sections, p. 61.

‡ An error for "from 1200 to 1300 feet."

§ This was not exactly the case; the first boring was sunk for water, the second for salt, and to test the strata below the salt-bed, rather than with the hope of actually reaching coal. See Bell, *loc. cit.* p. 133.

‖ Rep. Brit. Assoc. 1880, p. 11. The *italics* in this and the following quotations are mine.

¶ Rep. Brit. Assoc. 1880, p. 104. See also Seventh Report of the same Committee, Rep. Brit. Assoc, 1881, p. 310.

referring to the Middlesborough boring, says, "The limestones, *thick salt-beds*, and gypsum in that boring, *are probably referable to the Permian*; the intervening beds of red sandstone, 673 feet, are probably referable to the Waterstones and Lower Mottled Bunter, the Upper Mottled and Pebble-beds having thinned out." But in the Eleventh Report * of the same Committee we find that this author modifies his opinion as to the strata met with in the Middlesborough and Saltholme borings to the extent that he considered it "more probable that the pebbly character of the middle portion of the Bunter has died away northwards, and that the Middlesborough section represents Waterstones, pebbleless Middle Bunter and Lower Bunter."

In a paper read before the Geological Section of the British Association in 1886, on "The Stratigraphical Position of the Salt Measures of South Durham" †, Professor G. A. Lebour, M.A., F.G.S., gives reasons for suggesting "that much of the Salt-measures of the South Durham district is probably the representative of the Upper or Rauchwacke Permian of Germany."

The following table shows the classification Professor Lebour tentatively suggests for the strata met with in the Durham district, with an alternative arrangement of the strata which I would myself advocate.

Classification of the Permian and Triassic Rocks of the Durham district, according to

	Lebour.	The Author.
Avicula-contorta beds (proved in Eston shaft and boring)	Rhætic.	Rhætic.
7. Red and green marls with gypsum (known only South of Tees)	Upper Trias. (7 and 6)	Red Marls. — Upper Trias, viz. Upper Keuper. (7 to 4)
6. Red sandstone		Waterstones. (6 to 4)
Unconformity (?).		
5. Red sandstones and marls	(? Lower) Trias.	
Unconformity (?).		
4. Red marly sandstones, marls with lenticular beds of anhydrite, gypsum, and salt, and fœtid limestone in variable bands towards the base.	Upper Permian (Rauchwacke)	
		Unconformity.
3. Main Magnesian Limestone............	Middle Permian. (3 and 2)	Permian (Upper ‡). (3 to 1)
2. Marl-slate, with fish-bed		
1. Yellow sands	Lower Permian.	
Unconformity.		Unconformity.
Carboniferous rocks		Carboniferous.

* Rep. Brit. Assoc. 1885, p. 384.

† Rep. Brit. Assoc. 1886, Trans. of Sections, p. 673.

‡ That is to say, Upper or Zechstein &c. division, as contrasted broadly with the Lower or Rothliegende group.

The above classification of Professor Lebour's has been criticized by Professor Green, in 'Nature' *, on general grounds regarding the impracticability of making precise correlations of the minor divisions of a formation in dissociated areas, especially in the case of "a group of rocks like the Permian, formed in so many distinct basins and under changing conditions, the order and nature of which were probably never the same in any two basins." With the general tendency of these objections I coincide. To arrive at correct conclusions regarding the classification of the Permian (and the Triassic) rocks of the Durham district, we must compare these rocks with those of the same series in other portions of the same great North-eastern area or basin, with which they are in direct physical continuity, and of which they form a part. All attempts to correlate the Permian rocks of Cumberland and Lancashire with those of Durham, Yorkshire, &c., are, I believe, doomed to failure, because these two areas were physically disconnected in Permian times, and on that account the sequence of the possibly synchronous deposits in them is entirely different †. Still more hazardous would it be to attempt to correlate in minute detail, especially in the absence of any strongly confirmatory palæontological evidence, the minor divisions of the Magnesian Limestone of Durham with the rocks of the same series in the equally disconnected and far more distant continental areas. But that it is possible to compare the Permian (and the Trias) of Durham, in their subdivisions, with the same rock-series in other parts of the North-eastern basin I cannot doubt; and it would be a lame conclusion, I consider, to fall back on some general term, such as "Poikilitic" or "New Red Sandstone," for the united Permian and Trias of Durham, because the characters and succession of those rocks in that district are not precisely identical with what we find them to be further to the south.

Sir Lowthian Bell, in his essay "On the Manufacture of Salt near Middlesborough," does not himself consider the question of the geological age of the saliferous rocks of the district; but in the discussion which followed the reading of his paper several diverse opinions on this head were expressed by some eminent authorities. Sir W. W. Smyth said, "It had been already shown pretty clearly that the formation in which the salt was found was of a *different period*, and of a different quality to that of the Cheshire salt-beds." On the other hand, Professor Hull wrote that "The salt-rock under Middlesbrough seemed to occupy the *exact geological position* of that in Cheshire, Staffordshire, Warwickshire, and at Carrickfergus, near Belfast, being at the base of the New Red Marl (Keuper division of the Trias), and above the New Red Sandstone (Bunter);" whilst Mr. Bauerman observed that the subject of the paper was "very interesting, but, like many other interesting subjects, *obscure*."

The Geological Survey of England class the saliferous beds of South Durham with the lower or "Waterstones" section (f^5) of

* 'Nature,' vol. xxxvi. 1887, p. 289.

† "The Age of the Pennine Chain," Rep. Brit. Assoc. 1879, p. 343, and Geol. Mag. 1879, p. 500.

the Upper Keuper division of the Triassic series. Upon the recently published maps the rocks of this lower subdivision (Waterstones) are shown as occupying the larger portion of the low-lying country intervening between the Jurassic uplands of the Cleveland district and the Magnesian Limestone region north of the Tees, without the intervention of any Bunter Sandstone. The limits of the Permian and Triassic areas could not, however, be defined with precision, owing to the thick cloak of superficial deposits, which renders the study of the solid geology of this district so difficult; thus the boundary between the two had to be indicated by formal lines, and it is stated on the maps as approximate only.

From the foregoing references, then, it appears that there are three distinct views at present prevailing with regard to the geological age of the saliferous deposits of the Durham district. First, there is the view, originally expressed, I believe, by Sir Andrew Ramsay, that the principal bed of rock-salt belongs to the Keuper, and that the lower beds of rock-salt, marl, limestone, and gypsum belong to the upper portion of the Permian series. This is the view which Mr. Horace Woodward, F.G.S., adopts in the new edition of that work so valuable to all students of British Geology, 'The Geology of England and Wales' *. Then we have what I should call the more extreme view of Professor Lebour and Mr. C. E. De Rance, that *all* the salt-beds and associated strata, "Red marly sandstones" &c. (No. 4 in Prof. Lebour's classification), belong to the Permian formation, and that the overlying series of Red Sandstone and marls (No. 5) represent the Lower Trias or Bunter Sandstone. Lastly, there is the view that *all* the salt-beds and the whole of the saliferous marls, sandstones, and limestones met with in the lower part of the various borings in this salt-field † above the continuous strata of the Magnesian Limestone, as well as all the overlying red rocks of the Tees-valley district, belong to the Trias, and to the Upper or Keuper division thereof—to the same general series, in fact, as that which contains beds of rock-salt in Cheshire, Worcestershire, and the north of Ireland. This last is the view which the earlier geologists, judging by the limited evidence then available, took of the matter, and is the one which has always appeared the most probable to myself ‡. In addition to the authority of the Geological Survey, which, as the result of careful and detailed investigation on the spot by highly qualified men, must always carry very great weight, I think I am justified in quoting this as the opinion of Professor Hull; for in the correspondence relating to Sir L. Bell's paper §, the able author of the "Trias and Permian Rocks of the Midland Counties" refers the salt-rock under Middlesborough to the base of the Keuper Red Marls, and says nothing about 'Permian Salt.' It is only fair, however, to say that Prof. Hull refers solely to the Middlesborough

* 'The Geology of England and Wales,' 2nd ed. 1887, pp. 221, 241.

† See p. 772 and Sections facing p. 782.

‡ "The Permian Formation in the North-east of England," 'Midland Naturalist,' vol. iv. 1881, p. 188.

§ *Loc. cit.* p. 154.

section, and makes no mention of Messrs. Bell's trial-boring, *i. e.* the particular section upon which the hypothesis of Permian salt in Durham was first based. We must also interpret in a liberal sense the words "the exact geological position" used by Prof. Hull. It would not be correct to assume that the salt-beds of South Durham, of Cheshire, Worcestershire, and the North of Ireland lie at exactly the same horizon in the Triassic (Keuper) series, or that they were strictly synchronous deposits. As a matter of fact, the beds of rock-salt in Durham lie near the base of the Upper Keuper (f^5) and 1700 feet below the topmost Trias (or we will say the Rhætics, to fix the horizon still more definitely), whereas in Cheshire the salt-beds come high up in the Keuper Marls (f^6), whilst in Worcestershire and in Antrim they probably occupy intermediate positions.

I will now state the grounds upon which I conclude that the saliferous rocks of the Tees valley belong, neither wholly to the Permian formation, nor partly to the Permian and partly to the Trias, but wholly and solely to the Triassic series. In the year 1881 I made a careful examination of the cores of the rocks passed through in Messrs. Bell Brothers' Saltholme trial-boring, including the 150 feet or so of strata beneath the thick bed of rock-salt at that point. From this inspection I satisfied myself that the rock-salt belonged to the Keuper division of the Trias. The thick series of regularly bedded and fine-grained red and grey sandstones and marls which, in this and the other sections here referred to (see Appendix and Sections facing p. 782), overlie and graduate down into the saliferous marls, and which underlie and appear to graduate up into the gypsiferous red marls, show the closest resemblances in their general structure and mineral characters to the Keuper "Waterstones" of the Midland counties.

The development in this district of some 300 or 400 feet of red marls with beds of gypsum and rock-salt, having very much the character of the Upper Keuper "Red Marls," beneath a considerable series of red sandstones possessing the characters of the "Waterstones," does not, in my opinion, militate against the conclusion that all these rocks belong to the Keuper series, but, on the other hand, tends to bear out the view, which we have independent reasons for adopting, that the "Red Marls" and the "Waterstones" can only be *arbitrarily* separated from each other, that they really form portions of the same rock series, and that the same peculiar physical conditions were maintained during their deposition. The lowest beds met with in the Saltholme boring beneath the thick bed of rock-salt (154 feet proved), and described by Sir Lowthian Bell as 'Limestone and marls with gypsum and rock-salt,' also appear to me to belong to the Keuper division of the Triassic series.

The cores of these beds which I now exhibit, and which were kindly given me by Messrs. Bell on visiting their works at Port Clarence, appeared to be fair samples of the 67 feet or so of strata met with near the bottom of their trial-boring, and described in the sections as "Limestone" or "Magnesian Limestone." I should demur to the use of the term "Limestone" as applied to the whole of these beds, and would designate them instead "indurated marls." Although there appear to be dolomitic or calcareous, as well as dark bituminous beds among them, they show no sort of resemblance to any known beds of the Magnesian Limestone of Durham; on the other hand, they possess the characteristic greenish-grey colour of certain Keuper Marls, as well as a very similar texture and probably also mineral composition, although decidedly harder than most of the rocks of that series. It is also worthy of note that they contain gypsum, as well as that they overlie a thickish seam of rock-salt. It was upon the supposed identification of these 'limestones' as belonging to the Magnesian Limestone that Ramsay based his hypothesis of Permian salt in Durham. Whilst not prepared to accept the evidence of rock-salt in the Permian formation in England, I do not on abstract grounds contest the possibility of such an occurrence. With the hypothesis of direct chemical precipitation in inland salt lakes (or lagoons) of the dolomitic deposits of the British Permians I entirely concur, and elsewhere I have advanced arguments in support of this theory *. Although the idea of 'Permian salt' in Britain must, I believe, be abandoned, it is worthy of note that in certain of the deep borings in the Durham salt-field (see Appendix, pp. 779, 781), gypsum and anhydrite are found to occur in intimate association with the dolomites of the Magnesian Limestone; and in the Seaton Carew section these minerals are distributed, more or less abundantly, through the greater portion of that series. Surely this is a very significant fact and one that must tell strongly in favour of the chemical-precipitation hypothesis. Accepting the accuracy of the information as to the presence in the Saltholme section of dolomitic limestones above certain saliferous strata, it would not be safe to assume, failing more decisive evidence on the subject, that such beds belong to the Permian formation. Calcareous beds are met with in rocks of undoubted Triassic age exposed at the surface in South Durham, and dolomitic rocks are known to occur to a considerable extent in the Keuper sandstones and marls of the West of England and in other parts of the British area, especially where these rocks approach a margin of Mountain Limestone. In the same way we might naturally expect to meet with dolomitic beds towards the base of the Keuper in a district where these rocks rest on a margin of Magnesian Limestone.

The view that the upper portion of the saliferous rocks of South Durham belongs to the Trias and the lower to the Permian, seems to me, if anything, the most improbable of all. The chances, in the abstract, against two sets of beds of such an uncommon mineral as rock-salt occurring at the same point, and within 200 feet of each other in the same vertical section, in two distinct rock-series, are assuredly very great; but the chances against such a coincidence are vastly increased when we consider that there is no sort of sequence between the two formations in the district in question, but that, on

* "The Permian Formation in the North-east of England," 'Midland Naturalist,' vol. iv. pp. 202–208 (1881).

the contrary, there is a decided break and unconformity between them, indicated by the omission of the whole of the Lower Trias or Bunter Sandstone, not to mention the Middle Trias, or Muschelkalk of the continent.

I would here observe, parenthetically, that this discordance between the Permian and Trias of Durham is probably in a large measure due to want of conformity between the Upper and the Lower Trias, coupled also perhaps with an original northerly thinning out of the Bunter Sandstone. The very ample and Cheshire-like development of the Keuper series in the Tees valley (1800 or 1900 feet as compared with 600 or 800 feet in the East Midlands), taken in conjunction with the total absence of the Bunter Sandstone in South Durham, is certainly a very suggestive phenomenon.

In some parts of the Midland district there are evidences of rapid attenuations of the Bunter Sandstone, as well as of actual discordance between the Bunter and the Keuper *, and in passing across Yorkshire something of the same kind evidently occurs.

The arguments against the whole (as of any part) of the saliferous rocks of South Durham being Permian are also very strong. In addition to the indications of the graduation of these beds upwards into undoubted "Red Marls," and the evidence of their mineral characters, which I affirm indicate that they belong to the Upper Trias, we have the negative fact, that no deposits of rock-salt have ever been found in any British rocks which have ever (rightly or wrongly) been assigned to the Permian period. Gypsum is, indeed, known to occur in certain Permian marls in this country, and, as we have lately learnt, has been found associated with the Magnesian Limestone of South Durham. Although beds of rock-salt occur in certain continental Permians, not even a single pseudomorph of common salt has ever been found in any British rock of Permian age. On the other hand, rock-salt occurs in the Trias (Upper Keuper) of Cheshire, Staffordshire, Shropshire, Worcestershire, &c., and in the north of Ireland; and where we do not meet with actual beds of this mineral in these rocks, its former presence is very frequently indicated by salt-pseudomorphs or by brine-springs. A very little consideration will show that it is much more probable that beds of rock-salt should occur towards the base of the upper than towards the top of the lower of two discordant formations. Between the Permian and Triassic epochs in Durham there was certainly an interval in time unrepresented by rock-formation. Had any deposits of salt been formed towards the close of the Permian epoch, and thus left for long periods of time exposed near the surface, these beds would almost certainly have been destroyed during this interval. That the main mass of Rock-salt belongs to the *over*lying and not to the *under*lying rock-series is indicated by its persistence at a well-defined horizon † in the former for a distance of at least four miles (Eston to Greatham), in a direction at right angles to the average

* "On the Unconformity of the Bunter and Keuper," Geol. Mag. 1880, p. 309; 'Geology of England and Wales,' 2nd ed. 1887, pp. 221, 224.

† See Vertical Sections, facing p. 782.

strike of the non-conformable Permian and Triassic rocks. Sometimes the rock-salt is entirely wanting, but in none of the deep salt-borings, colliery-sinkings, or more superficial excavations into the Magnesian Limestone of Durham have any saliferous beds ever been found associated with any undoubted Permian rocks.

Area of the Salt-field, Limits of Distribution and Depth of the Rock-salt.

The question naturally arises at this point, Can we at present form any conception of the extent of the area of the Durham Salt-field? All experience in other salt-districts shows that this mineral does not, like coal, lie in continuous beds of pretty uniform thickness over very extensive areas, but that it is liable to rapid fluctuations and sudden total disappearances. This evidently applies to the South-Durham salt-field. As we have seen, the thick salt-bed was present at Middlesborough in full development (100 feet). At Messrs. Bell's Saltholme trial-boring, three quarters of a mile to the north, the bed was reduced to little more than half this thickness (65 feet); at the Newcastle Chemical Co.'s boring on the Tees, only three quarters of a mile west of these two points, the salt-rock had entirely run out. At Stone Marsh, about a mile further west, the rock-salt is present, but in a very attenuated condition; whilst at the equally distant Haverton-Hill borings it attains its maximum development in the district.

Again, at the Greatham boring, midway between Middlesborough and Hartlepool, the salt is present in full thickness; but at Seaton Carew, a little over two miles north of this point, it is absent. In the seven wells put down by the Newcastle Chemical Co. on the Tees-mouth shore, the salt-bed was found to vary from 90′ 6″ to 115′ 4″, *i. e.* 24′ 10″ in a distance of only 132 yards, a fluctuation at the rate of 1 in 16. Evidently, then, the bed consists of one or more * great lenticular masses.

There is little reason to doubt that in this form the salt-bed has a wide distribution beneath the estuary of the Tees and the bordering districts. It is fully developed at the Greatham boring on the north and at the Ormesby boring on the south, places four miles apart, and has so far been met with in good thickness at every exploration in a straight line between the two points. In a transverse direction (W.N.W. and E.S.E.) the salt-rock has been found well developed from the Eston Ironworks to Haverton Hill, a distance of very nearly three miles. How far the bed extends from the Greatham boring towards Seaton Carew can only be proved by actual sinkings; but its absence in the recent Seaton and earlier Oughton borings seems to indicate that there is a considerable Triassic area bordering the Magnesian Limestone country which is destitute of this mineral. As regards the southerly extension of the rock-salt, the ample development of the thick bed at points between two and three miles

* It is assumed as most probable that the thick salt-bed hitherto met with in the various deep borings in this district is one and the same bed. See Vertical Sections, facing p. 782.

apart on the south bank of the Tees is certainly hopefully suggestive of a wide distribution. It is probable that this mineral underlies a large area of the low-lying ground south of the estuary of the Tees, and it is quite possible that it extends beyond that region and beneath the Cleveland Hills of Yorkshire. Owing, however, to the prevailing south-easterly dips of the Secondary rocks of this part of England, and the consequent coming in of higher measures, the saliferous beds of the Trias and rock-salt can only be looked for at very considerable and constantly increasing depths the further we proceed in that direction. In the country north of the Tees, where the inclination of the New Red Sandstone is generally very small, viz. 2° to 3°, and in some portions of the district almost *nil*, the Salt-rock is found at depths of from 1200 to 900 feet or less. In the vicinity of the Tees the dip appears to increase to about 5°, so that at Ormesby and Eston, close to the south bank of the river, its depth from the surface is more considerable, viz. 1350 feet and 1570 feet respectively. South of the Tees the average inclination of the strata appears to be about 3°. Beneath the Cleveland Hills the greatest of these depths would be considerably exceeded, seeing that, partly on account of the dip and partly on account of the rise of the ground, the whole or the greater portion of the Lias, as well as almost the entire series of the Triassic rocks of the district, would have to be passed through before the rock-salt (if present) could be reached.

We are now in a position to indicate approximately what these depths would be. At the Cleveland Salt Company's Eston boring the salt-rock is reached through 1570 feet of Keuper marls and sandstones. At the gypsum-pit, midway between Eston Junction and the Eston Ironstone Mines, the highest stratum of the Keuper marls was reached at a depth of 190 feet from the surface, or about 154 feet below the sea-level *. Taking the dip between these two points as 3° S.E., and assuming that no faults intervene to affect our calculations, we should have to add 120 or 130 feet to the Eston salt-works section to arrive at the full thickness of the Keuper rocks down to the rock-salt. This would give 1700 feet, and the full development of the Triassic series, including the saliferous beds at the base, as probably 1900 feet or thereabouts. According to Messrs. Tate and Blake †, the Lias and Rhætics beneath Eston Moor attain a maximum development of 1325 feet. Adding this to the Triassic strata overlying the salt-bed, we find that in this portion of the Cleveland district any wells sunk to the rock-salt, granting it to be present, would have to be at least 3000 feet deep. It has been supposed by some geologists that productive coal-measures underlie the Jurassic uplands intervening between the Durham and Yorkshire coal-fields, although the opposite view has generally been taken (rightly, I believe) by most of those who are competent to speak on the subject. This is a question entirely beyond the scope of the present paper, and into which I do not intend to enter, beyond calling attention

* 'The Yorkshire Lias,' 1876, p. 30.
† *Ibid.* p. 193.

to the light recent explorations in the Durham salt-field have thrown on the very considerable depths to which any coal-explorations would have to be carried in the above district, even supposing productive Coal-measures to be there present. For, to the 3000 feet of Lias and Trias, we should have to add fully 800 feet of Permian strata, besides a more or less considerable capping of Lower Oolites. This would mean something like 4000 feet down to the surface of the Carboniferous rocks, a depth which was held by the Royal Coal Commission of 1871 as the limit at which it would be possible to mine coal.

To return, however, to our proper subject, I would again insist on the want of all certainty there is in the distribution of so fluctuating and unreliable a mineral as rock-salt. All that we can safely say is, that the thick bed of rock-salt of South Durham has already been proved to extend over an area four miles by three or four in extent; that it is highly probable that beneath the greater portion, if not the whole, of this area the salt-bed maintains a considerable (80 to 120 feet) and pretty uniform thickness; that it is improbable that so considerable a deposit should rapidly die away in every direction; and that, as previous explorations seem to show that the bed does die away in two given directions (N. and W.), there are reasonable grounds for anticipating its further extension in the opposite (E. and S.) directions. At the same time I do not mean to affirm that the disappearance of the salt-bed at a single point on the Tees is sufficient to prove that it is absent from the whole of the rest of the Triassic country beyond, stretching S.W. from the Tees mouth, or that its presence at three or four points on the S.E. bank of this river is sufficient to prove its continuous and indefinite extension in that direction.

It is a well-known fact that rock-salt never crops out at the surface, and it has been justly observed that so soluble a mineral as this is could not be expected to do so, since its outcropping portions would be speedily destroyed by the infiltration of surface waters. I do not, however, believe, as some have supposed, that this is the explanation of the absence of the rock-salt on the Tees opposite Middlesborough, and still less that such dissolution along the outcrop has originated the channel of that river. The point referred to is between four and five miles from the outcrop, and here the horizon for the salt-bed lies 1000 feet beneath the surface and is bounded by impervious marls. The salt-rock has also been met with at other points nearer the outcrop. At Seaton Carew which is about one mile and a half from the outcrop of the Magnesian Limestone, the horizon for the salt-rock would lie at about 500 feet from the surface. Here also the measures were, I understand, dry, and there was no evidence in the shape of brine or other springs at this horizon to explain its disappearance. We may broadly assert that in the South-Durham salt-district the salt-rock (or the stratum occupying its horizon) is always enclosed between impervious beds and is free from water, having what is known in the Cheshire district as "a dry rock-head." If this salt-bed ever did crop out at the surface, of which fact I am by no means satisfied, the effects of surface-infiltration would, I believe, be limited to a small lateral extent; because on the removal of the salt the impervious roof would subside on to the impervious floor and the surface-action would be brought to a standstill. It has been suggested that certain cavities and swallow-holes met with along the boundary of the Magnesian Limestone between Hartlepool and Darlington, and also near Ripon, may be due to the dissolution of saliferous beds; but it seems to me more probable that the true explanation of these hollows is the same as that for similar phenomena along other limestone boundaries, and that the peculiar forms of the cavities may be due to the rapidly varying character and solubility of beds of the Magnesian Limestone. I therefore conclude that the present extension of the rock-salt in South Durham is defined by the limits of its original area of deposition and not by subsequent dissolution by outcrop or other infiltration.

Method of winning the Salt, Waste in working &c.

It would be beyond my powers and outside the scope of this paper to consider the chemical and mechanical details of the mining and manufacture of salt in the Durham district. For full information on these matters I must refer those who are interested in the subject to Sir Lowthian Bell's admirable essay "On the Manufacture of Salt near Middlesborough"*. There are, however, certain consequences of the method of working the salt-bed there described which cannot be considered as altogether satisfactory, and to which I should like to call attention. The salt is extracted from its bed by solution, by a method which has for some time past been in operation at Nancy, in France, but was introduced for the first time into England by Messrs. Bell Bros. about twelve years ago at their Saltholme works. The process is as follows:—A hole from 6 to 12 inches or so in diameter is bored down to and through the Rock-salt, and is lined with an iron retaining tube; within this an inner tube of 2 or 4 inches less diameter is let down and secured below; both tubes are perforated with holes where they pass through the rock-salt; fresh water is let down the space between the two tubes, and this passing through the outer holes gradually dissolves the salt; the brine thus formed enters the inner tube and rises in it as high as a column of fresh water will support a liquid having a sp. gr. of 1·204 or thereabouts, and is drawn up the remaining height by pumping. Now it appears that this system of working the salt, although far more economical for raising this mineral from great depths, both as regards the capital and the labour employed, than by sinking a shaft and regularly mining as in the case of coal, is extremely wasteful, having regard to the proportion of the salt which is extracted from its bed. It is found that a single borehole will only extract a limited amount

* *Loc. cit.* See also paper on "The South Durham Salt-bed and Associated Strata," read by Mr. W. J. Bird to the Manchester Geological Society, June 5, 1888.

of salt. This is apparently due to the insoluble earthy residue of the rock-salt (which in the Durham salt-bed seems often to attain rather large proportions), coupled with falls from the roof, forming in time over the floor of the cavity eaten out of the salt-bed a thickish earthy layer which is impervious to the solvent water. Thus, after a while, the brine is found to become weaker and weaker, until in time it will not pay to raise. Again, the bed of rock-salt appears to be dissolved away by this process in a very unequal manner, viz. much more rapidly above than below, owing to the fact that the saturated brine which sinks to the lowest depths of the borehole has not nearly such solvent power as the comparatively fresh water which floats upon it. Hence the cavities eaten out in the rock-salt at the bottom of a brine well assume the form of inverted cones, of which the bottom of the well is the apex. This leads us to infer that in the course of time, when the inevitable subsidences set in, a number of cavities will be formed at the surface which will conform to the general contours of these subterranean cavities, and of course the unequal character of such subsidences would be particularly destructive to surface properties. It appears further that, as the law now stands, owners of land adjoining these wells, unlike owners of land undermined by coal-workings, have no legal claim for compensation on account of the damage done to the surface, nor for the loss of the mineral which has been abstracted from beneath their property—a palpable injustice which it seems impossible to suppose can be allowed long to continue. These special evils would be removed if the salt-rock were mined and in other respects treated in the same manner as coal. By that mode of working, too, a much larger proportion of the bed might be extracted, as well also as a good deal which extends beneath the sea; but whether it would, by any method of working, be practicable to mine the whole or even the greater portion of an immense mass of rock-salt 100 feet in thickness, lying at depths of from 1000 to 2000 feet, I am not able to say, nor can one forecast the precise limits of the destruction which might result through subsidence, were such a thing done. I would conclude with the remark that, vast as are the stores represented by this thick and widely distributed bed of Durham salt (about one hundred million tons per square mile), the supply of the mineral is not absolutely unlimited, and that the interests of future generations as well as those of ourselves and our own immediate successors ought in a matter of this kind to receive due consideration.

In addition to acknowledgments already made, I am indebted either for valuable information or for references to Mr. Horace B. Woodward, F.G.S., Mr. Alfred Allhusen, M.I.C.E., Manager of the Newcastle Chemical Works Company, to Mr. John Harrison, Secretary of the Cleveland Salt Company, and to Mr. Rowland Gascoyne, F.G.S., of Mexborough. I am also specially indebted to Mr. W. J. Bird, Mining Engineer of Sunderland, for the section and loan of cores of the Seaton-Carew boring.

Appendix.

Section of the Cleveland Salt Company's Boring at South Bank, Eston on Tees, 1885.

			ft.	in.	ft.	in.
Post-Tertiary.		Made ground	6	0		
		Blue sandy Clay	10	0		
		Dark brown Clay	7	0	41	0
		Soft red marl	2	0		
		Brown "Pinnel"	16	0		
Upper Keuper (Red Marls).	Red Marls and Gypsum.	Red marl	22	10		
		Red and blue marl with veins of gypsum	31	3		
		Red marl with veins of gypsum	46	8		
		Red and blue marl with veins of gypsum	15	3	453	0
		Red and blue shale with veins of gypsum	325	0		
		Blue shaly Sandstone	2	0		
		Red Sandstone with thin beds of gypsum and shale	10	0		
Upper Keuper (Waterstones).	Red Sandstones.	Sandstone with thin beds of shale	11	0		
		Red Sandstone	415	8		
		Red Sandstone with thin beds of marl	39	0		
		Red sandy Marl	8	6		
		Red Sandstone	29	0		
		Red sandy Marl	4	2		
		Red Sandstone with thin beds of Marl	46	0		
		Red Marl	8	6	793	6
		Red Sandstones with beds of Marl	34	6		
		Red Marl	17	8		
		Red Sandstone with beds of Marl	138	7		
		Red Marl with beds of red Sandstone	21	11		
		Red Sandstone with beds of Marl	14	6		
		Red Marl with Sandstone	4	6		
	Saliferous Marls.	Red Marl	43	0		
		Red sandy Marl with blue spots and veins of gypsum	42	6		
		Red sandy Marl with thin veins of gypsum	78	0		
		Red sandy Marl with veins of gypsum and blue spots	80	0	282	3
		Anhydrite	11	6		
		Red sandy Marl with Salt	21	0		
		Red Marl with Salt	6	3		
		Rock-Salt	81	0	81	0
		Anhydrite with Salt	1	6		
		Anhydrite	1	6	28	11½
		Anhydrite and a little Salt	25	11½		
			1679	8½		

Section of the Newcastle Chemical Works Co.'s No. 1 Boring, on the R. Tees, opposite Middlesborough.

			ft.	in.	ft.	in.
Post-Tertiary.	Alluvium, &c.	Peat and muddy sand	10	0	99	0
		Dark sandy Clay	16	0		
		Sandy Clay	19	0		
		Running Sand	35	0		
		Hard-bound Gravel	7	0		
		Red "Pinnel"	12	0		
Upper Keuper (Waterstones).	Red Sandstones.	Red sandy Shale with gypsum	35	0	783	0
		Grey sandy Shale with gypsum	10	0		
		Red and grey Shale with gypsum	29	0		
		Red and grey sandy Shale	36	0		
		Red Sandstone	314	0		
		Red Shale	5	0		
		Red Sandstone	33	6		
		Red Shale	5	0		
		Red Sandstone	46	6		
		Red Shale	5	0		
		Red Sandstone	47	0		
		Red Shale	7	0		
		Red Sandstone	79	0		
		Red Shale	8	6		
		Red Sandstone	29	6		
		Red Shale	9	6		
		Red Sandstone	35	6		
		Red Shale	5	0		
		Red shaly Sandstone	43	0		
	Saliferous Marls.	Red Shale with beds of Sandstone	86	0	170	6
		Red Shale with small blue joints and veins of gypsum	60	6		
		Red and grey Shale and gypsum	24	0		
Permian (Upper).	Magnesian Limestone.	Grey Stone	68	6	207	6
		Magnesian Limestone	40	0		
		Anhydrite gypsum	5	0		
		White gypsum	13	6		
		White Rock	11	0		
		Magnesian Limestone	39	6		
		Anhydrite-gypsum	3	0		
		Dark grey Limestone with gypsum	7	0		
		Magnesian Limestone and gypsum	20	0		
			1260	0		

Note.—No beds of Rock-Salt were found in this exploration. The occurrence of gypsum and anhydrite in association with Magnesian Limestone in this Section is worthy of notice.

Section of Messrs. Bell Bros.' Trial-Boring at Saltholme, near Port Clarence, Durham, 1874.

Post-Tertiary.	Soil	1	6	77	0
	Clay	4	0		
	Dark Sand	7	6		
	Clean Sand	26	0		
	Red Clay	3	0		
	Sand and Gravel	8	0		
	Boulder-Clay	27	0		
	Carried forward	77	0		

Section of Messrs. Bell Bros.' Trial-Boring (continued).

			ft.	in.	ft.	in.
		Brought forward	77	0	77	0
Upper Keuper (Waterstones).	Red Sandstones.	Red Marl	73	0	778	0
		Red Sandstone with veins of Marl	144	0		
		White Sandstone	1	3		
		Red Sandstone with veins of Marl	153	9		
		Red Sandstone	10	0		
		Soft Marl	3	0		
		Red Sandstone	6	0		
		Blue Vein		10		
		Red Sandstone	31	2		
		Red Sandstone with veins of Marl	27	0		
		Soft Marl	4	0		
		Red Sandstone	29	0		
		Red Sandstone with veins of Marl	49	0		
		Soft Marl	6	0		
		Red Sandstone with veins of Marl	37	0		
		Marl with blue veins of Sandstone	17	0		
		Red Sandstone with veins of Marl	66	0		
		Blue vein		7		
		Red Sandstone with veins of Marl	13	5		
		Strong Marl	9	6		
		Red Sandstone with veins of Marl	26	6		
		Blue vein		3		
		Strong Marl	6	3		
		Red Sandstone with veins of Marl	30	6		
		Strong Marl and Sandstone	17	0		
		Red Sandstone with veins of Marl	16	0		
	Saliferous Marls, &c.	Strong Marl	20	0	272	7
		Red Sandstone and Marl	19	0		
		Strong Marl with veins of Sandstone	6	0		
		Strong Marl	23	0		
		Strong Marl with veins of gypsum	7	0		
		Marl mixed with Sandstone	27	0		
		Marly Sandstone with veins of gypsum	141	0		
		Gypsum	4	0		
		Hard white Stone	3	9		
		Gypsum	3	6		
		Marly Sandstone, very salt	8	1		
		Red Marl decayed, with Salt	10	3		
		Rock-Salt, red	9	0	73	5
		Rock-Salt, good	16	0		
		Rock-Salt	48	5		
		Rock-Salt, Marl, and gypsum	35	0	136	0
		Shale, very soft, and gypsum	8	0		
		Gypsum	13	0		
		Gypsum and Limestone	12	0		
		Limestone and much gas	45	0		
		Grey "Limestone"	9	0		
		Grey "Limestone" and gypsum	11	0		
		Gypsum	2	0		
		Gypsum containing Salt	1	0		
		Rock-Salt	14	0	14	0
		Marl containing Salt	2	0	4	0
		Marl and gypsum	1	0		
		Impure Salt	1	0		
			1355	0		

Section of Messrs. Casebourne and Bird's Trial-Boring at Seaton Carew, near Hartlepool, 1888.

			ft.	in.	ft.	in.
Post-Tertiary.		Brown Clay	6	0		
		Red Clay	6	0		
		Red "Pinnel and Cobbles"	6	0		
		Soft red sandy Marl	12	0		
		Red sandy Marl	3	0	33	0
Upper Keuper (Waterstones).	Red Sandstones.	Red and grey Sandstone	7	0		
		Red Marl	2	0		
		Grey Sandstone	5	0		
		Red Marl with beds of Sandstone	10	0		
		Red and grey Sandstone	36	0		
		Red sandy Marl	47	0		
		Red and grey Sandstone	10	0	117	0
	Saliferous Marls.	Red Marl	15	0		
		Red Marl with beds of Red and grey Sandstone	8	0		
		Red Marl with blue joints	35	0		
		Red Marl with beds of grey Sandstone	24	0		
		Red Marl with beds of grey Marl	33	0		
		Red Marl with blue joints	24	0		
		Red Marl with blue joints and veins of gypsum	178	5	317	5
		Anhydrite	13	0		
		Blue Marl with veins of gypsum	3	0		
		Anhydrite	1	0		
		Red Marl with veins of gypsum (A)	10	0		
		Dark Marl and gypsum mixed	2	7		
		Anhydrite, with black joints	25	0	54	7
Permian (Magnesian Limestone).		Magnesian Limestone with spots of gypsum	27	0		
		Magnesian Limestone, light grey with spots and veins of gypsum	38	0		
		Limestone, dark grey with spots and veins of gypsum	16	0		
		Dark blue Shale, "with small feeder of coarse black petroleum"	3	0		
		Anhydrite, with beds of dark blue Shale and gypsum	35	0		
		Limestone, light grey, and gypsum	7	0		
		Blue Shale	2	0		
		Light grey Limestone	11	0		
		Limestone, white	90	0		
		Limestone, hard white, and gypsum	12	0		
		Limestone, dark grey, and anhydrite	20	0		
		Limestone, light grey, and gypsum	18	0		
		Limestone, light grey	29	0		
		Limestone and gypsum mixed	31	0		
		Limestone, grey and gypsum	11	0		
		Limestone, light grey and gypsnm	33	0		
		Limestone, light grey	50	0		
		Limestone, light with spots of gypsum	45	0		
		Limestone, white	107	0		
		Limestone, light grey	23	0		
		Limestone, pseudo-brecciated light grey (B)	23	0		
		Limestone, light grey	9	0		
		Limestone, light grey, with spar cavities	9	0		
		Limestone, light grey	7	0		
		Limestone, white	82	0	878	0
		Carried forward	1260	0		

Section of Messrs. Casebourne and Bird's Trial-Boring (continued).

		ft.	in.	ft.	in.
	Brought forward......	1260	0		
	Limestone, light grey with a little gypsum	23	0		
	Limestone, dark grey with gypsum.........	17	6		
	Limestone, dark grey with spots of gypsum	59	6		
	Details of boring up to date of paper, June 6, 1888.				
	Further details from information since received.				
	Limestone, dark grey	40	0		
CARBONIFEROUS (COAL MEASURES).	Grey and red Sandstones and black Shales, with one or two thin Coal-seams, penetrated to a depth of 361 ft. on 16th Aug., 1888	361	0	361	0
		1761	0		

(Proceeding.)

(A) Horizon of Salt Bed.

(B) Feeder of brine of strength 21°/₀, quantity unknown, but persistent at a depth of 1150 ft. in the Magnesian Limestone. It is supposed by the Engineer to the boring that this brine drains from the Salt-bed in the Trias on the south.

NOTE.—So far as Rock-Salt is concerned this boring was a failure, but for the brine, and in other directions possibly, it is thought the undertaking may be commercially remunerative.

The Magnesian Limestone dips pretty regularly at 3°. The Coal-measures have an inclination of about 6°. No fossils were detected in the cores of Magnesian Limestone or of the New Red Sandstone. The occurrence of gypsum and anhydrite in considerable quantities, in association with the Magnesian Limestone, is a noticeable feature in this Section.

Analyses.

Analysis of the Rock-Salt of Middlesborough *.

Chloride of Sodium	96·63
Sulphate of Lime	3·09
Sulphate of Magnesia	0·08
Sulphate of Soda	0·10
Silica	0·06
Iron Oxide	trace
Moisture	0·04
	100·00

Analysis of the Rock-Salt from one of Messrs. Bell Bros.' Saltholme Boreholes †.

Chloride of Sodium	98·42
Sulphate of Lime	0·21
Chloride of Magnesium..............	0·12
Water	0·10
Red Clay	1·50
	100·35

* Quoted from Mr. John Marley's paper (*loc. cit.*).
† Quoted from Mr. W. J. Bird's paper (*loc. cit.*).

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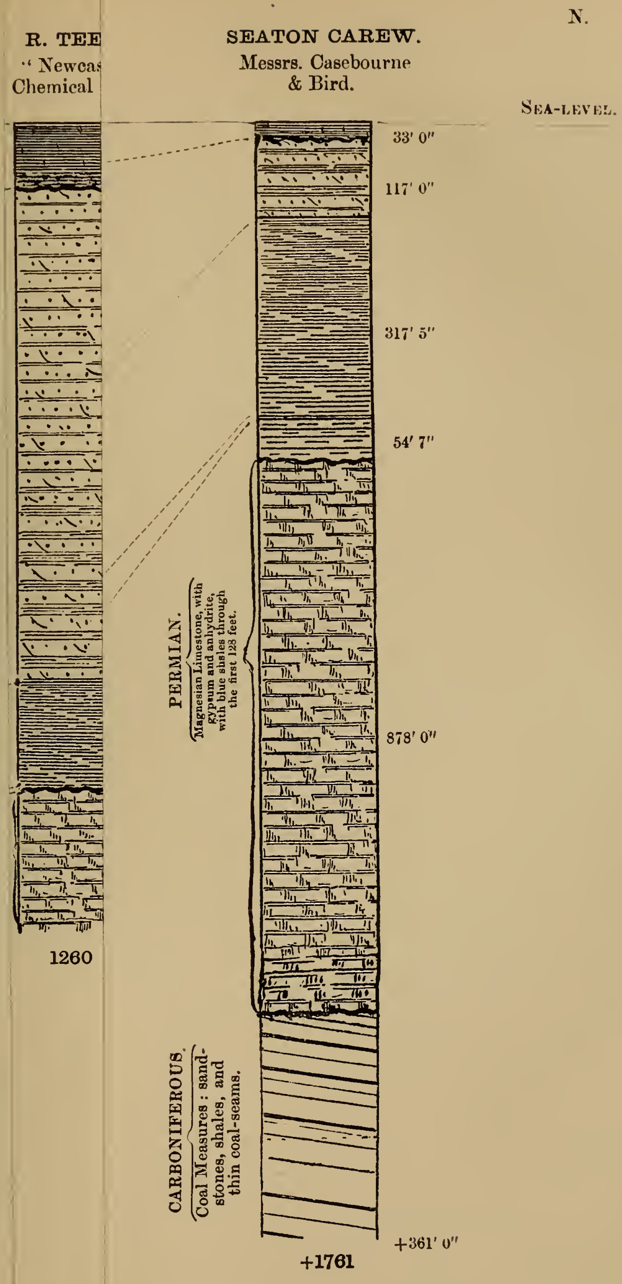

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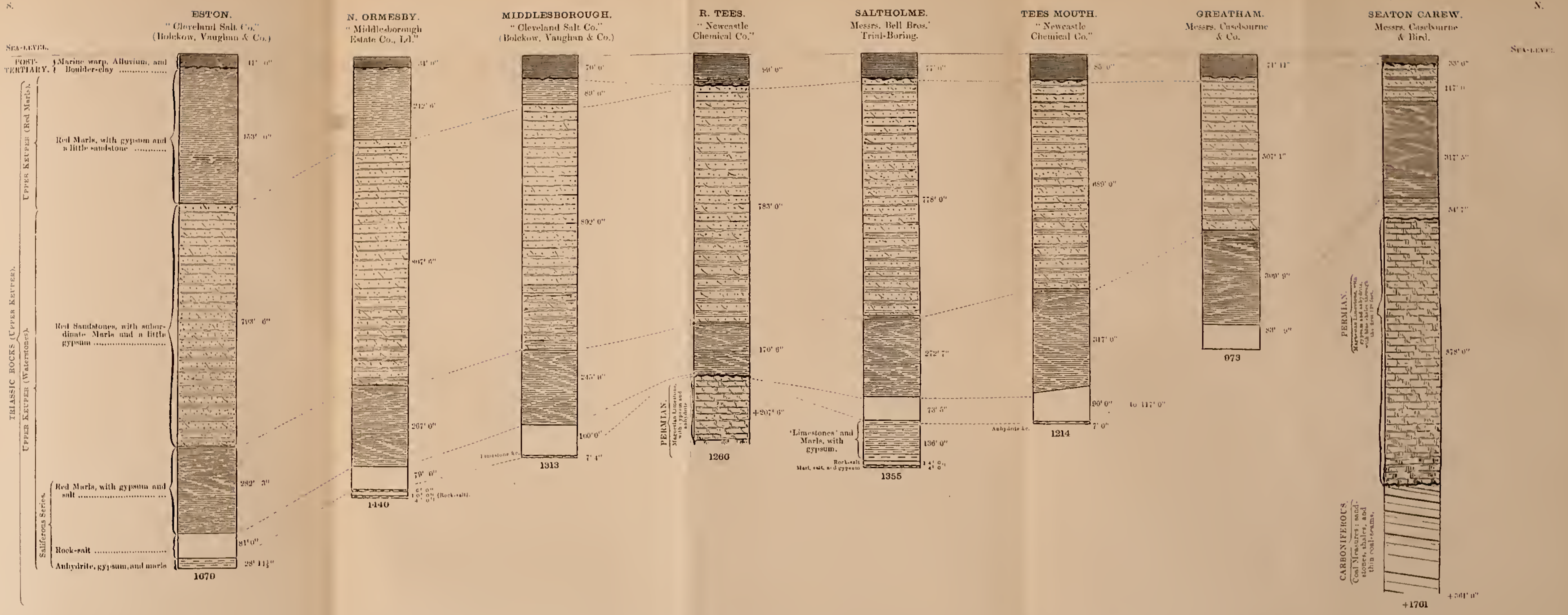
Sections of Deep Borings in the Durham Salt-District. (Scale: 300 feet to an inch.)



NOTE.—All these borings were made in a country which is remarkably flat and so little above the sea, that for all practical purposes we may assume them to start at the sea-level.

44. *On the* Horizontal Movements *of* Rocks, *and the* Relation *of these* Movements *to the* Formation *of* Dykes *and* Faults *and to* Denudation *and the* Thickening *of* Strata. By William Barlow, Esq., F.G.S. (Read April 25, 1888.)

I propose to call attention to some horizontal movements of rocks occasioned by gravitation, the importance of which has, I believe, been almost entirely overlooked, and shall try to show that the great forces of denudation in many cases owe much of their power to fissuring and dislocation produced by these movements, also that to these movements is to be referred the production of dykes and faults.

In the Grand Cañon District of the American Union a wide expanse of elevated horizontal strata, some thousands of square miles in extent, has been denuded in such a manner as to display a succession of huge terraces or steps of successive strata, each terrace being terminated by a sinuous line of cliffs or abrupt slopes.

Between the succeeding escarpments the strata dip slightly from the crest of the one below to the foot of the next above. In the median parts of any given terrace the strata are very nearly horizontal and have inclinations scarcely exceeding one degree; *but as we approach the escarpment of the next higher terrace, the inclination increases to three or four degrees, becoming a maximum at the base of this wall.*

The cumulative effect of the slight dip thus displayed, which for the most part has a northerly direction, is that the top of a certain stratum, the Carboniferous, is more than 8000 feet lower at the north, below the topmost terrace, than at the south, where it comes to the surface and forms a wide plateau, the lowest terrace. The difference in altitude between the highest and the lowest terrace is several thousand feet *.

In the same district of horizontal strata the forces of denudation have removed the upper strata to a great depth over a large area of elliptical form, producing in this way a great hollow, many miles in diameter, enclosed by cliffs and known as "The San Rafael Swell." Here also there are indications of a slight elevation of the unloaded strata within the denuded space as compared with the continuation of the same strata where they are heavily loaded beneath the surrounding cliffs †.

It has been suggested by Mr. Dutton that the phenomenon referred to is analogous to the action of creeping in deep mines; and Mr. Clarence King, in reference to the subsidence of strata in the same locality, makes a similar suggestion ‡.

* 'Tertiary Hist. of the Grand Cañon District,' C. E. Dutton, pp. 47, 70.
† 'Geology of the High Plateaus of Utah,' Dutton, pp. 18–21.
‡ U. S. Geological Exploration of the 40th Parallel.—I. Systematic Geology.

The phenomenon of creep * may be defined as the thickening of the parts of beds from which a load of superincumbent rock has been lifted, caused by a thinning of the adjoining parts of the same beds, which continue loaded, some of the substance of the latter being squeezed out to furnish the material for the thickening. The effects are, however, so extensively diffused that, although it is the *horizontal* components of the motions of the rock-particles which alone determine the extent of a creep, it is the *vertical* components of these motions which alone force themselves on our attention; thus Buddle tells us, "he has never noticed any tendency to a sliding or sideway movement in any subsidence of strata occasioned by the working of the coal, except the slight obliquity occasioned by the offbreak at the sides of the settlement where the strata are bent down and cracks formed" †.

If we regard the phenomenon recorded by Dutton as an instance of creep on a large scale, we must conclude that a lateral extension of the beds still remaining heavily loaded has taken place, and that a large mass of material has, somewhere below the surface, been squeezed out from beneath the cliffs. Further, the movement of this large mass must have produced a considerable horizontal thrust, which, as the process was no doubt very slow, and the lower ground at the foot of the cliffs of considerable extent, would be transmitted through the rocks underlying this lower ground to a very great distance.

The effects of such a horizontal thrust are, in the cases referred to, and in most other cases where masses of rock are similarly bounded by precipices or steep slopes, hidden from view, but there are instances where they are to be traced. Thus many evident examples of plication traceable to horizontal thrusts produced by gravitation are to be seen in Glacial drift.

And from the fact that comparatively small masses of rock have been able by their weight to squeeze up plastic Boulder-clays and soft sandy layers on which they rested into folds and contortions, we may fairly conclude that the unequal distribution of weight at the earth's surface, due to the presence of lofty cliffs and mountainous blocks, has been able during long periods of time to produce considerable plication, even of the more intractable rocks, in the same way.

It can scarcely be doubted that many instances of plication generally attributed to secular contraction of the earth's crust are traceable to the cause I have named. This will especially be the case with subsidiary plications found on the flanks of mountains; for wherever there are great inequalities of surface, rocks far beneath the surface and consequently having considerable plasticity, will be materially affected by the unequal distribution of the weight of the rocks above them, and will spread in the same way as the Boulder-clays referred to have done.

It has been suggested that much of the contortion and upheaval of the later Tertiary rocks of the sub-Himalayan zone has been

* See 'Student's Elements of Geology,' 2nd edition, p. 55.
† Proc. Geol. Soc. vol. iii. 1842, p. 149.

caused by a partial sinking of the central regions, due to a reflex action, the protracted adjustment of equilibrium after the great mountain-features had been fully developed *.

There is, I submit, another effect produced by the creeping movement of large masses of rock, where, owing to the presence of precipices or slopes, they are insufficiently supported on one or more sides, and it is one which I believe to be of considerable importance.

In the description of a creep given by Lyell reference is made to the production of cracks in the pillars of coal left standing in mines. These cracks are generally quite close, but very numerous; they are no doubt due to the strain induced by slight inequality in the yielding of the bed supporting the coal, and thus have a precisely similar origin to the joints and fractures artificially produced by Daubrée in different substances which he subjected to undulatory movement by torsion, or to simple pressure †.

Now the precipices of the Grand Cañon district indicate in a very remarkable manner the presence of joints and fissures. Over and over again, in the descriptions given by the geological explorers of these regions, we come upon expressions of surprise and admiration at the extraordinary architectural forms into which the cliff faces are carved ‡, and this is especially the case with regard to the higher cliffs §.

These sculpturings are, we know, mapped out by the joints and fissures present in the sculptured masses ||, just as in a quarry the readiest way of working the stone is determined by the positions of the joints and fractures. If therefore we conclude with Daubrée that joints and fractures occurring in nature are due to small torsional movements taking place in the rocks, we shall argue that some part at least of the effects referred to have been initiated by joints and fissures caused by creeping movements of the rocks due to their position in the faces of precipices, *i. e.* to their want of support on one side.

An observation made by Mr. Dutton confirms this view, and seems to indicate that fissuring produced by the small horizontal movements of rocks thus situated has important consequences in facilitating denudation. He tells us that he has repeatedly noticed that where a fault runs in a direction perpendicular to the trend of a cliff, the recession of the cliff is less on the side of the downthrow than on the other side of the fault ¶.

It is manifest that the higher the cliff the greater the superincumbent weight upon the rocks at its foot, and the greater the creeping movement and the jointing and fissuring consequent upon this movement. This jointing and fissuring weakens the rock and

* H. B. Medlicott, 'Mem. Geol. Survey of India,' iii. pt. 2, p. 174; and Quart. Journ. Geol. Soc. vol. xxiv. p. 48.

† Géol. Expérim. (Daubrée), Part 1, section 2, chapter 2.

‡ 'Geology of the High Plateaus of Utah' (Dutton), p. 254.

§ 'Tertiary Hist. of the Grand Cañon District' (C. E. Dutton), p. 204.

|| 'Géol. Expérim.' p. 324; and 'Tertiary Hist. Grand Cañon District,' p. 53.

¶ 'Tertiary History of the Grand Cañon District,' p. 200.

prepares it for degradation; and therefore the above phenomenon observed by Dutton is what we ought to expect if the jointing and fissuring produced in this manner in the cliffs of the great terraces are appreciable *.

I believe, then, that we have in this weakening effect of gravitation on rocks an important key to some of the peculiar features of the great erosion which has taken place in the plateau country of the American Union, and, indeed, that it is an important factor in the waste of almost all cliffs. I should not be surprised if it were found to have a very appreciable influence in all cases of mountain denudation.

From the consideration of the production of joints and small, comparatively superficial fissures by gravitation, I will now pass to the consideration of the production of extensive fissures by the same agency.

In a landslip the spreading of some underlying bed, which has become plastic through the percolation of water, or from some other cause, drags apart the more solid intractable beds above, and produces fissures and fractures transverse to the direction of movement †.

Familiar examples of fissuring produced in this way are often seen in railway-cuttings made through clay, also on the verge of sea-cliffs. The horizontal movement which produces the open fissures is in these cases, as in the case of most large landslips, due to a squeezing and lateral extension of the material some distance below the surface, and the consequent dragging apart of the mass above.

I suggest that most of the fissures produced in volcanic districts have a similar origin, and also that the same simple cause is the origin of trap-dykes.

First, as to the production of fissures. Wherever a considerable body of molten rock exists below the surface, its own weight and the weight of the solid rocks resting upon it will together produce considerable hydrostatic pressure throughout the molten mass. And the rigidity of the crust not being perfect, some movement, slight or otherwise, of the molten matter will take place towards points where the superincumbent weight is least—that is, provided there is not absolute equilibrium.

Therefore if the ground-surface is much higher over the tract of molten matter than it is just beyond its limits, the molten rock will tend to spread by its own weight and that of the solid crust resting upon it. And as all rocks are more or less plastic, we may, in this case, look for some horizontal movement, small though it be, of the solid rock at the confines of the molten mass, and which is subjected to its thrust.

* Dutton refers the phenomenon to the fact that those regions which have been elevated most have been most degraded by erosion; but this explanation does not appear to account for the lower portions of the higher cliffs having a greater rate of recession than the corresponding portions of the lower cliffs, but only for the greater erosion of the upper parts of the higher cliffs. Indeed, the lower portions of the higher cliffs are manifestly more protected from erosive agency owing to the greater amount of material which falls over them from above.

† Dana's 'Geology,' 3rd edition, p. 666.

Any such yielding of the solid rocks around to the pressure of the molten rock will tend to draw apart the solid crust resting upon it; and thus if the crust is not too strong, we shall have the ground opening along lines of weakness such as are produced by the presence of joints or other close fractures, and more or less extensive fissures will be formed. And in some cases, where there is any considerable adhesion of the crust to the spreading mass beneath, and the spreading is great in amount, the crust may be expected to break up into larger or smaller fragments, much as the ground-surface breaks up and separates in the case of landslips.

In cases where the quantity of molten matter spreading is large, relatively to the thickness of the solid crust, and the conditions are such that the mass spreads considerably in seeking equilibrium, the force operating to extend and rupture the crust will, it is evident, be both great and of long continuance. In all cases the degree of viscosity of the molten matter, and the degree of plasticity of the solid crust, and the presence of joints and fissures will all be important factors in determining what effects are produced *.

Next with regard to the production of trap-dykes. When a large mass of molten matter is present near to the surface, and a fissure is produced in the manner referred to, the weight of the ruptured crust will, if the plastic mass beneath be liquid enough, cause the latter to rise in the fissure, either as it forms or immediately after its formation.

The view that the production of the fissure precedes and is distinct from the extravasation of the matter forming the dyke, and that the latter is due to a relatively gentle hydrostatic force not capable of driving the lava into and through solid rocks, is supported by the fact that in many volcanic eruptions, lava flows out quietly and without explosive violence †; also by the fact that a subsidence of the strata around volcanic vents, such as would follow the hydrostatic movement of the lava, is sometimes seen ‡.

Dutton tells us that "a careful examination of the details of volcanic eruptions leaves the impression that they are pressed up by the weight of rocks which overlie their reservoirs, and that their extravasation is merely a hydrostatic problem of the simplest order" §.

The rending of the rocks preparatory to the extravasation of molten matter has, according to the view I have submitted, commonly taken place with suddenness and on a large scale. And I think we have evidence that this has been so in the case of many dykes, in the familiar fact that they generally take their course without regard to the irregularities in structure and disposition of the masses they

* An instance of a large body of solid rock, which overlay molten rock, shifting in the manner suggested, is given by Mr. Dana: see his 'Geology,' 3rd edition, p. 731.

† Scrope's 'Volcanos,' 1872, p. 160.

‡ Scrope's 'Volcanos,' 1872, p. 228. The formation of gases and heat-expansion of rock which occur beneath volcanic vents will, it is evident, operate to produce elevation of the crust; and it is not therefore surprising that subsidence should be observed but seldom. *Ibid.* p. 226.

§ 'Geology of the High Plateaus of Utah,' p. 130.

penetrate, preserving wonderfully straight courses, even across fractured and irregular strata, often for miles together.

An observation recorded by Mr. Dutton relative to the situation of some volcanic vents seems to be confirmatory of the view submitted above, that the presence of precipices or steep declivities has a weakening effect on the masses of rock which they bound, producing in these masses faulting and fissuring that greatly facilitate their degradation. Thus he tells us that basaltic vents occur very often upon the brink of cliffs of erosion, and never (within his observation) at the base of one; often upon the top of the wall of a cañon and never within the cañon itself, though the stream of lava often runs into the cañon; and he instances ten large cones standing upon the very brink of the Grand Cañon which have sent their lavas down into it. And he also mentions, away from the Cañon, a considerable number of craters upon the various cliffs near the Hurricane Ledge, and far to the north-eastward half a dozen upon the crests of the White Cliffs. He states that out of rather more than three hundred basaltic cones of this region, he has noted thirty-three, or nearly eleven per cent., occupying such positions *.

The fact of no vents being opened at the bases of the cliffs is quite in harmony with my views, for if the spread of the rock underlying the cliffs is producing a thrust against the crust lying near their bases, as I have argued it is, the tendency will be for this lateral pressure to keep fissures closed.

If, however, the underlying mass of lava is of great extent, and the ground-surface beyond it much lower than the ground-surface above it, so that the spreading movement of the lava is general and considerable, the local effect just traced may be partially lost in a more general one; the two walls of a cañon may move bodily further apart and produce a fissure within it, the site of the cañon being a line of weakness.

Even in this case, if the movement takes place gradually and slowly, it is possible that the local effect just referred to would keep the bottom of the newly forming vent closed, and prevent the extravasation of lava within the cañon.

An interesting case of a volcanic eruption on the verge of the Grand Cañon of the Colorado recorded by Mr. Dutton may be referred to in support of my views. On the south side of the cañon a lateral gorge or amphitheatre is excavated in the chasm-wall, very nearly as deep as the main abyss. At the summit of the wall of the inner chasm, just at the angle which it makes with this lateral gorge, a ruined basaltic crater stands upon the very brink, the dyke through which the lava came up and several neighbouring dykes being seen projecting from the face of the wall of the lateral gorge throughout a depth of half a mile. *The strike of all these dykes is parallel to the river, showing a probable connexion between the position of the river and the formation of the dykes.* The presence of some remnants of tufa-beds several hundred feet down indicates that the subsidiary

* 'Geology of the High Plateaus of Utah' (Dutton), note, p. 203.

chasm must have had some considerable depth when these dykes were formed*.

The uniform width of dykes throughout such great heights as are attained by those just mentioned† is manifestly a serious difficulty in the way of theories of dyke-formation which suppose the fissuring to have been caused by upheaval. It is almost equally incompatible with any theory of fissuring by the pressure of the intruded rock, supposed to act as a wedge; for surely the displacement of the material of a solid rock caused by the forcible intrusion of a thick mass of trap into the lower part of it would produce some torsional movement of the masses wedged apart, even supposing it did not cause any upheaval; and if there was a movement of this kind, how was the parallelism of the sides of the fissure preserved?

Again, the suggestion that the production of dykes proceeds from the dragging apart of the solid crust by a stretching force is in harmony with the fact that the deeper fractures from which igneous flows take place have occurred where there was little folding, and the more of the one, the less of the other. In the Appalachians, where we find indications of great lateral compression, no such outflows are known‡.

While, however, the bending of strata is not the immediate cause of the fissuring which has produced dykes, it is evident that in many cases it may be the cause of fractures or joints, which afterwards are converted into fissures by the spreading of underlying molten matter in the way suggested §.

That the body of trap injected is, in some cases, relatively so large ‖, is no difficulty in the suggested explanation. Where this is so we shall argue the presence of a large mass of molten matter beneath the crust at the time of the injection, and a large spreading movement of this mass.

It is, however, otherwise with theories of fissuring by contraction. For where *numerous* cracks or fissures are produced in a substance by unequal contraction due to unequal cooling, they always have a relatively small magnitude; and to account for large dykes in this way it is necessary to make some additional supposition, such as, that the molten matter exerts hydrostatic pressure laterally—a supposition very difficult to allow, when we find no effect of such a pressure in an upward direction, that is, in what is generally the direction of least resistance.

Most, if not all of the effects which I have thus far endeavoured to connect with horizontal movement produced by gravitation are displayed in a particularly instructive manner in the singular group of mountains in the Plateau Province of the American Union known as the Henry Mountains.

* Tertiary Hist. of the Grand Cañon District, p. 95.

† See also Scrope's 'Volcanos,' p. 165.

‡ Dana's 'Geology,' p. 791. Dana says that a lateral pull rather than a lateral pressure is apparently required for the origin of some dykes. *Ibid.* p. 803.

§ Dana's 'Geology,' p. 803.

‖ See Macculloch, 'System of Geology,' i. p. 110.

The elevations of the earth's crust which form these mountains are the outcome, on an exceptionally large scale, of the common phenomenon of lava penetrating but part way to the surface in dykes, and then diffusing itself between the beds and forming subterranean lakes or deposits of lava.

In this case very large deposits were formed, the intrusion of which lifted great thicknesses of superincumbent strata, and produced huge dome-shaped elevations of the otherwise nearly horizontal beds. These very regular protuberances were afterwards carved by denudation into rugged outlines of ridge and cañon.

The chambers occupied by the intruded trachyte are in some cases over three thousand feet high. They have in each case been made along a shaly layer in the formation where the cohesion was least*. They occur at different levels in the strata, and the lowest in geological position is 4500 feet below the level of the highest.

Large as is the scale on which the effects have been produced, it does not appear necessary to attribute them to the action of any other force than the force of gravitation acting in the manner I have already described.

Thus, first with regard to the frequent phenomenon of dykes stopping short before they reach the surface, a phenomenon of which we have here such important examples.

In most cases where a body of molten rock spreads and produces dykes the solid rock immediately over the liquid mass will experience the lateral pull first, and thus the vertical fissures which receive the molten rock *will begin to open from below.* And in cases where the upper strata are more plastic than the lower, or where they form an elevation on the surface, and thus are less completely attached to the rocks around them, it will often happen that, while the lower strata of the solid crust are fissured, the upper strata will make sufficient movement with respect to the lower to avoid rupture.

It would seem that the whole district about the Henry Mountains has experienced a force which ruptured the lower strata and extended the upper strata without breaking them. Thus Mr. Gilbert says respecting this district †: "It seems as though the crust of the earth had been divided into great blocks, each many miles in extent, which were moved from their original positions in various ways. Some were carried up and others down, and the majority were left higher at one margin than at the other. But although they moved independently they were not cleft asunder, the strata remained continuous, and were flexed instead of faulted at the margins of the blocks" ‡.

And further on the same writer adds: "It has been the opinion, not only of the writer, but of other students of the displacements of the West, that the ordinary sedimentary rocks, sandstone, limestone, and shale are frequently *elongated* as well as compressed by orographic

* 'Geology of the Henry Mountains,' by G. K. Gilbert, p. 58.

† *Ibid.* p. 11.

‡ The mountains stand within the province of the great flexures, but are independent of them.

movements, and that this takes place without any appreciable metamorphosism; but it is difficult to find opportunity for the demonstration of the phenomenon by measurement. . . . Of the unfractured quaquaversals of the Henry Mountains there is one which combines all the essentials of a crucial case. The 'Lesser Holmes' arch is nearly isolated; on three sides it rises from the undisturbed plateau, and on the fourth it joins a similar but fractured dome. The major part of its surface is composed of one bed, the Vermilion Cliff Sandstone, broken only by erosion. Comparing the length of this bed in its present curved form with the space it must have occupied before it was upbent, I find that in a distance of three miles it has been elongated 300 feet"*.

Second, as to the diffusion of lava between some of the beds which have been penetrated.

This may evidently be attributed to the lava having a less specific gravity than that of the strata which it penetrated, and to a lack of cohesion between some of the invaded layers which allowed portions of strata that were weakened by vertical fissuring to break away from the better-supported rock above, and gradually to bend down while the liquid lava passed into the horizontal rift which was thus forming.

Third, as to the elevation of the upper crust to form protuberances on the surface.

If the fissures had extended through the crust, the lava would have passed up, and, having a specific gravity less than that of the crust, would have welled out over the surface.

Now, suppose a very thick layer of plastic extensible clay had lain at the surface, and that the fissures formed extended through all the strata except the clay. The lava would in this case also have welled up, though while the clay remained unbroken it would not reach the surface, but would push up the clay; and it would continue to act thus until the hydrostatic pressure downwards, through the fissure, of the accumulating lava and the clay resting upon it balanced the hydrostatic pressure upwards caused by the slow sinking of the fissured crust.

The same line of argument manifestly applies to any case in which, as in that under notice, the upper crust is sufficiently flexible to yield to the pressure brought to bear upon it.

The reason why, in the Henry Mountains, the crust yielded in such a way as to produce the wonderful effects recorded is because in that particular spot the lava became very extensively diffused in wide sheets between the layers of strata. For we see that an exceptionally great diffusion of lava in this way must inevitably expose large surfaces to upward pressure†, at places where the solid crust has less thickness and therefore less resisting power than in the region around.

I will now call attention to some phenomena seen in these

* 'Geology of the Henry Mountains,' p. 80.

† As Mr. Gilbert remarks, the action of the liquid lava was exactly that of the water in a hydrostatic press. See 'Geology of the Henry Mountains,' p. 95.

mountains which I attribute to horizontal movements such as I have above treated of.

The very shape of the lava-deposits formed within the strata suggests that they have spread by their own weight and the weight of the superimposed crust. Circular or elliptical on plan, they are nearly flat in the middle, and curve down more and more rapidly towards the circumference*. Thus they have much the form taken by a drop of viscous fluid placed upon a level surface†.

Dykes rise from the upper surfaces of the deposits. *These are largest and most numerous about the centre,* and the largest of them mostly radiate from the centre outward. Where numerous they reticulate ‡.

This predominance of the dykes in the axial regions of the lava masses, a well-known phenomenon in volcanic mountains, is possibly due to the crust experiencing most strain where most motion of the molten matter beneath takes place, the spread of the molten matter facilitating the spread and rupture of the crust resting upon it.

Another phenomenon pointing in the same direction is that *faults are present in some cases which are subordinate phenomena of the uplift. They are restricted to its central portion*, and never occur so far from the centre as the zone of maximum dip of the domed strata. The strata of the upper part of the arch are in this case divided into a number of prismoid blocks, which stand at slightly different levels. All or nearly all of the fault-planes are occupied by dykes of trachyte §.

Further, the horizontal movement of some layers of strata on others is proved by the fact that in a number of instances the dykes are as even upon their upper surfaces as an artificial stone wall, the flat top of the dyke butting against an unbroken stratum of rock which bridges across it, and being parallel to the bedding of the enclosing strata. In one case a converse phenomenon is seen. A great dyke forms the crest of a ridge for half a mile, its base being buried in sandstone, and at the end of the ridge the strata are seen to be continuous beneath the dyke ‖.

Then there is a fact which we may refer to the presence of joints or close fissures caused by small horizontal motions of the parts of the strata. *The denudation has been far greater where the strata are uplifted to form the mountains than in the region around.* Thus, while from the base of the arch of one of the mountains 3500 feet of the Cretaceous and from 500 to 1500 feet of the Jura-Trias series have been removed, from the summit of the arch more than 2500 feet of the latter have disappeared. In cases where the lava deposits are so deep that the denudation has not laid them bare, the arched sedimentary rocks of the uplift have often been eroded down to

* 'Geology of the Henry Mountains,' p. 55. † *Ibid.* pp. 20, 23.

‡ Many mountain uplifts have much this form, *e.g.* the Uinta Mountains, the Kaibab Plateau, and the Black Hills of Dakota. See Geology of the Black Hills of Dakota,' p. 207.

§ 'Geology of the Henry Mountains,' p. 23.

‖ *Ibid.* pp. 28, 34.

substantially the same level as that of the surrounding plain, the mountain originally formed having quite disappeared *.

The source of additional jointing and fissuring which would account for the greater rate at which these uplifted rocks have been disintegrated is evidently to be found in the lateral strain and stretching to which over a long period they were subjected. Some increased weakening will also have been caused by the presence of precipices and steep slopes in the way before explained.

If the production of fissures by horizontal movement, unattended by upheaval, has been as common an occurrence as the foregoing would lead us to conclude, it may, I think, be fairly questioned whether sufficient prominence has of late been given to the influence exerted by it in determining the directions taken by rivers and streams.

The opening of a very narrow fissure across the bed of a river might suffice to initiate the complete diversion of the course of the water, and, in cases where no faulting or upheaval accompanied the fissuring, there would commonly be no evidence to betray the origin of the diversion.

Unfilled fissures have often been produced concurrently with dykes in modern times, and must have been frequently produced in the past. And we have in some cases a correlation of the locality and direction of dykes and the direction of watercourses† pointing to a common or connected origin.

Moreover, I have suggested that the existence of elevated ground over plastic rock causes the spread of the latter to be more considerable on account of the greater weight pressing upon it, so that fissuring by this means will commonly have been more prevalent among mountains and elevated lands than elsewhere. And this would furnish an explanation of the well-known fact that gorges, ravines, and cañadas are found in every high country, and also go far to account for the great number of cases of rivers intersecting elevated and isolated rocks.

In harmony with this explanation, we find that the examples of rivers whose courses are thus out of conformity with the features of the land-surface and also with the dip of the strata are most numerous in countries where dykes and other traces of the presence in the past of very plastic or fluid rock near the surface are found.

Thus, in the country of the great cañons in North America we have innumerable instances of want of conformity between the courses of considerable streams and the contour of the ground-surface and the dip of the strata‡, and in the same district we have a recurrence over wide areas of similar and evidently related phenomena of faulting and contortion, which indisputably proves

* 'Geology of the Henry Mountains,' pp. 25, 33, & 35.

† In Scotland, for instance.

‡ 'Tertiary Hist. of the Grand Cañon District' (C. E. Dutton), pp. 2, 49, 50, 73, 201, 203, 204, 220; and 'Geology of the High Plateaus of Utah,' pp. 17, 257. Report of the U.S. Geological and Geographical Survey of the Territories, Colorado, &c., 1876, pp. 52, 54; 'Geology of the Black Hills of Dakota,' p. 216.

that large tracts of the earth's crust have in this district experienced related movements, and points to a liquid or very plastic state of the underlying rocks at the time. The probability that separation by strain has in many cases initiated the diversion of rivers in the Western States has been recognized by some American geologists*.

Other explanations of the want of conformity referred to appear to me to involve very serious difficulties. Take the supposition that the Plateau-region has been elevated so slowly that the corrasion of the Colorado River has kept pace with it, and that, in this way, the position of this river has remained constant, while the ground-surface has been changed and new structural features created by the movement of the rocks. To this there is the following important objection. However slow the rate of elevation of an uplift, there must be some effect from the lessening of the gradients of the watercourses where they are approaching the uplift, and from the steepening of the gradients where they are leaving it, and consequently, in the case referred to, diminished erosion should be found on one side of the uplift and increased erosion on the other, and the modification of the bed and banks of the stream resulting from this distribution of force should be apparent.

Now whatever uplift has taken place has, in the main, taken place without materially affecting the horizontality of the strata, consequently it is only where the river leaves the elevated tableland that any increase whatever in the fall of the river can be supposed to have been directly produced by the uplift, and the extreme erosion should, it would seem, if this were the explanation, be confined to this end of the river.

The facts that the river has sunk its bed deep into the strata throughout the whole length of the elevated tract and that steep gradients are not at all confined to its lower end prove, I submit, that, whatever the explanation, it is not this.

If when the uplift, which has raised the Plateau-region to its present altitude, began, the Colorado river was peacefully meandering along a nearly level surface of horizontal strata since cut away by denudation, it appears to me that any such elevation as that which has taken place must, however slowly it occurred, have diminished the rate of flow of the river and have converted it into a succession of sluggish pools, and finally have dammed it back and obliged it to take a new course†.

If, on the other hand, the course of the river was marked out by the opening of a fissure by horizontal strain, one can see how the weakening of the rocks bordering the precipices by the creeping movements to which I have called attention would pave the way for rapid erosion‡.

* Report Geological and Geographical Survey of Colorado, 1874, pp. 105, 193, 201, 220, and 227; and Report Idaho and Wyoming, 1877, p. 65.

† A very slight movement of the rocks is often sufficient to change the course of a river. It requires a movement of a few feet only to change the outlets of Lakes Michigan, Huron, and Superior from Illinois River to the St. Clair.

‡ See 'Geology of the High Plateaus of Utah,' p. 37.

In the same way I attribute to this weakening of the rocks by creep the formation of *branch cañons*, the creeping movements working back into the rocks from every new precipice as it is formed*.

Next, just a word as to the formation of faults. It appears to me that, as reverse faults are admittedly due to horizontal compression, so faults of "normal" hade should be attributed to horizontal extension. For if, when a fissure is formed in the way I have explained, the rock on one side of the fissure overhangs, there will, on account of the greater weight pressing on the plastic material beneath on this side, be a subsidence of the rock on this relatively to that on the other side of the fissure. The movement will generally go on until, by the shifting which takes place, the fissure is closed†, and, if the spreading or extension is continued for a long period of time, so as to allow the complete plasticity which all rocks ultimately manifest to come into play, I think most, if not all, of the peculiarities of this kind of faulting could be readily accounted for.

A few words in conclusion with reference to the extent of that horizontal compression of the earth's superficial crust which is seen to have been extensively associated with the elevation of mountain ranges, and which reveals itself by greater or lesser folds and contortions of the strata ‡.

In making the familiar comparison between a bale of cloth folded and puckered by lateral pressure and crumpled, stratified, or laminated rocks, it has sometimes been overlooked that, while in the one case, the length of the cloth after it has been puckered is the same as when it lay flat, so that the extent of the compression can be easily estimated from the curves produced, this is not so in the case of folded rocks, as concurrently with the bending of the layers some amount of plastic thickening or thinning takes place.

The evidence of this partial plasticity is found in differences in the thickness of contorted layers of strata, depending on the direction into which the lines of bedding have been forced. This is well shown in an interesting section figured by Sorby §.

In weighing the evidence of thickening afforded by such a section, it should moreover be remembered that in the early stages of the deforming process, while the curving was inconsiderable, the contorted layers must have suffered thickening throughout their entire length, and not only at the vertices of the curves, and further that this early stage must have been protracted owing to the resistance to the deformation being greater at first.

I submit, then, that wherever folds or tiltings and displacements have been produced in stratified rocks by lateral pressure, very great thickening of the strata has taken place, particularly in the early stages of the disturbance, before the puckering became considerable;

* See 'Tertiary Hist. of the Grand Cañon District,' p. 62.

† The closing of the fissure will, no doubt, be accelerated by the spreading of the rock in which it occurs caused by gravitation.

‡ See Dana's 'Geology,' 3rd edition, p. 785.

§ H. C. Sorby, "On Origin of Slaty Cleavage," Edin. New Phil. Journ. vol. lv. 1853, p. 139.

and, consequently, that the lateral compression has been very far more than the curving taken alone would seem to indicate; and this especially applies to large folds.

Again, as to the extent of the lateral compression of strata in cases where it is not associated with any contortion, but is revealed by the deformation of the contained fossils *, I would remark that for the deformation of a fossil organism to furnish a measure of the amount of thickening which the deposit containing it has undergone, the organism must at the time it was subjected to the strain have been as plastic as the deposit, a condition which, perhaps, will but seldom have been fulfilled in the case of organisms durable enough to insure their good preservation in the fossil state.

That fossils do resist the deforming influence exerted by the thickening of the deposit containing them is evidenced by the well-known facts that thicker and harder shells are not found deformed where thinner shells, Algæ and Trilobites, associated with them in the same formation, have suffered deformation †, and that sometimes particular organisms are found less distorted in beds of one kind than in beds of another at the same spot ‡.

Again, where no contortion of the strata, or deformation of fossils, affords evidence of lateral compression, we frequently have an indication of its occurrence in the simultaneous thinning of a series of different strata in the same direction, and that whether the convergence of the surfaces separating the strata is only slight or very great, as in the well-known fan-shaped structure often displayed in mountains.

For I submit that for a series of superimposed deposits to be *originally* laid down all having their thickness increasing in the same direction, would seem to involve that during the whole period of their deposition the position of the shore-line continued nearly the same; and that, as this seems untenable, we must suppose that, generally, deposits thus related have been thickened up at one place, or thinned out at another, since their deposition. And the only agent we know of, adequate to produce this effect on a large scale, is lateral compression.

The thinner as well as the thicker parts of the deposits will generally, it is manifest, have been thickened in the process.

These conclusions appear to me to have some interest and importance, because the thickness of deposits is very generally regarded as furnishing a clue to the length of time which was taken to form them. If they are sound, we must, I think, conclude that *most* indurated and disturbed strata have suffered *considerable thickening* by lateral compression since their deposition.

* See Dana's 'Geology,' 3rd edition, p. 98.

† "Report on Cleavage and Foliation," John Phillips. Brit. Assoc. Rep. 1856, p. 386.

‡ Sharpe, "On Slaty Cleavage," Quart. Journ. Geol. Soc. vol. iii. 1847, p. 77.

45. *On the* Eozoic *and* Palæozoic Rocks *of the* Atlantic Coast *of* Canada, *in* Comparison *with those of* Western Europe *and of the* Interior *of* America. By Sir J. William Dawson, K.C.M.G., LL.D., F.R.S., &c. (Read May 23, 1888.)

Since the year 1845 the author has contributed from time to time to the Journal of this Society more than forty papers on the geology of Nova Scotia, New Brunswick, and Prince Edward Island, in which frequent comparisons were made between the rocks and fossils of the Atlantic coast-region and those of the inland plateau of the North-American continent on the one hand, and those of Europe on the other *. Many additional details bearing on the more uncertain parts of these subjects have been accumulated in unpublished notes in recent years, while large additions to our information have resulted from the extension of the Geological Survey of Canada, under Logan and Selwyn and their assistants, to those provinces, and from the Geological Survey of Newfoundland under Murray and Howley †, while new facts have been accumulating with reference to the continuation of the Atlantic rocks southward on the coast of the United States, and also with regard to the intermediate or "inner marginal" series observed on the Lower St. Lawrence and thence southward. The time seems thus to have arrived when some further and useful comparisons may be made, as well as corrections and amplifications of previous statements; and these seem to be the more necessary, inasmuch as it is evidently difficult for geologists who have not personally studied these districts to correlate with accuracy the geological features of the marginal belts of the two sides of the Atlantic.

The subject is, however, so extensive that within the limits of this paper it will be necessary to confine attention to the most salient points, and to state these as briefly as possible. I shall also confine the descriptive part to the rocks of the Atlantic border of North America, especially of Canada, and shall merely mention the parallel formations of other districts.

It may be useful to explain that I shall use the term "System" for the larger divisions of the great geological ages, and "Series" for their most important subdivisions, and the term "Group" in its ordinary sense as indicating a number of associated beds without reference to precise classificatory value.

* I find that, of forty-three papers on the Geology of Canada which I have contributed to the Society's Journal, ten are on subjects connected with the Eozoic and older Palæozoic rocks, twenty-nine relate to the Devonian and Carboniferous, and four to the Mesozoic and Modern.

† Though Newfoundland is not, politically, a portion of Canada, it is necessary to include its geology in any general survey of that of the Canadian coast.

I. The Laurentian System.

It is, I think, becoming more and more evident that in every part of the world the oldest rocks exposed are of the nature of orthoclase-gneisses associated with various kinds of crystalline schists, and locally with quartzites and limestones. This statement applies with equal force to the Acadian Provinces of Canada and to western Europe. In these districts, however, the old Laurentian substratum is represented, not by great continuous areas, as in the interior of North America, but by rugged islets and ridges of crystalline rock, in most places so imperfectly exposed that their subdivisions can scarcely be made out, and that geologists may even be excused for doubting the stratified character of their rocks. It is only by comparing them with the magnificent series exposed in the country north of the St. Lawrence, and worked out so ably by Logan, that the more limited exposures of the Atlantic margins can be understood.

In the Journal of this Society for February 1865 will be found a summary statement by Logan of the structure of this formation, which still holds good*. He there divides the Laurentian into two series, the lower and the upper, the former largely composed of othoclase-gneiss, but with beds of limestone, quartzite, and micaceous and hornblendic schists in its upper parts; the latter composed of similar gneisses and limestones, but with beds of gneissose anorthosite and labradorite, and great masses of coarsely cleavable labradorite and hypersthene.

It is perhaps unfortunate that these last masses, many of them, no doubt, accidental and intrusive, so forcibly attracted the attention of Logan that he characterized the upper Laurentian as a labradorite series, whereas the true aqueous rocks of this series would afford better terms of comparison with other districts than merely igneous masses or beds. A similar objection, I think, applies in some degree to the name Norian, as more recently given by Hunt; and I have no doubt, from my own observations in the typical districts, that Logan's division must stand, though perhaps it would be well to separate the lower gneiss from the remainder of his Lower Laurentian and to recognize a Lower, Middle, and Upper group, all of which are distinctly crystalline rocks †. The upper member, as developed in the west, should, I think, include some of the crystalline rocks which have been classed as Huronian, and which seem to fill part of the gap between the latter and the Lower Laurentian in the regions further east ‡. This view will in

* "On the Eozoic and Palæozoic Rocks."

† The two principal members have been named respectively the Ottawa and Grenville series. The third, or upper member, in Logan's typical district has been separated as the Norian series by Hunt; and by Selwyn (Reports Geol. Survey of Canada, 1879–80) is regarded as mainly composed of igneous rocks. In the maritime Provinces, as we shall see, only two members have been recognized.

‡ Dr. Bigsby, "On Lake of the Woods," Journal of Geol. Society, 1851–2; Dr. G. M. Dawson, Report on 49th Parallel, 1875; Mr. Lawson, Reports Geol. Survey of Canada, 1885. The latter has proposed the name "Keewatin" for some of these rocks in the west.

any case afford better means of comparison with the Laurentian of other districts, and the occurrence of masses of binary granite and syenite in the Lower group and of labradorite in the Upper need not interfere with such comparisons, though it is to be observed that in the Upper member plagioclase felspars are much more abundant than in the Lower. Prof. Bonney has some very judicious remarks on this in his Anniversary Address before this Society in 1886.

Whatever views may be entertained as to the origin of these old rocks, no one who has studied the typical districts of the Ottawa River can doubt for a moment that they are regularly bedded deposits, and that in the middle Laurentian those conditions which in later periods have produced beds of limestone, sandstone, iron-ore, and even of coal, were already in operation on a gigantic scale *. At the same time it may be admitted that some areas of the lower gneiss may be cooled portions of an original igneous mass, and that many of the schistose rocks may be really bedded igneous materials.

Turning now to the Atlantic coast, the greatest area of Laurentian rocks is that forming the nucleus of the Island of Newfoundland. In the northern part of that island the absence of the great crystalline limestones would seem to indicate that the lower member of the series alone is represented. The same remark applies to the continuation of the formation in the south of the island, with the exception that indications of graphitic limestone and of magnetic iron-ore have been found in two places †.

It is to be noted here that the great uplift in Pre-Cambrian times of the Laurentian nucleus of Newfoundland seems to have acted as an outwork to the formations to the westward, protecting the area of the Gulf of St. Lawrence from those thrusts from the eastward which have piled up in gigantic earth-waves the older formations of other parts of Eastern Canada and the Appalachian region. In consequence of this the area of the Gulf of St. Lawrence has throughout Palæozoic time remained undisturbed, and has conformed in its conditions of deposit rather to the internal plateau than to the maritime districts.

In Cape Breton the isolated mass of St. Ann's Mountain seems to be a representative of the Lower Laurentian of Newfoundland, and Mr. Fletcher's observations render it probable that rocks of this kind exist in the northern extremity of the island. In Nova Scotia proper I have not been able to recognize any true Laurentian, the rocks attributed by some other observers to this age being, in my judgment, intrusive granite masses of much later date associated with altered rocks ‡.

In southern New Brunswick, however, the Laurentian reappears. As seen near St. John, the lower part consists of red and grey gneiss with chloritic gneiss and diorite. The occurrence of hydrated silicates

* Q. J. G. S. vols. xxiii., xxv., xxxii., xxxv. In these papers I have set forth not merely the evidence for the organic character of *Eozoon*, but for that of the Laurentian limestones and graphites and phosphates in general.

† Murray's 'Geol. Survey of Newfoundland,' 1881.

‡ Supplement to Acadian Geology, 1878, p. 89.

in some parts of these old gneisses may be attributed to changes subsequent to their original formation. The upper member contains much limestone, with graphite and serpentine *, grey quartzites and diorite. This last series, which I hold to be really Laurentian, as it certainly underlies, and probably unconformably, the Huronian system, must belong to the upper member of the series. There is, indeed, nothing in its mineral character to exclude it from the Upper Laurentian as developed further west except the absence of certain igneous rocks.

The resemblance of this interrupted belt of Laurentian along the Atlantic coast of America to that which extends southward from Scandinavia along the west of Europe is patent to every observer. The relation to the next succeeding formations is also identical, and on both sides of the Atlantic those great foldings which have bent and crumpled the old crystalline rocks seem to have occurred at the close of the Laurentian and before the next succeeding formation. It is to be observed here, however, that in the case of the Laurentian these foldings pervaded the whole of what are now the Continental areas, as well as those marginal lines which were alone affected by the succeeding movements. This general disturbance of the Laurentian over the whole breadth of our continents, and this before any of the succeeding beds were deposited, impresses us with the conviction that the earth-movements immediately following the Laurentian were more extensive than those of any subsequent period, that they form a sufficient explanation of the very different character of the next succeeding formations, and that they produced wide areas of elevated rock which formed the nuclei of all later depositions and movements.

In comparing the Upper Laurentian of New Brunswick with the rocks which elsewhere, as in New Hampshire †, the district of St. Jerome, the Madoc district in Ontario, and the country west of Lake Superior, rest on the older Laurentian gneisses or on rocks regarded by some as primitive granites, one is obliged to admit either that this formation is of a somewhat protean character, or that, as Hunt maintains, there are several different formations of post-Laurentian crystalline rocks occurring in these different localities.

In the Lewisian gneiss of Murchison we have in Britain an adequate representative of the Lower Laurentian, and in the two members of the Dimetian of Hicks a sufficient parallel to the middle and upper members of this great series ‡, which undoubtedly also appear in the isolated mass of the Malverns, and have been recognized by Barrois and Bonney in the ancient crystalline rocks of Brittany §.

* In this limestone there occur fragments of *Eozoon*, and the graphite shows obscure fibrous structures.

† Hitchcock's Report. The beds called Montalban by Hitchcock occupy this position.

‡ Hicks's "Classification of Eozoic and Lower Palæozoic Rocks," Popular Science Review, 1881.

§ Bonney, Quart. Journ. Geol. Soc. vol. xliii.

II. The Huronian System.

In the typical area of Lake Huron, as originally described by Logan and Murray *, this system rests unconformably on the Lower and Middle Laurentian, and presents a great contrast in point of mineral character to these formations. It is comparatively little disturbed, and is clastic rather than crystalline in character. This point has been well insisted upon by Dr. Bonney and by Mr. Irving in recent papers †. Further, its conglomerates contain pebbles of Laurentian rock in the same crystalline state in which these rocks are found at present. It consists chiefly of quartzites, conglomerates of different kinds, limestone, and slates, sometimes chloritic, with interbedded diorite. Without discussing those more or less crystalline rocks west of Lake Superior and in the Appalachian region which have been by Logan himself and later authors identified with the Huronian, and which may, in part, belong to the interval between the Huronian and Laurentian or to the upper beds of the latter, or may even be later sediments in an altered state, we may attend at once to the beds which on the Atlantic coast succeed the Laurentian. We may remark, however, that, associated with the Huronian at the west of Lake Superior and extending thence northwards to Hudson's Bay and the Arctic sea, are the dark slates, sandstones, &c. constituting the Ainimiké series of Hunt. Whether these constitute an upper member of the Huronian or a distinct formation does not certainly appear. It is, however, certain that this formation is very widely distributed, especially in the north ‡. It is also to be observed that many of the bedded rocks of the Huronian are really of volcanic origin, being bedded volcanic ashes or muds in an altered state §.

In Newfoundland the older slate-series of Jukes ||, which Murray originally called the intermediate series, but afterwards mapped as Huronian, consists, in ascending order, of quartzites with diorites and jaspery bands, slate-conglomerate, green, purple, and red slates, and dark-brown or blackish slates. In the upper part of this or the lower part of the next group are the worm-burrows known as *Arenicolites spiralis* and the uncertain fossils described by Billings as *Aspidella*. The lithological correspondence here between Newfoundland and Lake Huron is very close, and is increased by the fact that a series of red sandstones and conglomerates, the Kewenian of the West and the upper Huronian or Signal-Hill beds of Jukes and Murray, overlie the typical Huronian in both districts ¶.

* Geology of Canada, 1863.

† Anniversary Address, 1886. Amer. Journ. of Science, 1887.

‡ G. M. Dawson, "Notes on northern part of Dominion of Canada," Geol. Survey, 1887, p. 8; Dr. R. Ball, "Report on Hudson Bay, 1877 to 1885," Geol. Survey of Canada.

§ Dawson, 'Canadian Naturalist,' 1857; Nicholson, Quart. Journ. Geol. Soc. 1873; G. M. Dawson, Geol. Mag. 1875.

|| Report on Newfoundland, 1843.

¶ Geology of Newfoundland, 1881.

Passing from Newfoundland to the coast of southern New Brunswick, we find in the "Coldbrook" and "Coastal" series of Bailey a group corresponding essentially to that in Newfoundland, except perhaps in the fact that felsitic rocks occur to a larger extent in the lower part, and that the upper part presents not only conglomerates, ash-rocks, and amygdaloids, but also chloritic and hydro-mica schists. This upper part, distinguished as the "Coastal Series," is regarded by Prof. Bailey as distinct from the Huronian proper, and as either an upper member of that system or perhaps of later age, though pre-Cambrian *.

As in Newfoundland, the typical Huronian of New Brunswick is overlain by reddish and purple conglomerates, sandstones, and shales, which are, however, here regarded as the base of the Cambrian †. Matthew has recently found in them not only worm-burrows and fucoids, but a Linguloid shell. They appear, however, to underlie unconformably the lowest division of the *Paradoxides*-beds.

With these rocks, whether of Lake Huron, Newfoundland, or New Brunswick, I have no hesitation in comparing the Pebidian of Wales, as well as certain portions of the older Malvern rocks and those of Charnwood Forest. Some of these groups I have seen on the ground, others are well known to me by suites of specimens. Similar rocks also succeed the Laurentian in Scandinavia and in other parts of Europe as well as in Africa and portions of Asia. Thus the Huronian type is very widely distributed, even if we take it in the restricted sense as originally used by Logan and, later, by Irving ‡, and leave out doubtful deposits which have been connected with it.

The Huronian marks a period of igneous disturbance and coarse mechanical deposition succeeding to the Laurentian foldings. It is essentially a coastal or marginal deposit, and indicates that at the close of the Laurentian considerable areas of land had been elevated in the northern hemisphere. It was along the margins of this old Laurentian land that the Huronian was deposited, and its outcrops mark these margins, which in America before the rise of the Appalachians extended westward from the Atlantic coast along the southern shores of the Laurentian land. The conditions of deposit in Wales at the same period were evidently in general similar, though with local peculiarities.

Two important questions arise from the above statements. The first relates to possible deep-sea deposits of this age, differing from the coarse marginal detritus and volcanic accumulations. These must have existed; but to what an extent are they known to us? The limestones associated with the Huronian probably belong to their margins; but they have so far afforded no fossils except obscure indications of sponge-spicules in the chert-nodules which they

* Bailey, "Geology of New Brunswick," Geol. Survey Report 1877–8; Ells, 'History of New-Brunswick Geology,' 1887.

† Geological Survey Reports, 1878.

‡ Amer. Journal of Science, 1887.

contain *. I confess, however, that I am inclined to suspect that some of the beds known as Ainimiké and Taconian may prove to be of this character, as well as some of the disputed Huronian of the Appalachian region †.

The second question relates to the extent to which conditions similar to those of the Huronian may have been repeated in subsequent periods; and here it is evident that wherever on continental margins coarse aqueous rocks were being accumulated, in the vicinity of igneous foci and mixed with their detritus, rocks lithologically resembling the Huronian may have been deposited. This consideration imposes much caution as to the possible correlation of such deposits with the true Huronian on the ground of mineral character alone. In Nova Scotia and New Brunswick as well as in Great Britian there are rocks having in many respects the aspect of the Huronian which belong to Palæozoic times, and there is reason to believe that on the Pacific coast there are certain rocks of this kind of much later date. These, as has been shown by Dr. Selwyn and Dr. G. M. Dawson, are in great part bedded volcanic ash-rocks in an altered condition ‡.

An important new light has recently been thrown on the supposed upper Huronian of Newfoundland by Mr. Matthew, who has found that in New Brunswick the conglomerate and red sandstone underlying the *Paradoxides*-beds are, as before stated, unconformable to these, and that, like the Basal or Caerfai beds of Hicks in Wales, which somewhat resemble them in mineral character, they contain worm-tracks and a Linguloid shell as well as remains of Algæ. He therefore regards these as basal Cambrian beds. This may also prove to be the position of the Newfoundland Signal-Hill rocks, and of the Kewenian series of the west. This basal series of New Brunswick is estimated at 1200 feet in thickness. If it be reckoned as the equivalent of the Caerfai, the lower members of the St. John group proper will be the equivalent of the Solva group, and the upper members will represent the Menevian §. In a letter recently received from Mr. Irving, of the U. S. Geological Survey, he informs me that "an obscure Linguloid shell" has been found in the quartzite of south-western Minnesota, a formation which he regards as probably below the Kewenian, and possibly even Huronian. These facts render it possible that an upper Huronian series containing precursors of the Cambrian fauna may yet be recognized, or probably a new intermediate system to be designated by some other name ||. It will also be observed that, like the typical Huronian, such series, whether

* I find such indications in the chert of the limestones on Georgian Bay. They are apparently simple acerate siliceous spicules, resembling those of some Cambrian sponges.

† See, however, Dr. Sterry Hunt, "Elements of Primary Geology," Geol. Mag., Nov. 1887, for his classification of the western rocks of these groups.

‡ Report Geol. Survey of Canada, 1871–1885.

§ Matthew, 'Canadian Record of Science,' 1887.

|| Irving has proposed to call all the formations between the Laurentian and the base of the Cambrian "Agnotozoic;" but the term Huronian seems sufficient at present for this purpose.

Huronian or Kewenian or intermediate, will be common to the coastal and interior regions, thus differing from the true *Paradoxides*-zone.

III. The Cambrian System.

For a long time the base of the Palæozoic, in the eyes of the geologists of America, was the Potsdam Sandstone, which over great areas of Canada and the United States rests unconformably and directly on the Laurentian.

The marginal areas of the continent have since afforded a great series parallel to the Cambrian of Wales and of Scandinavia.

In southern Newfoundland the Huronian rocks, or the Signal-Hill red sandstones and conglomerates overlying them, are succeeded, according to Jukes and Murray, by a thick formation of sandstones and slates with a little limestone and conglomerate, and near the base of this the great *Paradoxides Bennetii* and other forms of like age are found. These are Lower Cambrian and obviously parallel with the beds holding the rich fauna of this age in New Brunswick, originally described by the late Prof. Hartt *, and more recently and more fully by Mr. Matthew †. The strata holding these fossils in Newfoundland have conglomerate, slate, and limestone below, and a great thickness of variously coloured slates above, overlain by sandstones and slate. Very similar beds constitute the lower Cambrian series of St. John, New Brunswick.

I have already stated that there exists in southern New Brunswick a series of red, purple, and grey conglomerates and sandstones not unlike the Signal-Hill series, unconformable to the Huronian below and the *Paradoxides*-beds above, and holding not only worm-tracks, but Linguloid shells. These are regarded as a basal Cambrian series, perhaps equivalent to the Caerfai group of Hicks, while above this are the equivalents of the Solva and Menevian groups of the same geologist, corresponding in mineral character and fossils so closely as to indicate portions of the same sea-bottom ‡. The Braintree slates in Massachusetts with their underlying conglomerates may be considered a continuation of the New Brunswick beds §.

Above these in Newfoundland is a slender representation of the lower part of the Upper Cambrian, now called Middle Cambrian by some, and consisting of sandstones and flags, often micaceous, with *Lingulæ*. Similar beds cap the Lower Cambrian in southern New Brunswick. Mr. Fletcher, of the Canadian Survey, has found fossils indicating what is probably the same horizon in the slaty districts of southern Cape Breton. Mr. Matthew regards these series as covering the whole succession from the Caerfai group of Hicks to the *Lingula*-flags, and the two great zones A and B of Angelin in Sweden.

* Acadian Geology, 1868.
† Trans. Royal Society of Canada, 1885 to 1888.
‡ Matthew, 'Canadian Record of Science,' 1888.
§ Crosby, 'Boston Society of Nat. History,' 1884.

There is, however, no certain evidence that any of these beds reach so high as the horizon of the Potsdam *.

These rocks of Newfoundland and the Acadian Provinces, constituting what I formerly named the "Acadian group" †, are in their lithological characters and fossil remains precise equivalents of the Longmynd, Menevian, and Lower Lingula-flag groups of England.

In this connexion an important group of rocks is the Atlantic coast series, or gold series of Nova Scotia, described by me in this Society's Journal as far back as 1850 ‡, and subsequently in 'Acadian Geology' and supplements thereto §. This great series, extending for more than 200 miles along the Atlantic coast of Nova Scotia, consists of dark-coloured quartzite and slate in massive bands, the former predominating below and the latter above, and the whole attaining to a thickness of perhaps 10,000 feet. In its western extension it appears to rest on rocks of Huronian aspect, and where it is invaded by granitic masses and veins (Devonian in age) it assumes the condition of mica-schist and imperfect gneiss, being then similar in mineral character to the rocks elsewhere known as Montalban. It has unfortunately afforded no well-characterized fossils. The markings called Eophyton ‖ and certain radiating bodies (Astropolithon) ¶ found in it are, however, similar to those occurring elsewhere in Lower Cambrian rocks. Murray was disposed to regard this formation as corresponding to his Huronian in Newfoundland; but it does not agree with this either in mineral character or in fossils, and is perhaps rather to be regarded as a great development of the lowest member of the Cambrian, an exaggerated equivalent of the Harlech Grits and Llanberris Slates. In this case, however, it may be expected that it will yet afford true Cambrian fossils.

In Western Europe, as Hicks has shown, great movements of depression must have occurred in this period, and we have evidence of a similar character in America. If we roughly divide the Cambrian system into three great series, characterized respectively by the prevalence of the large Trilobites of the genera *Paradoxides*, *Olenellus*, and *Dikelocephalus*, we shall find that the former, the true Lower Cambrian, is unknown over all the great continental plateau of America **. It is strictly a marginal deposit formed at a time when there was probably a great continent west of the then infant Appalachians. But the second, or *Olenellus*-group, slenderly represented on the coast, appears in force immediately within the great Laurentian axis of Newfoundland ††. It is known in the valley of the St. Lawrence by the great masses of limestone full of fragments of

* Fletcher, 'Report Geol. Survey of Canada'; Matthew, Trans. Roy. Soc. Can. 1886; Canadian Record of Science, 1887.

† Acadian Geology, 1868.

‡ Quart. Journ. Geol. Soc. vol. vi.

§ 1868 and 1878.

‖ Selwyn, Report Geol. Survey.

¶ Acadian Geology, Supplement, p. 82.

** Walcott apparently places the lower portion of the Wahsatch section in Utah in the Lower Cambrian; but this may belong to a western marginal area.

†† Murray's 'Newfoundland'; Billings's 'Palæozoic Fossils.'

Olenellus, *Solenopleura*, *Hyolithes* &c. in the conglomerates of the Quebec group*, and it also appears in the Georgia series of Vermont †, nd, according to Walcott, as far west as Nevada and Utah ‡. On the other hand the upper members of the Cambrian, the *Dikelocephalus*-group or Potsdam Sandstone, is apparently altogether absent n the Acadian provinces, which at that time must have been under ocean-depths in which deposits of a very different kind would be produced, or elevated into land, perhaps the border of an Atlantic island now mostly submerged. It seems doubtful if any good equivalent of the Potsdam exists in England or Wales.

It is otherwise, however, with the next succeeding formation, that passage-series between the Cambrian and Ordovician known in Wales as the Tremadoc. This, in America, takes a more inland position, and becomes an interior or submarginal formation connected with the Quebec group to be mentioned in the sequel. At Matane and Cape Rosier, as noted by me in 1883 §, and as Lapworth has more fully proved in 1886 ||, we have a true Tremadoc filled with *Dictyonema sociale* and containing also fragments of characteristic Trilobites. Further inland, on the main American plateau, these beds are not found, but are represented by the peculiar "Calciferous" formation, a dolomite formed apparently in an inland sea and having a characteristic fauna of its own.

A very remarkable and exceptional feature in British geology is the appearance in the sandstone and limestone of the Durness series of Scotland of a group of fossils long ago recognized by Salter as of the interior American type ¶. In other words there existed in Scotland, within the shelter of the old Laurentian and Huronian ridges, an area which sustained a fauna similar to that of the internal plateau of America, and which, so far as known, did not exist in Wales or on the American coast. This curious case of apparent isolation we might better understand did we know the exact geographical arrangements of the period. One consideration bearing on it is the probability that the Trilobitic and Graptolitic faunas of the coast mainly belonged to cold northern currents, while the Plateau-faunas, richer in Cephalopods, Gasteropods, and Corals, belonged to the superficial warm currents passing over shallow plateaus, or to the tepid waters accumulated in closed basins. This is, I think, quite manifestly the case with the very dissimilar marginal and continental faunas to be noticed under the next heading. Salter seemed to suppose that the occurrence of these fossils in Scotland, and not to the south, indicated a climatal difference. In this he was justified; but the character of the climate was probably different from that which he imagined.

* At Metis, St. Simon, &c.

† Emmons's 'American Geology;' Billings's 'Palæozoic Fossils.'

‡ Bulletin U. S. Survey.

§ Report Peter Redpath Museum, No. ii. Richardson's observations at Matane.

|| Transactions Royal Society of Canada.

¶ Quart. Journ. Geol. Soc. vol. xv. These rocks are also recognized by Geikie in Skye (Quart. Journ. Geol. Soc., Feb. 1888).

Before leaving the Cambrian, it may be well to state that Mr. Matthew informs me that he hopes to make out in the St. John series the equivalents of all of the subdivisions of the *Paradoxides*-zone established by Linnarsson in Sweden, so that there would seem to be a correspondence even in the minor details of the deposits on the opposite sides of the Atlantic *. This, as we shall see, also appears to Prof. Lapworth to hold in the case of the Graptolitic fauna of the Upper Cambrian and Ordovician on the two Atlantic margins.

IV. The Ordovician System.

With the incoming of this new age a more marked distinction occurs in America between the marginal and plateau-deposits. I have already referred to this in the Calciferous; but it is more distinct as between the marginal and submarginal areas and those inland, in the period on which we now enter.

In Newfoundland, Murray and Howley have described large areas of Quebec-group rocks in the west and north of the island which seem to be continuations of the submarginal area of the Lower St. Lawrence. There is also one limited exposure of Trenton Limestone on the west coast, and belonging to the area of the Gulf of St. Lawrence, the peculiar conditions of which I have already mentioned. In Nova Scotia we have as yet no representatives of the Ordovician system except slates associated with igneous rocks, resembling in mineral character the Borrowdale series of the North of England, and destitute of fossils. In northern New Brunswick we find a belt of slaty beds representing the Quebec group of Logan, which is the characteristic form of the submarginal development of this system occupying the St. Lawrence valley. This group, resembling in many respects the Arenig of England, and consisting principally of slates, sandstones, and conglomerates, constitutes the eastern representative of the great Upper Calciferous and Chazy Limestones widely spread over the internal plateau, and probably of part of the Trenton as well.

The origin of this formation and its true relations to the interior plateau-deposits were early defined by Logan, who regarded the Quebec group as an Atlantic deposit thrown down in the open sea along the margin of the old Laurentian plateau, while thinner and differently constituted beds were being formed in the shallower and warmer waters of the plateau itself. It was further found and illustrated by Logan that in the great earth-movements which closed the Ordovician period these marginal and submarginal deposits had been crushed and folded against the old Laurentian border, and even, in places, pushed over the inland formations by reversed faults, while the latter remained comparatively undisturbed. These peculiar arrangements, which extend southward along the Appalachian ranges, led to much discussion among the geologists of the New York Survey, and to that "Taconic" controversy which is still scarcely terminated.

So far as our present subject is concerned, it is sufficient to

* Amer. Journ. of Science, May 1887.

observe that the Quebec group is not strictly an outer marginal formation, but rather submarginal, and belongs to a period when the principal area of coastal deposition of sediment from the north was inland of the Acadian provinces, or between them and the main American plateau, and separated from the outer ocean by a belt of active volcanos. Its conditions of deposit and characteristic fossils may fairly be compared with those of the Skiddaw and Arenig of England *. The Ordovician series of Shropshire extending upward from the Stiper Stones to the Caradoc is also a counterpart of the Quebec group †.

Perhaps no term of comparison for these beds is more satisfactory than that of the Graptolitic fauna ‡. This has been studied in the case of the Canadian series with great care by Hall, whose monograph on the Graptolites of Canada is a classical work, and subsequent observations have ascertained several divisions between the Matane series of the Lower St. Lawrence and the Utica §. The whole subject has, however, recently been reviewed by Lapworth ||, in connexion with material placed in his hands by the Director of the Geological Survey of Canada, and his results are of the greatest interest as indicating the precise correspondence in those truly pelagic forms on the two sides of the Atlantic. They may be summed up as follows, in ascending order:—

Quebec Group of Lower St. Lawrence.

1. *Matane Beds* ¶.—Grey, red and black shales, sandstones and limestone, equivalent to Lower Calciferous of inland America and Tremadoc of England. Characterized by *Dictyonema sociale*, *Bryograptus*, *Clonograptus*, &c.

2. *Levis Beds*.—Dark shales, with sandstones and limestone-conglomerates. Limestone-bands and dolomite. Characterized by *Phyllograptus*, *Tetragraptus*, *Didymograptus*, &c. Remains of siliceous sponges also occur in some places **. This corresponds to the Chazy of inland America and the Arenig or Skiddaw of England.

3. *Marsouin Beds*.—Shales, limestones, dolomites, and sandstone, with *Cœnograptus*, *Diplograptus*, &c. Equivalent to the Trenton formation of interior America, including the Normanskill Shales of Hall, and to the Llandeilo formation of England.

4. *Utica Series*.—Soft shales, often highly bituminous or carbonaceous, with *Leptograptus*, *Diplograptus*, &c. This is the Utica-Slate formation of inland America, and corresponds to the Hartfell and Caradoc group of England.

* Hicks, 'Classification of Lower Palæozoic Rocks,' 1881.

† Lapworth, Geol. Magazine, 1887.

‡ Mr. A. M. Ami, F.G.S., of the Geological Survey of Canada, has devoted much labour to these fossils.

§ Report Redpath Museum, 1883. Paper by Mr. H. M. Ami, 'Ottawa Field Club,' &c.

|| Transactions Royal Society of Canada, 1886.

¶ Cape Rosier Zone of Lapworth.

** Dawson and Hinde, Canadian Record of Science, 1888; also "Redpath Museum Notes," 1888.

It will be observed here that the Graptolitic faunas referred to by Lapworth extend from the Tremadoc to the Caradoc inclusive; but the Quebec group proper may be regarded as limited by these groups above and below.

It is also to be observed that the Quebec group conditions of shale- and sandstone-deposit with cold-water animal species seem, in the later Trenton and Utica periods, to have become prevalent over the interior plateau as well as the marginal area.

This appears not only from the wide extension of the Graptolitic fauna over all the plateau west of the Appalachians in this later Ordovician time, but from the occurrence of these fossils in the extreme west. Graptolites of this age are reported by White in Nevada *, and have recently been found by M^cConnell and identified by Lapworth in the Wapta Pass in the Rocky Mountains of Canada †. Thus, what we have regarded as marginal and submarginal conditions may in the later Ordovician have prevailed from the Atlantic to the Pacific. This was undoubtedly a consequence of the gradual subsidence going on in the Ordovician age. It was naturally followed by the settlement of the ocean-bed, which raised again the continental area and folded the marginal and submarginal Ordovician rocks on both sides of the Atlantic.

I may add that the above views correspond closely with those I have held for many years, as the result of much study of these rocks in my summer vacations on the Lower St. Lawrence, and which are thus expressed in a paper published in 1883 ‡:—

"There seems reason to believe from Mr. Richardson's recent observations that Graptolitic zones reaching from the Lower Tremadoc to the Upper Llandeilo may be discriminated in the great mass of sediments known as the 'Quebec Group,' which the writer has long believed, on the evidence of the fossils he has himself observed, to represent a lapse of geological time extending from the base of the Potsdam to the Chazy limestone." Prof. Lapworth's recent memoir extends the range of this comparison as far upward as the Trenton and even the Utica.

One feature of the Quebec Series is especially characteristic and American; this is the great limestone-conglomerates, which form conspicuous features in its middle portion. These conglomerates, which are very irregular in their distribution, and swell out rapidly to great thickness, degenerating as rapidly to mere sandstones, are remarkable for the quantity of boulders and pebbles of limestone which they contain, and which often afford Cambrian fossils, though in other cases they appear to belong to the limestone of the lower part of the Quebec group itself. The only means of explaining these conglomerates seems to be the action of the coast ice, which at this period appears to have been as energetic on the American shores as at the present day, and seems to have had great reefs of limestone, probably in the area of the Gulf of St. Lawrence, to act

* Report on the 100th Meridian, vol. iv.

† "Report on Rocky Mountains," Geol. Surv. of Canada, 1887.

‡ Report on Peter Redpath Museum.

upon and to remove in large slabs and boulders, piling these up on banks, to constitute masses of conglomerate. This would bespeak a cold ice-laden sea as that in which the Graptolites lived, and it may account for the survival in these areas of old Trilobitic genera which were not represented in the warmer waters of the continental plateau. This circumstance has perhaps some connexion with the greater apparent survival of these in America as compared with Europe, though I suspect that the observed appearances depend in part upon collectors attributing species belonging to fragments of older limestones to the Quebec group itself.

The importance of the Quebec group of Logan is thus vindicated, as representing widely spread local conditions and great lapse of geological time; and the prescient view which he entertained of it may be indicated by the following extract from a note appended by him to Murray's Report on Newfoundland in 1865:—

"The sediments which in the first part of the Silurian period were deposited in the ocean surrounding the Laurentian and Huronian nucleus of the present American continent, appear to have differed considerably in different areas. Oscillations in this ancient land permitted to be spread over its surface, when at times submerged, that series of apparently conformable deposits which constitute the New York system, ranging from the Potsdam to the Hudson River formation. But between the Potsdam and Chazy periods, a sudden continental elevation, and subsequent gradual subsidence, allowed the accumulation of a great series of intermediate deposits, which are displayed in the Green Mountains on one side of the ancient nucleus, and in the metalliferous rocks of Lake Superior on the other, but which are necessarily absent in the intermediate region of New York and central Canada.

"At an early date in the Silurian period, a great dislocation commenced along the south-eastern line of the ancient gneissic continent, which gave rise to the division that now forms the western and eastern basins. The western basin includes those strata which extended over the surface of the submerged continent, together with the Pre-Chazy rocks of Lake Superior, while the Lower Silurian rocks of the eastern basin present only the Pre-Chazy formations, unconformably overlaid, in parts, by Upper Silurian and Devonian rocks. The group between the Potsdam and Chazy, in the eastern basin, has been separated into three divisions, but these subdivisions have not yet been defined in the western basin. In the western basin the measures are comparatively flat and undisturbed; while in the eastern they are thrown into innumerable undulations, a vast majority of which present anticlinal forms overturned on the north-western side. The general sinuous north-east and south-west axis of these undulations is parallel with the great dislocation of the St. Lawrence, and the undulations themselves are a part of those belonging to the Appalachain chain of mountains. It is in the western basin that we must look for the more regular succession of the Silurian rocks, from the time of the Chazy, and in the eastern, including Newfoundland, for that of those anterior to it."

Of Ordovician rocks other than the Quebec group and nearer to the Atlantic margin, perhaps the best example is that of the area in Central and Western New Brunswick described by Prof. Bailey*. This consists, in ascending order, of (1) gneiss and mica-schist with chloritic and hornblendic schists, (2) grey and purplish micaceous sandstones and slates with limestone and conglomerate and felspathic slates, (3) black graphitic and pyritous slates, (4) schistose felspathic rocks and conglomerates, (5) amygdaloid and felsite with sandstone and slate, (6) felsites capped with sandstones and slates, often chloritic. These remarkable rocks, which are of great thickness and have evidently experienced much metamorphism, have been found at one locality to contain fossils of Trenton age equivalent to Bala and Llandeilo. Similar rocks come out from beneath Silurian beds in various parts of the hilly districts of Nova Scotia †. They resemble the Cumberland Ordovician more nearly than other British developments of these rocks. In the continuation of these beds in Northern New Brunswick Graptolites were discovered some years ago by Mr. Robb and Dr. Ells, of the Canadian Geological Survey, and are believed to be of Upper Ordovician age.

V. The Silurian System.

In the inland plateau of North America this period begins with shallow-water conditions passing into the great and long-continued depression marked by the Niagara Limestone. There is then a second elevation, that of the Salina, succeeded by the very widely distributed Helderberg Limestones. There are thus two depressions separated by an intervening elevation.

In Newfoundland the Silurian rocks occur in a narrow trough extending through the centre of the island, and, so far as can be ascertained from the Reports of the Survey of Newfoundland, are not dissimilar from the exposures in Nova Scotia.

In the latter province the great limestones are absent or represented by comparatively insignificant and impure bands. Shales with some sandy beds (Lower Arisaig beds of previous papers) represent the Clinton and contain *Graptolithus clintonensis*; coarse impure limestone and shale (New Canaan beds of previous papers) correspond to the Niagara, holding characteristic corals of this age, and shaly beds with thin layers of limestone (Upper Arisaig of previous papers) represent the Helderberg. In Nova Scotia these occur in the New Canaan, Arisaig, and Pictou districts, and their characters correspond to those seen in Newfoundland, New Brunswick, and Maine. In the Cobequid Mountains of Nova Scotia, however, and in New Brunswick, these beds, especially in their upper part, show great contemporaneous emissions of igneous rock. These are partly felsitic and partly doleritic and amygdaloidal. They correspond in age with those isolated igneous masses of the

* Report Geological Survey of Canada, 1884–5.

† Quart. Journ. Geol. Soc. 1850. 'Acadian Geology' and Supplement.

plain of the St. Lawrence to which the Montreal and Belœil Mountains belong.

In proceeding to the west and north the Helderberg Limestones appear in great force at Cape Bon Ami in Northern New Brunswick, where they are rich in fossils and associated with beds of trap. Both limestones are largely developed in Bonaventure and Gaspé, and the lower member in the Island of Anticosti, so that here as in previous periods the area of the Gulf of St. Lawrence corresponds with the interior plateau rather than with the coastal region. In some respects, indeed, this area presents an exaggeration of the interior conditions, since in Anticosti there is apparently a gradual passage from the limestones of the Hudson-river group to those of the Clinton, without the intervention of sandstones similar to the Oneida and Medina of New York and Ontario. In so far as I am aware there is also an absence of beds representing that condition of deserts and salt lagoons represented by the Salina or Onondago salt-group. In this last respect, as in so many others, the conditions of the eastern districts of America conform to those of Europe, and not to those of the interior plateau of America.

In America as in England the Silurian of the maritime districts is unconformable to the Ordovician, though this does not hold in Anticosti or in the inland region.

Lithologically the English Silurian is more perfect than that of the East Coast of America, as containing, in the Wenlock Limestone, a better representative of the Niagara formation. The unequal character of this limestone, however, and its thinning out toward the south-west, bring the series into harmony with that in Nova Scotia. The Ludlow rocks are perfect representatives of the Upper Arisaig series of Nova Scotia, and the fossils are remarkably similar, much more so than in the case of the Arisaig and the inland Helderberg in any locality known to me*.

In England the trees which I have named *Nematodendreæ* appear first in the Denbighshire Sandstone at the base of the Silurian †. In America they appear in the Helderberg series. Placoganoid fishes have recently been recognized in the Silurian in New Brunswick ‡.

The eurite and tufaceous rocks of the Silurian of the West of Ireland appear to be the principal British representatives of the abundant rocks of volcanic origin associated with the Upper Silurian in Nova Scotia and New Brunswick §.

In summing up the Eozoic and older Palæozoic rocks of the Maritime Provinces I may reproduce here, with some slight additions, the table given in the Supplement to 'Acadian Geology,' 1878.

* Acadian Geology and Supplements.

† Hicks, Quart. Journ. Geol. Soc. vols. xxxvii. and xxxviii.; Dawson, *ibid.*

‡ Matthew, 'Canadian Record of Science,' 1886.

§ Murchison, 'Siluria.'

England, &c.	Nova Scotia and New Brunswick.
Silurian.	
Ludlow, Wenlock and Llandovery, or Mayhill.	Upper Arisaig Series, Nova Scotia; Mascarene Series, New Brunswick; Lower Arisaig, New Canaan and Wentworth beds of Nova Scotia; and Restigouche series, New Brunswick.
Ordovician.	
Caradoc and Bala, with Snowdon felsites and ash-beds, Coniston and Knock Series.	Upper Cobequid Series, slates, felsites, quartzites, and greenstones. Ordovician of Western and Central New Brunswick.
Great felsite and trap-ash Series of Borrowdale (Ward).	Lower Cobequid Series, felsites, porphyrites, agglomerates, and massive syenite of Cobequids, Pictou, and Cape Breton? *
Lower Llandeilo flags and shales, Arenig Series, Skiddaw slates, &c.	Middle Graptolitic or Levis Series of Quebec and North New Brunswick, part of Cape Breton Series?
Cambrian.	
Tremadoc slates and Lingula-flags.	Matane or Cape Rosier Graptolitic beds. Miré and St. Andrew's Channel Series in Cape Breton?
Menevian and Longmynd Series, Harlech grits, and Llanberis slates.	Acadian Series of St. John, New Brunswick. Quartzite and slate of Atlantic coast of Nova Scotia.
Caerfai Group of Hicks.	Basal Cambrian of Southern New Brunswick.
Huronian.	
Pebidian Series (Hicks), containing felsite, chlorite-schist, and serpentine.	Huronian felsites, chloritic and epidotic rocks of Southern New Brunswick, Yarmouth, and of Cape Breton in part.
Laurentian.	
Older gneisses of Scotland and of Scandinavia, Dimetian?	Gneiss, quartzite and limestone of St. John, Portland Group, gneiss of St. Anne's Mountain.

VI. The Erian, or Devonian System.

This formation, most largely and completely represented in the great "Erie Division" of the Geological Survey of New York, which occupies an immense area in the district around the lake from which it is named, and attains therein its maximum thickness and development, appears on the eastern coast entirely in the form of sandstones and shales, which may be compared with those of the Old Red Sandstone of Scotland and England. They differ entirely in mineral character from the great limestone- and shale-deposits of the interior of America, where, in the Province of Ontario, the Corniferous Lime-

* It seems impossible at present to separate these perfectly from the Huronian, in some localites at least.

stone is perhaps the richest of all the palæozoic limestones in fossil corals, and indicates a long continuance of truly marine conditions. These beds abound in fossil plants and, locally, in remains of fishes, and both the fishes and the plants are generically similar to those of Britain, and divisible into two series, representing the lower and the upper members respectively. The beds do not appear, however, to be lake-deposits but, rather, estuarine and littoral. They have been fully described in the papers referred to below *.

In the Baie de Chaleur, for example, the lowest series is characterized by *Psilophyton* and *Nematophyton*, and by fishes of the genera *Cephalaspis*, *Coccosteus*, *Ctenacanthus*, and *Homacanthus*†. The upper division is characterized by ferns of the genera *Archæopteris* and *Platyphyllum*, and by fishes of the genera *Pterichthys*, *Diplacanthus*, *Phaneropleuron*, *Glyptolepis*, *Cheirolepis*, and a new genus named by Whiteaves *Eusthenopteron*‡.

The only truly marine portion of the system in the Maritime Province is the lower part, corresponding to the Oriskany of the interior, and this may perhaps be regarded as an equivalent of the Downton Sandstones of England.

The greatest granitic intrusions of Nova Scotia belong to the close of the Devonian, as do many granitic masses in New Brunswick and Quebec. These are the equivalents of the Devonian and Cornish granites, though perhaps a little earlier in date, and are also represented by the felsites of the Scottish Devonian.

The remarkably rich flora of the Erian of the east of Canada was first made known in the Journal of this Society, and still holds its position as probably the most copious known in this age, though I have been obliged to withdraw two of its species, *Selaginites formosus* and *Equisetites Wrightianus*, as probably Crustacean, and the genus *Dictyophyton* as certainly belonging to sponges and not vegetable §.

VII. The Carboniferous System, &c.

The Carboniferous formations of Nova Scotia have been described by the writer in a number of papers in the Journal of this Society‖. Like the Carboniferous of Britain, these rocks present many local diversities. Their subdivisions are :—

1. A lower series corresponding to the Tuedian of the North of England and Calciferous of Scotland both in mineral character and fossils (the *Horton Series* of my later papers) ¶.

2. A Carboniferous Limestone, associated, however, with gypsum, and marly and red sandstones, but having fossil remains for the most

* Quart. Journ. Geol. Soc. vols. xv. and xviii.

† Dawson's Report on Erian Plants. Whiteaves, Trans. Roy. Soc. Can. vol. iv. "On Devonian Fishes."

‡ *Ibid.*

§ Quart. Journ. Geol. Soc. vols. xv., xviii., xxvii., xxix., xxxvi., xxxviii. The Devonian Flora of Scotland and that of Belgium, as described by Créspin, and exhibited in the Brussels Museum, are closely allied to that of Eastern Canada.

‖ Quart. Journ. Geol. Soc. vols. i., ii., v., ix., x., xi., xv., xix., xxii., xxix., xxx

¶ Acadian Geology, 3rd edition.

part specifically identical with those of England (*Windsor Series* of recent papers).

3. A Millstone-grit series consisting of coarse sandstones and shales with conglomerate, mostly of red colours.

4. The Main or Productive Coal-measures, precisely similar in character to those of Britain. Of 135 species of fossil plants which I have catalogued from these beds more than one half are specifically identical with those of England. The animal fossils of these beds, Batrachians, Fishes, Crustaceans, and Mollusks, are also akin to those of England. In the class of Batrachians a still more close approximation appears in those obtained by Fritzsch in the Upper Carboniferous of Bohemia.

5. A Permo-Carboniferous series, perhaps corresponding in age to the Lower Permian of England, and consisting largely of Red Sandstones with species of plants characteristic in Europe of the Lower Permian, but including no limestones.

The conditions of the Carboniferous are on the whole similar throughout North America, except in the extreme West and locally in the Appalachian region; but in Nova Scotia, Newfoundland, and New Brunswick they are more nearly allied to the British type, except in the abundance of red marls and gypsum in the Lower part.

Interstratified trappean rocks, similar to those in Scotland and England, occur in Nova Scotia and New Brunswick, especially in the Lower Carboniferous.

The details of the Carboniferous and Permian of Nova Scotia and Prince Edward Island are so fully given in the papers referred to in the notes, that the above general mention will be sufficient here.

One fact of general application which is admirably illustrated in the Carboniferous of Nova Scotia is the extreme sensitiveness of the earth's crust to unequal pressure. The Coal-formation of the Cumberland district, 5000 feet in thickness, and consisting wholly of beds which must have been deposited almost exactly at the sea-level, shows that for every inch of sediment or of vegetable matter there must have been a corresponding depression of the crust. This accurate correspondence of sedimentation with subsidence has long appeared to me one of the most striking facts in geological dynamics.

The Triassic Red Sandstone of Nova Scotia and Prince Edward Island and the associated Traps closely resemble the same formations in England. Like them they contain no important marine limestones, and their fossils are limited thus far to a single Dinosaurian reptile and a few fossil plants. In these it is far inferior to deposits of the same age further to the south on the Atlantic coast of the United States. In America, as in Europe, the Triassic flora and land- and freshwater-faunas seem to have been of southern origin.

The maritime region of Eastern Canada is remarkable for its deficiency of Mesozoic rocks newer than the Trias. If there are such deposits, they must be, like the Cretaceous rocks believed to exist further south on George's Banks, still under the sea. It is only on Greenland and the Arctic Islands that we find beds ranging from the Lias to the Eocene, and these belong rather to the Arctic basin than to that of the Atlantic *. In this respect the maritime region of Canada differs materially from that of Europe, though it is noteworthy that the extreme coastal region of Great Britain to the west is also somewhat deficient in such rocks.

The question of Palæozoic climates in the northern hemisphere has some bearings on the subjects discussed in this paper, and is well illustrated by a map of the Arctic districts of Canada recently issued by the Geological Survey †. From this it appears that there are no indications of a warm climate in the Arctic basin up to the close of the Cambrian. The later Ordovician and the Silurian were, however, signalized by the deposition in the Arctic seas of thick and extensive organic limestones, holding fossils comparable with those of the temperate regions at the same time. The Lower Erian may perhaps indicate a short relapse to cold; but in the Upper Erian and Lower Carboniferous we have warm seas tenanted by marine animals and a rich land-vegetation appearing both in the Arctic Islands of Canada and in Spitzbergen. The Upper Coal-formation and the Permian and Trias indicate a return of cold, and the temperature seems to increase in the Jurassic, attaining its maximum in the later Cretaceous and Eocene, and gradually diminishing to the glacial age, between which and the modern there seems to have been a warm period of short duration, evidenced in the deposition of mammoth bones, &c., on the Arctic coasts. The cycles of cold and warm climate thus indicated in the Arctic region have. I think, an important bearing on the succession of life further south, at least in Eastern America, and their correlation with the climatal changes in Europe would be a subject of much interest, on which, however, I do not feel in a position to speak positively; but I imagine that the warm and cold periods will be found to correspond with those of the Arctic basin and of America.

The general sketch above given is sufficient to show that in the rocks from the Laurentian to the Trias inclusive we have on the two sides of the Atlantic a continuous parallelism in the following points:—

1. In mineral character and order of succession of aqueous deposits.
2. In the occurrence of great earth-movements of elevation, depression, and plication, at corresponding times.
3. In the ejection of like kinds of igneous rocks in connexion with like members of the aqueous series.
4. In the order of introduction and extinction of animals and plants.
5. In the specific identity of animals and plants in corresponding formations.

All this, I think, points to an actual contemporaneity of the successive changes on the two sides of the Atlantic basin, and to a special correspondence of the formations of the respective marginal

* For references see 'Notes on Geological Map of Northern Canada' by Dr. G. M. Dawson.

† 'Geology of Northern Canada,' Dr. G. M. Dawson, 1887.

areas as contrasted with those of the continental plateaus. It also indicates a persistence, on the whole, of the oceanic character of the Atlantic depression.

Lastly it shows the necessity in any system of geological classification of distinguishing the continental plateaus, the lines of great foldings and of igneous action, and the ancient ocean-margins from each other, and of adapting our arrangements and nomenclature to their actual diversity. In order to do this, while adopting common designations for the great ages of geological time, and for those systems of formations which mark the successive submergences and emergences of the continental plateaus, separate classifications must exist for the different kinds of areas, in their details. It is also, I think, necessary that we should not tie ourselves down to hard-and-fast lines either as to the limits of systems or as to the relative values of their divisions in widely separated localities, as these differ in nature, and nothing is to be gained by conventional arrangements overlooking these differences.

Finally, I can imagine that many questions which have not occurred to me may present themselves to the minds of other geologists who may read or hear this paper. Should I possess any facts tending to the solution of such questions, and not stated in the above pages, they will be at the service of any one desirous to use them for the advancement of science.

Discussion.

The President, whilst recognizing the importance of the paper, doubted whether the question of correlation of the Pre-Cambrian rocks on either side of the Atlantic was ripe for discussion.

Dr. Hicks felt sure that the paper would be welcomed on this side of the Atlantic. He agreed with most of the conclusions of the Author, including the correlation of the Huronian with the Pebidian. This was borne out, not only by similarity of lithological characters, but by the exact correspondence of the succeeding beds in the two areas as shown by Mr. G. F. Matthew. The difficulty of correlation lay with the rocks below the Huronian. He noticed that fragments of granitoid rocks occurred in the Huronian as in the Pebidian. He also had called attention to the contrast between the Palæozoic rocks of the ocean borders and those of the interior of the continents, in papers read before the Society and elsewhere.

Dr. Scott referred to Mr. Walcott's work, and mentioned the occurrence of great deposits of Pre-Cambrian rock in Arizona. Where terrestrial species play an important part, difficulties of correlation were much increased.

Dr. Hinde noticed the difference between the coast-geology of America and that of the interior.

Mr. Marr stated that the paper referred very fully to the point noticed by the last speaker.

46. *On the* Occurrence *of* Elephas meridionalis *at* Dewlish, Dorset. By the Rev. O. Fisher, M.A., F.G.S. (Read June 20, 1888.)

In the year 1877 I saw in the Blackmore Museum at Salisbury two molars of an elephant, labelled "Dewlish, Dorset." I at once attributed them to *E. meridionalis*, and they interested me much, because I had been lately engaged upon the geology of Norfolk*, only in the pre-glacial Forest-bed of which county, so far as I was aware, that species had been found in this country. It was not, however, till the autumn of the year 1887 that I obtained any information upon the subject, when Mr. E. Cunnington, of Dorchester, told me that large bones had been lately found at the same place; and he gave me an extract from an old notice by the late Mr. Hall, a local antiquarian, that a memorandum of the original find of these remains was published in the 'Monthly Magazine' for May, 1814, in which Mr. Hall states that "there is a hill in the parish of Dewlish which was always supposed to be formed of chalk only; but last summer (1813), about 100 feet above the level of the foot of the hill, some sand was observed to be drawn out by a mouse. It was taken notice of, and General Michel [the proprietor of the land] sent workmen to seek for sand." At about 5 feet below the surface they found the teeth of the elephant, of which two are now exhibited. The section observed by Mr. Hall is recorded below. His description of the fossil remains is diverting.

Mr. Blackmore, of Salisbury, in reply to my inquiries, writes that the specimens in their Museum were obtained by his grandfather, Mr. Shorto, in 1814; and an exceedingly sensible letter, written by him to Mr. Hall, was published in 'Flint Chips,' page 20†. Mr. Blackmore says that Dr. Falconer, from rubbings only, attributed these teeth to *E. antiquus*. But Mr. Ashford Sandford, on seeing the specimens themselves, at once said, "*Elephas meridionalis* without doubt," adding, "I have just been looking over the specimens at the British Museum, and can speak positively." And this identification was published in 'Flint Chips' in 1870. Mr. Boyd Dawkins also saw the specimens, and mentioned them to Dr. Leith Adams, who had sketches forwarded to him, but would not allow that they could be *E. meridionalis*, *because* that species had never been found so far west; he also mistook Dewlish for Dawlish, in Devonshire.

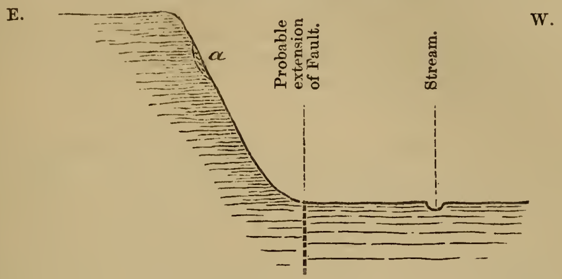
Mr. Cunnington's information revived my interest in the subject; and I visited the locality on September 23rd, 1887, in company with my brother-in-law, Mr. H. B. Middleton. We were received by Mr. C. Kent, the tenant of the farm, and by great good fortune

* See "On the Denudations of Norfolk," Brit. Assoc. Norwich meeting, 1868; Geol. Mag. vol. v. Dec. 1868. Also other papers on Norfolk by the author in the same magazine.

† 'Flint Chips,' by Joseph Stevens. London, 1870.

my old friend, Mr. Mansel-Pleydell, F.G.S., F.L.S., heard that I was coming, and met me there. Mr. Kent possessed a molar found in 1883, and also now exhibited.

Fig. 1.—*Section of Chalk-Escarpment at Dewlish, Dorsetshire.* (Scale 100 feet to 1 inch.)



a. Elephant-bed.

The locality from which these remains have been obtained is situated just opposite the village, near the top of a remarkably steep, straight escarpment of a plateau of chalk, facing the west, and is in a district consisting entirely of chalk. The angle of the hill was estimated by me by the eye to be about 55°. But Mr. Pleydell considers it more steep than that. He has measured the position of the pit, if such it can be called, and has found it 90 feet above the foot of the hill, and 10 feet below its brow (fig. 1). The opposite side of the valley, in which the village is situated, rises with a gentle slope towards the East. The escarpment trends nearly North and South, and the Geological Survey map shows it to be on the course of a fault, which, where it runs out among the subjacent strata to the North, appears to be downcast towards the East. This shows that the scarp has not been caused by elevatory action; but the effect of the fault may possibly have been to harden the chalk along its course, and to turn up the edges of the beds, both of which effects would present obstacles to its denudation. A very remarkable circumstance is, that there is not a trace of a gravel terrace or the slightest outward indication of the existence here of anything except chalk, so that, had it not been for the geological explorations of the mouse, the deposit probably would have remained concealed to the present day. A small stream called the Dewlish runs near, but not close to, the bottom of the hill.

Upon my visit, which lasted only two or three hours, with a man to dig for me, I did not get sufficiently into the deposit to observe any distinct stratification. I found only some angular gravel, impacted in an extremely fine sandy silt, and in this were numerous fragments of ivory, disseminated, forming a constituent part of the gravel, much as other stones would do*. Towards the bottom of

* Possibly this had been disturbed in 1814.

the deposit I found the gravel much coarser and subangular; and here I met with a portion of a nearly worn-down molar (exhibited). I did not see any vestige of shells; but I found some extremely curiously polished flints, of which more anon.

Lady Michel, the present owner of the property, most courteously gave me the loan of the two molars which were obtained in 1813, and are now in her possession. Mr. Mansel-Pleydell has since carried on excavations with great success. He has sent me a section of the gravel-beds; and it is interesting to compare it with that made by Mr. Hall 75 years ago.

Mr. Hall's Section.

1. Chalk	about 3	feet.
2. White clay	2	"
3. Sand	3	"
4. Chalk	2	"
5. Gravel with large flints	3	"
6. White clay	2	"
7. Chalk		

Mr. Mansel-Pleydell's Section.

1. Mould	about	3 inches.
2. Chalk rubble	10	"
3. Fine impalpable sand and flints, remains of elephant		3 feet.
4. Sand and ferruginous gravel		?
5. Flint material, water-borne		?
6. Sand, the lower portion with different-sized flints		?
7. Chalk		?

Mr. Mansel-Pleydell has sent me some small samples of the various kinds of gravel that he met with. The fine sand consists of subangular grains of quartz with a few well-rounded grains probably of limonite, for they are not attracted by the magnet.

We were both of opinion that the deposit has been water-borne, and is not the contents of a pot-hole. It is not deposited upon a shelf of chalk, but is undercut into the face of the escarpment. The length from North to South is considerable, but has not been exactly ascertained. The explanation seems to be that, when the stream formerly flowed 90 feet higher than it does at present, at this point it undercut a cliff-like chalk-bank. A somewhat similar relation of the stream to a chalk-bank may now be seen on the north side of Poundbury, near Dorchester, and under similar circumstances of faulting on the south side of Maiden Castle. In estimating the lapse of time which is indicated by a difference of 90 feet between the former and present levels of the stream, it must be borne in mind that all surface-features are more emphasized in the West of England than they are in the East, the land appearing to have been always in a state of greater unrest. One might have attributed the elevation to a movement on the line of fault, had not the deposit been upon its downcast side. Had the elephants (for more than one individual has been entombed at the spot) been *E. primigenius* or *E. antiquus*, their occurrence would hardly need to have been chronicled; but *E. meridionalis* being, so far as it is known in this country, a pre-glacial species, this renders its occurrence, in a district in which, so far as I am aware, no glacial phenomena have been certified, more interesting. Mr. Mansel-Pleydell and myself have thought it therefore worth while to bring this notice before the Society.

Polished flints have been already mentioned as being found among the gravel. Most of these are polished only upon a portion of their surface. Prof. Prestwich and myself in the year 1873 found a deposit of gravel in Portland which, in my opinion, overlay a swallow-hole, where the pebbles were similarly polished, and formed almost a pudding-stone, the interstices being occupied by a cement of calcite. In that instance it appeared to me that the polishing was due to the long-continued percolation of water, carrying fine silt with it, and I suspect that a similar process has been at work at Dewlish since the deposit was laid high and dry, the unpolished portions of the flints being where they were held fast, and the polished surfaces the portions past which silty water has percolated.

The discovery of the molar in 1853 by Mr. Kent led Mr. Mansel-Pleydell to resume the search, and he soon found a left humerus, four feet long. This was left protected by a covering of sacks and hurdles, but a rough party from a neighbouring village visited it on the next day, which was a Sunday, and demolished it. Since my visit he has continued his excavations, and, including the humerus, the following bones have been found*:—

1. A left humerus 4 feet long.
2. A radius 2 feet long.
3. An ulna, length 2 feet 2 inches.
4. An entire scapula with ridge and recurved process.
5. The anterior border and fossa of a scapula 3 feet 6 inches long, and 9 inches from the border to the ridge and spine.
6. The left side of a pelvis, ischium missing; length of ilium a outer border 3 feet 10 inches.
7. An ischium (?) detached; length (transverse) 2 feet 2 inches, breadth at broadest end 1 foot 1 inch, at most constricted part 8½ inches.
8. A femur, length 2 feet 3 inches.
9. A tibia, length 1 foot 10 inches.
10. The massive left alveolus of an upper jaw, the cavity of which corresponded with a magnificent tusk which lay near it. The orifice for the insertion of the latter was cylindrical and 6 inches in diameter; the other extremity was somewhat flattened, expanding into a thin, wing-like plate on one side. Dr. Falconer considered the angle which this part makes with the frontal plane to afford a mark of distinction between *E. meridionalis* and *E. primigenius*, but unfortunately, owing to the detachment of the two, this angle could not be observed. The length of the bone was 3 feet 9 inches.
11. A tusk 6 feet 2 inches long, and 6 inches in diameter at its base. The point, for about 18 inches, rested perpendicularly upon a bed of waterworn flints, mingled with fine quartz-sand. By a bold

* These descriptions are by Mr. Mansel-Pleydell.

upward curve the middle portion, at about 16 inches distance, was raised two feet four above the base line, and from that point it lay nearly horizontally, though with a slight inclination downwards. The posterior end lay within a few inches of the alveolus just described.

12. Another tusk of much larger dimensions, 7 feet 6 inches long, and 2 feet 3 inches in circumference at the base. About 18 inches of the anterior end missing. It was probably in this condition when the superincumbent bed of clay was deposited, as they are in contact. This tusk differs in shape from the preceding; the curve (which bore its whole weight as it lay in the bed) had an upward and forward direction. Both extremities touched the clay-bed above. The deficient extremity probably had an outward direction.

13. Remains of other tusks were scattered in several parts of the deposit. In some places the fragments of ivory were so numerous as to predominate over the other materials.

14. A molar; crown in use $4\frac{1}{2}$ inches long, consisting of 6 plates (the anterior missing); 6 others unexposed and not in use. Breadth of fourth plate in use $3\frac{3}{4}$ inches, depth $4\frac{1}{2}$ inches.

15. Another molar; crown $7\frac{1}{2}$ inches long, consisting of 10 plates. Breadth of fourth plate $3\frac{1}{2}$ inches; depth from tenth plate (posterior) to the fang 5 inches. This molar appears to be that of a broad-crowned *Elephas antiquus*; although the enamel is as thick as in *E. meridionalis*, the cement-wedges are much thinner.

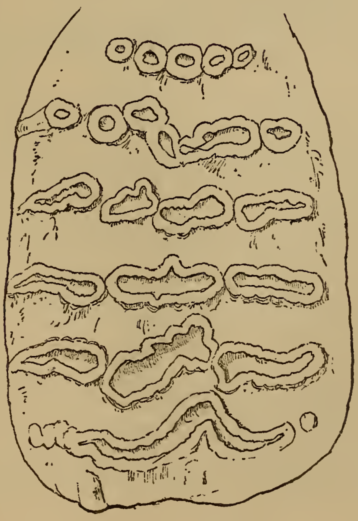
16. Several other molars of *Elephas meridionalis* have been found, the whole number from the first until now being seven, including three plates and part of the fourth in which the digitations are worn down into continuous ridges. A right upper molar is figured on the opposite page (figs. 2, 3). (The specimen, the two tusks, the alveolus, the femur and the tibia, have been presented by Mr. Mansel-Pleydell to the Dorset County Museum.)

17. Several isolated plates of other molars are scattered in various parts of the deposit.

There is considerable variety in the various layers of the deposit; but only one of them contains bones. Some large blocks of chalk seem formerly to have fallen from the top, and it is to the protection which one of these has afforded, that Mr. Mansel-Pleydell attributes the preservation of the tusk. As yet no data have been obtained to fix the geological age of these remains. No vestiges of other animals have been found, nor any shells or microscopic organisms. The position of the deposit, close to the summit of a lofty escarpment, suggests a far-gone age, which may have been even pre-glacial; and the absence of any terrace-like feature may point to a stream of ice, abrading gravel and chalk alike down to a uniform cliff-like face, as having been the sculpturing agent. It is not, however, impossible that a stream, continuously attacking the base without meandering away, might produce such a cliff-like escarpment. But its unusual steepness is, no doubt, partly due to the hardening of the chalk along the course of the fault.

Fig. 2.—*Side view of Right Upper Molar of* Elephas meridionalis, *from Dewlish, Dorsetshire.* ($\frac{1}{4}$ nat. size.)

Fig. 3.—*Grinding-surface of Right Upper Molar of* Elephas meridionalis. ($\frac{1}{2}$ nat. size.)



Discussion.

The President would like to have a further explanation of the polished pebbles referred to. The peculiar manner in which the bones occurred was very interesting; was there any possibility of the deposit being an eroded pipe?

The Author said that the pipe-theory had at first occurred to him; however, the beds where the fossils were obtained are distinctly water-deposited

Mr. Mansel-Pleydell agreed that the beds were stratified. He gave a description of them. The lower beds consisted of one containing broken chalk and flints, between two others half an inch thick, ferruginous, and composed exclusively of thin flints, like shells; then came the bone-bed of the finest sand, associated with large and small flints more or less polished, the smaller at the top. Fragments of ivory, owing to their being lighter, occurred immediately above, and there was some more broken chalk and clay—the point of a tusk just reached this clay. He then enumerated the bones found, which he thought might belong to two species, one being much larger than the other. The teeth shown by Mr. Fisher were those of *E. meridionalis*.

Mr. Newton had little doubt that some, at least, of these teeth belonged to *E. meridionalis*, and those which were not like *E. meridionalis* resembled very closely certain other Forest-bed forms. The question of age, too, was a matter of importance. Unfortunately nothing was known of the associated fauna; but it seemed more likely that these beds would prove to be of about the age of the Cromer Forest-bed, than that *E. meridionalis* should be found passing up into Pleistocene deposits.

The Author asked if the extremely steep escarpment might not have been due to ice-action.

47. SECOND NOTE *on the* MOVEMENT *of* SCREE-MATERIAL. By CHARLES DAVISON, M.A., Mathematical Master at King Edward's High School, Birmingham. (Read June 6, 1888.)

(Communicated by Prof. T. G. BONNEY, D.Sc., F.R.S., F.G.S.)

[Abridged.]

THE first results of the experiment described in this note, namely, those relating to the period from May 5 to September 22, 1887, have already been recorded in a paper read before the Geological Society on February 29, 1888 *.

After a brief interval the experiment was continued under the same conditions as before, from October 4, 1887, to May 5, 1888, with the object of comparing the rates of descent in the winter and summer halves of the year, and also of determining the effects on creeping of rain and snow.

Allowing a distance of $\frac{1}{2}$ mm. for the interval of 12 days during which the experiment was suspended, the total descent during the year was $13\frac{1}{6}$ mm. (*i. e.* a little more than half an inch), the mean rate of descent being therefore ·00140 inch per day.

Comparison of the Rates of Descent during the Winter and Summer Months.—Dividing the year of the experiment into winter, from October 4, 1887, to April 3, 1888, and summer, from May 5 to October 4, 1887, and April 3 to May 5, 1888, we have:—

	Average daily range of temperature †.	Total descent in mm.	Rate of descent in inches per day.
Summer (184 days)......	14°·4 F.	8	·00171.
Winter (182 days)......	8°·0	$5\frac{1}{6}$	·00112.

Had the creeping movement been proportional to the range of temperature, the average daily descent during the winter, compared with that during the summer, would have been rather less, namely ·00095 inch per day. Not only, however, is the heat of the sun more intense in summer than in winter, and consequently the effects produced by passing clouds so mnch the greater, but also for about three months of winter the experimental stone was entirely shielded from the sun by surrounding houses. Clearly, then, other causes must have operated in producing the comparatively rapid rate of descent during the winter months.

Influence of Snow.—The heavy snow-storms which visited many parts of England during the last winter were represented at Birmingham by very meagre falls. Except between February 14 and March 28, the snow seldom lay upon the ground, and when, on several occasions between these dates, it did lie for a short time, the

* Quart. Journ. Geol. Soc. for May 1888, p. 232.

† Excluding 20 days from August 6–25, and 8 days from February 15–22.

snow was nearly always driven by the wind from the experimental stone before the middle of the day, or melted by the increasing heat of the sun.

During the 12 weeks from November 23 to February 14, the average daily range of temperature was 7°·5 F., and the average daily descent only ·00078 inch. From February 15 to April 3, a period of 7 weeks, the average daily range of temperature (during all but the first 8 days) was 8·2 F., and the average daily descent (during the whole time) ·00147 inch, nearly twice as great as in the preceding period. I believe that this difference was chiefly, though not entirely, due to the influence of snow.

By contact with the snow the upper stone is more thoroughly and quickly cooled than by contact with the air. Moreover, the lower stone is directly cooled only by the air, and as the movement depends on the difference of the temperatures to which the stones are at any time subjected, the effect of short and repeated contact with a covering of snow is evidently to increase the rate of descent.

On the other hand, snow, when it lies thickly and for long periods, prevents the stones from fully participating in the range of temperature to which they would otherwise be subjected, and the effects of mere creeping are then reduced to a minimum.

48. Directions *of* Ice-flow *in the* North *of* Ireland, *as* determined *by the* Observations *of the* Geological Survey. By J. R. Kilroe, Esq. (Read June 20, 1888.)

(Communicated by Prof. E. Hull, F.R.S., F.G.S.)

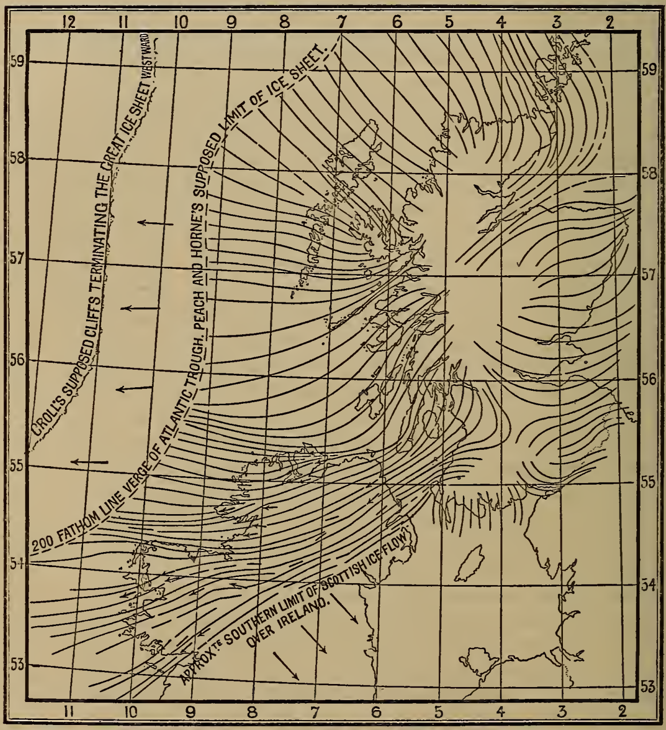
The field observations of the Geological Survey, Ireland, being completed, it was considered desirable by the Director to represent those bearing on glacial phenomena in the northern half of the country on a general map, scale ten miles to one inch. Data for this were amply furnished by the one-inch sheets already published, and by those in course of preparation, upon which the usual map-indications of glacial striæ are numerous and distinctly shown. These indications consist of circles denoting the places of observation, lines crossing those circles giving the trends of striæ, and arrow-heads attached thereto indicating the directions of ice-flow when these are determinable.

In carrying out this transfer a remarkable circumstance became apparent, namely, that the striæ were capable of being resolved into two distinct sets, nearly at right angles to each other; which rendered it convenient to appropriate two copies of the general map to the two sets of striæ. The striæ thus transferred have been further connected by continuous lines about three eighths of an inch apart, or have served as guides when the lines do not happen to pass through the exact points of observation. So constant in direction are the striæ of each set over an area of some 16,000 square miles, that they maintain an almost unswerving parallelism to those continuous, though slightly waved lines. Comparatively few deviate more than a few degrees to one side or the other of the general direction, such deviation being adequately accounted for by local inequalities of the surface. Of more than 600 recorded observations, the trend of striæ at some nine or ten points cannot be thus accounted for, and they have been relegated to a third copy of the general map. They are doubtless attributable to local ice-flows; and as an instance may be cited evidence for a glacial movement *southeastward* from the Sperrin mountains of Londonderry, which at some period thus seem to have been the centre of an independent glacial system. Probably several other minor systems existed, evidences for which are now wanting, or merge with those going to establish more extended and general systems of glaciation.

Now, while the striæ to the east of a line drawn from Strangford Lough to Galway Bay all trend in one direction, *two sets* of striæ occur north-west of that line, and these generally at right angles to each other, as above mentioned. This, it will be conceded, is an interesting fact, and cannot be accounted for, as has been attempted, by conceiving that the same general ice-flow could have produced both. The remarkable absence of two sets south-east of the line mentioned is perhaps the strongest argument against this supposition. The sequel, too, makes manifest how unnecessary such a supposition is. With this may here be mentioned that both sets have been observed on the same flat surface in several instances, and that both are alike found in the valleys and on the flanks and summits of some of the highest hills.

Directions of Striæ.—Of the two sets of striæ referred to, the direction of one varies from north to north-west, which, as evidence of ice-movement, will be considered hereafter. The direction of the second set is W. 25° S., swinging round to W. in Donegal, and S.W. towards Galway Bay, and is strikingly persistent throughout. The value of this fact will be appreciated when it is stated that if we select a few scattered points by way of illustration, the direction of striæ is almost the same whether at 1200 feet above the sea at Glenarm, or near the sea-level at Belfast and Londonderry; 700 feet above datum, S.W. of Draperstown; 1250 in Slieve Beagh, co. Tyrone; 1200 in Sl. League, co. Donegal; 1100 in the Nephin

Fig. 1.—*Map showing Glaciation of the Northern Parts of the British Isles.*



Group, co. Mayo, or on the shore of Sligo Bay. To account for this uniformity of direction, whether at the sea-level or more than 1000 feet above it, whether in Antrim, Tyrone, Donegal, or Mayo, we must conceive the passage of an ice-sheet of vast thickness across the country with uninterrupted flow.

We proceed to show that an ice-sheet crossed the North Channel from the Scottish coast opposite, forming a portion of the *Mer de glace* which originated in the Central Highlands, and which we may for this reason speak of as "The Scottish Glacial System" (see Map, fig. 1). That an ice-flow has invaded the east of Antrim from seaward has been fully established by my colleagues Messrs. Symes and McHenry, who were engaged on the Survey of that part of Ulster, and who have indicated on the Government maps several instances of striæ in this direction. Confirmatory evidence of this westerly movement is found in the occurrence of blocks of the characteristic columnar basalt of Fair Head, westward of their original site, included in the drift which overlies the schist and Carboniferous-Limestone areas near Ballycastle. Mr. Symes informs me that he found blocks of chalk in Carnlough Glen, due west of Glenarm, 400 feet above the sea-level, and resting upon basalt one mile within its boundary, which must obviously have travelled westward and upward from their parent mass. Blocks of schist from Cantire bestrew the surface of Rathlin Island, where striæ also are numerous, most of which indicate a westerly ice-movement.

In Ayrshire and Wigton numerous striæ are represented on the Goverment published maps, which seem separable into two distinct sets, as in the case of those in the North of Ireland, the directions moreover being strikingly similar to those maintained by the two sets in the Irish area. It will at once be seen that those bearing westward indicate an outward flow towards the Irish coast, and strongly suggest the connexion of this flow with that which moved landward from the North Channel over the counties of Antrim and Down. The small map published by Dr. Geikie in his 'Scenery of Scotland' *, showing the glaciation of that country, clearly suggests the theory we maintain, and has supplied matter for the preparation of the small map (fig. 1) accompanying this paper. This author has likewise given us numerous interesting data, with deductions therefrom, as to the vast extension of the *Mer de glace* which centred in the Scottish Highlands. Eastward it coalesced with the Great Scandinavian ice-sheet, and south-westward united with the Irish Glacial system, so as to form a vast glacier, probably extending from Cape Clear to the North Cape, a distance of 1500 miles.

Considering the movements of this ice-sheet, as it spread itself outward to reach the open ocean, Dr. Geikie informs us that part of it moved southward along the floor and over the shores of the German Ocean. We also know that part moved northward and north-westward over the Orkney Group †, and that westward it crossed the Minch and Outer Hebrides ‡, to fill the contiguous

* Pp. 251 *et seq.*

† Paper and map by Messrs. Peach and Horne, Quart. Journ. Geol. Soc. vol. xxxvi.

‡ Paper by Jas. Geikie, LL.D., F.R.S., Quart. Journ. Geol. Soc. vol. xxxiv.

ocean-bed, probably to the verge of the Atlantic trough, some 90 miles distant from the Lewisian chain of islands *.

It may perhaps be questioned whether the Scottish ice-sheet, impinging on the Irish coast, was of sufficient thickness to breast and overtop the Antrim coast-line, when little less precipitous than it now is, and achieve those phenomena with which we accredit it in the Irish area. As bearing upon this interesting point, the following data and considerations are presented, viz. :—

Striæ bearing *westward* have been observed† about the centre of the Nephin Group, Co. Mayo, at the 1100-feet contour. Dr. J. Geikie states that an ice-sheet, after crossing the Minch from the Scottish Highlands, attained an elevation of not less than 1600 feet in North Harris ‡; that in South Uist glaciation is traceable up to about 1650 feet or more, on Beinn-Mhor ‡; and that "scratches may be traced . . . . up to an elevation of 3500 feet at least," in the Highlands §. The same author believes that ice buried Scotland to a depth of several thousand feet, only a few hill-tops rising above the general level of the *Mer de glace* §. And in his 'Scenery of Scotland,' Dr. Archibald Geikie records striæ at a height of 2250 feet on Ben Lomond ||.

If we conceive these points connected by an ideal plane, the plane would mark a minimum upward limit of glaciation during the period of intensest cold; and ascending by an imperceptible gradient towards the Grampians, would be some 2000 feet above the present sea-level at the Antrim coast-line. Allowing for unobserved and effaced glacial traces, at higher elevations than the points referred to, also for the depth of ice and *névé* necessary to leave appreciable traces on the more elevated surfaces of rock over which the mass moved, the "general level of the *Mer de glace*," mentioned in the above extract, probably attained a much higher level than the plane which indicates the limit of observed glaciation. The ice-sheet probably exceeded 3000 feet in the North Channel, the present depth of water being 700; and urging its way westward, it overtopped the coast escarpment by some thousand feet or more.

It has hitherto been supposed that the Irish *Mer de glace* was sufficient to obstruct the Scottish ice-current and divert it northward, after its encroachment to some extent upon the territory of the former. But striæ have been observed bearing westward, from the entrance to Lough Foyle throughout the county of Donegal to the western sea-board, which could not have resulted otherwise than from ice continuous with and moving *en masse* with the sheet which blocked up the adjacent oceanic area, as already described. Such an ice-movement alone satisfactorily accounts for the occurrence of chalk-flints in the drift of Inishowen which bestrews the Northern Donegal coast from Inishowen Head to Malin Head. What thus at this period hindered the northward flow in Donegal would, *a*

* See Messrs. Peach and Horne's map above referred to. Dr. Croll supposes the ice-cliff terminating the great ice-sheet westward to have been about 170 miles distant, see Chart, p. 449, 'Climate and Time,' 1875.

† By myself in 1878.

‡ Paper *sup. cit.* p. 832.

§ 'Great Ice Age,' ed. 1 (1874), pp. 83, 86.

|| 'Scenery of Scotland,' ed. 2 (1887), p. 252.

fortiori, further inland, hinder a northward movement; and it follows that we find striæ in Tyrone, Fermanagh, Mayo, &c., bearing south of west, all obviously due to the prevalence of a Scottish ice-system over the Irish, so far southward as the occurrence of westward striæ warrant us to predicate its influence. Confirmatory evidence for the westward movement is to be found in the absence of granitic blocks from the Lower Boulder-clay of Glen Swilly *, and from the boulder-clay which rests on the granite at the north entrance of Barnesmore Gap. Hence the ice-sheet which passed off the Wigton and Ayrshire coast flowed on to Irish soil, and urged its way across the country, bearing previous accumulations before it, to escape on the western coast by the various bays of Donegal, Sligo, Mayo, and Galway, and over mountain groups which were unable to command an independent glacial system sufficient to obstruct or divert its flow. Dr. Hull considers that a glacial system, centred in the Mourne Mountains, presented such an obstacle; and this would account for an absence of westward striæ south of the Strangford-Lough and Galway-Bay line.

The Irish Glacial System (Map, fig. 2).—Much has been done by

Fig. 2.—*Map of the North of Ireland, showing the North-Irish system of glaciation, after Professor Hull.*

the Rev. M. Close towards the elucidation of glacial phenomena in the Irish area †; and his map of the glaciation of Iarconnaught,

* As observed by Mr. M^cHenry.

† Paper on the "General Glaciation of Ireland," with Map, Journ. Roy Soc. Irel. vol. i. new series, p. 207.

prepared in conjunction with Mr. G. H. Kinahan, and published in 1872, has furnished important aid in the preparation of the maps accompanying this paper. Dr. Hull, in his 'Physical Geology of Ireland,' has described the glaciation of the country in considerable detail; and on his map* indicates an axis of glacial movement, coincident with a great central snowfield which sent its flows northward and southward. This the author represents as stretching north-eastward between the counties of Galway and Antrim; and it is satisfactory to be able to state that all the evidence brought to light since the publication of his book in 1878 goes to establish his conclusions beyond question, with some additional details to be mentioned presently.

It has been stated in the opening pages of this paper, that the prevailing direction of one set of glacial striæ in Ulster is northerly. More exactly the striæ trend N. by W. in Antrim and Londonderry; N.W. over the highlands of Fermanagh; and N.E., N., and N. by W. in Donegal, &c., all indicating a northerly ice-flow. South of the axis of glaciation, the flow has unquestionably been south-easterly, over the central plain of Ireland and towards the Irish Sea, even across the Mourne Mountain. This group is well glaciated from the seashore at Carlingford Lough up to 1200 feet, and probably above it; the Fermanagh hills up to 1000 feet, and those in Donegal to 1340. The Irish glacial system thus attained important proportions.

South-easterly striæ abound on the east coast of the county of Down, and some bearing northward occur in Rathlin Island. It is therefore obvious that the central snow-field extended at least *to* the coastline of Antrim, perhaps beyond it towards the Scottish coast opposite. And it would seem, judging from the directions of striæ in Fermanagh and Donegal, that a spur or projection from the central snow-field extended westward to the head of Donegal Bay, across Barnesmore Hill.

Relative Ages.—It remains to consider the Irish and Scottish systems of glaciation with reference to their relative ages.

Unfortunately the comparative freshness of striæ belonging to the two sets when occurring in proximity has not received the special attention which alone could invest this class of evidence with due weight. For it will be remembered that until of late both sets were believed to indicate but one general ice-movement, and therefore to be practically contemporaneous. It is, however, reasonable to suppose that a very considerable accumulation of snow and ice obtained in the Irish area, during the period of intensest cold, while the Scottish system was gathering maximum strength, and that an ice-movement outward was concomitant with this accumulation. Such a movement would obviously be northward in Ulster; and would maintain this direction until the Scottish ice-sheet invaded this area, to move westward uninterruptedly. Previously formed striæ would thus be to a large extent effaced and replaced by those bearing westward. Some might remain, to indicate a more ancient date for

* P. 211.

the former probable ice-flow; but they would obviously be very few. Striæ bearing northward are, however, by far the most numerous; from which we conclude that during the decline, or possibly after the decline and subdued revival of glacial conditions, an independent Irish *Mer de glace* flowed northward and southward, finding its axis of movement in the Great Central Snow-field.

It need scarcely be added that south of the Galway Bay and Strangford-Lough line, the ice-movement appears to have continued unchanged in direction throughout the glacial epoch, until the *Mer de glace* gave place to numerous independent local systems, with their glaciers and moraines, which marked the decline and extinction of glacial conditions in this country.

Discussion.

Mr. Marr commented upon the supposed partial obliteration of one set of striæ by the ice which had produced a second; whilst the latter appeared to be comparatively fresh, though overridden by a third ice-flow.

The President noted that Prof. Dana had brought forward evidence to show that the ice passing down valleys in Connecticut moved in quite a different direction from that passing over the ridges.

49. *On the* Sudbury Copper-Deposits. By J. H. Collins, Esq., F.G.S. (Read June 6, 1888.)

[Abridged.]

The extensive deposits of copper-ore in the neighbourhood of Sudbury, to the north of Georgian Bay on Lake Huron, have attracted a great deal of attention during the past two years.

The geological and mineralogical characters of the Huronian rocks of the Sudbury district were described by Prof. Bonney in a paper read before the Geological Society of London in November of last year *. The copper was discovered about the time of his visit; but as he does not refer to it in his paper, I presume his attention was not called to it. At first it was thought to be an immensely important discovery, likely to revolutionize the copper-trade, and to reduce the price of copper, then, and for a long time after, only £40 per ton, to a figure which would render such mines as Rio Tinto, Calumet and Hecla, and Anaconda quite unremunerative. One of the deposits, the Stobie Mine, which had been tested by a series of shallow trial pits, was reported to consist of "a mass of solid sulphides of copper and iron, 1600 ft. long and 1200 ft. across," the depth being supposed practically unlimited. The description (published only a few months before my visit in October 1887, but written some time before) runs accurately enough as follows :—"It is in the form of a wide round hill, covered, like the surrounding region, with burnt trees, and in appearance it does not differ in any way from the other low hills around, except in the presence of a large proportion of oxide of iron, which gives a red appearance to the surface soil. Beneath this is a kind of 'pan' of iron oxide resembling bog iron-ore, and still deeper fragments of partially decomposed pyrites" †. At first the ore-bodies were supposed to be as extensive as these surface-gozzans, and as similar gozzans may be traced at intervals for eight miles in a south-westerly direction as far as Kelly Lake, nearly following the strike of the rocks, the most exalted notions were entertained as to the value of the deposits.

The principal mine-workings are about eight miles apart. These are known as the Copper Cliff and the Stobie respectively. Other smaller works have been started and are known as McConnell, the Eyre Mine, the Evans, the Lady Macdonald, and Kelly Lake.

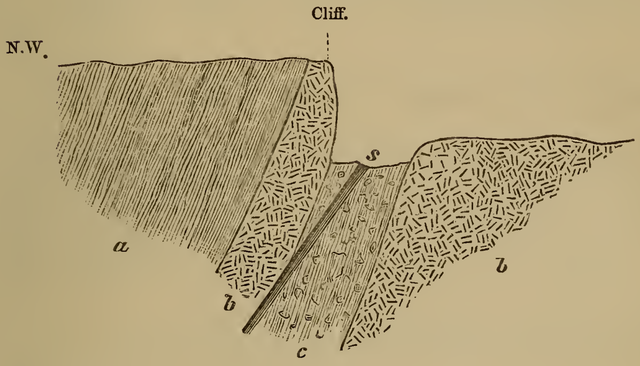
Copper was first discovered at a point on the main line about two miles north-west of Sudbury in 1883, and the *Canadian Copper Company* was formed to work the Copper Cliff and Stobie in 1885.

At the former place the ore was found in the face of a cliff of diorite forty or fifty feet high. By digging away at the foot of this cliff a total height of 80 or 90 ft. was soon exposed. This was thought to be a cutting in a veritable mountain of ore—decomposing

* Quart. Journ. Geol. Soc. vol. xliv. p. 32.
'Canadian Mining Review,' Sept. 1887.

sulphides with oxides and carbonates near the surface, solid copper-pyrites with magnetic pyrites (*pyrrhotite*) below. Blocks of nearly pure copper-pyrites, weighing half a ton or more, were raised, and about four thousand tons of ore were actually taken out and shipped for smelting to New York, some assaying as high as 18 per cent. of copper, a still larger quantity, running only 3 or 4 per cent., being rejected. As might have been expected, however, it proved to be merely a rich bunch in a cupriferous belt, and not a "mountain of ore." A shaft has been sunk following the dip of the belt to a depth of more than 100 feet on what seems to be a sort of ore-vein running diagonally across the belt, and levels have been commenced right and left at various depths. A section of the workings at the Copper-Cliff Mine is given in fig. 1. The mine is

Fig. 1.—*Section of Ore-deposit at Copper Cliff.*
(Scale about 130 feet to 1 inch.)



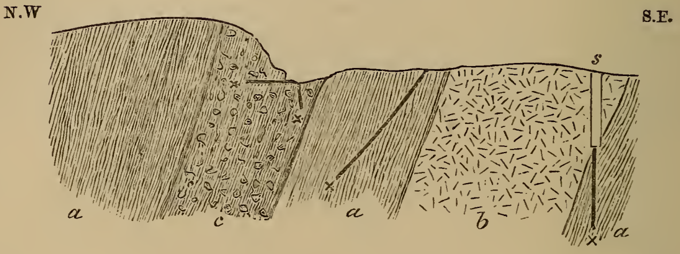
a. Huronian deposits. *b.* Diorite. *c.* Ore-mass. *s.* Shaft on diagonal vein.

connected with the Algoma branch by a siding about a mile in length, built by the Canadian Pacific Railway Company.

At the Stobie Mine the ore-body has been exposed for a length of several hundred feet, and to a depth of forty or fifty feet. By means of bore-holes it has been tested to a further depth of 30 ft. A section of this deposit is given in fig. 2. It was at first thought that the ore dipped to the south-east, and the shaft shown at *s* was actually sunk to a depth of 70 ft. at a point about 450 ft. away from where the works were first started, in the assured expectation of coming upon mineral. As none was found, a bore-hole was put down in the bottom of the shaft to a further depth of 80 ft., but still without success. Another bore-hole was then commenced much nearer the ore-body, and inclining towards it, but still no ore was found, although it was carried to a depth of 200 ft. In fact, at the time of my visit, all the appearances were in favour of the deposit dipping to the north-west, but very steeply, as indicated by the section.

As at the Copper Cliff, a very large proportion of the ore has to be rejected, being of too low a grade to bear the expense of transport to the smelting-works. At first an annual output of at least

Fig. 2.—*Section of Ore-deposit at Stobie Mine.*
(Scale about 130 feet to 1 inch.)



a. Huronian strata. *b.* Diorite. *c.* Ore-body. *s.* Shaft. xx. Bore-holes.

30,000 tons was confidently anticipated; but up to the present time the total production of two seasons has not amounted to 10,000 tons.

Some small workings have also been made at the "6 in 6," the McConnell, the Eyre, and other places; but none of them of any extent, and none have as yet yielded saleable ore. These various works, although so far not at all profitable to their owners, have yet sufficed to demonstrate several important facts.

The ore exists in three distinct forms as follows:—

1. As local impregnations of certain siliceous and felspathic beds or belts of rock of clastic or fragmentary origin, in the form of spots, patches, and strings of cupreous pyrrhotite, or magnetic pyrites.

2. As contact-deposits of the same mineral lying between the impregnated beds just mentioned and certain large interbedded or intrusive masses of diorite.

3. As segregated veins of copper-pyrites and of highly nickeliferous pyrrhotite of secondary formation filling fissures and shrinkage-cracks in the ore-masses of the second class.

There is much in this mode of occurrence to suggest that the copper occurring in the first mode was an original, or at least a very ancient, constituent of the beds, while the richer masses of the second and third modes of occurrence have resulted from later segregations into openings produced either by the intrusion of the diorites or by internal movements of the rocks.

A comparison is at once suggested with the cupreous pyrites of the Sierra Morena, and especially of Rio Tinto, described by me in 1885*. Although the containing rocks at Sudbury, and the de-

* "On the Geology of the Rio Tinto Mines," Quart. Journ. Geol. Soc. vol. xli. p. 245.

posits themselves, are so different in age and in mineral character, yet the modes of origin have apparently been very similar. In each region we have highly inclined stratified beds penetrated by dykes of igneous origin which have followed the stratification so closely that they present the appearance of interbedding, and suggest a contemporaneous origin until very closely examined. The following conclusions seem to me to be fully warranted in both regions:—

(1) The rocks immediately enclosing the ore-deposits were originally, or at a very early period, pyritous and probably cupriferous.

(2) The intrusions of igneous matter gave rise to lines of weakness along the planes of contact.

(3) Subsequent fissuring and, to a certain extent, faulting occurred at these contact-planes.

(4) The filling-in of these fissures was mainly by solution from the pyritous and cupreous material of the enclosing stratified rocks.

(5) There is, in places, a pyritous breccia indicating a partial mechanical filling.

(6) There is, in places, a concentration of mineral matter in those portions of the "country rock" which adjoin the more solid deposits occupying the fissures.

(7) The formation of rich veinlets or "leaders" of ore within the masses has been the result of subsequent operations, probably at many very different times. These veins appear to occupy minor faults and shrinkage-cracks, and to have been filled by segregation of more richly cupreous material derived from the main masses of pyrites.

(8) Abundant evidence of partial movements within the masses of pyrites is afforded by the numerous slickensides which are everywhere and continually met with.

So far, the phenomena observable in the two sets of deposits are parallel, if not absolutely identical. The following differences may now be noted:—At Sudbury the stratified rocks are Huronian, the intrusive masses dioritic, and the mineral deposits mainly pyrrhotite, a monosulphide of iron, or nearly so, with less than 40 per cent. of sulphur when free from foreign matter. At Rio Tinto and in the south of Spain generally the stratified rocks in which the pyritous deposits occur are Upper Devonian, the intrusive masses are generally, if not always*, quartz-porphyries, and the deposits always consist in the main of bisulphide of iron with 50 per cent. or more of sulphur, pyrrhotite being unknown. In addition to the great differences of age and of mineral composition, we may observe in these two series of deposits the following differences in their surroundings:—

a. At Sudbury there is little or no evidence of kaolinization of the felspathic ingredients of the country rocks in the immediate

* According to R. Wimmer some of the deposits in the neighbourhood of Tharsis are associated with dioritic intrusions.

neighbourhood of the deposits. It is true there is not much felspar present, and that little is not orthoclase, hence perhaps the difference in this respect. At Rio Tinto kaolinization is very marked.

b. As at Rio Tinto and in the Sierra Morena generally, so at Sudbury, the actual presence of pyritous matter is indicated by the existence of a highly ferruginous subsoil; but in the latter region there are no ancient lake-deposits of iron-ore like those capping the Mesa de los Pinos at Rio Tinto*. This, however, is a local difference in respect only of a secondary deposit of comparatively recent origin and of no genetic importance.

In conclusion, I would remark that whatever may be the cause of the important differences in the nature of the pyrites at Sudbury and in the south of Spain, there is no reason to suppose that it results from the differences in the containing rocks, since similar differences are frequently observed in the pyritous deposits of Canada when the country rocks are identical. It is possible that a more minute examination of the various Canadian deposits would throw light on this important subject; but hitherto such an investigation does not seem to have been made.

[Note, *October* 22, 1888.—Very little work has been done since the above was written except at the Evans Mine, where the ore is said to have the following average composition:—copper 3 per cent., nickel 3½, iron 40, sulphur 24, rock 49½. It is proposed to erect concentration- and smelting-works, and to ship the nickeliferous "matter" to the United States for subsequent treatment; but as yet this is a proposition only.]

Discussion.

The President observed that the comparison of these deposits with those of other regions constituted a valuable feature in the paper.

Mr. Attwood confirmed the statements of the Author as to these deposits occurring in the Huronian, consisting of gneiss, quartzites, and clay-slates. There was an abundant occurrence of diorites, which in his opinion had brought up the metals. These diorites strike N.E. and S.W. He had seen no evidence of contact-deposits; the diorite-intrusions were very plainly shown intersecting the clay-slates, &c., by examining the railway-cutting south of Sudbury, on the Algoma branch.

* *Op. cit.* pp. 253, 263.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

[The fossils referred to are described; and those of which the names are printed in italics are also figured.]

END OF VOL. XLIV.

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PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1887–88.

November 9, 1887.

Prof. J. W. Judd, F.R.S., President, in the Chair.

James Harvey Hichens, Esq., M.A., Radley School, Radley, near Abingdon, was elected a Fellow, and Professor J. P. Lesley, of Philadelphia, a Foreign Member of the Society.

The list of Donations to the Library was read.

The President read the following communication from the Home Secretary :—

"Whitehall,
July 22, 1887.

"Sir,

I have had the Honour to lay before the Queen the loyal and dutiful Address of the President, Council, and Fellows of the Geological Society of London on the occasion of Her Majesty attaining the Fiftieth year of Her Reign. And I have to inform you that Her Majesty was pleased to receive the same very graciously.

I have the Honour to be,
Sir,
Your obedient Servant,
Henry Matthews."

"The President of
The Geological Society of London,
Burlington House, W."

The following communications were read :—

1. "Note on the so-called 'Soapstone' of Fiji." By Henry B. Brady, Esq., F.R.S., F.G.S.

2. "On some Results of Pressure and of Intrusive Granite in Stratified Palæozoic Rocks near Morlaix, in Brittany." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

3. "On the Position of the Obermittweida Conglomerate." By Prof. T. McK. Hughes, M.A., F.G.S.

4. "On the Obermittweida Conglomerate; its Composition and Alteration." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

5. "Notes on a part of the Huronian Series in the Neighbourhood of Sudbury (Canada)." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

The following specimens were exhibited:—

Specimens and microscopic rock-sections, exhibited by Prof. T. G. Bonney, D.Sc., F.R.S., V.P.G.S., in illustration of his papers.

Specimens exhibited by Prof. T. McKenny Hughes, M.A., F.G.S., in illustration of his paper.

November 23, 1887.

Prof. J. W. Judd, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. "Note on a New Wealden Iguanodont and other Dinosaurs." By R. Lydekker, Esq., B.A., F.G.S.

2. "On the Cae-Gwyn Cave." By T. McKenny Hughes, M.A., F.G.S., Woodwardian Professor of Geology, Cambridge.

The following specimens were exhibited:—

Specimens of remains of *Bos primigenius*, *Elephas antiquus*, *Cervus elaphus* (?), *Hippopotamus amphibius*, Rhinoceros, and a piece of wood, possibly pointed by a blunt instrument, found in digging foundations at 26 and 27 Cockspur Street, S.W., at a depth of between 15 and 20 feet below the surface, exhibited by Messrs. Higgs and Hill, the contractors.

Casts exhibited by R. Lydekker, Esq., F.G.S., in illustration of his paper.

Specimens and photographs exhibited by Prof. T. McKenny Hughes, M.A., F.G.S., in illustration of his paper.

Sketches by C. E. De Rance, Esq., F.G.S., and photographs and diagrams, exhibited by Dr. H. Hicks, F.G.S., in illustration of his remarks on the Cae-Gwyn Cave.

A Special General Meeting of the Society was held at 8 P.M., when the following Resolution was passed:—"That this Meeting authorizes the payment of the bills for cleaning, repairing, and redecorating the Society's House, amounting in all to £512 1*s.* 6*d.*, and sanctions the sale of such an amount of Stock as may be necessary for that purpose."

December 7, 1887.

Prof. J. W. Judd, F.R.S., President, in the Chair.

Alfred Edward Carey, Esq., M. Inst. C.E., 9 Dean's Yard, Westminster, S.W.; Walter F. Ferrier, Esq., Montreal, Canada; Howard Fox, Esq., Falmouth; Thomas Freeman, Jun., Esq., St. Augustine's, Florence, Stoke-on-Trent; William Horne, Esq., Leyburn, Yorkshire; Harold Macandrew, Esq., 8 Nevern Square, Earl's Court, S.W.; Charles Edward Newton, Esq., 17 Cooper Street, Manchester; Charles Champion Rawlins, Esq., Armadale, near Melbourne, Victoria; Joseph Gurdon Leycester Stephenson, Esq., Assoc. M. Inst. C.E., 6 Drapers Gardens, E.C.; William Thomas, Esq., Tuckingmill, Camborne, Cornwall; and Herbert Frederick Tomalin, Esq., Colombo, Ceylon, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "A Letter from H.M. Secretary of State for the Colonies, enclosing an account of recent Discoveries of Gold in the Transvaal."

The deposits in which gold has been found, locally known as "banket," consist of a quartz-conglomerate forming so-called "reefs," which traverse the veldt parallel to, but at a short distance from, the rocky ridge of Witwatersrand. These masses always dip to the south, but at angles varying from 30° up to 90°. The "reefs" are believed to have been discovered by Mr. Struben, an English gentleman long resident in the country. The "main reef" has been traced for twenty-five or thirty miles, and varies in breadth from 3 feet 6 inches to 15 feet; parallel and branching "reefs" of smaller dimensions have also been found. The yield of gold is said to be very variable in different portions of the "reef," samples with from 3 oz. to ½ oz. per ton occurring in close proximity. So far as observation has gone (and the deepest workings have only reached a depth of from 70 to 150 feet), the yield of gold has generally increased as the reefs are followed downwards.

DISCUSSION.

Prof. T. RUPERT JONES said the interesting question was the mode of occurrence of the gold, whether in the pebbles, which are of white and dark-grey quartz, or in the matrix of this almondrock-like "banket." On this point further information was desirable.

2. "On the Age of the Altered Limestone of Strath, Skye." By Dr. Archibald Geikie, F.R.S., V.P.G.S.

3. "On the Discovery of Trilobites in the Upper Green (Cambrian) Slates of the Penrhyn Quarry, Bethesda, near Bangor, North Wales." By Dr. Henry Woodward, F.R.S., V.P.G.S.

4. "On *Thecospondylus Daviesi*, Seeley, with some Remarks on the Classification of the Dinosauria." By Prof. H. G. Seeley, F.R.S., F.G.S.

The following specimens were exhibited:—

Specimens exhibited by Dr. Archibald Geikie, F.R.S., V.P.G.S., in illustration of his paper.

Three specimens of *Conocoryphe viola*, exhibited by Dr. Henry Woodward, F.R.S., V.P.G.S., in illustration of his paper.

December 21, 1887.

Prof. J. W. JUDD, F.R.S., President, in the Chair.

Joseph Carl August Hall, Esq., Grosvenor House, Swansea; Edward Wilton Newton, Esq., 4 Cross Street, Camborne, Cornwall; and James William Stroud, M.D., Port Elizabeth, Cape Colony, South Africa, were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that the Fourth Meeting of the International Geological Congress will be held in London in September next on the 17th and following days. An Organizing Committee has nominated the following Officers:—*Honorary President*: Prof. T. H. Huxley, D.C.L., LL.D., F.R.S. *President*: Prof. J. Prestwich, M.A., F.R.S. *Vice-Presidents*: The President of the Geological Society, the Director-General of the Geological Survey, and Prof. T. McKenny Hughes, M.A. *Treasurer*: F. W. Rudler. *General Secretaries*: J. W. Hulke, F.R.S., and W. Topley. Steps are being taken to enlist the cooperation of all persons interested in Geology and the allied branches of science. Particulars will be immediately announced by the Committee.

Fellows of the Society are invited to join the Congress and to assist in making the Meeting a success.

The following communications were read:—

1. "On the Correlation of some of the Eocene Strata in the Tertiary Basins of England, Belgium, and the North of France." By Prof. Joseph Prestwich, M.A., F.R.S., F.G.S.

2. "On the Cambrian and Associated Rocks in North-west Caernarvonshire." By Prof. J. F. Blake, M.A., F.G.S.

The following specimens were exhibited:—

Rocks and Rock-sections, exhibited by Prof. J. F. Blake in illustration of his paper.

January 11, 1888.

Prof. J. W. Judd, F.R.S., President, in the Chair.

Percy John Ogle, Esq., 4 Bishopsgate Street Within, E.C., and Frederick Danvers Power, Esq., of the Geological Society of Australasia, 17 Queen Street, Melbourne, Victoria, were elected Fellows; Baron F. von Richthofen of Berlin, and Prof. G. Vom Rath of Bonn, Foreign Members; and Prof. W. C. Brögger of Stockholm, and Dr. Anton Fritsch of Prague, Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Law that governs the Action of Flowing Streams." By R. D. Oldham, Esq., F.G.S.

2. "Supplementary Notes on the Stratigraphy of the Bagshot Beds of the London Basin." By the Rev. A. Irving, B.Sc., B.A., F.G.S.

3. "The Red-Rock Series of the Devon Coast Section." By the Rev. A. Irving, B.Sc., B.A., F.G.S.

The following specimens were exhibited:—

Casts of Shells from Bagshot Beds (? Upper) in Sandpit at West-street, near Highclere, Hants, exhibited by R. S. Herries, Esq., F.G.S.

Specimens from the Red-Rock Series, exhibited by the Rev. A. Irving, F.G.S., in illustration of his paper.

January 25, 1888.

Prof. J. W. Judd, F.R.S., President, in the Chair.

Thomas Adair Masey, Esq., Adelaide, Blinman, South Australia, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On *Ailurus anglicus*, a new Carnivore from the Red Crag." By Prof. W. Boyd Dawkins, M.A., F.R.S., F.G.S.

2. "A Contribution to the Geology and Physical Geography of the Cape Colony." By Prof. A. H. Green, M.A., F.R.S., F.G.S.

3. "On two new Lepidotoid Ganoids from the early Mesozoic Deposits of Orange Free State, South Africa." By A. Smith Woodward, Esq., F.G.S.

The following specimens were exhibited:—

Specimen of *Ailurus anglicus* from the Red Crag, Felixstowe, Suffolk, exhibited by Prof. W. Boyd Dawkins, F.R.S., F.G.S., on behalf of the Yorkshire Philosophical Society, in illustration of his paper.

Specimen of the skull of *Ailurus fulgens*, Cuv., from Nipal, exhibited by R. Lydekker, Esq., F.G.S.

Rock specimens and microscopic sections, exhibited by Prof. A. H. Green, F.R.S., F.G.S., in illustration of his paper.

Specimens of *Clithrolepis Extoni*, sp. nov., from the Stormberg beds, Orange Free State, exhibited by Dr. H. Woodward, F.R.S., F.G.S., on behalf of Dr. H. Exton, F.G.S., in illustration of the paper by A. Smith Woodward, Esq., F.G.S.

Remains of *Squatina Cranei*, sp. nov., and mandible of *Belonostomus cinctus*, Agass., from the Chalk of Sussex, exhibited by Henry Willett, Esq., F.G.S.

February 8, 1888.

Prof. J. W. Judd, F.R.S., President, in the Chair.

William Duncan, Esq., 25 Tavistock Road, London, W.; Alexander McKay, Esq., New Zealand Geological Survey, Wellington, New Zealand; James Park, Esq., New Zealand Geological Survey, Wellington, New Zealand; and Frederick Wilkinson, Esq., 2 Vernon Street, Bolton, Lancashire, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On some Remains of *Squatina Cranei*, sp. nov., and the Mandible of *Belonostomus cinctus*, from the Chalk of Sussex, preserved in the Collection of Henry Willett, Esq., F.G.S., Brighton Museum." By A. Smith Woodward, Esq., F.G.S.

2. "On the History and Characters of the Genus *Septastræa*, D'Orbigny (1849), and the Identity of its Type Species with that of *Glyphastræa*, Duncan (1887)." By George Jennings Hinde, Ph.D., F.G.S.

3. "On the Examination of Insoluble Residues obtained from the Carboniferous Limestone at Clifton." By E. Wethered, Esq., F.G.S.

The following specimens were exhibited:—

Remains of *Squatina Cranei*, sp. nov., and mandible of *Belonostomus cinctus*, Agass., from the Chalk of Sussex, exhibited by Henry Willett, Esq., F.G.S., in illustration of the paper by A. Smith Woodward, Esq., F.G.S.

Specimens of *Septastræa Forbesi*, belonging to the Scarborough Museum, exhibited by C. Fox Strangways, Esq., F.G.S., in illustration of Dr. Hinde's paper.

Specimens of *Septastræa Forbesi*, E. & H., of *Astræa? marylandica*, Conrad, and *Astræa? bella*, Conrad, from the Tertiaries of the United States, exhibited, by permission of Prof. Angelo Heilprin, of Philadelphia, by Dr. G. J. Hinde, F.G.S., in illustration of his paper.

Photographs and microscopic specimens, exhibited by E. Wethered, Esq., F.G.S., in illustration of his paper.

Glassy Volcanic Bombs which float on water, picked up 15 miles from Mount Tarawera, New Zealand, after the outburst of June 1886, exhibited by H. B. Armstrong, Esq., B.A., F.G.S.

ANNUAL GENERAL MEETING,

February 17, 1888.

Prof. J. W. Judd, F.R.S., President, in the Chair.

Report of the Council for 1887.

In presenting their Report for the year 1887, the Council of the Geological Society have much pleasure in being again able to congratulate the Fellows upon the continued prosperity of the Society. The Income of the Society has been considerably larger than in 1886, so that notwithstanding the Investment of a sum of £250, and the extraordinary expenditure incurred in connexion with the Redecoration, Repairs, and Alterations made in the Society's House, the Accounts still show a balance in favour of the Society.

The number of Fellows elected during the year is 46, of whom 43 paid their fees before the end of the year, making with 10 previously elected Fellows, who paid their fees in 1887, a total accession during the year of 53 Fellows. During the same period, however, there was a loss by death of 39 Fellows, and by resignation of 15 Fellows, while 6 Fellows were removed from the List for non-payment of their annual contributions, making a total loss of 60 Fellows. There is thus an actual decrease of 7 in the number of Fellows of the Society. Of the 39 Fellows deceased, 10 were Compounders, and 12 non-contributing Fellows; the number of contributing Fellows is increased by 7, being now 840.

The total number of Fellows, Foreign Members and Foreign Correspondents was 1423 at the end of the year 1886, and 1413 at the close of 1887.

At the end of 1886 there was one vacancy in the List of Foreign Members, and this was filled up in the course of 1887. During that year, intelligence was received of the decease of 4 Foreign Members. In the List of Foreign Correspondents there was also one vacancy at the end of 1886, and intelligence was received during 1887 of the decease of 2 Foreign Correspondents. This loss, with the filling up of 2 vacancies among the Foreign Members, caused in all 5 vacancies in the List of Foreign Correspondents, 3 of which were filled up during the year. Thus, at the close of the year 1887, there were 3 vacancies in the List of Foreign Members, and 2 in that of the Foreign Correspondents of the Society.

The total Receipts on account of Income for the year 1887 were £2760 15*s*. 9*d*., being £263 15*s*. 9*d*. more than the estimated Income for the year. The ordinary current Expenditure of the year, leaving out of account the sum of £254 7*s*. 6*d*. expended in the purchase of £250 Reduced 3 per cent. Stock, was £2453 8*s*. 2*d*., or £3 12*s*. 2*d*. in excess of the Estimate. Actually, however, the Expenditure of the year was £2961 15*s*. 8*d*., or £511 19*s*. 8*d*. in excess of the printed Estimate. This is due to the fact that the cleaning, repairs, redecoration, and ventilation of the Society's rooms have been carried out in the course of the past year, and the Council consider it desirable that the Fellows of the Society should be fully informed of the reasons for undertaking the work, and the circumstances under which it was carried out.

When the Society, in 1874, accepted from H.M. Government the apartments now occupied in Burlington House, free of rent, it was with the condition that the cost of all necessary internal repairs, painting, and redecoration should be borne by the Society. In 1887 upwards of thirteen years had elapsed without any internal painting or repairs, and for some years past it had been evident that a considerable expenditure would be needed for these purposes. Had the necessary Funds been in hand the work would have been undertaken three or four years ago. For the last two years, by reducing expenditure, the Council have succeeded in accumulating a considerable sum, and £500 has been invested in two instalments to meet the contemplated expenses. In February last the Council announced in their Report, which was accepted by the Fellows, that it might be advisable in the course of the coming summer to make use of a part of the balance then available for the execution of the necessary repairs, painting, &c., of the interior of the Society's House. It would have been exceedingly difficult, at the time, to give an estimate of the cost, for until the work was actually in hand no one could tell what the expenditure might be.

In the course of the summer, as had been hoped, it was found that the state of the Society's finances justified the expenditure now considered essential. By the time that the necessary inquiries had been made, and estimates of the cost obtained, the Ordinary General Meetings of the Society had come to an end for the Session; and had the procedure laid down in the Bye-Laws been followed, all action must have been delayed for a year, a course which might have involved the Society in greatly increased expense, besides postponing the cleaning of the building, which had become necessary. Under these circumstances the Council determined, on their own responsibility, to order the necessary work to be carried out, and subsequently asked the Fellows of the Society to sanction the expenditure. This was done at a special General Meeting held for the purpose on the 23rd of November, 1887.

Some doubt, however, has been expressed whether the course adopted by the Council was strictly in accordance with the Bye-Laws. Under these circumstances the Council trust that the present Meeting, by adopting this Report, will express its approval of the course followed.

The Council are of opinion that the time has arrived when the Bye-Laws might be reconsidered, in order to ascertain whether the introduction of any modifications would be to the advantage of the Society.

It will be remembered that the Special General Meeting of November 23rd authorized the sale of such an amount of Stock as might be necessary for the purpose of defraying the cost of painting, repairs, &c. It is with much pleasure that the Council are able to announce that no sale of Stock has been found requisite, but that the whole cost of cleaning, painting, repairs, and ventilation has been paid out of Income and the balance remaining at the Society's credit after the Investments already mentioned had been made. Thus an addition of £500 has been secured to the Society's permanent Investments, besides defraying all expenses, ordinary and extraordinary. The Council have no doubt that the very material improvement thus manifested in the financial position of the Society, as compared with that at the close of 1885, will be considered very satisfactory.

At the desire of many of the Fellows, a Conversazione, which was well attended and gave general satisfaction, was held in the rooms of the Society on the evening of the 2nd November last.

The Council have to announce the completion of Vol. XLIII., and the commencement of Vol. XLIV. of the Society's Quarterly Journal.

The Council have awarded the Wollaston Medal to H. B. Medlicott, Esq., F.R.S., F.G.S., in recognition of the additions made by him to our knowledge of the Geology of India.

The Murchison Medal, with the sum of Ten Guineas from the proceeds of the Fund, has been awarded to Prof. J. S. Newberry, M.D., F.M.G.S., of New York, as a mark of appreciation of the long series of researches made by him into the Geology and Palæontology of Ohio and of other parts of the United States.

The Lyell Medal, with a sum of Twenty-five Pounds from the roceeds of the Fund, has been awarded to Prof. Henry Alleyne Nicholson, M.D., D.Sc., F.G.S., in testimony of the value of his Geological investigations in the Lake District and in Canada, and of his studies of many obscure forms of Ancient Life.

The balance of the proceeds of the Wollaston Donation Fund has been awarded to John Horne, Esq., F.R.S.E., F.G.S., in token of appreciation of his contributions to the Geology of the Volcanic and Glacial Rocks of Scotland, and to assist him in the further prosecution of his researches.

The balance of the proceeds of the Murchison Geological Fund has been awarded to E. Wilson, Esq., F.G.S., in recognition of the alue of his researches into the Geology of the Midland and South-western counties of England, and to aid him in further investigations.

One moiety of the Balance of the proceeds of the Lyell Geological Fund has been awarded to Arthur Humphreys Foord, Esq., F.G.S., as a testimony to the importance of the additions made by him to our knowledge of the Monticuliporidæ and other fossil organisms in Canada and this country, and to assist him in continuing his studies.

The remainder of the balance of the Lyell Geological Fund has been awarded to Thomas Roberts, Esq., B.A., F.G.S., in token of appreciation of his investigations into the correlation of the Jurassic rocks, and to aid him in the prosecution of similar inquiries.

The Council have decided to apply the sum of Thirty Pounds from the proceeds of the Barlow-Jameson Fund to the improvement and re-arrangement of the contents of the Society's Museum.

Report of the Library and Museum Committee.

Library.

Since the last Anniversary Meeting a great number of valuable additions have been made to the Library, both by donation and by purchase.

As Donations the Library has received about 128 volumes of separately published works and Survey Reports, and 234 pamphlets and separate impressions of Memoirs, besides about 159 volumes and 97 detached parts of the publications of various Societies. Further, 9 volumes of independent Periodicals, presented chiefly by their respective Editors, and 15 volumes of Newspapers have been received. This constitutes a total addition to the Society's Library, by donation, of about 330 volumes and 234 pamphlets.

A considerable number of Maps, Plans, and Charts have been added to the Society's Collection by presentation, chiefly from the Ordnance Survey of Great Britain, whose donations amount to 899 Sheets, large and small. From the French Dépôt de la Marine 4 sheets of charts and coast-plans have been received.

Of Geological-Survey publications the Society has received 34 sheets of Maps and Sections from the Geological Survey of Italy, 9 sheets from the Swedish Geological Survey, 4 sheets from the Roumanian Geological Bureau, and 1 sheet from the Imperial Geological Survey of Japan. Of the Geological Map of Queensland 2 copies have been received, one from the Queensland Department of Public Works, the other from the author, Mr. R. L. Jack; and a copy of a revised edition of the Geological Map of South Australia has been presented by the Colonial Geologist, Mr. H. Y. L. Brown. Seven sheets of the Atlas of New Jersey were presented by the State Geologist. Other additions are Mr. E. Best's new small Geological Map of the British Isles; and a Map of the English Lakes and adjacent country, geologically coloured by Mr. J. Ruthven (in 1855), the latter presented by Mr. W. Whitaker. The total number of Maps, Charts, and Plans presented during the year was 967.

Several photographs of interest were also presented to the Society in 1887.

The Books, Maps, &c. above referred to have been received from 156 personal Donors, the Editors or Publishers of 15 Periodicals, and 189 Societies, Surveys, and other Public Bodies, making, in all, 360 Donors.

By purchase, on the recommendation of the Standing Library Committee, the Library has received the addition of 57 volumes of books, and of 12 volumes and 60 parts (making about 20 volumes) of various Periodicals, besides 32 parts of certain works in course of publication serially.

Of the Geological-Survey Map of France 6 sheets have been obtained by purchase, as also 8 sheets of the smaller Geological Map of France and the neighbouring districts, by MM. Vasseur and Carez.

The cost of Books, Periodicals, and Maps purchased during the year 1887 was £50 9*s.* 6*d.*, and that of Binding £120 11*s.* 11*d.*, making a total of £171 1*s.* 5*d.*

Museum.

No additions have been made to the collections in the Museum during the past year.

The Committee having taken into consideration the fact that no general cleaning of the specimens in the Society's Museum has taken place since the Collections were placed in their present cabinets, and also that a partial rearrangement of some of the series was desirable, recommended to the Council that the necessary work should be undertaken in the course of the coming spring and summer. The Council have adopted this recommendation, and the work will be carried out accordingly.

Comparative Statement of the Number of the Society at the close of the years 1886 and 1887.

	Dec. 31, 1886.		Dec. 31, 1887.
Compounders	314	......	312
Contributing Fellows	833	......	840
Non-contributing Fellows	198	......	186
	1345		1338
Foreign Members	39	......	37
Foreign Correspondents	39	......	38
	1423		1413

Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1886 *and* 1887.

Number of Compounders, Contributing and Non-contributing Fellows, December 31, 1886			1345
Add Fellows elected during former year and paid in 1887			10
Add Fellows elected and paid in 1887			43
			1398
Deduct Compounders deceased		10	
Contributing Fellows deceased		17	
Non-contributing Fellows deceased		12	
Contributing Fellows resigned		15	
Contributing Fellows removed		6	
		—	60
			1338
Number of Foreign Members, and Foreign Correspondents, December 31, 1886		78	
Deduct Foreign Members deceased	4		
Foreign Correspondents deceased	2		
Foreign Correspondents elected Foreign Members	2		
	—	8	
		70	
Add Foreign Members elected		2	
Foreign Correspondents elected		3	
		—	75
			1413

Deceased Fellows.

Compounders (10).

Baber, J., Esq.
Callard, T. K., Esq.
Coxon, S. B., Esq.
Eyre, G. E., Esq.
Fraser, Rev. C.
Jenkins, H. M., Esq.
King, W. P., Esq.
Richards, W. P., Esq.
Thomas, C., Esq.
Witchell, E., Esq.

Resident and other Contributing Fellows (17).

Brickenden, J. G., Esq.
Bright, H. E. R., Esq.
Brook, T., Esq.
Carrick, Rev. J. L.
Champernowne, A., Esq.
Cooke, J. S., Esq.
Haast, Sir J. von.
Heckels, M., Esq.
Morris, A., Esq.
Newman, F., Esq.
Phillips, J. A., Esq.
Price, Major W. E.
Routledge, T.
Stevenson, T.
Twamley, C.
White, Rev. F. le Grix.
Wilson, C. H., Esq.

Non-contributing Fellows (12).

Bastérot, Comte de.
Breton, Capt. W. H.
Evans, T., Esq.
Guise, Sir W. V.
Hervey, Rev. Lord C. A.
Hymers, Rev. J.
Ingram, Rev. Canon.
Lee, J. E., Esq.
Lees, E., Esq.
Sharp, J., Esq.
Symonds, Rev. W. S.
Thornton, Rev. J.

Foreign Members (4).

Desnoyers, M. Jules.
Hayden, Dr. F. V.
Koninck, Prof. L. G. de.
Studer, Prof. B.

Foreign Correspondents (2).

Cornet, M. F. L.
Marschall, Count A. F.

Fellows Resigned (15).

Galton, C. E., Esq.
Harris, E., Esq.
Heighton, H. J., Esq.
Hunt, Rev. H. G. B.
I'Anson, J., Esq.
I'Anson, J. C., Esq.
Kernahan, Rev. J.
Lester, W., Esq.
Lucas, A. H. S., Esq.
Pankhurst, E. A., Esq.
Ridgway, J., Esq.
Roberts, Rev. W. W.
Shelford, W., Esq.
Stainton, H. T., Esq.
Wood, C. J., Esq.

Fellows Removed (6).

Luke, G. B., Esq.
M^cCann, Rev. J.
Nevill, W. J., Esq.
Read, N. W. R., Esq.
Thomas, D., Esq.
Warwick, F., Esq.

The following Personages were elected from the List of Foreign Correspondents to fill the vacancies in the List of Foreign Members during the year 1887.

Professor J. P. Lesley, of Philadelphia.
Professor J. D. Whitney, of Cambridge, U.S.

The following Personages were elected Foreign Correspondents during the year 1887.

Senhor J. F. N. Delgado, of Lisbon.
Professor A. Heim, of Zurich.
Professor A. de Lapparent, of Paris.

After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and distributed among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Professor J. W. Judd, retiring from the office of President.

That the thanks of the Society be given to H. Bauerman, Esq., Professor T. G. Bonney, and Dr. A. Geikie, retiring from the office of Vice-President.

That the thanks of the Society be given to Dr. W. T. Blanford, retiring from the office of Secretary.

That the thanks of the Society be given to H. Bauerman, Esq., Professor T. G. Bonney, T. Davies, Esq., Prof. P. M. Duncan, and J. J. H. Teall, Esq., retiring from the Council.

After the Balloting-glasses had been duly closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

OFFICERS.

PRESIDENT.

W. T. Blanford, LL.D., F.R.S.

VICE-PRESIDENTS.

John Evans, D.C.L., LL.D., F.R.S.
Prof. T. McKenny Hughes, M.A.
Prof. J. Prestwich, M.A., F.R.S.
Henry Woodward, LL.D., F.R.S.

SECRETARIES.

W. H. Hudleston, Esq., M.A., F.R.S.
J. E. Marr, Esq., M.A.

FOREIGN SECRETARY.

Sir Warington W. Smyth, M.A., F.R.S.

TREASURER.

Prof. T. Wiltshire, M.A., F.L.S.

COUNCIL.

W. T. Blanford, LL.D., F.R.S.
John Evans, D.C.L., LL.D., F.R.S.
L. Fletcher, Esq., M.A.
A. Geikie, LL.D., F.R.S.
Henry Hicks, M.D., F.R.S.
Rev. Edwin Hill, M.A.
W. H. Hudleston, Esq., M.A., F.R.S.
Prof. T. McKenny Hughes.
J. W. Hulke, Esq., F.R.S.
Prof. T. Rupert Jones, F.R.S.
Prof. J. W. Judd, F.R.S.
R. Lydekker, Esq., B.A.
Col. C. A. McMahon.
J. E. Marr, Esq., M.A.
E. Tulley Newton, Esq.
Prof. J. Prestwich, M.A., F.R.S.
Prof. H. G. Seeley, F.R.S.
Sir Warington W. Smyth, M.A., F.R.S.
W. Topley, Esq.
Rev. G. F. Whidborne, M.A.
Prof. T. Wiltshire, M.A., F.L.S.
Rev. H. H. Winwood, M.A.
Henry Woodward, LL.D., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1887.

Date of Election.

1827. Dr. H. von Dechen, *Bonn.*
1848. James Hall, Esq., *Albany, State of New York.*
1851. Professor James D. Dana, *New Haven, Connecticut.*
1853. Count Alexander von Keyserling, *Raykül, Russia.*
1856. Professor Robert Bunsen, For. Mem. R.S., *Heidelberg.*
1857. Professor H. B. Geinitz, *Dresden.*
1859. Dr. Ferdinand Römer, *Breslau.*
1866. Dr. Joseph Leidy, *Philadelphia.*
1867. Professor A. Daubrée, For. Mem. R.S., *Paris.*
1871. Dr. Franz Ritter von Hauer, *Vienna.*
1874. Professor Alphonse Favre, *Geneva.*
1874. Professor E. Hébert, *Paris.*
1874. Professor Albert Gaudry, *Paris.*
1875. Professor Fridolin Sandberger, *Würzburg.*
1875. Professor Theodor Kjerulf, *Christiania.*
1875. Professor F. August Quenstedt, *Tübingen.*
1876. Professor E. Beyrich, *Berlin.*
1877. Dr. Carl Wilhelm Gümbel, *Munich.*
1877. Dr. Eduard Suess, *Vienna.*
1879. Major-General N. von Kokscharow, *St. Petersburg.*
1879. M. Jules Marcou, *Cambridge, U. S.*
1879. Dr. J. J. S. Steenstrup, For. Mem. R.S., *Copenhagen.*
1880. Professor Gustave Dewalque, *Liége.*
1880. Baron Adolf Erik Nordenskiöld, *Stockholm.*
1880. Professor Ferdinand Zirkel, *Leipzig.*
1882. Professor Sven Lovén, *Stockholm.*
1882. Professor Ludwig Rütimeyer, *Basle.*
1883. Professor J. S. Newberry, *New York.*
1883. Professor Otto Martin Torell, *Stockholm.*
1884. Professor G. Capellini, *Bologna.*
1884. Professor A. L. O. Des Cloizeaux, For. Mem. R.S., *Paris.*
1884. Professor G. Meneghini, *Pisa.*
1884. Professor J. Szabó, *Pesth.*
1885. Professor Jules Gosselet, *Lille.*
1886. Professor Gustav Tschermak, *Vienna.*
1887. Professor J. P. Lesley, *Philadelphia.*
1887. Professor J. D. Whitney, *Cambridge, U.S.*

LIST OF
THE FOREIGN CORRESPONDENTS
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1887.

Date of Election.

1863. Dr. F. Senft, *Eisenach.*
1864. Dr. Charles Martins, *Montpellier.*
1866. Professor Victor Raulin, *Bordeaux.*
1866. Baron Achille de Zigno, *Padua.*
1872. Herr Dionys Stur, *Vienna.*
1874. Professor Igino Cocchi, *Florence.*
1874. M. Gustave H. Cotteau, *Auxerre.*
1874. Professor G. Seguenza, *Messina.*
1874. Dr. T. C. Winkler, *Haarlem.*
1877. Professor George J. Brush, *New Haven.*
1877. Professor E. Renevier, *Lausanne.*
1877. Count Gaston de Saporta, *Aix-en-Provence.*
1879. Professor Pierre J. van Beneden, For.Mem.R.S., *Louvain.*
1879. M. Édouard Dupont, *Brussels.*
1879. Professor Gerhard Vom Rath, *Bonn.*
1879. Dr. Émile Sauvage, *Paris.*
1880. Professor Luigi Bellardi, *Turin.*
1880. Professor Leo Lesquereux, *Columbus.*
1880. Dr. Melchior Neumayr, *Vienna.*
1880. M. Alphonse Renard, *Brussels.*
1881. Professor E. D. Cope, *Philadelphia.*
1882. Professor Louis Lartet, *Toulouse.*
1882. Professor Alphonse Milne-Edwards, *Paris.*
1883. Baron Ferdinand von Richthofen, *Leipzig.*
1883. Professor Karl Alfred Zittel, *Munich.*
1884. Dr. Charles Barrois, *Lille.*
1884. M. Alphonse Briart, *Morlanwelz.*
1884. Professor Hermann Credner, *Leipzig.*
1884. Baron C. von Ettingshausen, *Gratz.*
1884. Dr. E. Mojsisovics von Mojsvár, *Vienna*
1885. M. F. Fouqué, *Paris.*
1885. Professor G. Lindström, *Stockholm.*
1885. Dr. A. G. Nathorst, *Stockholm.*
1886. Professor H. Rosenbusch, *Heidelberg.*
1886. Professor J. Vilanova y Piera, *Madrid.*
1887. Senhor J. F. N. Delgado, *Lisbon.*
1887. Professor A. Heim, *Zurich.*
1887. Professor A. de Lapparent, *Paris.*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE "DONATION FUND"

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., &c.

To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,"—"such individual not being a Member of the Council."

1831. Mr. William Smith.
1835. Dr. G. A. Mantell.
1836. M. Louis Agassiz.
1837. Capt. T. P. Cautley. / Dr. H. Falconer.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Professor A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. M. Elie de Beaumont. / M. P. A. Dufrénoy.
1844. Rev. W. D. Conybeare.
1845. Professor John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Rev. Dr. W. Buckland.
1849. Professor Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir H. T. De la Beche.
1856. Sir W. E. Logan.
1857. M. Joachim Barrande.
1858. Herr Hermann von Meyer. / Mr. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Professor Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Professor Gustav Bischof.
1864. Sir R. I. Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Professor Carl F. Naumann.
1869. Dr. H. C. Sorby.
1870. Professor G. P. Deshayes.
1871. Sir A. C. Ramsay.
1872. Professor J. D. Dana.
1873. Sir P. de M. Grey-Egerton.
1874. Professor Oswald Heer.
1875. Professor L. G. de Koninck.
1876. Professor T. H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Professor Bernhard Studer.
1880. Professor Auguste Daubrée.
1881. Professor P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. W. T. Blanford.
1884. Professor Albert Gaudry.
1885. Mr. George Busk.
1886. Professor A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON "DONATION-FUND."

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. Professor G. P. Deshayes.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Professor Edward Forbes.
1842. Professor John Morris.
1843. Professor John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape-of-Good-Hope Fossils. M. Alcide d'Orbigny. }
1849. Mr. William Lonsdale.
1850. Professor John Morris.
1851. M. Joachim Barrande.
1852. Professor John Morris.
1853. Professor L. G. de Koninck.
1854. Dr. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Professor G. P. Deshayes.
1857. Dr. S. P. Woodward.
1858. Mr. James Hall.
1859. Mr. Charles Peach.
1860. { Professor T. Rupert Jones. Mr. W. K. Parker. }
1861. Professor A. Daubrée.
1862. Professor Oswald Heer.
1863. Professor Ferdinand Senft.
1864. Professor G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. W. Carruthers.
1870. M. Marie Rouault.
1871. Mr. R. Etheridge.
1872. Dr. James Croll.
1873. Professor J. W. Judd.
1874. Dr. Henri Nyst.
1875. Mr. L. C. Miall.
1876. Professor Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Professor W. J. Sollas.
1879. Mr. S. Allport.
1880. Mr. Thomas Davies.
1881. Dr. R. H. Traquair.
1882. Dr. G. J. Hinde.
1883. Mr. John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. S. Gardner.
1887. Mr. B. N. Peach.
1888. Mr. John Horne.

AWARDS OF THE MURCHISON MEDAL

AND OF THE

PROCEEDS OF "THE MURCHISON GEOLOGICAL FUND,"

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

"To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing geological science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any inquiries bearing upon the science of geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of geological science."

1873. Mr. William Davies. *Medal.*
1873. Professor Oswald Heer.
1874. Dr. J. J. Bigsby. *Medal.*
1874. Mr. Alfred Bell.
1874. Professor Ralph Tate.
1875. Mr. W. J. Henwood. *Medal.*
1875. Professor H. G. Seeley.
1876. Mr. A. R. C. Selwyn. *Medal.*
1876. Dr. James Croll.
1877. Rev. W. B. Clarke. *Medal.*
1877. Professor J. F. Blake.
1878. Dr. H. B. Geinitz. *Medal.*
1878. Professor C. Lapworth.
1879. Professor F. M'Coy. *Medal.*
1879. Mr. J. W. Kirkby.
1880. Mr. R. Etheridge. *Medal.*
1881. Professor A. Geikie. *Medal.*
1881. Mr. F. Rutley.
1882. Professor J. Gosselet. *Medal.*
1882. Professor T. Rupert Jones.
1883. Professor H. R. Göppert. *Medal.*
1883. Mr. John Young.
1884. Dr. H. Woodward. *Medal.*
1884. Mr. Martin Simpson.
1885. Dr. Ferdinand Römer. *Medal.*
1885. Mr. Horace B. Woodward.
1886. Mr. W. Whitaker. *Medal.*
1886. Mr. Clement Reid.
1887. Rev. P. B. Brodie. *Medal.*
1887. Mr. Robert Kidston.
1888. Professor J. S. Newberry. *Medal.*
1888. Mr. E. Wilson.

AWARDS OF THE LYELL MEDAL

AND OF THE

PROCEEDS OF THE "LYELL GEOLOGICAL FUND,

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal "to be given annually" (or from time to time) "as a mark of honorary distinction as an expression on the part of the governing body of the Society that the Medallist has deserved well of the Science,"—"not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced."

1876. Professor John Morris. *Medal.*
1877. Dr. James Hector. *Medal.*
1877. Mr. W. Pengelly.
1878. Mr. G. Busk. *Medal.*
1878. Dr. W. Waagen.
1879. Professor Edmond Hébert. *Medal.*
1879. Professor H. A. Nicholson.
1879. Dr. Henry Woodward.
1880. Mr. John Evans. *Medal.*
1880. Professor F. Quenstedt.
1881. Sir J. W. Dawson. *Medal.*
1881. Dr. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. Dr. J. Lycett. *Medal.*
1882. Rev. Norman Glass.
1882. Professor C. Lapworth.
1883. Dr. W. B. Carpenter. *Medal.*
1883. Mr. P. H. Carpenter.
1883. M. E. Rigaux.
1884. Dr. Joseph Leidy. *Medal.*
1884. Professor Charles Lapworth.
1885. Professor H. G. Seeley. *Medal.*
1885. Mr. A. J. Jukes-Browne.
1886. Mr. W. Pengelly. *Medal.*
1886. Mr. D. Mackintosh.
1887. Mr. Samuel Allport. *Medal.*
1887. Rev. Osmond Fisher.
1888. Professor H. A. Nicholson. *Medal.*
1888. Mr. A. H. Foord.
1888. Mr. T. Roberts.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially "as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much."

1877. Professor O. C. Marsh.
1879. Professor E. D. Cope.
1881. Dr. C. Barrois.
1883. Dr. Henry Hicks.
1885. Professor Alphonse Renard.
1887. Professor Charles Lapworth.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

"The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science."

1880. Purchase of microscope.
1881. Purchase of microscope lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Professor Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.

ESTIMATES *for*

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Due for Arrears of Annual Contributions	130	0	0			
Due for Arrears of Admission-fees	20	0	0			
				150	0	0
Estimated Ordinary Income for 1888:—						
Annual Contributions from Resident Fellows, and Non-residents, 1859 to 1861				1500	0	0
Admission-fees				208	0	0
Compositions				199	0	0
Annual Contributions in advance				42	0	0
Dividends on Consols and Reduced 3 per Cents.				248	1	4
Sale of Transactions, Library-catalogue, Ormerod's Index, Hochstetter's New Zealand, and List of Fellows	3	0	0			
Sale of Quarterly Journal, including Longman's account	170	0	0			
Sale of Geological Map, including Stanford's account	7	0	0			
				180	0	0
				£2527	1	4

THOMAS WILTSHIRE, TREAS.

2 *Feb.* 1888.

the Year 1888.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes and Insurance	43	10	0			
Gas...	30	0	0			
Fuel	32	0	0			
Furniture and Repairs	15	0	0			
House-repairs and Maintenance	15	0	0			
Annual Cleaning	20	0	0			
Washing and Sundries	33	0	0			
Tea at Meetings	16	0	0			
				204	10	0
Salaries and Wages:						
Assistant Secretary	350	0	0			
Assistants in Library, Office, and Museum	225	0	0			
House Steward	105	0	0			
Housemaid	40	0	0			
Errand Boy	48	0	0			
Charwoman and Occasional Assistance	30	0	0			
Attendants at Meetings	8	0	0			
Accountant	10	10	0			
				816	10	0
Official Expenditure:						
Stationery	25	0	0			
Miscellaneous Printing	22	0	0			
Postages and other Expenses	75	0	0			
				122	0	0
Library				175	0	0
Publications:						
Quarterly Journal	950	0	0			
,, ,, Commission, Postage, and Addressing	100	0	0			
List of Fellows	33	0	0			
Abstracts, including Postage	110	0	0			
				1193	0	0
Balance in favour of the Society				16	1	4
				£2527	1	4

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
Balance in Bankers' hands, 1 January 1887.	563	16	10			
Balance in Clerk's hands, 1 January 1887 .	13	2	3			
				576	19	1
Compositions				241	10	0
Arrears of Admission-fees	63	0	0			
Admission-fees, 1886	270	18	0			
				333	18	0
Arrears of Annual Contributions				156	13	6
Annual Contributions for 1887, viz.:						
Resident Fellows	1516	14	6			
Non-Resident Fellows ...	15	15	0			
				1532	9	6
Annual Contributions in advance				54	1	6
Dividends on Consols	203	8	5			
,, Reduced 3 per Cents.	44	12	11			
				248	1	4
Taylor & Francis: Advertisements in Journal, Vol. 42..				6	8	0
Publications:						
Sale of Journal, Vols. 1–42	91	14	1			
,, Vol. 43 *	79	11	9			
Sale of Library Catalogue	2	2	0			
Sale of Geological Map	11	4	8			
Sale of Ormerod's Index.......................	1	4	9			
Sale of Hochstetter's New Zealand	0	4	0			
				186	1	3
Journal Subscriptions in Advance..................				1	12	8
*Due from Messrs. Longmans, in addition to the above, on Journal, Vol. 43, &c......................	58	11	1			
Due from Stanford on account of Geological Map...	5	4	7			
	63	15	8			
				£3337	14	10

We have compared this statement with the Books and Accounts presented to us, and find them to agree.

(Signed) E. HILL, F. W. RUDLER. } *Auditors.*

2 *February*, 1888.

Year ending 31 *December,* 1887.

EXPENDITURE.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes	27	18	4			
Fire-insurance	15	0	0			
Gas	32	0	6			
Fuel	31	1	0			
Furniture and Repairs	5	16	9			
House-repairs, Ordinary	5	8	9			
Ditto, Extraordinary	508	7	6			
Annual Cleaning	19	4	6			
Washing and Sundries	32	7	9			
Tea at Meetings	17	0	0			
				694	5	1
Salaries and Wages:						
Assistant Secretary	350	0	0			
Assistants in Library, Office, and Museum	215	0	0			
House Steward	105	0	0			
Housemaid	40	0	0			
Errand Boy	48	2	6			
Charwoman	21	19	9			
Attendants at Meetings	8	10	0			
Accountant's Fee	10	10	0			
				799	2	3
Official Expenditure:						
Stationery	25	7	5			
Miscellaneous Printing	21	17	8			
Postages and other Expenses	82	8	5			
				129	13	6
Library				171	1	5
Soirée				46	15	0
Publications:						
Geological Map	1	0	6			
Journal, Vols. 1–42	10	10	2			
,, Vol. 43 ... 859 10 10						
,, ,, Commission, Postage, and Addressing ... 102 1 10						
	961	12	8			
List of Fellows	33	12	8			
Abstracts, including Postage	114	2	5			
				1120	18	5
Investment of £250 Reduced 3 per Cents. at $101\frac{5}{8}$				254	7	6
Balance in Bankers' hands, 31 Dec. 1887	115	18	11			
Balance in Clerk's hands, 31 Dec. 1887	5	12	9			
				121	11	8
				£3337	14	10

H. D. STEAD, *Accountant*,
27 *January*, 1888.

"Wollaston Donation Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1887	31	8	10	Cost of striking Gold Medal awarded to Mr. J. W. Hulke	10	10	0
Dividends on the Fund invested in Reduced 3 per Cents.	31	10	2	Award to Mr. B. N. Peach	20	18	10
				Balance at Bankers', 31 December, 1887	31	10	2
	£62	19	0		£62	19	0

"Murchison Geological Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1887	19	6	8	Award to Rev. P. B. Brodie, with Medal	10	10	0
Dividends on the Fund invested in London and North-Western Railway 4 per cent. Debenture Stock	38	14	2	" Mr. Robert Kidston	27	6	4
				Cost of Medal	0	17	0
				Balance at Bankers', 31 December, 1887	19	7	6
	£58	0	10		£58	0	10

"Lyell Geological Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1887	51	0	3	Award to Mr. S. Allport, with Medal	25	0	0
Dividends on the Fund invested in Metropolitan 3½ per cent. Stock	68	3	2	" Rev. O. Fisher	41	19	4
				Cost of Medal	1	1	0
				Balance at Bankers', 31 December, 1887	51	3	1
	£119	3	5		£119	3	5

"Barlow-Jameson Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1887	19	16	7	Balance at Bankers', 31 December, 1887	34	7	2
Dividends on the Fund invested in Consols	14	10	7				
	£34	7	2		£34	7	2

"BIGSBY FUND." TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
Balance at Bankers', 1 January, 1887	12	3	0	Medal awarded to Prof. C. Lapworth	12	3	0
Dividends on the Fund invested in New 3 per Cents.	6	1	8	Balance at Bankers', 31 December, 1887	6	1	8
	£18	4	8		£18	4	8

VALUATION OF THE SOCIETY'S PROPERTY; 31 December, 1887.

PROPERTY.	£	s.	d.	£	s.	d.		£	s.	d.
Due from Longman & Co., on account of Journal, vol. xliii. &c.				58	11	1	Balance in favour of the Society	8872	12	9
Due from Stanford on account of Map				5	4	7				
Due from Subscribers to Journal				1	12	8				
Balance in Bankers' hands, 31 Dec. 1887				115	18	11				
Balance in Clerk's hands, 31 Dec. 1887				5	12	9				
Funded Property:—										
Consols, at 100	6999	7	4	6999	7	4				
Reduced 3 per Cents. at 100	1536	5	5	1536	5	5				
Arrears of Admission-fees (considered good)				20	0	0				
Arrears of Annual Contributions (considered good)				130	0	0				
				£8872	12	9		£8872	12	9

[*N.B.—The above does not include the value of the Collections, Library, Furniture, and stock of unsold Publications.*]

THOMAS WILTSHIRE, *Treas.*

2 *Feb.* 1888.

Award of the Wollaston Medal.

In presenting the Wollaston Gold Medal to Mr. Henry Benedict Medlicott, M.A., F.R.S., the President addressed him as follows :—

Mr. Medlicott,—

The Council of this Society are not unmindful of the fact that many of our Fellows are engaged in the promotion of geological science in every part of a vast empire; in awarding to you the highest honour which is at their disposal, they are following a precedent which was established more than fifty years ago, by the presentation of the Wollaston Medal to Cautley and Falconer. In that great Indian dominion where those famous geologists carried on their important researches, you commenced your labours as far back as the year 1854; and for more than a third of a century you have continued the almost incessant exertions which have led to very important additions to our knowledge, often obtained only at the price of severe hardships and at the risk of serious dangers. During the last eleven years you have occupied the important and responsible position of Director of the Indian Survey; and it is to your administrative ability in that position that we owe many of the valuable results obtained by that Survey in recent years; more especially are we indebted to you, and to our Secretary, Dr. Blanford, for that useful Compendium of Indian Geology which has now become indispensable to all students of our science. We feel it to be singularly appropriate that we are able to make this award to you just at the time that you return to your native country for the rest you have so well earned.

Mr. Medlicott replied :—

Mr. President,—

The award of the Wollaston Medal by the Geological Society is the most gratifying distinction that a Geologist can receive. It is only as a recognition of devotion to our Science that I can venture to accept so great an honour. My work has been chiefly in combination with others, and it gives me much consolation to think that my colleagues of the Geological Survey of India will share in this reward and will appreciate it.

Award of the Wollaston Donation Fund.

In handing the Balance of the Proceeds of the Wollaston Donation Fund to Archibald Geikie, LL.D., F.R.S., for transmission to Mr. John Horne, F.G.S., the President addressed him as follows:—

Dr. Geikie,—

The Council of the Geological Society being desirous of aiding Mr. John Horne in carrying on his important investigations in the Volcanic and Glacial geology of the northern part of our islands, have awarded to him the Wollaston Fund for the present year. Seeing that in their researches Messrs. Peach and Horne have been so constantly united, it was felt that in the recognition of their services to science they ought not to be divided; in the roll of honour containing the names of those who have received this award the name of Mr. Horne will appropriately follow that of his friend. In transmitting this award to our fellow-worker, will you express the hope that it may be of some service to him in enabling him to continue those studies which have already done so much towards elucidating the structure of the land of his birth?

Dr. Geikie, in reply, said:—

Mr. President,—

At the request of my friend and colleague, Mr. Horne, I have much pleasure in receiving for him the Wollaston Fund, and in conveying to the Society his cordial thanks for this mark of its appreciation. If anything could add to the pleasure with which he receives this prize, it would be the association with his friend and companion in geological labour, Mr. Peach, to which you have alluded. A member of the Geological Survey, placed in a distant and inaccessible region, has need of all the enthusiasm of his nature when he has to combat with great and difficult geological problems amid the lesser troubles of hard fare, poor lodging, and the absence of all those sympathies of human intercourse which so help us in our pursuits. To such a far off and, as it were, forsaken brother there can come no greater encouragement and stimulant than recognition of his labours from those who stand nearer to the central pulse of life in the country. Mr. Horne is so enthusiastic in the discharge of his official duties and in the cause of science as sometimes to risk his health by prolonged exposure to the inclemencies of the boisterous north. In this award he feels that his work, remote though its area may be, has not escaped the friendly notice of the Geological Society of London, and that it encourages him to give himself as heartily in the future as in the past to the advancement of the science to which we are all devoted.

Award of the Murchison Medal.

The President then handed the Murchison Medal to Archibald Geikie, LL.D., F.G.S., for transmission to Prof. J. S. Newberry, M.D., F.M.G.S., and said :—

Dr. Geikie,—

The Council of this Society in awarding the Murchison Medal to Dr. Newberry, desire to place on record their sense of the very high value of his geological researches in various parts of the United States. Dr. Newberry's studies have been pursued, during the last thirty years, in connexion with every branch of Geological Science. The maps and memoirs of the Geological Survey of Ohio afford the highest proofs of his skill as a stratigraphical geologist; numerous papers dealing with the phenomena of the Glacial Formations testify to the attention which he has devoted to that important subject; while several of his memoirs treat of petrographical questions. In Palæontology Dr. Newberry has made many valuable contributions to our knowledge, especially in connexion with Fishes and Plants. Nor have the great problems of Geological Philosophy been neglected by our esteemed Foreign Member, who now occupies so important a post in connexion with one of the greatest educational institutions of his native country. When the Director-General of our own Geological Survey transmits to one of the pioneers of American Geology a medal founded by a father of British Geology, the action may be fairly held to typify the universal brotherhood of Science.

Dr. Geikie, in reply, said :—

Mr. President,—

On the part of Dr. Newberry I am commissioned to receive the Murchison Medal which has been awarded to him. Were my friend here himself, he would express, far more fittingly than I can, his gratification that the Geological Society of London has conferred this honour upon him. But there is one advantage perhaps in his absence, that we can freely speak of him and his work, regarding which he would himself wish to be silent; and it is of him and his work that the Fellows doubtless wish to hear.

It is now nearly forty years since he began his scientific career. During this long interval of constant and enthusiastic labour, as you have so well observed, there are few departments of Geology into which he has not entered, and where he has not left the impress of his clear insight, his singular mastery of detail, and his faculty of broad and luminous generalization. And yet this record of fruitful work has been achieved in the midst of continual demands on his time and thought made by professional and official duties—demands which for most men would have been enough to fill up a busy life. To geologists on this side of the Atlantic who know him only by his published writings, there are more especially three lines of research with which his name is associated. It was he who in the expedition under Lieutenant Ives, eight-and-twenty years ago, first made known to the world the wonders of the Colorado River of the West, who recognized in that region monuments of the most stupendous denudation, and who by his clear and graphic descriptions inaugurated a new era in the discussion of the problem of land-sculpture. His researches on Fossil Plants have placed him in the very front rank of those who have made known to us the characters of the vegetation of former periods of the earth's history. As a fitting crown to these researches he will shortly publish a large monograph, with two hundred plates, descriptive of the fossil floras of North America. And, thirdly, his long and minute investigation of Fossil Fishes has enabled him to repeople the ancient waters of the North-American continent with the abundant and often extraordinary types which characterized them. Another great monograph, with sixty plates, on this subject is also in the press.

There seems to me something peculiarly appropriate in the award of the Murchison Medal to such a man. He is a geologist after Murchison's own heart—keen of eye, stout of limb, with a due sense of the value of detail, but with a breadth of vision that keeps detail in due subordination.

If I may be permitted, I would fain add a word of personal gratification that it has fallen to my lot to be intermediary on this interesting occasion between the Geological Society of London and one of the most distinguished men of science in the United States. The geologists of North America are drawn to us by stronger ties and closer sympathy than most of us are perhaps aware. They look on our Society as the parent of their own kindred associations. Our fathers in geology are also theirs. They wait for the advent of our Journal, and keep themselves far more fully conversant with what is done within these walls than most of us, I am afraid, do with their work. I confess that, for myself, I often feel ashamed and mortified that I can do so little to keep myself abreast of the rapid and astounding progress of our science on the other side of the ocean. We hardly realize and recognize as fully as we should the nature and bearing of the work of our brethren across the sea. So I hail this opportunity of holding out the right hand of fellowship, for I am certain that the geologists of the United States will feel that in doing honour to Dr. Newberry the Geological Society of London wishes at the same time to express its appreciation of American geologists and its best wishes for the advance of American geology.

Award of the Murchison Geological Fund.

In handing the Balance of the Proceeds of the Murchison Geological Fund to Henry Woodward, LL.D., F.R.S., for transmission to Mr. Edward Wilson, F.G.S., the President addressed him as follows:—

Dr. Woodward,—

The Council of this Society, being desirous of marking their sense of the great value of Mr. Edward Wilson's geological investigations, have awarded to him the Balance of the Murchison Fund for the present year. Both at Nottingham and at Bristol Mr. Wilson has shown his ability as a careful observer and trustworthy exponent of the stratigraphy of the surrounding country; and it is our hope that this Award may afford him both encouragement and assistance in continuing those important researches in fields of study where he has already laboured with such devotion and success.

Dr. Woodward, in reply, said:—

Mr. President,—

Mr. Edward Wilson is, I am happy to say, only one out of a large number of local geologists (many of whom are Fellows of this Society) all doing good work and all deserving of recognition, were it possible to extend to many more the same expression of approbation of their labours. Such assistance affords to them facilities for travel or for the acquisition of books for carrying on their work.

These are only a few of the trivial advantages; but *the highest of all* is the sense of recognition which this Society's Award gives to such solitary workers, who are often without any local support or encouragement for their efforts. Mr. Edward Wilson's published work dates back to 1868, and is represented by more than 12 papers, dealing mostly with the Red Marls, Keuper and Bunter Beds, the Rhætic and the Lias, one of his latest papers being on the Liassic Gasteropoda, with descriptions and figures of 14 species.

Dr. Woodward further read the following communication from Mr. Wilson:—

"Will you kindly convey to the President and Council my grateful sense of the honour which they have conferred upon me? At the same time would you please express my regret at not being able to be present on this occasion?

"Notwithstanding the progress which has been made in our knowledge of the late Palæozoic and early Secondary Rocks, since the illustrious Murchison established his Permian system, now nearly fifty years ago, a great deal remains to be accomplished in this special department of British geology. In several districts the true ages of the 'Red Rocks'—whether Permian, or Trias, or Carboniferous, or even Old Red Sandstone—have yet to be determined. Of the many other interesting matters relating to these rocks which require further elucidation, one of the most important perhaps is the question of the extension of the older rocks, and in particular of productive Coal-measures, beneath the newer formations. In the above field of Geology, then, there is scope for plenty of good work in the future, and it is in this field that my highest ambition would be to contribute some useful results."

Award of the Lyell Medal.

In presenting the Lyell Medal to Prof. H. Alleyne Nicholson, M.D., F.G.S., the President addressed him as follows:—

Prof. Nicholson,—

The Lyell Medal has been awarded to you as a mark of appreciation of your valuable researches among the older Palæozoic rocks, both in the Old and New World, and of your continued and patient investigations into the organization of some of the obscurer forms of life which abounded at the period of the deposition of those rocks. Your researches among the Graptolitidæ, the Stromatoporidæ, the Monticuliporidæ, and the Tabulate Corals have given you a high place among palæontologists; while the difficulties which surround such studies as those you have undertaken are so great that geologists may well feel admiration for the courage and perseverance which you have shown in steadily devoting yourself to the study of such seemingly unpromising materials. The bequest of Lyell could certainly not be more appropriately bestowed than in recognition of labours like your own, which have been especially directed to a comparison of the fossil faunas of Britain and North America.

Prof. Nicholson, in reply, said:—

Mr. President,—

It would not be easy for me to adequately express my grateful sense of the very high honour which has been conferred upon me by the Council and Fellows of the Society in awarding to me the Lyell Medal. In common with all British workers, I regard the Geological Society of London as the supreme head and source of honour in matters connected with Geology and Palæontology. Under any circumstances, therefore, I should have deeply valued the distinction which I have to-day received, the more so that it is associated with the name of one whose memory will ever be honoured by students of Geological science. To a very special degree, however, and in a very special sense—a sense only to be fully comprehended by those similarly placed—is there a gratification and a stimulus in such an award to a worker so unfortunately isolated by his geographical position as it is my lot to be, and with such limited opportunities of coming in contact with his fellow-workers. The pleasure I have felt has been enhanced by the friendly words of encouragement and approbation in which you, Mr. President, have seen fit to speak of my past work. If I cannot feel that I have sufficiently deserved, by anything I have yet been able to accomplish, the high honour I have to-day received, I can assure the Council and Fellows that I shall do what in me lies to make myself more fully worthy of it in the future.

Award of the Lyell Geological Fund.

The President then presented one moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Arthur Humphreys Foord, F.G.S., and addressed him in the following terms:—

Mr. Foord,—

Your skill with the microscope and pencil have stood you in good stead in investigating and illustrating the minute structures of many wonderful fossils from the older rock-masses of our globe. To our knowledge of some of these remarkable organisms, which alike from their aberrant characters and from the very remote period at which they lived, must ever have the greatest fascination both for Geologists and Biologists, you have made some very valuable contributions; and the Council of this Society trust that an Award from the Lyell Fund will serve as a stimulus and aid to you in carrying on these and kindred researches.

Mr. Foord, in reply, said:—

Mr. President,—

I beg to return my warmest thanks to the Council of the Geological Society for this most acceptable and quite unlooked-for mark of their approval of the slight services I may have rendered to Geological Science. While the gift itself will afford me material aid in the further prosecution of my palæontological studies, the thought that I have been deemed worthy of such a great distinction will add a new impulse to those labours.

The President next presented the second moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Thomas Roberts, F.G.S., and addressed him as follows:—

Mr. Roberts,—

Among the most valuable methods for solving the great problems of stratigraphical geology is the one which has been chosen by yourself, namely the direct comparison of a series of beds and of their characteristic fossils in one typical district with those of another and now isolated area. The Council of the Geological Society, hoping to encourage you in work of this kind, so well begun, have awarded you a portion of the Fund bequeathed to us by one who was among the first to recognize the value and to pursue with success that method of research in which you are now engaged.

Mr. Roberts, in reply, said:—

Mr. President and Gentlemen,—

I beg to express my grateful acknowledgment of the honour the Council of the Geological Society have conferred upon me by the award of the moiety of the Lyell Fund. It is especially gratifying to me to find that the small contributions which I have hitherto been able to make to the Society have been thought worthy of recognition. In making the award the Council seem also to have taken into account the work involved in teaching others, and thus preparing myself for that accurate observation which is the first essential in Palæontological research.

It will stimulate me to further exertions; for there is still much to be done in the correlation of our Jurassic rocks as well as in other branches suggested to me by the rich collection in the Woodwardian Museum.

I hope, from time to time, to offer to the Society further contributions, and I shall be proud and pleased to co-operate with other workers in the same field, and to assist them in availing themselves of the magnificent collection in the Museum with which I am officially connected.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

Professor J. W. Judd, F.R.S.

Gentlemen,

During the past year the hand of death has fallen very heavily upon that important class of geologists who, by their labours in connexion with local societies and field-clubs, do so much in promoting the study of our science in the provinces.

First among those whose loss we have to deplore, I must mention Arthur Champernowne, who at the last Anniversary was elected a Member of our Council. He was the eldest son of Henry Champernowne, Esq., of Dartington Hall, near Totnes, and was the representative of a very old Devonshire family. Born March 19th, 1839, he had the misfortune to lose his father when only 12 years of age; he was educated at Eton and at Trinity College, Oxford.

Soon after his settlement in the home of his family, we find Mr. Champernowne in active co-operation with the geologists, naturalists, and antiquaries of Devonshire, such as Pengelly, John Edward Lee, and H. J. Carter, who, by promoting the Devonshire Association for the Advancement of Science, Literature and Art, and in other ways, have done so much towards making known the past history of their county and of its inhabitants from the earliest times.

Alone, or in company with some of his fellow geologists of Devonshire, Mr. Champernowne visited Italy, Spain, Germany, and Belgium, for the purpose of studying the equivalents of the Devonshire rocks, upon which he had begun to concentrate his studies. He was elected a Fellow of this Society in 1868. Mr. Champernowne was a man possessing the widest sympathy with all branches of science, and he laboured assiduously in every department of geology. He studied the relations of the Devonshire rocks with such care, and laid down his observations upon the Ordnance Survey maps with so much skill and accuracy, that the Director-General of the Geological Survey offered to use his results as a basis for the revision of the mapping of the area.

As a palæontologist, he was well known by his studies of the Corals and Stromatoporidæ of the Devonshire rocks. His splendid collections and beautiful sections of these organisms were always placed with the greatest liberality at the disposal of his fellow-workers in the same field.

Some time before his death Mr. Champernowne entered with his well-known enthusiasm on the study of the microscopic structure of rocks. Many of us recollect the thoroughness with which he devoted himself to this work; we call to mind his determination, by a careful study of crystallography and optics, to obtain a secure basis for future investigations; and we remember his unwearied patience in tracing the localities and geological position of the interesting rocks found in his native county.

In addition to his scientific labours, Mr. Champernowne was very active in his duties as a landlord and a magistrate; and was always ready with his aid to philanthropic objects. Everyone who knew him must have been struck with his singular modesty and kindliness of disposition, and must join in the regret that he should have been so early taken from our midst.

It has always been a subject of regret to the Council of the Geological Society that, as a general rule, it is impossible for Fellows of the Society living at great distances from London to take part in the management of our affairs. When, therefore, it was found that Mr. Champernowne was not unwilling to undertake the long journeys from Devonshire in order to render service to the Society, it was with especial pleasure that we hailed his election to the Council last year. This rejoicing, however, was of short duration, for intelligence reached us that, after attending our meeting on the 11th of May last, he had, upon his return, caught a chill and become prostrated. Mr. Champernowne was never a man of robust health, and it is to be feared that in his desire to promote the interests of our science he overtaxed his strength. He died on the 22nd of May, 1887, at the early age of 48, leaving a widow and ten children to mourn his loss. Deeply must we all sympathize with them when we think how excellent a geologist, how good a man, and how warm a friend we have lost in ARTHUR CHAMPERNOWNE.

Devonshire geology has sustained another severe loss in JOHN EDWARD LEE, who did not long survive his friend Champernowne. Born at Hull, December 21st, 1808, Mr. Lee early made the acquaintance of the late Professor John Phillips, then residing at York, and they became lifelong friends. On account of the weak state of his health, Mr. Lee was compelled to travel for some years in Scandinavia, Russia, and other parts of Europe; but he afterwards settled down at Caerleon Priory, Monmouth, and subsequently at Torquay. He was elected a Fellow of this Society in 1859, and although he formed a very fine collection of fossils, which in 1885 he presented to the British Museum, and wrote several papers for the 'Geological Magazine,' he never contributed to our own Journal. He was very well known for his antiquarian researches, through his own writings on the subject, and his translations of Dr. Keller's, Conrad Merck's, and Professor Roemer's works bearing on the antiquity of Man. Mr. Lee, who had been in failing health for some years, died August 18th, 1887, at the age of 79.

Among those who by their labours and writings have endeavoured to promote the cultivation of our science in districts lying remote from the great centres of thought, few have been more indefatigable or successful than the late Rev. William S. Symonds. He was born in 1818 at Hereford and was educated at Cheltenham and at Christ's College, Cambridge. Becoming curate of Offenham, near Evesham, Mr. Symonds made the acquaintance of Hugh Strickland and was by his influence led to devote much attention to the study of Natural History. At a subsequent date he became rector of Pendock.

Mr. Symonds took a very active part in the affairs of many of the local societies of the west of England—the Woolhope Naturalists' Field Club, the Warwickshire Natural History Society, and the Cotteswold Naturalists' Field Club. In promoting the interests of such societies he was always unsparing of his time and labour; and he was never so happy as when conducting geological friends over the districts which he had studied so carefully and knew so well.

Mr. Symonds became a Fellow of this Society in 1853, and contributed several valuable papers on the geology of the West of England to our publications; he also wrote a number of geological memoirs, which were published in other journals. He was a very active member of the British Association, and his labours in the cause of our science were held in the highest estimation by Lyell, Murchison, and others among the last generation of geologists. Mr. Symonds made frequent journeys abroad for the purposes of geological study, and on these occasions was accompanied by Sir William Guise, Mr. C. Lucy, or other geological friends.

In 1857 he published a little work entitled 'Stones of the Valley'; and in 1859 took an important part in the discussions at the Aberdeen meeting of the British Association upon the age of the Reptiliferous Sandstone of Elgin. Upon this question he was led to adopt the views of Lyell in opposition to those of Murchison; and a valuable paper on the subject from his pen appeared in the 'Edinburgh New Philosophical Journal' in 1860. In 1859 he published his 'Old Bones, or Notes for Young Naturalists,' a second edition of which appeared in 1864. His larger and more comprehensive work, 'Records of the Rocks,' saw the light in 1872, and his 'Severn Straits' in 1883. In the year 1870 Mr. Symonds acted as a Member of the Council of the Society.

But antiquarian subjects, equally with geological ones, engaged much of Mr. Symonds's attention, and he was the author of those pleasant historical romances, 'Malvern Chase' and 'Hornby Castle,' in which his great knowledge of local antiquities is very conspicuously displayed.

The later years of his life were clouded by ill health and much suffering. Those who associated with him during these years of decline could not but admire the courage, cheerfulness, and resignation with which he bore his sad lot; in the intervals of relief from pain he continued to the last to find solace and pleasure in the studies he had so devotedly loved. Mr. Symonds died at Cheltenham, 15th September, 1887. A man of most amiable and courteous manners, he was characterized by broad sympathies, liberal views, and a warm heart; who, among those of us who knew him, does not remember his lovable character?

Within a few days of his friend the Rev. W. S. Symonds, passed away Sir William Vernon Guise, Baronet. The son of an old Peninsular officer, he was born in 1816, and succeeded to the baronetcy in 1865. Though he joined this Society in 1841, and took much interest in Geology, Archæology, and Natural History generally, he did not undertake any special researches. He was a very active member of the Cotteswold Naturalists' Field Club, having held the office of President for a period of 28 years. He died September 24th, 1887.

The same useful society, the Cotteswold Club, has lost in the person of its late Treasurer and Vice-President, Mr. Edwin Witchell, another of its most hardworking and useful members. Mr. Witchell, who was born in 1823, received a legal education and became a solicitor at Stroud, in Gloucestershire. In his earlier years he became associated with the late Mr. G. Poulett Scrope, by whose influence his love of geological study was fostered and confirmed. He contributed papers on local geology to the Cotteswold Club

Proceedings and also to our own Journal; and he also wrote a little book on the 'Geology of Stroud.' He took a very active part in promoting the formation of a local Museum and in the establishment of schools for teaching science. He was elected a Fellow of this Society in 1861.

Canon the Rev. A. H. Winnington Ingram, who was elected a Fellow of this Society in 1858, and contributed a short paper to our Journal in 1879, resided at Harvington, near Evesham, and was well known for his acquaintance with local geology and antiquities. On the 6th March, 1887, he was seized with illness while performing his clerical functions and died within a few hours.

Among those engaged upon the geological exploration of our colonies and dependencies we have had to deplore several serious losses during the past year.

First among these we must notice Sir Julius von Haast, so well known for his important researches in the geology and natural history of the South Island of New Zealand. He was born May 1st, 1824, at Bonn, and received his early education first in the gymnasium of his native town, and afterwards in that of Cologne. He then entered upon a course of study at the Bonn University, devoting especial attention to geology and mineralogy. Many of us have heard him dwell on the happy times he spent in studying under the guidance of Nöggerath, von Dechen, and other naturalists who have made the great University of Rhine-Prussia so famous. To the last von Haast continued to maintain a correspondence with some of the scientific men of Bonn, and he failed not to visit his *alma mater* during what proved to be his last sojourn in Europe in the summer of last year.

After leaving the University, Dr. Haast spent some time in travelling in France and other parts of Europe; but in the year 1858 he accepted the offer of an English company to visit New Zealand in order to report on the suitability of that colony as a field for German emigrants. It so happened that Dr. Haast reached New Zealand just at the same time as the Austrian surveying-ship 'Novara;' and when Dr. von Hochstetter was induced by the Colonial government to remain behind in order to study the geology of the islands, he found in Haast a zealous and well-trained coadjutor.

After the completion of this preliminary survey and the departure of von Hochstetter, Dr. Haast accepted an offer from the government of Nelson to examine the geology of that district, and his

Report on the province was published in 1861. In the year 1860, a similar offer was made to him by the Government of Canterbury, and in the following year he commenced that important Geological Survey of the Province of Canterbury with which, in the future, his name will always be identified.

In 1863 Dr. Haast was elected a Fellow of our Society, and shortly afterwards we find him communicating to our publications the first of his valuable memoirs on the geology of New Zealand, with especial reference to the glacial phenomena of the country. He visited the great glaciers of the New-Zealand Alps, and was led to propound a theory of the mode in which lake-basins might have been excavated, as a consequence of the resistance offered to the advancing glaciers by their terminal moraines. He at the same time offered a strong and much needed protest against the view that the extension of glaciers necessarily involves a universal lowering of the temperature, enforcing his views on this subject by pointing to the interesting discovery he had made of the bones of *Dinornis* and *Palapteryx*, imbedded in the materials of terminal moraines.

Dr. Haast took much interest in all questions connected with the ancient birds of New Zealand; he published a number of papers on the subject, and it was through the exchanges which he arranged that the bones of the *Dinornis* found their way into all the chief museums of Europe. In 1867 the importance and value of his scientific labours were recognized by his election as a Fellow of the Royal Society.

The last twenty years of Dr. Haast's life were devoted to the completion of the maps and memoir illustrating the geology of Canterbury and the gold-bearing district of Westland, and in efforts to render the museum of Christchurch as complete as was possible. He used to declare it to be his highest desire to render this the finest museum in the southern hemisphere, and he certainly spared neither labour nor pains in seeking to attain the object of his ambition.

During the Colonial Exhibition of last year, von Haast was present in England, taking charge of the important exhibits sent by the New-Zealand Government; and on that occasion many of us had an opportunity of becoming acquainted with him and knowing how great was his devotion to scientific investigation. In connexion with the exhibition, von Haast laboured so unremittingly as to overtax his strength, and for the services he rendered he received the honour of knighthood before returning to his adopted country. Great, however, was the grief of the numerous friends he had found in this country when they learned that Sir Julius von Haast had, shortly after reaching New Zealand, fallen a victim to heart-disease, leaving a widow and several children to mourn his loss.

Another worker in the field of colonial geology was Charles Henry Wilson, who last year laid before this Society the first draft of a geological map of British Honduras. Mr. Wilson was the son of the Rev. E. Wilson, Vicar of Nocton, Lincolnshire, and was educated at Eton and at King's College, Cambridge. Subsequently he studied for a time at the Royal School of Mines, and then extended his practical knowledge by working as a surveyor in a colliery. Mr. Wilson was elected a Fellow of this Society in 1881. He undertook the work of geologist and surveyor to the settlement at Rugby, Tennessee, and on the completion of his work there, accepted an engagement with the Government of British Honduras to explore the geography and geology of the interior of that colony—a district almost unknown and very difficult of access. All who saw what Mr. Wilson had already accomplished in the face of almost overwhelming difficulties, anticipated the most valuable results from his further researches; but, sad to relate, his useful career was cut short by one of those diseases incident to the climate of the country of his labours. He died at Belize on the 9th of September, 1887, at the early age of 36.

Mr. Alfred Morris, C.E., of West Australia, who was elected a Fellow of this Society in 1882, and in the following year read a paper on Australian geology, died early in the past year.

In Mr. Robert George Bell the Society has lost a palæontologist of great promise, one who, in spite of ill health, was to the last engaged assiduously in the prosecution of very important researches. He was born in London, April 12th, 1833. His studies were chiefly devoted to the Mollusca of the Crag and of recent deposits, and concerning these he had acquired a wide and accurate knowledge. When the remarkable Pliocene outlier of St. Erth was discovered, he seemed the man who by previous training was best qualified for dealing with the remarkable assemblage of Mollusca which it yielded; and, in connexion with Mr. Kendall, he threw himself into the investigation with his accustomed zeal. In the spring of 1886, a preliminary paper on the subject was communicated to our Society; and it is well known that at the time of his death Mr. Bell was busily engaged with the vast mass of materials he had accumulated. The frail body in which his earnest spirit was enshrined was unable to withstand the severe weather of last month, and he died January 18th, 1888, at the age of 54.

Mr. Rooke Pennington was a barrister who distinguished himself so greatly during his first circuit that he was received into partnership by a firm of solicitors at Bolton, and practised there for many years. He was a man of great capacity and varied interests; and in conjunction with Professor Boyd Dawkins explored the Cave of Windy Knoll and other caves in Derbyshire, as well as the cairns belonging to the bronze-age in the neighbourhood of Castleton and Eyam, from which he obtained valuable antiquities. He was elected a Fellow of this Society in 1875, and during the same year contributed a paper to our Journal. His principal work was the establishment of an excellently arranged museum at Castleton, which is unfortunately about to be dispersed. Mr. Pennington was also an occasional contributor to the Proceedings of the Geological Society of Manchester.

Among the losses which the Society has sustained during the past year we have to regret the decease of some of our oldest Members. The Baron de Basterot was elected a Fellow in 1825. He contributed a paper on the Geology of Folkestone to the first series of our Transactions in the year 1827, and also wrote on geological subjects in several French journals. During his later years he resided in Rome, where he died last year, after being no less than sixty-two years a Member of this Society.

Five others among the Fellows who passed away last year had maintained a connexion with the Society for more than half a century. Foremost among these we must mention Mr. Edward I'Anson, the distinguished architect, to whose skill in design modern London owes many of her finest buildings. He was born in 1812, became a Fellow of this Society in 1834, and at the time of his death was President of Royal Institute of British Architects. Captain W. H. Breton, was also elected in 1834; G. E. Eyre, Esq., in 1835; The Rev. Lord Charles Hervey, in 1835; and A. Crichton, Esq., in 1837.

Nor can we omit to notice the loss of Mr. James Baber (elected in 1843), and of Dr. John Millar (elected in 1858), who, as the faithful and devoted friends of the late Professor John Morris, rendered no small services to the cause of our science.

Bernhard Studer, the greatest geologist that Switzerland has produced since de Saussure, was born at Berne in 1794. He belonged to an ancient family in that city, many of whose members had shown a marked taste for natural-history pursuits, but was himself educated as a clergyman. No sooner had young Studer passed his theological examinations, however, than he determined to prosecute his studies in mathematics and science, and for that purpose resided in turn at the Universities of Göttingen, Freiburg, Berlin, and Paris. On his return to his native country in 1816 he was appointed teacher of Mathematics and Physics in the Berne Academy.

It is evident that at a very early age the writings of de Saussure exercised a very powerful influence upon Studer's mind. He travelled constantly in the Alps, and in other parts of his native country, and after some preliminary papers, produced in 1825 his admirable 'Monographie der Molasse,'—a work which at once established his reputation as a geologist of the first rank.

In the meanwhile Studer was rapidly acquiring fame as a teacher. His lectures on various branches of science attracted great numbers of pupils, and, refusing to be drawn aside by political or theological controversies, he threw all his energies into the development of the educational institutions of his native town. It was largely through his influence, and by the aid of his great powers of organization, that, in 1834, the University of Berne was established, Studer becoming the first professor of mineralogy. During this period of his life Studer wrote a number of text-books for students upon physics, mathematical and physical geography, and geology; and these works were remarkable alike for the excellence of their plan and the thoroughness of their treatment of the several subjects.

At the same time Studer was busily engaged upon what was destined to be the greatest work of his life. He visited every portion of the Alpine Chain, filling many note-books with detailed accounts of the phenomena observed, and the most accurately constructed sections. He also entered into co-operation with Escher von der Linth, Peter Merian, and other Swiss geologists, the result being a number of separate papers and monographs on Swiss geology, published between the years 1825 and 1850.

At this time Studer's fame had already become so widely known that he was elected, in 1850, a Foreign Member of this Society.

His great work, the 'Geologie der Schweiz,' made its appearance between the years 1851 and 1853; and in the latter year there was published, with the co-operation of Escher von der Linth, the well-known Map of Switzerland upon which they had been so long engaged. Numerous papers on the geology of his native country appeared from time to time during subsequent years, Studer travelling to all parts of Europe to examine the rocks of other districts and make comparisons of them with those of the Alps.

Studer's merits as a geologist were recognized both at home and abroad. He was elected a Correspondent of the French Academy, and he received the Prussian order "pour le mérite." In 1879 he was awarded the Wollaston Medal of this Society.

No sooner had the celebrated Map of Switzerland been completed than Studer engaged in a scheme for securing a systematic geological survey of the whole of Switzerland. For this work the fine topographical survey of the country by Dufour, commenced in 1843, afforded the necessary basis. Of the commission appointed to carry on this work, Studer acted as chairman, and it was only when advancing age and impaired eyesight rendered his superintendence of the work no longer possible that he resigned the office.

Beloved in his native town, honoured in every State of the Swiss Confederation, and respected abroad, Studer, to the last, continued to travel and work at his favourite pursuits. On the 2nd of May, 1887, the proofs of the last sheet of the 'Atlas of Switzerland' were brought to him—the great work that had occupied so much of the latter half of his life was completed; and on the same day he passed away without pain at the advanced age of 93.

Professor Laurent-Guillaume de Koninck was born at Louvain, May 3rd, 1809, and was educated for the profession of medicine; he soon, however, developed such a taste for scientific pursuits that in 1831 he was appointed an assistant in the chemical schools of the University of his native town. During the years 1834 and 1835 he studied in the laboratories of Gay-Lussac and Thénard at Paris, of Mitscherlich at Berlin, and of Liebig at Giessen, and in the latter year commenced the teaching of chemistry, first at Ghent and then at Liége. After occupying subordinate posts in the University of the last-named town for nearly twenty years, he became Professor of Chemistry in the year 1856.

But although de Koninck was throughout his life Professor of Chemistry, and made from time to time by no means unimportant contributions to that science, there is evidence that at a very early period he had begun to develop a taste for those palæontological studies, the successful pursuit of which constitutes his chief title to fame. The Carboniferous rocks around the town where he resided afforded abundant materials for study, and the results of his labours appeared in the well-known 'Description des Animaux Fossiles qui se trouvent dans le Terrain Carbonifère de Belgique,' a work consisting of two volumes and a supplement, which appeared between the years 1842 and 1851.

In 1853 he was awarded the Wollaston Fund from this Society, to aid him in his important researches, and in the same year was elected one of our Foreign Members.

For many years de Koninck laboured unweariedly in the investigation of the fossils of the Carboniferous Limestone of Belgium, and the comparison of them with those of other districts. The results of these studies appeared in a great number of papers contributed to various journals and in the five volumes of the 'Annales du Musée' of Brussels, of which he was the author.

In the year 1875 de Koninck received from this Society the Wollaston Medal, in recognition of his palæontological researches, though it is a curious circumstance that it was not till the following year that he became titular Professor of Palæontology. De Koninck was the author of elementary treatises on both Chemistry and Geology, and of several papers and addresses dealing with the philosophical aspects of the branch of science to which he devoted the greater part of his energies. Deeply beloved by a large circle of pupils and friends, honoured by many marks of favour not only from his own Sovereign but from those of other States, and acknowledged all the world over as the greatest authority on all questions pertaining to his own particular studies, our distinguished Foreign Member died on the 16th of July, 1887.

M. JULES DESNOYERS was born in 1801. As early as the year 1822 we find him writing on the subject of calcareous rocks possessing a peculiar odour, and during the next forty years he wrote a number of valuable memoirs on the Jurassic, Cretaceous, and Tertiary strata of the Paris Basin and of Northern France. M. Desnoyers became a Member of the Geological Society of France at the period of its first establishment in 1830; he was a Member of the Institute of France, and librarian of the Natural History Museum of Paris. M. Desnoyers's latest contributions to Geological Science related to the controversy concerning the occurrence of human remains with extinct animals. He was elected a Foreign Member of our Society in 1864, but since that time does not appear to have taken any active part in Geological research. He died last year, at Nogent-le-Rotrou, at the advanced age of 86.

Dr. FERDINAND VANDEVEER HAYDEN was born at Westfield, Mass., Sept. 7, 1829, but spent the earlier years of his life in the State of Ohio. He studied for some time at Albany, N.Y., where he obtained his medical degree in 1853, and having attracted the notice of Professor James Hall, was induced to accompany Mr. F. B. Meek in an exploration of "the Bad Lands" of Nebraska, their object being to examine an almost unknown tract of country and to collect and study the fossils which were reported to occur there. During two following years Hayden revisited Nebraska and extended his explorations to Kansas; the vertebrate fossils which he collected were among those studied by Dr. Leidy, and served to call general attention to the palæontological wealth of the Far West.

In the year 1856 Dr. Hayden commenced that series of investigations of the Western Territories, under the auspices of the United States Government, which have resulted in such important and valuable additions to our knowledge of the geological structure of those interesting regions.

Year after year, except during the period of the Great War, when he became an army surgeon, Dr. Hayden returned to different parts of the Western Territories for the purposes of exploration. In 1867 he was appointed Geologist-in-Charge of the United States Geological and Geographical Survey of the Territories. The result of his twelve years of labour as an administrator are seen in a series of splendid volumes in which not only the Geology and Palæontology, but the Natural History, Topography, Ethnology, and Economics of those hitherto inaccessible regions were made known to the world. His services to the cause of our science were recognized by Dr. Hayden's election as a Foreign Correspondent of this Society in 1875, and as a Foreign Member in 1879.

Upon the establishment of the United States Geological Survey, Dr. Hayden was nominated as one of the Geologists, and in that capacity continued to superintend the publication of the results of his former surveys, and, so far as was possible, to inaugurate new investigations.

During the last few years, however, Dr. Hayden's numerous friends have heard with regret of the gradual failure of his health, and on the 22nd of December, 1887, he died at Philadelphia. He will always be remembered as one of the ablest among the pioneers in the study of the Geology and Palæontology of the Western Territories of the United States, and for the indomitable energy and liberality of mind with which he carried on the important survey of which he was placed in charge.

August Friedrich, Count Marschall, of Burgholtzhausen and Tromsdorf, was born in 1805. Interested in many branches of science, he did more in the way of correlating and making widely known the investigations of others, than in the prosecution of original researches. He was elected a Foreign Correspondent of this Society in 1863, and contributed to our Journal a great number of very valuable abstracts of geological papers which had been published abroad. He was the author of the 'Nomenclator Zoologicus,' which appeared in 1873, and, with Dr. A. von Pelzeln, of the 'Ornis Vindobonensis,' published in 1882. He occupied an official position in Vienna, where he died 11th October, 1887.

It is with great pleasure that I congratulate the Fellows of the Society upon its great and increasing prosperity. In spite of exceptionally heavy losses by death, and of a slight augmentation in the number of resignations (due to the steps which it has been found necessary to take in order to prevent the accumulation of arrears of subscription), the number of effective Members of the Society shows a very satisfactory increase.

Financially, the Society is in such a flourishing state that we have been able to pay for extensive repairs and redecoration without trenching upon the amount put aside for the purpose; and thus the funded property of the Society has been increased by the sum of £500. Seeing that each year we receive a considerable amount as composition for annual subscriptions, I need scarcely point out that such additions to our funded property from time to time are not only desirable but are actually necessary for the security and stability of the Society.

The work of redecorating and repairing the Society's house has now been carried out in all parts of the premises except the Museum. After careful consideration a plan was adopted for treating the walls which will permit of their being cleaned from time to time, and thus we hope that the next redecoration may be put off for a considerable period. The question whether we should follow the example of some of the other Societies domiciled in Burlington House, and introduce the electric light, was the subject of anxious deliberation; but the Council were compelled to decide that they could not at present recommend the Society to indulge in this desirable, but unfortunately rather expensive, luxury.

We may point to the forty-third volume of our Journal as the best evidence of the activity of the Society in promoting the cultivation of every branch of Geological Science. For my own part I regard this work of making known new discoveries, by means of our Abstracts and Journals, as the highest function that the Society performs, and I think that we ought to spare no expense, either in printing or in illustrations, which may be requisite to enable our publications to maintain the high character which they have acquired. It must be remembered that only a comparatively small proportion of those who subscribe to the funds of the Society are able to avail themselves of the advantages offered by our Library and Museum, or can attend our evening meetings; but the publications of the Society constitute the one benefit in which all our Fellows participate. At the same time the ever-extending line of volumes, with the tendency of each succeeding one to increase in bulk, may well awaken grave reflections from time to time as to the possible danger of the demands upon the Society, as a publishing body, proving greater than the means at our disposal.

My predecessor in this Chair has suggested that when difficulties of this kind are felt, the pruning-knife ought first to be applied in the case of papers relating to the Geology of distant regions, in which the great bulk of our Fellows may be naturally supposed to take the least interest. Accepting the justice of the general principle laid down, and agreeing that all subjects of purely *local* interest, either British or Colonial, might well be dealt with by the numerous provincial societies so rapidly growing up both at home and abroad, yet I should deeply regret that this Society should ever decline to publish any paper on Colonial, or even Foreign Geology, which constitutes a real and important addition to the sum of geological knowledge.

Of the Fellows of this Society I find that no less than 18 per cent. live outside the British Islands, and that more than 10 per cent. of our Members (exclusive of our Foreign Members and Correspondents) are resident in British Colonies and dependencies.

I would venture to suggest another remedy which would not involve us in the risk of alienating the sympathies of so large and important a section of our Fellows. It seems to me that the tendency towards bringing immature and controversial papers before the Society is on the increase—I mean such papers as are avowedly of the nature of "preliminary notes," or constitute only a single phase of a long discussion. Now considering the wide circulation and established position of our Journal, I venture to think that all papers intended for insertion in it ought to be the result of carefully matured effort, and that matters of fugitive interest might more appropriately be communicated to periodicals which are issued at much shorter intervals. If, in addition to this, the authors of papers would recollect that in these days, when the mass of scientific literature has become well nigh overwhelming, those memoirs have the greatest chance of being read in which, by a judicious concentration, a compact arrangement, and a direct mode of expression, the reader is aided in arriving at the results with as little expenditure of time as possible, I believe our chief difficulties in regard to publication would disappear. It will then be possible for this Society to continue to maintain the position that it has long since attained, and to represent the geologists of the whole of the British Empire.

Outside the sphere of activity of our Society there is no diminution in the efforts of those engaged in geological investigation and exposition. Professor Prestwich signalizes his retirement from the Chair of Geology at Oxford by the publication of a treatise which enlarges his class by making all English- and French-reading students his pupils. I am fortunately able to place before you a copy of the second and concluding volume of the work of the *doyen* of British Geologists, a work which is opportunely published this very day. While sympathizing with Oxford in what she loses by Professor Prestwich's retirement, we cannot but reflect that her loss is our gain; for we hope to see him much oftener among us than has been the case of late.

From the Clarendon Press, which sends forth Professor Prestwich's 'Geology,' there will also issue, in the course of the next few weeks, the first volume of a work which has been long and anxiously looked for by geologists—Mr. Etheridge's 'Fossils of the British Islands, Stratigraphically arranged.' This first part, including the whole of the Palæozoic fossils, will form a quarto volume of more than 400 pages.

During the present year the International Congress of Geologists is to hold its fourth triennial meeting in this city. Opinions are naturally divided as to the amount of agreement which can possibly be effected as the result of its deliberations; doubts may even be entertained by some as to the desirability of certain of the reforms which it is sought to effect by means of its conferences; but the most sanguine and the most cautious are alike desirous of testifying their respect and admiration for the numerous representatives of Geological Science in foreign countries whom we hope to have with us as our guests. All Fellows of this Society will, I am sure, unite in receiving with the warmest welcome those fellow-workers from other lands who, we trust, will visit us in great numbers on this occasion.

There is one other subject which I approach with much hesitancy. Your President, now counting the last moments of his official life, desires to speak with a seriousness befitting the occasion, and trusts that his words may be received with those kindly feelings which such farewell utterances usually evoke. It is not surprising that in a science like our own grave divergences of opinion should sometimes arise between Fellows of the Society, who are alike honestly seeking after truth, though, perhaps, by somewhat different methods. Hitherto it has been the boast of this Society that, except in a very few regrettable instances, such differences of opinion, while accompanied by healthy freedom of speech, have not led to personal estrangements or engendered bad blood. It is always unfortunate when, in cases of this kind, appeals have to be made to the governing body of the Society; but when this is done, it may be hoped that disputants, if they cannot agree with the decisions arrived at (and it is proverbially difficult to be a judge in one's own cause), will give those who are elected by you to manage your affairs the credit of doing their best to act in an impartial and conciliatory spirit.

On another point my retirement from your service, after having been elected ten times in succession to act as one of the officers of the Society, may entitle me, without offence, to say a word or two. The management of the affairs of a Society like this is by no means a light burden. With a considerable experience of other societies, I can safely assert that there is none more diligently or more patiently served by its Council than the Geological Society. Some of the Members of our Council travel great distances in order to attend its deliberations; and all are busy men, by whom the time spent in the work of the Society could be agreeably and profitably devoted to original research or to other duties.

Under these circumstances I think it is not too much to ask that the action of the Council, elected by you to manage the affairs of the Society, should be regarded by the Fellows in a spirit of generous trust and not in one of captious criticism. The Members of your Council are often compelled to arrive at decisions upon questions of no little difficulty and delicacy, and the documentary or other evidence upon which they found their judgment cannot possibly be submitted to every individual Fellow of the Society. The Council do not lay any claim to be free from liability to error; but they do ask you to give them credit for acting to the best of their judgment in striving to promote the best interests of the Society.

Our Bye-Laws, drawn up at a time when the conditions, the numbers, and the finances of the Society were very different from what they are at present, doubtless need revision and amendment; and in this work it may be hoped that the Fellows not upon the Council will cordially cooperate with those who have some experience in the management of the Society's affairs. But bearing in mind that an assembly which contains more than a hundred eminent lawyers confesses itself unable to draw up acts through which the proverbial coach-and-four cannot be driven, I should not put my trust in any revised Bye-Laws, however excellent, but rather in that good feeling between all sections of the Society which has in the past made our history one of such continued peace and prosperity.

In the remarks which at our last Anniversary I had the honour of offering from this Chair, I congratulated the students of Geology and Mineralogy upon the new and intimate relations which, to their mutual advantage, are now growing up between those departments of science. It has, however, been suggested that while Geologists are thus being brought into closer alliance with Mineralogists, the strong bonds of union which have so long united us with the Biologists are becoming somewhat relaxed, and, indeed, stand in no small danger of actual dissolution.

Highly as I estimate the value of the *rapprochement* between the Geological and Mineralogical sciences, I for one should regard such a result as far too dearly purchased if it necessarily involved any interruption of the close relations which have so long subsisted between Geology and Biology. But I cannot for one moment believe that such a grievous misfortune seriously threatens the cultivators of the two great departments of Natural Science.

Notwithstanding certain divergences of opinion which have made themselves heard within an ancient university, and have awakened a faint echo in the halls of our National Museum, I cannot doubt that the teachers of Geology and Biology will easily discover a *modus vivendi* upon what is, after all, a subject of very secondary importance—the arrangement of Natural-History collections.

No one can read recent declarations of the present Director of our National Museum without being impressed by his manifest desire to make the splendid collections under his care reflect as completely as possible the present condition of our knowledge of Biological science. And if, on the other hand, we turn to the remarks made by the Keeper of the Zoological Department at Swansea in 1880, and to those of the Keeper of the Palæontological Department at Manchester last year, we shall find in those utterances ample guarantees that, in the arrangement of their collections, questions of practical convenience will not be lost sight of; we shall be satisfied indeed that there is not the smallest danger of revolutionary ideas leading to the removal of "ancient landmarks," or of unattainable ideals being sought through the wholesale commingling of incongruous elements. The collections of our Universities are happily free from the conditions which must always hamper an institution where the interests of popular amusement have to be reconciled with those of scientific work; and it is for the teachers of Natural Science in those centres of thought to agree upon an arrangement which may best serve to illustrate their courses of instruction.

But while the discussion on museum-arrangement may be regarded as a purely academical one—which, after scintillating for a while in letters and pamphlets, died out in some not very formidable explosions at the recent meeting of the British Association—it may be wise on our part not to pass by quite unnoticed some indications of the attitude of the younger school of Biologists towards palæontological science, this attitude having been very conspicuously manifested during the discussion in question.

If I rightly apprehend the views of some of my Biological friends, as gathered not only from their published utterances, but also from private conversations, the position they are inclined to take up may be expressed somewhat as follows:—

"Palæontology has no right whatever to separate existence as a distinct branch of science. Fossils are simply portions of animals and plants, and ought to be dealt with as such; for scientific purposes it is quite immaterial whether the organism which we are called upon to study expired only an hour since or died millions of years ago. Imperfect fragments can only be properly interpreted in the light afforded by the more complete structures found in recent organisms; and hence the naturalist who is engaged in studying a particular group of living organisms is the only person competent to deal with its fossil representatives. In our laboratories and our museums alike, therefore, fossil remains ought to be studied side by side with the living types which most nearly resemble them, and always by the same investigators. This being the case, it is neither necessary nor expedient that there should be a class of students whose chief concern is with extinct forms of life; and as for the geologists, they have really no further concern with fossils than just to find them, attach a label indicating the period at which they must have lived, and hand them over to the biologist for study and incorporation in his collections. Any action beyond this can only be regarded, indeed, as an act of usurpation on the part of geologists, and must tend, not to the advancement, but to the injury of true science."

Such, so far as I have been able to gather them, are the extreme opinions which some biologists now entertain. It may perhaps seem presumptuous on my part to venture to offer a plea for Palæontology; but there are considerations which may induce us to regard such a plea as coming better from one whose place in the ranks of the geological army lies nearer its centre than in the Biological wing; from one who regards Palæontology as the borderland of the Geological and Biological sciences—a borderland where the cultivators of both ought ever to meet, not for rivalry and aggression, but for the necessities of intellectual commerce and the advantages of mutual help.

The view of Palæontology which I have ascribed, I believe not unjustly, to some biologists is one which has just such an amount of truth in it as to render it plausible, but at the same time, I cannot help thinking, is one of those half-truths which are proverbially more dangerous than downright errors. Palæontology is not, as has often been confidently asserted, simply a branch of Biology; it is equally a part of Geological science, and there are the strongest grounds both of reason and expediency for retaining it in that position. All Geological science is based on the principle that the past can only be interpreted by the study of the present; Darwin was the intellectual child of Lyell, and the 'Origin of Species' was the logical outcome of the 'Principles of Geology.' No palæontologist, worthy of the name, has ever dreamed of studying fossils except in the light afforded by the investigation of their recent analogues. Indeed, if we were to carry out the aggressive ideas of some biologists to their legitimate consequences, there would be left to us no science of Geology at all; for why, it may be asked, should the study of physical processes in the past be carried on separately from the investigation of the same processes as exhibited at the present time? But then, by a strange Nemesis, I fear the same all-devouring Physics, after swallowing up Geology, would make very short work indeed with Biology itself. And there is still in the background another claimant for universal empire in the realms of thought, for are there not some who dream of all sciences ultimately becoming the victims of that new portent of ambition—"Geography"?

In considering the present position and future claims of Palæontology, I may be permitted at the outset to offer a protest against a class of objections which has sometimes been very unfairly urged against the votaries of that branch of science. It has often been assumed that the students of fossils are contented with a lower standard of excellence than that which is aspired to by the cultivators of other branches of Natural History. Now, setting aside for a moment the very important consideration that, owing to the imperfection of the remains which they are called upon to study, palæontologists are confronted by difficulties which do not beset the investigators of recent forms, I maintain that the charge is an altogether unjust one. Palæontologists are no more responsible for the unwise use made of fossils by incompetent persons than are zoologists for the vagaries of shell- and butterfly-hunters, or botanists for the absurdities of fern- and diatom-collectors.

Doubtless there has been much work done in connexion with fossils, as well as with other Natural-History objects, of which we can only speak with shame and regret as having been undertaken unadvisedly and performed ignorantly,—work which, prompted by an unwise ambition, has been conceived in error and brought forth in presumption.

It would ill become anyone from this Chair to speak lightly of the great, the inestimable services rendered to our science by the collectors of fossils. How many interesting and novel forms have been brought to light by their patient efforts! How often has the structure of obscure types been rendered clear through their constant and persevering endeavours to obtain more perfect specimens! Yet, sometimes the very zeal of collectors has led them astray. Despairing of finding systematic zoologists and botanists who could devote the necessary time and attention to the study of objects which they have obtained with so much trouble and pains, they have unwisely undertaken, without the necessary training and knowledge, the naming and description of forms of life which required for their proper interpretation all the skill and experience of the most able comparative anatomist or vegetable morphologist.

I feel sure that if those who have thus erred, through acting with "a zeal which is not according to knowledge," could realize the injury done to science by such proceedings, they would pause before burdening scientific literature with premature names, imperfect diagnoses, and ill-digested materials. Fossils are, it is true, "the Medals of Creation," and for the purposes of the historian of past geological times it may seem that any name, however bad, which can be employed for purposes of reference must be better than none at all. But fossils, it must be remembered, are much more than mere "medals." They are the precious relics of the faunas and floras of bygone times; landmarks—the only ones we can ever hope to discover—which may serve to guide us in tracing the wonderful story of the evolution of the existing forms of life. Reverently, as the mineralogist treats meteorites—those pocket planets and errant members of the outer universe—should the biologist regard fossils—the fragments of an earlier life, the collateral, if not the direct, ancestors of living types.

So far am I from thinking that the study of fossils ought in all cases to be undertaken by those who are actually engaged in working out their recent representatives, that I believe such a practical abolition of Palæontology as a distinct branch of science would tend, not to the advantage, but to the injury of both Biology and Geology. And I will venture to set forth my grounds for this conclusion.

It may be remarked at the outset that at a time when all the tendencies of Biological science appear to be towards an extreme specialization, it is strange to find that there are advocates for the suppression of what is now so well-developed a department of Biological science as Palæontology. When the work to be done has become so vast that some Biologists feel themselves compelled to restrict their studies and labours to the Morphological, or even to the Histological department, others to the Embryological, the Physiological, the Taxonomic, or the Chorological branches of Zoology or Botany respectively—why should not some concentrate their efforts upon the elucidation of the ancient forms of life? When the study of a single group, often a very limited group, of animals or plants is sufficient to exhaust the energies of a particular naturalist, it is surely not unreasonable that forms which have become extinct and have left only very imperfect evidence of their structure and affinities, and these requiring peculiar methods for their study, should attract the attention of special investigators.

The study of fossils, we may remark, if it be undertaken by any biologists, must fall to systematic zoologists and botanists, and these have become somewhat rare and out-of-fashion in modern times—so few in numbers, indeed, do they seem as to be scarcely able to cope with the ever-increasing array of living forms; and it would be a hopeless task if upon them were also cast the overwhelming mass of fossil ones.

Imagine the embarrassment and dismay of a student of living sponges, whose favourite (possibly his only) method of research has consisted in studying with the microscope innumerable thin slices cut from tissues and embryos, if a cartload of chalk flints were thrown down at his door, and he were required to interpret the fragments of sponge-skeletons which they contained in every conceivable variety of disguise through peculiar processes of mineralization!

There are, indeed, a variety of special reasons why ordinary systematic zoologists and botanists become, by the very habits acquired in their daily pursuits, singularly ill fitted for dealing with fossil forms.

In studying recent forms the zoologist or botanist is bound to take into consideration, in fixing the systematic position of an organism, not only its skeleton, but all its soft parts, and even the structure and mode of development of its embryo; he may also be called upon to note physiological peculiarities, before he is in a position to arrive at a decision as to its place in the zoological or botanical series. But for the student of fossil forms none of these aids are available, he is compelled to do his best without them. Investigators of the recent Mollusca are, of course, "Malacologists," but he who studies the extinct forms of the group must perforce labour under the stigma of being "a mere Conchologist." In examining recent vertebrates it is allowable to make every possible use of the aid afforded by a study of the ligamental skeleton in unravelling their affinities; but he who works on fossil vertebrates is and must remain a pure Osteologist. Botanists have been led to the conclusion that for the classification of plants the reproductive organs always afford the safest guides; but palæontologists, alas! are frequently called upon to do their best in deciphering fragmentary remains of the vegetative organs.

It is not, as some biologists would almost seem to imagine, that palæontologists are led by any perversity of mind to reject the light which is afforded to them, or that they are not deeply sensible of the great value and importance of many recent researches in respect to living forms; but simply that they realize—often very sadly realize—the impossibility of availing themselves of the help afforded by such researches, in connexion with the very imperfect materials with which they are called upon to deal.

If we suppose that a surveying-ship brought home from a newly-discovered island a heterogeneous mixture of isolated bones and teeth, of shells, bits of stick, and fallen leaves, zoologists and botanists might be perfectly justified in refusing to waste their time upon such unsatisfactory materials. But if, subsequently, news arrived that after the departure of the ship the whole island had sunk beneath the ocean, then the circumstances would have completely changed, and no pains and care would be felt to be too great if expended in dealing with such a unique collection, however imperfect it might be. Or, to take a case which has actually occurred: the curators of the Ashmolean Museum were fully justified in ordering the destruction of the moth-eaten Dodo-skin, so long as they had no reason for doubting that other and better specimens were procurable; but now no labour and pains is considered too great in studying the most imperfect fragment of the bird.

And here I may perhaps be permitted to say a word in defence of what has been treated as an absurd practice on the part of palæontologists—that of giving names to small fragments of organisms. It must be admitted that when subsequent investigation proves that distinct generic and specific names have been given to the root, the stem, the outer and the inner bark, the pith, the foliage, and the fruit of the same plant, the absurdity does seem striking. But it is impossible to defer giving a name to a fossil until all doubts about its structure and affinities have been completely settled by the finding of exceptionally perfect specimens. Nevertheless, it ought certainly to be insisted on that names should be given to very fragmentary fossils only by a competent naturalist, and that he must accept the responsibility of his act. A single tooth of a mammal may afford good grounds for the establishment of a genus and species, while it might be utter folly to treat the tooth of a shark in the same manner.

The remains of many extinct forms are in such a peculiarly mineralized condition as to require special skill and training for their proper interpretation. Skeletal elements which were originally siliceous are now represented by pseudomorphs in calcite, and *vice versâ*. Characteristic structures in bones, shells, or wood may be wholly obliterated, and mineral structures of a strangely deceptive kind may be developed in their place. The curious story of *Eozoon canadense* and its supposed allies is surely a sufficient justification for the existence of palæontologists—that is, of specialists trained equally in the interpretation of biological and petrological structures. Dr. Sorby has shown that whole families of Mollusca may disappear from a fauna because of the unstable condition of the calcic carbonate which composes their shells, and his conclusions have been confirmed by Mr. Kendall.

Professor Sollas has similarly shown that the absence of the Porcellanous types of the Foraminifera from the palæozoic rocks may be due not to their non-existence when those rocks were formed, but to the fact of their shells being composed of the unstable Aragonite.

Such facts as these must convince any unprejudiced person of the absolute necessity to the naturalist, who attempts to study extinct forms, of an acquaintance with the nature of the mineral changes which organic remains undergo. In his interesting memoir upon those curious and enigmatical fossils, the Receptaculitidæ, Dr. Hinde has admirably illustrated the advantages of this combination of Biological and Petrographical study.

In this connexion I cannot avoid alluding to a very prevalent and, as I cannot help thinking, very erroneous notion, that an intermingled zoological and palæontological collection, however inconvenient, would certainly be very instructive. Against this view I offer the strongest protest, for I believe that the mistakes which would arise from the examination of such a collection would far outweigh any instruction to be derived from it.

To begin with, I fail to see what useful lesson would be taught by burying the collection of the lizards, snakes, tortoises, and crocodiles of the present day, among the vast slabs containing the relics of Reptilia which have lived in periods ranging from the Permian to the Pliocene. Nor is it apparent to me why the precious remains of *Archæopteryx* should be hidden away among a wilderness of bird-skins.

But my most serious objection arises from the conviction that any arrangement which would lead to the idea that even the richest collection of fossils is in any way commensurable with the assemblages of specimens that in our museums represent the existing fauna is very greatly to be deprecated. So numerous are the gaps among fossil faunas, owing to the fact that only animals with hard parts and, as a rule, only those that lived in the sea, had any chance of preservation, that the finest palæontological collections are, and must always remain, extremely fragmentary. We have, in the past, fallen into so many and such grievous errors by ignoring the imperfection of the Geological Record, that we may well hesitate before doing anything that would propagate this mischievous delusion.

On the other hand, it may be pointed out that our acquaintance with extinct forms of life has increased to such an extent in recent years, that a biologist may well be pardoned for not realizing the vastness and importance of the problems involved in the study of fossils. It can only be a very inadequate idea of the value of palæontological evidence which leads fossils to be regarded (like the fauna and flora of a newly-discovered territory) as simply supplying a few missing links required to fill up gaps in a Natural History classification—or as the appropriate ballast for a Noah's Ark on a scale of national grandeur. Small as may be the whole bulk of a palæontological collection in the eye of the student of recent forms, its great and transcendent value depends on the fact that the objects composing it belong to the faunas and floras of periods widely separated from the present and from one another. The discovery of a new type of reptiles in the Trias is a very different matter from the detection of an equally remarkable form living in New Zealand. The latter may, it is true, be a singular survival of some old type; but the former is an actual landmark in the course of reptilian development; and by the study of the fossil we are actually brought much nearer to the solution of the problems connected with the history of that development than is possible by the study of any recent form.

In pointing out how vast has been the progress of our knowledge in recent years concerning the ancient life of the globe, I may remind you of the estimates made by Professor Huxley when speaking from this Chair a little more than a quarter of a century ago. He then characterized "the positive change in passing from the recent to the ancient animal world" as "singularly small;" and he regarded the extinct orders of animals as not amounting "on the most liberal estimate" to more than one tenth of the whole number known. The evidence which has been accumulated during the last twenty-five years, however, has modified this estimate in a remarkable manner, as no one would be more ready to admit than the author of it himself.

There is no little difficulty in making a calculation of the proportion of living to extinct orders, owing to the discrepancies in the opinions of zoologists and comparative anatomists as to what are the characters which ought to be regarded as of ordinal value. For my present purpose I very gladly avail myself of the useful Synopsis of the Animal Kingdom prepared by Mr. E. T. Newton, which is "founded on the Classification proposed by Professor Huxley, with such modifications as are rendered necessary by recent discoveries."

We may, I think, take the whole number of living orders of animals generally accepted by zoologists at about 108. But in any comparison of these with fossil forms it is only fair to exclude from our consideration such as possess no hard parts and stand little or no chance of being preserved in a fossil state. Few would be bold enough to doubt that such soft-bodied forms must have existed in the past, or that they probably bore about the same proportion to the forms with hard skeletons as in the existing fauna; even the boldest sceptic on this subject would, I should think, be convinced by such singular accidents as that of the finding of the impressions of *Rhizostomites*, one of the Discophora, preserved in the soft calcareous mud of the Solenhofen Slate.

Now among the 108 living orders of animals, at least 36 are totally destitute of any hard parts capable of being preserved in a fossil state, and we have thus left 72 living orders with which our comparison of the extinct ones must be made.

What is the number of orders which must be created to receive extinct forms, is a question that has given rise to wide diversities of opinion in recent years. While few naturalists would consider 18 as an excessive estimate, there are others who would probably double that number.

Taking the lower estimate and comparing the 18 extinct orders with the 72 living ones which contain animals with hard parts, we find the proportion of extinct orders to be 20 per cent. of the whole number known at the present time.

But, in comparisons of this kind, it must be remembered that there is an unconscious tendency among the students of recent forms of life to *underestimate* the differences between extinct and living forms. If we take such groups as the *Graptolitidæ*, the *Monticuliporidæ*, and the *Stromatoporidæ*, of the nature of the polyps, of which we can know nothing, it is only possible to place them in existing orders on the ground of some very general analogies in the skeleton. How little this may be worth, recent zoological researches, like those of Professor Moseley on the *Milleporidæ* and the *Stylasteridæ*, have amply shown.

The students of existing forms of life have arranged their pigeon-holes; and into those pigeon-holes our unfortunate fossils are too often *made* to go. If there were no other objection to the wholesale commingling of recent and fossil types in a museum, there would always be the valid and insuperable one arising from the fact that there are very considerable and important groups of fossils which cannot, without violence, be made to find any place in our accepted classification of existing animals—and perhaps never will.

If, however, we consider the modifications which have been brought about in our views concerning the relations of extinct to living forms by the important discoveries that have been made since 1862, we shall be impressed by the conviction that no comparison of the numbers of living and extinct orders can give any adequate idea of the important influence of palæontological studies upon biological thought. The discovery of transitional forms, like the *Archæopteryx*, the toothed birds of America, and the reptiles with avian affinities; the working out of the rich faunas of the Rocky Mountains, of Pikermi, Quercy, and the Siwaliks; of the Pampean formations of South America, the Karoo beds of South Africa, and the caves of Australia,—these have already done much towards revolutionizing the ideas held twenty-five years ago by biologists concerning the significance and value of fossil forms. While the recognition of the less specialized precursors of such types as the Horse and the Elephant has perhaps produced most effect in removing objections to evolutionary doctrines, the light thrown by the study of fossil forms on the manner in which individual structures have arisen, as has been so well shown by Professor Alexander Agassiz in the case of the Echinodermata, opens up to us a wide and perhaps far more hopeful field of inquiry. We are, however, as yet only at the beginning of the great task of utilizing the grand palæontological collections of mammals, of reptiles, of fishes, and of the various groups of the invertebrates, for explaining the significance and tracing the origin of the structures found in living types.

While maintaining that studies of this kind demand and justify the concentration of the labours of a special class of investigators, I feel sure that no one will misinterpret my meaning as to the qualifications required by the students of fossil forms. Far from suggesting that the palæontologist may be one destitute of a proper biological training, or that he may be satisfied with an equipment of knowledge which would be insufficient for a systematic zoologist or botanist, I would maintain that no one has a right to take up the study and description of any fossil group until he has made a very careful and exhaustive study of its nearest living allies; but, in addition to this, he ought to have made himself acquainted with the peculiar mineral changes which organic remains are liable to undergo. He will, moreover, be far more likely to interpret aright and to make the best use of the materials that come to his hand if he have at least a general knowledge of what others working on similar materials belonging to other departments of the animal or vegetable world have been able to accomplish, and of the methods which they have followed. Such palæontologists, I insist, have as much right to recognition as any other class of biological specialists.

Still less should I wish it to be implied that I think systematic biologists can afford to be ignorant of the results of palæontological studies, in their own particular fields of labour. One of the most mischievous weeds that have accompanied the evolutionist in his incursions into various parts of the biological field is the preposterous "genealogical tree." We can scarcely turn over the leaves of a modern systematic work without finding it flourishing in full luxuriance. No sooner has the student of a particular group arranged his families, genera, and species, than he thinks it incumbent upon him to show their genetic relations. Very admirably has Professor Alexander Agassiz pointed out the utter fatuity of such a proceeding. As Lyell used to say, in speaking of such proceedings, the imagination of the systematist, untramelled by an acquaintance with the past history of the group, "revels with all the freedom characteristic of motion *in vacuo*." If for no other reason, zoologists and botanists ought to study fossil forms in order that, by encountering a few hard facts in the shape of fossils, they may be saved from these unprofitable flights of the imagination.

In the remarks which I have hitherto made I have confined myself to the purely Biological aspects of Palæontology. Palæontology has relations with Biology, similar to those of Astronomy to Physics; for as Astronomy exhibits to us the orderly working of physical and chemical laws in other and far distant orbs, so Palæontology presents us with the Biological phenomena of many and widely-separated periods.

But besides the biological, there are two other aspects in which fossils may be viewed; and in these aspects their relations are almost entirely with geological science. It is the recognition of this fact which prevents the Geologist from acquiescing in the claim of Biologists to treat Palæontology as nothing more than a branch of their own science.

The assemblage of fossils found in a particular deposit furnishes us with the most valuable evidence concerning the conditions—such as salinity of water, depth, temperature, pressure, &c.—under which the deposit must have been formed. And, again, in the changes which the materials of fossils can be shown to have undergone we have very accurate data for determining the succession of processes which the materials of the deposit must have been subjected to since their original accumulation.

It is true that this evidence of fossils concerning the conditions under which deposits have been formed is of a kind which has been sadly misread in the past. Until the study of deposits which are being formed in the existing seas was taken up in a systematic manner, it was almost hopeless to avoid numerous sources of error; but at the present day the advantages accruing to Geology from the results of deep-sea researches are at least as great as those which by the same means have been conferred upon Biology.

It is almost needless to call attention to the fact that there are vast masses of rock, including most of the calcareous and carbonaceous, and many of the siliceous and ferruginous types, of which the materials have been accumulated entirely by the agency of living organisms; and it is impossible to study the petrology of such deposits without an acquaintance with the nature and functions of the organisms by which they were formed. But, even in the case of many arenaceous and argillaceous deposits, living organisms have played a very important part in their formation. Much of the materials of such rocks can be shown to have at one time formed part of the external skeletons of organisms, to have filled up their dead shells, or to have been passed through their bodies—before being finally buried under other masses. Rocks destitute of all other traces of animal life often abound with worm-tracks, burrows, or casts.

The study of the processes by which similar formations are being accumulated at the present day constitutes the only safe guide to us in interpreting the structures presented by ancient rock-masses. Geologists look forward with much interest to the publication of those volumes of the 'Challenger' reports in which Mr. Murray and M. Renard will deal with these important questions.

We may especially call attention to two classes of errors which have had much to do with the false conclusions that have been arrived at concerning the conditions under which various deposits have been formed in past geological times.

In the first place, it has been tacitly assumed that all marine organisms which come from regions bordering the equator must necessarily have lived under tropical conditions. It would be quite as reasonable to treat the mosses and dwarf willows which fringe the eternal snows of Chimboraço and Kilima-Njaro as tropical plants. Just as mountains rising in Equatorial lands to the limit of perpetual snow exhibit on their slopes every gradation of climate from tropical to frigid, so the depths of ocean, as we now know, exhibit a perfectly similar transition. As we go downwards not only heat, but light also, rapidly diminishes, and many forms which, because they came from Equatorial regions, we have hitherto regarded as tropical, we now know to live in icy-cold water, as well as in almost utter darkness.

The large size and abundant development of Cephalopods, Crustaceans, and Fish we now know, from recent deep-sea researches, to be no evidence whatever of the presence either of warmth or of light; and Sir Josoph Hooker has abundantly shown the fallacy of similar reasoning when applied to plant-life. I feel sure that when the full consequences of these important considerations come to be appreciated, the apparent anomalies of many of the supposed climatal conditions of past geological times will altogether disappear. For my own part, I have never felt any difficulty in accepting, as fully equal to the explanation of the facts of the case, the Lyellian doctrine of climate being determined by great changes in the relative positions of the land and water of the globe.

The other cause of misconception with respect to the conditions which must have prevailed during the accumulation of geological deposits consists in the acceptance of an utterly false proposition, which, though seldom formulated, is often tacitly acted upon, namely, "If two organisms exhibit similarity of structure, their environment must have been the same."

There never has been wanting abundant evidence of the fallacy of this doctrine. The general structure of the piscivorous bear of the Arctic regions, and of the frugivorous bear of the Malay peninsula, the osteology of the deer of Lapland and India respectively, exhibit no such differences as would lead us to infer their diversity of habits and surroundings. It has long been known that, during the Glacial Period, elephants, rhinoceroses, and hippopotami, with lions, tigers, and hyænas, flourished under subarctic conditions. The deep-sea researches have so added to our knowledge concerning the conditions under which different forms of life exist—especially those belonging to marine faunas—as to demand a complete reconsideration of the conclusions usually accepted by geologists. For there is a general consensus of opinion among the naturalists who have studied the different groups of the deep-sea faunas, that, contrary to what might have been anticipated from the very remarkable conditions under which they live, the deep-sea forms belong, for the most part, to the same families, and often indeed to the same genera, as shallow-water forms.

The bearing of this important conclusion upon the great problem of the distribution of marine forms of life is obvious. Botanists have naturally availed themselves of the proved occurrences of colder climates in many areas to explain difficult facts of plant-distribution, such as the occurrence of well-known arctic species on the tops of mountains in what are now temperate, or even tropical, districts. But zoologists, now that they know it to be possible for littoral forms to stray into abysmal portions of the ocean, and then subsequently, without profound modification, to re-emerge in other littoral areas, may find a clue to some very remarkable facts concerning the distribution of marine forms of life, without having to resort to explanations which seem necessary in the case of the terrestrial types, which appear to be more dependent than the marine ones on the circumstances of their environment.

The whole problem of the distribution of marine forms of life requires indeed to be worked out afresh on the basis of these new discoveries; and when this is done, the first to profit by the new generalizations will be geologists, who have long been confronted by seemingly insuperable difficulties in connexion with this problem.

As for the very prevalent notions that Ammonites and Belemnites, Trigoniæ and Brachiopods, with Ichthyosaurs, Pliosaurs, and Plesiosaurs, could only have lived in warm, if not actually tropical, climates, I know of no grounds whatever for any such belief. The nearest living allies of the Invertebrates referred to flourish at considerable depths in icy-cold water; and, seeing that large marine mammals now live amid snow and ice, I cannot understand why the great marine reptiles may not have done the same. Just as little reason is there for inferring that Sigillarids, Lepidodendrids, and Calamites could only have lived in tropical jungles, as there is for the once popular notion that they flourished in an atmosphere supplied with a very exceptional proportion of carbonic acid!

The sooner geologists recognize the fact that all our ideas concerning the distribution of the forms of marine life have been completely revolutionized by the discovery that there are cold and dark abysses which are tenanted by numerous organisms having many affinities with those which live in shallow water,—though the latter is warmed by a tropical sun and flooded with light—the more likely will they be to avoid the errors into which we have fallen in the past. Not until the exact distribution of life-forms at different depths in the ocean has been much more perfectly worked out than it has been at present, will it be safe to reason with any confidence concerning the distribution of extinct types; and even then we shall ever have to be on our guard against the prevalent fallacy which assumes that analogies in structure are indicative of similarities in the conditions of life.

And here it may be remarked that the imperfect methods employed on board the 'Challenger' and most other surveying-ships, leave almost everything yet to be done in the way of determining the limits of depth, temperature, pressure, and other conditions under which the different forms of marine life can flourish. It is much to have obtained so great an insight into the characters of some of the creatures inhabiting the deepest parts of the ocean, and of the peculiar conditions which must exist in some of those places where marine life is abundant. But the work which has yet to be done requires the employment of dredges and nets which can be opened when they have reached a certain depth in the ocean, and which can be closed again before being drawn to the surface. Only by the employment of such apparatus can we hope to avoid those sources of error which vitiate all our present generalizations concerning the bathymetrical distribution of the existing forms of marine life.

When, in addition to these biological studies, we have equally careful determinations of the physical characters of deposits formed at varying depths and distances from the shore, and under diverse influences of tides and currents, we may hope, by combining the physical and biological evidence, to arrive at something like certain conclusions concerning the exact conditions under which various geological formations have been accumulated; for at present our speculations upon the subject are often little better than haphazard guesses.

The conditions which must have prevailed during the deposition of a particular bed having been determined, the present state of mineralization of the organic remains becomes a subject of very interesting study; for here we may find a clue which will enable us to unravel the series of physical and chemical changes which must have gone on in the mass, since the first accumulation of its materials. In cases of difficulty of this kind, the nature and degree of alteration of a shell or bone, of which the original composition is known, becomes an especially valuable piece of evidence.

I am convinced that the future progress of geological thought is closely bound up with the increase of our knowledge concerning the conditions under which the various forms of marine life flourish, and under which their remains become imbedded in sedimentary deposits; though what has been already accomplished in this direction, it must be admitted, is but small, and much of it will have to be done over again.

We hear much—far too much, as I think—at the present day of an "irrational Uniformitarianism." Is not the real source of danger in an exactly opposite direction? Does not the irrationality characterize him who, without attempting to obtain a more complete knowledge of the processes going on during the original deposition and subsequent changes of rock-masses, is ready, as each new difficulty presents itself, to fall back upon some old discredited *Deus ex machinâ* in the form of deluges of water, floods of fire, boiling oceans, caustic rains, or acid-laden atmospheres?

Considering how little we as yet know of many of the conditions under which deposits are being formed at the present day, and remembering how large a part of the little we do know has been acquired within the last few years, we might pause before declaring that the path upon which Geology entered in earnest only some fifty years ago is a wrong one, and that the sooner we begin to retrace our steps the better.

Can we even now be in danger of forgetting that "Slough of Despond," wherein the geologist, laden with a grievous burden of traditional assumptions and irrational theories, so long and so hopelessly floundered, till one Help pointed out a way of escape, and sent him on his way rejoicing, with the 'Principles of Geology' in his hand?

The second aspect in which Palæontological science presents itself to the geologist is as affording a key to the Chronology of the rock-masses of the globe. We still regard fossils as the "Medals of Creation," and certain types of life we take to be as truly characteristic of definite periods as the coins which bear the image and superscription of a Roman emperor or of a Saxon king.

But in the application of the principle that "strata are to be identified by their organic remains," we have now to admit as many limitations, and to exercise as much caution, as when judging of the conditions under which rock-masses must have been deposited from the characters of the fossils which they contain.

Within the restricted area of the South-west of England, where William Smith achieved his epoch-making discovery, the doctrine which he announced seemed to be absolutely true; each formation exhibited a peculiar and perfectly characteristic assemblage of organic remains, by means of which it could at once be recognized. The still more detailed studies of strata of the same age, by Hunton and Williamson in Yorkshire, by Marcou in the Jura, and by Quenstedt in Swabia, seemed to indicate that the principle had a wider application than even its author himself could have imagined, and that zones a few feet or even inches in thickness might be followed over considerable districts, everywhere marked by some particular type of Ammonite or other characteristic fossil.

But the more thorough and systematic study of corresponding formations over wide areas, which was inaugurated by Oppel and has been carried on by many palæontologists since, has abundantly demonstrated that, striking as is the parallelism of the zones in such a formation as the Lias, when studied in England, France, and Germany, yet the species and varieties found on the same horizon at distant points are in many cases not identical, but merely representative; and, further, that as we pass away from any typical area, the sharp distinction between the several zones seems gradually to vanish.

The same facts come out very strikingly when we study any other great geological period. In the oldest fossiliferous strata, those of the Cambrian, nothing can be more striking than the similarity of the faunas in North America, Britain, Scandinavia, and Bohemia; and yet the species which occur at the several different horizons in these countries are certainly, for the most part, not identical but only representative. No fact, it seems to me, could more clearly indicate that, even at that early period, there were life-provinces with a distribution of organisms in space quite analogous to that which exists at the present day.

To pass to slightly younger rocks. What can be more striking than the evidence of the juxtaposition of two life-provinces, afforded by the Calciferous strata of North America and the similar rocks of Scotland and Northern Europe, which contain the remarkable *Maclureæ*, a peculiar assemblage of Cephalopods, and other fossils? for these are seen at Girvan to come into close contiguity with the more southern type of Silurian, containing a very different fauna, so well exhibited in the Lake-district and in North Wales.

Another striking example of the same kind is afforded by the Cretaceous, of which the Southern type, marked by the abundance of *Hippurites*, *Orbitolites*, and other remarkable forms, comes into close relations, as has been so well shown by Hébert, with the type which yields the ordinary Cretaceous fauna of Central Europe. In these and similar cases which might be mentioned we trace the existence of two approximating marine provinces, like those which at the present day are separated by the Isthmus of Panama.

Professors Neumayr and Mojsisovics have indeed shown that there are good causes for believing that the distinction between the marine zoological provinces in Triassic and Jurassic times was at least as clearly marked as between the similar provinces of the present day; and the former naturalist has in addition pointed out that within the geographical provinces we have also very recognizable climatic zones.

In the year 1862, Professor Huxley, speaking from this Chair, uttered a much needed warning against the growing practice among palæontologists of treating Geological equivalence as meaning the same as actual contemporaneity; and against the assumption, without positive proof, that ancient faunas and floras had an indefinite and even world-wide distribution. Palæontological discoveries during the last quarter of a century in Western North America, in India, in the Cape Colony, Australia, and New Zealand have abundantly justified these cautions, and have shown how much such a term as "homotaxis" is needed, in order to guard against errors resulting from the abuse of the phrase "geological contemporaneity."

But when Professor Huxley went on to suggest that "a Devonian fauna and flora in the British Isles may have been contemporaneous with Silurian life in North America and with a Carboniferous fauna and flora in Africa," I think that geologists, with the evidence they have now before them, must take exception to so sweeping a generalization. Finding, as we do, on both sides of the Atlantic the same succession of Cambrian, Ordovician, Silurian, Devonian, and Carboniferous strata, containing strikingly representative, if not identical faunas, it is impossible to doubt their general parallelism; however ready we may be to admit that the migration or development of new forms of life in the two areas need not have occurred synchronously, and that thus a certain amount of overlapping of the periods represented at distant points by the same system may exist.

On the other hand, I believe that the study of fossils from remote parts of the Earth's surface has abundantly substantiated Professor Huxley's alternative suggestion that "Geographical provinces and zones may have been as distinctly marked in the Palæozoic epoch as at present." The ever accumulating mass of evidence seems to me to be all pointing in this direction; and I confidently anticipate that the palæontological anomalies which in the past have caused so much doubt and difficulty, will, by the establishment of this principle, receive a full and satisfactory explanation.

So long ago as 1846 Darwin, in his "Observations on South America," showed that certain assemblages of fossils presented a blending of characters, which in Europe are only found apart in faunas which are of Jurassic and Cretaceous age respectively. Since that date, the study of the fossil faunas and floras of South Africa, India, Australia, New Zealand, and the Western Territories of North America has furnished an abundance of facts of the same kind, showing that no classification of geological periods can possibly be of world-wide application; that we must be contented to study the past history of each great area of the Earth's surface independently, and to wait patiently for the evidence which shall enable us to establish a parallelism between the several records. Attempts to set up a universal system of nomenclature or classification of sedimentary rocks are indeed greatly to be deprecated, for if the zoological and botanical distribution of past geological times were at all comparable to that of the present day, any such universal system must be impossible.

The suggestion made to this Society by Professor Huxley at a somewhat later date is equally valuable and important. Referring to the fauna of the Trias, he said, "It does not appear to me that there is any necessary relation between the fauna of a given land and that of the seas of its shores. At present our knowledge of the terrestrial faunæ of past epochs is so slight that no practical difficulty arises from using, as we do, sea-reckoning for land-time. But I think it highly probable that, sooner or later, the inhabitants of the land will be found to have a history of their own."

The growth of our knowledge concerning the terrestrial floras and faunas of ancient geological periods, since these words were written in 1869, has constantly forced upon the minds of many geologists the necessity of a duplicate classification of geological periods, based on the study of marine and terrestrial organisms respectively.

Upon this important question the judicious remarks of my colleague Dr. Blanford must still be fresh in the minds of all geologists and biologists. He showed that not only are terrestrial provinces independent of marine ones, but that at present, as well as in the past, the former are more circumscribed and have an amount of distinctness which does not exist in the case of the latter.

Nor is it difficult, in the present state of our biological knowledge, to give a reason for the existence of this state of things. Between completely separated land-areas, migration can only take place by such accidents as the transport of seeds or eggs, or as the consequence of the great but slow changes in the relations of sea and land. Forms adapted only for living in cold climates are isolated by tracts of low-lying tropical land, and, conversely, tropical forms are divided off from one another by snow-covered mountain-chains, almost as distinctly as by actual oceans. The fact that well-known arctic plants are found at the top of mountains in tropical or temperate lands has seemed to many botanists to be quite inexplicable without calling in the agency of a general refrigeration, like that which is supposed to have marked the glacial period.

But with marine forms of life the case is totally different. The oceans are not only much larger than the continents, but they are all more or less completely connected with one another; and this more or less complete connexion of the oceanic areas must have been maintained from the earliest geological times.

Forms which live at the surface of the ocean may wander freely in all directions, and know but few limitations except those imposed by temperature, absence of food, &c.; forms which characterize moderate depths may migrate along shore-lines or submarine ridges from one area to another; and even when abysmal tracts of ocean intervene between two littoral faunas, recent researches seem to show that the littoral forms of life may wander into such tracts, and eventually, perhaps, cross them, without undergoing extreme or profound modification. In this way, I think, we may account for the important fact so prominently brought into view by Dr. Blanford, that marine life-provinces are and always must have been less restricted in area, and less sharply cut off from one another, than terrestrial provinces.

With the clear recognition of this principle there falls to the ground one of the most frequently urged objections to the Uniformitarian doctrines—that, namely, which is based on the supposed differences in geographical distribution in ancient times as compared with the present. We have been in the habit of comparing ancient marine distribution with modern terrestrial distribution. I have always doubted whether there is any evidence to show that the marine life-provinces of Silurian or Carboniferous times were of greater extent than those of the present day.

I believe that the doctrine that strata can be identified by the organic remains which they contain is as sound as when it was first enunciated by William Smith; but the problems of stratigraphical palæontology, as they now present themselves to us, are infinitely more complicated than they could possibly have seemed to him. In every fauna and flora which we are called upon to study we have to resolve a function of three variables, these being environment, space, and time. Only after the most careful investigation, in the first place, of the complicated effects produced by the varied conditions which we group together under the term environment—temperature, food, absence of enemies, and the innumerable influences which, as we now know, determine the existence and affect the multiplication of living beings—and by the thorough study, in the second place, of the laws of geographical distribution of plants and animals, can we hope to eliminate the effects due to environment and position, and arrive at the conclusion of what must be ascribed to time.

The task will be long, the work to be done arduous, and the efforts to be made prodigious and sustained; but the result is one which is not hopeless and unattainable, or, indeed, even doubtful. But let us by all means remember that the real work is really only just commenced, and that we are very far indeed from our goal.

One of the greatest sources of danger to the progress of geological knowledge at the present day is the impatience which is so frequently shown at the rate of that progress, an impatience which leads to attempts to cut the tangled skeins of research by hasty and ill-considered speculation. Geologists, no less than Biologists, need to recollect and keep ever before their minds the important fact that the geological record, although it is one of enormous value, is exceedingly imperfect—and that this imperfection is quite as conspicuous in respect to physical as it is to palæontological data. How sadly is this important truth lost sight of by those who, on the strength of a few isolated facts and fragmentary observations, are prepared to construct maps of large portions of the earth's surface at far distant periods of its history! Such maps are to the Geologist what "genealogical trees" are to the Biologist—"Will-o'-the-Wisps" leading us aside from the safe paths of scientific induction.

It is, I suspect, from the obvious failure of attempts of this kind —attempts which had better never have been made—that such frequent attempts at revolt against the principles of Uniformitarianism take their origin. For myself, instead of disappointment, I feel a constant surprise that these doctrines have enabled us to explain so much, when our knowledge of the causes now at work around us is still so imperfect; and I am continually impressed by the fact that each new discovery concerning the present order of nature removes old difficulties in the explanation of the past. In saying that I adhere to the doctrines of Uniformitarianism, I, of course, mean the Uniformitarianism which Lyell himself taught, and not the absurd travesty of that doctrine sometimes ascribed to him.

The well-grounded conviction which results from observing the triumph of a great principle, when applied in an overwhelming number of cases, and which refuses to abandon that principle at the first appearance of difficulty, is surely not out of place in a student of nature. It was this scientific "faith" which led Scrope to believe, in spite of difficulties arising from the imperfect knowledge in his day of physics, chemistry, and mineralogy, that massive and schistose crystalline rocks have been formed from ordinary lavas and sediments, when subjected to enormous pressures and complicated earth-movements; which induced Lyell to seek for and find the key to physical changes during past times in the operations going on everywhere around us; and which finally conducted Darwin, by the application of the same principle in the case of living beings, to the doctrine of organic evolution.

But, alas! this "faith" seems often sadly wanting among us to-day. At a time when the mineralogical constitution of rocks and of the changes which they undergo is becoming daily more clearly revealed, when innumerable researches are throwing fresh light on the great physical processes taking place everywhere in the world around us, and when each department of biological science is contributing new "facts and arguments for Darwin," such scientific pusillanimity on the part of geologists seems, to say the least of it, singularly inopportune.

Doubtless there are difficulties still unresolved; but does not every advance in our knowledge see the removal of some of them? True the task of interpreting the fragmentary record of the rocks is one the end of which seems very far off; but is not every step we take clearly an approximation towards that end?

If any arguments were needed in favour of the continued and close co-operation of geologists and biologists, it would be found in the circumstance that the most important step in the progress of scientific thought which has been accomplished in modern times has been the direct result of a combination of geological and biological researches.

That remarkable biography, for which we are so greatly indebted to Mr. Francis Darwin, is not simply the record of a life, simple, blameless, and noble beyond that of ordinary men, the story of the workings of an intellect, truth-loving, patient, and powerful, above that of all his contemporaries; it is the history of a most wonderful revolution in human thought—one which will perhaps be regarded in future times as the most striking event of the nineteenth century.

The grand secret of Darwin's success in grappling with the great problem of "the Origin of Species" is found in the fact that he was at the same time a geologist and a biologist. The concentration of the later years of his life upon zoological and botanical researches has led many to forget the position occupied by Darwin among geologists. Not only are his geological writings of the highest value for the wealth of accurate observations which they contain, and for the important generalizations which they put forward, but in his more purely biological works the value of his geological training and experience is constantly exemplified.

It was, indeed, a fortunate circumstance that Darwin, after being repelled by the narrow and soulless system of "geognosy" taught by Jameson at Edinburgh, came at Cambridge under the spell of Henslow, a man of most catholic taste, extensive acquirements, and widest sympathy with all branches of Natural Science. By intercourse with Henslow, Darwin's flagging interest in science was rekindled and kept alive. It is a proud boast for a university to have nourished the intellectual development of Darwin; and as that university has in the past remained faithful to the memory of Newton—making his mathematical teachings the characteristic and leading feature of its studies—so, we may hope, it will in the future aim at that complete union of geological and biological investigation of which Darwin's labours constitute so grand an example.

In the dedication of his 'Journal of Researches,' Darwin acknowledged "with grateful pleasure" that "the chief part of whatever scientific merit this journal and the other works of the author may possess, has been derived from studying the well-known and admirable 'Principles of Geology;'" and well do I recollect how, in almost every conversation I had with him, he would enlarge with warmth of feeling upon his indebtedness to Lyell, not only for his lucid teaching, but for his constant and helpful sympathy. How he used to speak in terms of reverence of his "Master," and extol the magnanimity of one who, though twelve years his senior, had abandoned—slowly and cautiously, as was the habit of his mind, yet in the end completely and ungrudgingly—his own conclusions and prepossessions, and had accepted the doctrines of a pupil!

Of Darwin's three geological books, the record of the observations made by him during the voyage of the 'Beagle,' it is impossible to speak in terms of praise that will seem, to those acquainted with the merits of those admirable writings, to be too high; and some portions of those works, especially the chapters dealing with the great problem of foliation, are, I am convinced, very far indeed from having received from geologists the amount of attention which they deserve.

After Darwin's return to England, in 1836, his attention was for some years almost exclusively devoted to geological researches; and it was to this Society and to its officers that he constantly came for help, advice, and sympathy. He writes at this time, "If I was not more inclined for geology than the other branches of Natural History, I am sure Mr. Lyell's and Lonsdale's kindness ought to fix me."

Before reaching England, Darwin had written to Henslow from St. Helena, on July 9th, 1836, asking that he might be proposed a Fellow of this Society, and on November the 30th of that year he was elected. In the following February he became a member of our Council, and at the next Anniversary, in 1838, undertook the duties of Secretary. This office, after he had held it for five years, he was compelled to resign through ill health; but even after he had been driven from London through the same cause, it was the evening meetings of this Society which from time to time tempted him from the seclusion of Down, till at last painful experience proved to him that he must forego this too-exciting pleasure.

Even after being compelled to lay aside his hammer, when he had taken up scalpel and microscope to study the Cirripedia, he did not forget the fossil forms of the same group.

Whether it was the phenomena of the distribution of organic forms in space, or the curious facts connected with the order of their appearance in time, which had had most to do in turning Darwin's thoughts into those currents which finally led him to Evolution, it would be idle to speculate; but it may safely be asserted that the geological aspects of Natural History had at least as much to do with the conception of the origin of species as had the biological.

How warm was Darwin's interest, all through his life, in the progress of every branch of geological research may be gathered from his letters to Lyell and other geological friends. In the work which he had a presentiment would be, and which actually proved, his latest, 'The Formation of Vegetable Mould through the Action of Worms,' he returned in his old age to a geological problem which had occupied him during the years of his most intimate connexion with our Society.

No memories can possibly have such fascination for myself as those of the conversations which, during the last seven years of his life, I was privileged to hold with Mr. Darwin upon the current topics of geological interest. It was his habit when he came to town, twice a year, to ask me to meet him, in order to talk over geological questions, and thus I had opportunities for close intercourse and discussion. No geological researches were too minute, none too remote from the ordinary subjects of his study, to engage his attention and command his sympathies. How keenly did he recall the pleasures of his labours in this Society, and the happiness of the friendships which he had formed here! How generously and with what warmth of appreciation did he ever speak of the labours of those who had succeeded him in endeavouring to carry out the objects of this Society! Of the gentleness, the sympathy, the contagious enthusiasm of the man, I dare not trust myself to speak!

At a time when there is perhaps some danger that the excessive specialization which seems to have become a necessity in both the geological and the biological sciences may lead to narrowness of view, restriction of aims, and petty jealousies among the workers in circumscribed departments of those sciences, it may be well to remember how Darwin, while engaged in the most minute and detailed investigations upon barnacles, earthworms, or pigeons, upon orchids, primroses, or climbing plants, could ever keep his mind open to the influence of each new discovery in every branch alike of geological and of biological science.

The great principles which lie at the foundation of Modern Geology and of Modern Biology are the same; and Darwin did but furnish a new testament to the old covenant already accepted by geologists. Now, more than ever in the history of Natural Science, is there reason for the warmest sympathy, the most thorough understanding, and the completest union in effort between the cultivators of the geological and the biological sciences. It is not by petulant unfaithfulness to the tried methods of those two sciences, and a readiness to abandon the principles which have led us to such real and important conquests for the older methods that have been so often discredited and found wanting, that we can hope to advance those sciences.

Lyell once wrote to Darwin as follows:—"I really find, when bringing up my Preliminary Essays in 'Principles' to the science of the present day, so far as I know it, that the great outline, and even most of the details, stand so uninjured, and in many cases they are so much strengthened by new discoveries, especially by yours, that we may begin to hope that the great principles there insisted on will stand the test of new discoveries."

And to this Darwin replied with characteristic enthusiasm:—

"*Begin to hope?* Why the *possibility* of a doubt has never crossed my mind for many a day. This may be very unphilosophical, but my geological salvation is staked upon it! . . . . . It makes me quite indignant that you should talk of *hoping*."

Fifty years have elapsed since these words were written. How infinitely more complicated seem to us the problems involved in the explanation of the past by the study of the processes going on around us at present, than they possibly could have done to the great pioneers of the Uniformitarian doctrines! But the reasons for Lyell's hope and Darwin's confidence are still valid—nay, are stronger than ever. For does not every new discovery remove some difficulty or supply fresh illustrations of these views? May every geologist to-day be endowed with a due share of Lyell's caution! but, for my own part, I see no reason why he should not also possess a full portion of Darwin's faith.

The time has now come to resign the trust which, ten years ago, you so generously reposed in me by electing me one of your officers. I do so in the full assurance that the good feeling between the Governing Body and the Fellows of this Society, which has so long characterized us, will not in the future become impaired; and this confidence is increased by the fact that you have chosen as my successor a man of wider knowledge and more tried experience than my own—one who has distinguished himself alike in the fields of Geological and of Biological research. Before retiring, however, I must thank you for the great honour you have done me, and assure you that to serve a Society to which I owe so much, has not only been a duty and an honour, but also the highest of pleasures. I cannot be insensible of your kindly indulgence towards my shortcomings, of your more than generous appreciation of my efforts, and of your warm support upon all occasions. The friendships which I have formed here, among fellow-workers in the same fields of thought, are such as make bright the disillusioned half of a life; and, if I ever could for one moment forget my indebtedness to this Society, I should be recalled to duty and to faithfulness by the reflection that but for the Geological Society I could never, in all probability, have enjoyed what must always constitute my brightest retrospect—the kindly interest, the warm sympathy, and the honouring friendship of three such men as Scrope, Lyell, and Darwin.

February 29, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

Percy Leonard Addison, Esq., Assoc.Memb.Inst.C.E., Park House, Bigrigg, *viâ* Carnforth; Edward Cross, Esq., 11 High Street, Birmingham; and William Herdman, Esq., Westgate, Weardale, by Darlington, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "An Estimate of Post-Glacial Time." By T. Mellard Reade, Esq., C.E., F.G.S.

2. "Note on the Movement of Scree-Material." By Charles Davison, Esq., M.A. (Communicated by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.)

3. "On some Additional Occurrences of Tachylyte." By Grenville A. J. Cole, Esq., F.G.S.

4. "Appendix to Mr. A. T. Metcalfe's paper 'On Further Discoveries of Vertebrate Remains in the Triassic Strata of the South Coast of Devonshire, between Budleigh Salterton and Sidmouth.'" By H. J. Carter, Esq., F.R.S. (Communicated by A. T. Metcalfe, Esq., F.G.S.)

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by G. A. J. Cole, Esq., F.G.S., in illustration of his paper.

March 14, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

William Brindley, Esq., Pergola House, Denmark Hill; George James Crosbie Dawson, Esq., Memb.Inst.C.E., Stoke-upon-Trent; the Rev. George W. James, Oleander, Tresno Co., California, U.S.A.; and Charles Algernon Moreing, Esq., 25 Queen's Mansions, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced the appointment and constitution of a Committee appointed for the purpose of revising the existing Bye-Laws of the Society.

The President also announced that it was proposed to build, in memory of the late Mr. Champernowne, a moderate-sized cottage-hospital in Totnes. Mr. Champernowne was greatly interested in a temporary hospital, erected in 1885, and was anxious that a permanent institution should be established for the same purpose.

The following communications were read:—

1. "On the Gneissic Rocks off the Lizard." By Howard Fox, Esq., F.G.S. With Notes on Specimens by J. J. H. Teall, Esq., M.A., F.G.S.

2. "The Monian System." By the Rev. J. F. Blake, M.A., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by the Rev. J. F. Blake, F.G.S., in illustration of his paper.

Rock-specimens and microscopic sections, exhibited by Howard Fox, Esq., F.G.S., and J. J. H. Teall, Esq., M.A., F.G.S., in illustration of their paper.

March 28, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

Henry Glenny, Esq., Ballarat, Victoria, Australia; Christian Horrebow Homan, Esq., Christiania, Norway; Henry John Marten, Esq., M.Inst.C.E., The Birches, Codsall, Wolverhampton, and 4 Storey's Gate, Great George Street, S.W.; Henry John Spooner, Esq., Assoc.Memb.Inst.C.E., 309 Regent Street, W.; A. Norman Tate, Esq., 9 Hackins Hey, Liverpool; and James George Wood, Esq., M.A., LL.B., 8 Lansdowne Crescent, W., and 7 New Square, Lincoln's Inn, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On some Eroded Agate Pebbles from the Soudan." By Prof. V. Ball, M.A., F.R.S., F.G.S.

2. "On the Probable Mode of Transport of the Fragments of Granite and other Rocks which are found imbedded in the Carboniferous Limestone of the neighbourhood of Dublin." By Prof. V. Ball, M.A., F.R.S., F.G.S.

3. "The Upper Eocene, comprising the Barton and Upper Bagshot Formations." By J. Starkie Gardner, Esq., F.G.S., Henry Keeping, Esq., and H. W. Monckton, Esq., M.A., F.G.S.

The following specimens were exhibited :—

Eroded Agate Pebbles from the Soudan, and Specimens of Carboniferous (Encrinital) Limestone from near Dublin containing fragments of Granite, Quartz, and Schist, exhibited by Prof. Valentine Ball, F.R.S., F.G.S., in illustration of his papers.

Specimens of *Spirophyton cauda-galli*, Vanux., from the Carboniferous Limestone of Scotland, exhibited by R. Kidston, Esq., F.G.S.

Fossils from the Upper (?) Bagshot Beds, Penwood Railway-cutting, Highclere, Hants, exhibited by R. S. Herries, Esq., F.G.S.

Ironstone nodules containing sand, from the Lower Greensand, Moor Park, Farnham, Surrey, exhibited by J. F. La Trobe Bateman, Esq., F.R.S., F.G.S.

April 11, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

William Wild Clarke, Esq., care of H. Byron, Esq., Victoria Arcade, Auckland, New Zealand; George Hodson, Esq., Memb.Inst.C.E., Regent Cottage, Loughborough, Leicestershire; Rev. Thomas Enraght Lindsay, B.A., The College, Epsom, Surrey; Tom Kirke Rose, Esq., 94 Camberwell Grove, S.E.; and Anthony Taaffe, Esq., 3 Prince's Terrace, Kensington Gardens, were elected Fellows; Prof. Pierre J. van Beneden, Louvain, a Foreign Member; and Dr. Edward S. Dana, Yale College, Newhaven, Conn., and M. Ernest Van den Broeck, Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "On the Lower Beds of the Upper Cretaceous Series in Lincolnshire and Yorkshire." By W. Hill, Esq., F.G.S.

2. "On the Cae-Cwyn Cave, North Wales." By Henry Hicks, M.D., F.R.S., F.G.S., with an Appendix by C. E. De Rance, Esq., F.G.S.

The following specimens were exhibited :—

Specimens exhibited by W. Hill, Esq., F.G.S., in illustration of his paper.

Photographs and specimens, exhibited by Dr. H. Hicks, F.R.S., F.G.S., in illustration of his paper.

Additional specimens of *Conocoryphe viola*, H. Woodw., obtained by Prof. J. J. Dobbie from the Llanberis green slates, Bangor, exhibited by Dr. H. Woodward, F.R.S., V.P.G.S.

Plants (seeds &c.) from Interglacial Beds near Edinburgh, collected by J. Bennie, Esq., exhibited by Clement Reid, Esq., F.G.S.

April 25, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

Henry Louis, Esq., Assoc.R.S.M., 125 Fellowes Road, N.W.; and John Stoddart, Esq., Takashima Colliery, Nagasaki, Japan, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "Report on the Recent work of the Geological Survey in the North-west Highlands of Scotland, based on the field-notes and maps of Messrs. Peach, Horne, Gunn, Clough, Hinxmann, and Cadell." Communicated by A. Geikie, LL.D., F.R.S., F.G.S., Director-General.

2. "On the Horizontal Movements of Rocks, and the relation of these movements to the formation of Dykes and Faults and to denudation and the thickening of Strata." By William Barlow, Esq., F.G.S.

3. "Notes on a Recent Discovery of *Stigmaria ficoides* at Clayton, Yorkshire." By Samuel A. Adamson, Esq., F.G.S.

The following specimens were exhibited:—

Rock-specimens exhibited by the Director-General of the Geological Survey, in illustration of the Report on the North-west Highlands of Scotland.

Zeolites from Cyprus, exhibited by H. Bauerman, Esq., F.G.S.

Plaster casts of five Ammonites from the Upper Jurassic, Fly River, New Guinea, exhibited by Dr. H. Woodward, F.R.S., V.P.G.S.

May 9, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

William Beswick Myers, Esq., M.Inst.C.E., 21 Adamson Road, South Hampstead, N.W.; James Oddie, Esq., Ballarat, Victoria; and Charles Wilkins, Esq., Springfield, Merthyr, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "The Stockdale Shales." By J. E. Marr, Esq., M.A., Sec.G.S., and Prof. H. A. Nicholson, M.D., D.Sc., F.G.S.

2. "On the Eruptive Rocks in the Neighbourhood of Sarn, Caernarvonshire." By Alfred Harker, Esq., M.A., F.G.S.

The following specimens were exhibited:—

Specimens from the Woodwardian Museum, Cambridge, exhibited in illustration of the papers by Messrs. Marr, Nicholson, and Harker.

May 23, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Spheroid-bearing Granite of Mullaghderg, Co. Donegal." By Frederick H. Hatch, Ph.D., F.G.S. (Communicated with the permission of the Director-General of the Geological Survey.)

2. "On the Skeleton of a Sauropterygian from the Oxford Clay, near Bedford." By R. Lydekker, Esq., B.A., F.G.S.

[Abstract.]*

A description was given of a considerable portion of the skeleton of a Sauropterygian from the Oxford Clay of Kempston, consisting of several upper teeth, most of the mandible (of which the symphysial region is entire), a considerable number of vertebræ mainly from the "pectoral" and dorsal regions, the greater portion of the two pelvic, and fragments of the pectoral limbs, and a considerable proportion of the pectoral and pelvic girdles. These remains were referred to *Plesiosaurus philarchus*, Seeley, and the various parts described in detail.

The Author discussed the advisability of retaining the forms described under various generic names by Professor Seeley, under the name of *Plesiosaurus*, and stated his intention of employing the latter term in its widest sense for the present. With this definition, the form under consideration was shown to present characters intermediate between those of *Plesiosaurus* and *Pliosaurus*, but was retained provisionally in the former genus. Although a direct link in the chain connecting the two genera, *P. philarchus* was not regarded as an ancestor of *Pliosaurus*, since teeth undistinguishable from those of the latter genus occur in the Coralline Oolite.

* This paper has been withdrawn by the Author.

Finally it was concluded that the evidence brought forward was sufficient to render necessary the abolition of the name Pliosauridæ, and the inclusion of *Plesiosaurus* and *Pliosaurus* in a single family.

Discussion.

The President welcomed the reunion of the various *Plesiosaurus*-like forms under one genus.

Mr. Hulke considered that Mr. Lydekker had established his case. He regretted that old genera should be split up on account of minute differences, and congratulated the Author upon the abolition of the minor divisions.

Dr. Scott agreed with Mr. Hulke on the desirability of not splitting up forms prematurely. He commented upon the range of variation of forms whilst still keeping to the generic type. There was a difficulty in correlating the faunas of N. America and Europe in Mesozoic and later times.

The Author thanked the Society for their reception of his paper.

3. "On the Eozoic and Palæozoic Rocks of the Atlantic coast of Canada in comparison with those of Western Europe and the Interior of America." By Sir J. W. Dawson, LL.D., F.R.S., F.G.S.

4. "On a Hornblende-biotite Rock from Dusky Sound, New Zealand." By Captain F. W. Hutton, F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by F. H. Hatch, Ph.D., F.G.S., in illustration of his paper.

Vertebræ of *Plesiosaurus philarchus* and *P. megadirus* belonging to the type specimens, exhibited by Prof. T. M'Kenny Hughes, F.G.S., and portions of skeleton of *P. philarchus*, exhibited by R. Lydekker, Esq., F.G.S., in illustration of his paper.

June 6, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

Edmund Dickson, Esq., 30 Eastbourne Road West, Berkdale, Southport, was elected a Fellow, and M. Charles Brongniart, Paris, a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

The following names of Fellows of the Society were read out for the first time, in conformity with the Bye-Laws Sect. VI b, Art. 6, in consequence of the non-payment of the arrears of their contributions:—Rev. T. C. B. Chamberlin; Rev. G. Clements; W. M. Cole, Esq.; A. Colvin, Esq.; W. F. Fremersdorff, Esq.; F. Gillman, Esq.; A. Leech, Esq.; Rev. E. R. Lewis; G. Paul, Esq.; J. Parkinson, Esq.; H. K. Spark, Esq.; Dr. G. Tate; and R. B. N. Walker, Esq.

The following communications were read:—

1. The following letter from H.M. Secretary of State for India accompanying some specimens of rubies in the matrix from Burmah:—

India Office, Whitehall, S.W.
2nd June, 1888.

SIR,—

I am directed by the Secretary of State for India in Council to present to the Geological Society some specimens of Burmese rubies attached to their matrix, which were procured by Mr. Barrington Brown, at present employed by Government in examining the mines which came into their possession on the annexation of Upper Burmah.

Mr. Barrington Brown writes concerning these specimens thus:—

"I send * * six specimens of rubies in granular limestone, where they were formed. They were obtained by blasting, under my direction, in a place formerly mined by natives * * * *. As I believe the fact of the ruby being traced to its matrix is new to science, the specimens may prove of interest to scientific men * * *. I should like Professor Judd, President of the Geological Society, to see the specimens."

I am, Sir,
Your obedient Servant,
(Signed) J. A. GODLEY.

Professor JUDD,
President, Geological Society.

2. "On the Sudbury Copper Deposits (Canada)." By J. H. Collins, Esq., F.G.S.

3. "Notes on some of the Auriferous Tracts of Mysore Province, Southern India." By George Attwood, Esq., F.G.S., F.C.S., &c.

4. "On the Durham Salt-district." By E. Wilson, Esq., F.G.S.

5. "On the Occurrence of *Calcisphæræ*, Williamson, in the Carboniferous Limestone of Gloucestershire." By E. Wethered, Esq., F.G.S., F.C.S.

[Abstract.]

The small hollow spheres, with varying forms of peripheral appendages, described by Prof. Williamson as *Calcisphæræ*, were found in the Carboniferous Limestone of Flintshire, and were suggested by him to be possibly Foraminifera or the reproductive capsules of some marine form of vegetation, although he admitted that no forms hitherto discovered afforded any definite support to this hypothesis. Prof. Judd expressed a belief that the objects were Radiolaria; whilst Mr. Shrubsole discovered similar bodies in the Mountain Limestone near Llangollen, and conjectured that the described forms included both Foraminifera and Radiolaria.

The Author has discovered the *Calcisphæræ* in great numbers in the Carboniferous Limestone of Gloucestershire. He discussed the identity of certain calcareous rings ·005 in. in diameter, seen in sections of the limestone of Clifton, &c., with siliceous bodies which he had described in a recent paper read before the Society, and gave an account of the calcareous and siliceous forms, which were both referable to *Calcisphæræ*. He commented upon the character of the carbonate of lime of the calcareous bodies, which presented a granular structure characteristic of the truly organic portion of the limestone, and not a clear crystalline aspect like that of the infilling or replacing calcite; he concluded therefore that the tests had been originally calcareous, and not siliceous replaced subsequently by carbonate of lime. This was urged as a strong argument against regarding the organisms as Radiolaria, and the Author, whilst considering it unwise to come to a decided conclusion, believed it safe to say that they were Protozoa.

6. "Second Note on the Movement of Scree-material." By C. Davison, Esq., M.A. (Communicated by Prof. T. G. Bonney, D.Sc., F.R.S., F.G.S.)

The following specimens were exhibited:—

Specimens of Rubies in their original matrix (crystalline limestone) from Upper Burmah, collected by C. Barrington Brown, Esq., F.G.S., exhibited in illustration of the letter from H.M. Secretary of State for India.

Rocks and microscopic sections, also a Mortar used by the ancient miners to crush the gold-bearing quartz; the latter was *in situ* with numerous others and was removed by hand-drilling; exhibited by G. Attwood, Esq., F.G.S., in illustration of his paper.

Rock-cores from the Seaton Carew trial-boring, lent by W. J. Bird, Esq., to illustrate the paper by E. Wilson, Esq., F.G.S.

Microscopic sections exhibited by E. Wethered, Esq., F.G.S., in illustration of his paper.

June 20, 1888.

W. T. Blanford, LL.D., F.R.S., President, in the Chair.

James E. Bedford, Esq., Clifton Villa, Cardigan Road, Leeds; William King, D.Sc., B.A., Director of the Geological Survey of India, Geological Survey Office, Calcutta; R. E. Leach, Esq., M.A., St. Mary's Cottage, Beccles; John Leechman, Esq. 92 Sinclair Road, West Kensington Park, W.; Peter McKeller, Esq., Fort William, Canada; Major Harold Parminter Molineux, Lewes, Sussex; the Rev. George Frederick Handel Rowe, 30 Gladstone Road, Halifax, Yorkshire; and William Thompson, Esq., O'Sullivan Chambers, Ipswich, Queensland, were elected Fellows of the Society.

The List of Donations to the Library was read.

The List of Donations to the Museum was read, and included:—

Specimens of Rubies in their original matrix (crystalline limestone) from Upper Burmah, collected by C. Barrington Brown, Esq., F.G.S., presented by the Secretary of State for India.

A collection of Rocks and Minerals from the Island of Porto-Rico, presented by Antonio J. Amadeo, M.D.

The following names of Fellows of the Society were read out for the second time, in conformity with the Bye-Laws Sect. VI B, Art. 6, in consequence of the non-payment of the arrears of their contributions:—Rev. T. C. B. Chamberlin; W. M. Cole, Esq.; A. Colvin, Esq.; W. F. Fremersdorff, Esq.; F. Gillman, Esq.; A. Leech, Esq.; Rev. E. R. Lewis; G. Paul, Esq.; J. Parkinson, Esq.; Dr. G. Tate; and R. B. N. Walker, Esq.

The following communications were read:—

1. "On the Occurrence of Marine Fossils in the Coal-Measures of Fife." By Jas. W. Kirkby, Esq. (Communicated by Prof. T. Rupert Jones, F.R.S., F.G.S.)

2. "Directions of Ice-flow in the North of Ireland, as determined by the Observations of the Geological Survey." By J. R. Kilroe, Esq. (Communicated by Prof. E. Hull, F.R.S., F.G.S.)

3. "Evidence of Ice-Action in Carboniferous Times." By John Spencer, Esq., F.G.S.

[Abstract.]

The Author combated the notion that there is any *à priori* improbability in the action of ice during the period in question. In the case under consideration, of the two agents, land-ice or floating-ice, he was inclined to adopt the latter, as having been the cause of the phenomena he described. The bed affected is the Haslingden Flag-rock, a member of the Millstone-Grit series, which is directly covered by a shale of the same series. The surface of this Flag-rock is largely striated, the striæ having a N.E. and S.W. direction, and being nearly parallel. The area exposed is 200 square feet. The Flag-rock dips to the east at an angle of 30°; but there seems no possibility of these striæ having been produced by landslips or local disturbance. A quarry on the same horizon, near Rochdale, exhibits similar phenomena. As collateral evidence of ice-action, he alluded to the boulders frequently found in the coal-seams.

Discussion.

Dr. Hinde considered that the markings on one of the specimens exhibited more nearly resembled slickensides than striæ produced by ice-action.

Mr. Topley said the question of the striæ was difficult to decide; but he thought the reference to boulders in a coal-seam a thousand feet above did not help matters. He considered the appearances due most probably to movement of the nature of slickensides. It was too hazardous to put it down to ice-action.

4. "The Greensand Bed at the base of the Thanet Sand." By Miss Margaret I. Gardiner, Bathurst Student, Newnham College, Cambridge. (Communicated by J. J. H. Teall, Esq., M.A., F.G.S.)

5. "On the Occurrence of *Elephas meridionalis* at Dewlish, Dorset." By the Rev. O. Fisher, M.A., F.G.S.

6. "On Perlitic Felsites, probably of Archæan Age, from the flanks of the Herefordshire Beacon, and on the possible Origin of some Epidosites." By Frank Rutley, Esq., F.G.S.

7. "The Ejected Blocks of Monte Somma.—Part 1. Stratified Limestones." By H. J. Johnston-Lavis, M.D., F.G.S.

[Abstract.]

Introductory.—The Author referred to the Hamilton collection, now in the British Museum, and to the work of Prof. Scacchi, who enumerates 52 mineral species as having been found in the ejected blocks, and indicated the importance of these from a geological and volcanological point of view. His own collection contains over 600 specimens, showing the gradation from unaltered limestones, through various stages of change into numerous varieties of "true metamorphic rocks," which, in their turn, shade into igneous rocks more and more approaching the several modifications of the normal cooled magma of the volcano. Moreover, such rocks come from depths where they have not been affected by alterations of a secondary nature.

He then gave a classification of the varieties of ejected blocks. The Tertiary rocks are but slightly metamorphosed, while the limestones of Cretaceous or earlier age afford an almost unlimited series of mineral aggregates. Physical changes have converted them into carbonaceous and saccharoidal marbles; next oxides and aluminates have separated, and silicates have been introduced. Such rocks come under the definition of *accidental* ejectamenta. They are only ejected when the apex of the crater-cavity, formed by an explosive eruption, extends below the platform of the volcano into the underlying rocks. He then traced the history of the eruptions of Somma-Vesuvius through divers phases, showing that it was only at a comparatively late period that limestone-fragments were blown out, though this had taken place long before the Plinian eruption. The stratified limestones have been chosen for the first part of this paper, because their original lithological structure acts as a guide as we proceed from a normal limestone to its extreme modifications.

Part I.—The character of the limestones which underlie the platform of Vesuvius may be studied in the peninsula of Sorrento, where the mass attains a thickness of 4700 feet. They are magnesian in varying proportions. A table was given showing twenty-seven analyses, made principally by Ricciardi, the amount of MgO ranging from 1 to 22 per cent. Silica rarely exceeds 2 or 3 per cent., whereas in the greater number of limestones it is absent. The bituminous matter, though a powerful colouring agent, usually exists in quantities too small for estimation, but sometimes reaches 3 per cent. Such are the materials out of which the extraordinary series of silicate-compounds have been developed, and as these materials of themselves could not form peridotes, micas, pyroxenes, &c., it is clear that the silica, alumina, iron, fluorine, &c. must have been introduced from without, viz., from the neighbouring igneous magma. The Author then discussed the question of the probable methods, being inclined to favour the notion of vapour in combination with acid gases.

The bulk of the paper was occupied with a detailed description of the microscopic structure of these stratified limestones and their derivatives. The Author remarked that the same metamorphic changes may be traced on a much grander scale amongst the ejected blocks, and hinted at the similarity of these changes to those of contact-phenomena as seen elsewhere, and even of regional metamorphism, the two main factors to be considered being the composition of the rock to be acted upon and that of the magma acting.

The changes which ensue in an impure limestone are, in the first place, the carbonization of the bituminous contents, which are converted into graphite; and a kind of recrystallization, approaching the saccharoidal structure, seems to have taken place, although the stratification &c. is preserved. A few grains of peridote now begin to make their appearance, chiefly as inclusions within the calcite crystals, and thus by degrees the results already recorded are effected. In the early stages only is the metamorphism selective. The order in which the new minerals seem to develop is the following:—

(1) Peridote, Periclase, Humite.
(2) Spinel, Mica, Fluorite, Galena, Pyrites, Wollastonite.
(3) Garnet, Idocrase, Nepheline, Sodalite, Felspar.

Many of these minerals are crowded with microliths, which, there is reason to believe, consist of pyroxene.

Discussion.

The President spoke of the difficulty of adequately placing so elaborate a paper before the Meeting in the absence of the Author.

Mr. Rutley had heard sufficient to appreciate its importance. There were many points of interest, especially those relating to periclase, a mineral almost, if not exclusively, confined to this district. It was interesting to know of its hydration and passage into brucite.

Mr. Teall spoke of the special interest attaching to the behaviour of limestone blocks in the presence of igneous masses. He referred to the presence of idocrase in the Coniston Limestone near Shap. He alluded to a communication recently made by Mierisch, published in Tschermak's 'Mittheilungen,' where similar phenomena were recorded.

The following specimens were exhibited:—

Specimens of *Elephas meridionalis* from Dewlish, Dorset, and of the deposit in which they were found, exhibited by the Rev. O. Fisher, M.A. F.G.S., in illustration of his paper.

A collection of similar specimens from the same deposit, and photographs, exhibited by J. C. Mansel-Pleydell, Esq., F.G.S.

Right lower molar of *Elephas antiquus* from Whittlesea, Cambridge, exhibited by Prof. T. McKenny Hughes, M.A., F.G.S.

Specimens exhibited by John Spencer, Esq., F.G.S., in illustration of his paper.

Microscopic slides exhibited by Miss Margaret I. Gardiner, in illustration of her paper.

Rock-specimens and microscopic sections exhibited by F. Rutley, Esq., F.G.S., in illustration of his paper.

Rock-specimens and microscopic sections exhibited by H. J. Johnston-Lavis, M.D., F.G.S., in illustration of his paper.

ADDITIONS

TO THE

LIBRARY AND MUSEUM OF THE GEOLOGICAL SOCIETY.

Session 1887–88.

I. ADDITIONS TO THE LIBRARY.

1. Periodicals and Publications of Learned Societies.

Presented by the respective Societies and Editors, if not otherwise stated.

Academy. Nos. 790–817. 1887.

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G. Scoular. Sketch of the Geology of the Southern and Western Parts of the Lake Eyre Basin, 39.—R. Tate. The Lamellibranchs of the Older Tertiary of Australia, 142.—R. Tate. The Scaphopods of the Older Tertiary of Australia, 190.—R. Tate. The Pteropods of the Older Tertiary of Australia, 194.

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A. S. Woodward. On a new Species of *Semionotus*, from the Oolite of Brora, Sutherlandshire, 175.—A. S. Woodward. On the so-called *Microdon nuchalis*, Dixon, from the Chalk of Sussex, a new Species of *Platax*, 342.—A. H. Foord. On "*Orthoceras* (*Endoceras*) *duplex*," Wahlenberg et auctt., with Descriptions of three new Species of *Endoceras* from the Ordovician of Sweden and Russia contained in the British Museum, 393.

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H. Alleyne Nicholson. On the Structure and Affinities of the Genus *Parkeria*, Carp., 1.—A. Smith Woodward. Notes on the Determination of the Fossil Teeth of *Myliobatis*, with a Revision of the English Eocene Species, 36.—A. Smith Woodward. Note on the Extinct Reptilian Genera *Megalania*, Owen, and *Meiolania*, Owen, 85.—P. Martin Duncan. On some Points in the Anatomy of the Temnopleuridæ, 109.—P. Martin Duncan. On *Glyphastræa sexradiata*, Lonsdale, sp., 160.—H. J. Carter. On two new Genera allied to *Loftusia*, from the Karakoram Pass and the Cambridge Greensand respectively, 172.—J. Young. On the Structure of *Fistulipora incrustans*, Phill. (*F. minor*, M'Coy), 237.—H. J. Carter.

On the Nature of the Opaque Scarlet Spherules found in the Chambers and Canals of many Fossilized Foraminifera, 264.—F. A. Bather. Shell-growth in Cephalopoda (Siphonopoda), 298.—A. Smith Woodward. Note on the Early Mesozoic Ganoid, *Belonorhynchus*, and on the supposed Liassic Genus *Amblyurus*, 354.—J. F. Blake. Remarks on Shell-growth in Cephalopoda, 376.—T. Rupert Jones. Notes on the Palæozoic Bivalved Entomostraca, No. XXV. On some Silurian Ostracoda from Gothland, 395.—R. Kidston. On the Fructification and Affinities of *Archæopteris hibernica*, Forbes, sp., 412.—F. A. Bather. Professor Blake and Shell-growth in Cephalopoda, 421.

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C. Schlüter. Ueber Scyphia oder *Receptaculites cornucopiæ*, Goldf., sp., und einige verwandte Formen, 1.—M. Verworn. Zur Entwicklungsgeschichte der Beyrichien, 27.—C. Struckmann. Die Portland-Bildungen der Umgegend von Hannover, 32.—A. Penck. Bericht über eine gemeinsame Excursion in den Böhmerwald, 68.—A. von Groddeck. Dritter Beitrag zur Kenntniss der zinnerzlagerstätte des Mount Bischoff in Tasmanien, 78.—P. J. van Beneden. Ueber einige Cetaceen-Reste vom Fusse des Kaukasus, 88.—G. Gürich. Beiträge zur Geologie von West Africa, 96.—F. Römer. Notiz über ein als Diluvial-Geschiebe vorkommendes Bilobiten-ähnliches Fossil, 137.—F. Frech. Die Versteinerungen der unter-senonen Thonlager zwischen Suderode und Quedlinburg, 141.—G. Böhm. Das Alter der Kalke des col dei Schiosi, 203.—G. Böhm. Die Facies der venetianischen grauen Kalke im Département de la Sarthe, 204.—K. Œbbeke. Ueber Glaukophan und seine Verbreitung in Gesteinen, 211.—A. von Groddeck. Ueber die Abhängigkeit der Mineralfüllungen der Gänge von der Lage derselben, 216.—F. Römer. Ueber den Granatenfund auf der Dom-Insel in Breslau, 219.—A. von Groddeck. Ueber Turmalinenthaltende Kupfererze vom Tamaya in Chile nebst einer Uebersicht des geologischen Vorkommens der Bormineralien, 237.—K. A. Penecke. Ueber die Fauna und das Alter einiger paläozoischer Korallriffe der Ostalpen, 267.—O. Jäkel. Ueber diluviale Bildungen im nördlichen Schlesien, 277.—C. Ochsenius. Ueber das Alter einiger Theile der südamerikanische Anden, II., 301.—C. Diener. Ein Beitrag zur Kenntniss der syrischen Kreidebildungen, 314.—H. Pröscholdt. Ueber die Gliederung des Buntsandsteins am Westrand des Thüringer Waldes, 343.—F. Frech. Die paläozoischen Bildungen von Cabrières (Languedoc), 360.—J. Lemberg. Zur mikrochemischen Untersuchung von Calcit, Dolomit und Predazzit, 489.—A. Jentzsch. Ueber eine diluviale *Cardium*-Bank zu Succase bei Elbing, 492.—A. Jentzsch. Ueber den Seehund des Elbinger *Yoldia*-Thones, 496.—G. Gürich. Ueber *Encrinus gracilis* von Gogolin i. O.-S., 498.—O. Zeise. Ueber das Vorkommen von Riesenkesseln bei Lägerdorf, 514.—J. Felix. Untersuchungen über fossile Hölzer, Drittes Stuck, 517.—C. E. Weiss. Mittheilungen über das ligurische Erdbeben.—H. Eck. Bemerkungen über einige Encrinus-Arten, 540.—J. Lemberg. Zur Kenntniss der Bildung und Umbildung von Silicaten, 559.—C. Struckmann. Notiz über das Vorkommen des Moschus-Ochsen (*Ovibos moschatus*) im diluvialen Flusskies von Hameln an der Weser, 601.—M. Neumayr. Ueber *Paludina diluviana*, Kunth, 605.—H. Landois. Ueber einen ungewöhnlich grossen *Ammonites coesfeldiensis*, Schl., 612.—F. Frech. Ueber das Devon der Ostalpen, nebst Bemerkungen über das Silur und einem paläontologischen Anhang, 659.—F. Frech. Ueber Bau und Entstehung der Karnischen Alpen, 739.—H. Gylling. Zur Geologie der cambrischen Arkosen-Ablagerung des westlichen, 770.—J. G. Bornemann. Der Quartzporphyr von Heiligenstein und seine Fluidalstructur, 793.—H. Pohlig. Ueber *Elephas trogontherii* und *Rhinoceros Merckii* von Rixdorf bei Berlin, 798.—E. Kayser. Ueber eine Bereisung des Hohen Venn, 808.—H. Pohlig. Ueber einige geologische Aufschlüsse bei Bonn, 811.—C. Dalmer. Ueber das reichliche Vorkommen von Topas im Altenburger Zwitter, 819.—R. Wagner.

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A. Nehring. Ueber fossile *Arctomys*-Reste vom Süd-Ural und vom Rhein, 1.—A. Krause. Ueber *Harpides*-Reste aus märkischen Silurgeschieben, 55.—W. Dames. Ueber *Titanichthys pharao*, nov. gen. nov. sp., aus der Kreideformation Aegyptens, 69.—W. Dames. Ueber die Gattung *Saurodon*, 72.

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E. Koken. Die Dinosaurier, Crocodiliden und Sauropterygier des norddeutschen Wealden, 309.

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C. J. Woodward. The Minerals of the Midlands, 11.

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W. Mathews. The Halesowen District of the South Staffordshire Coal-Field, 313.—F. W. Martin. On the Sections of the Drift between Soho and Perry Barr, near Birmingham, 364.

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A. J. Noguès. El Oro, 109, 139.—R. B. White. Los mares de hielo —" Glaciers "—de los Andes del Tolima, 145.

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