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THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

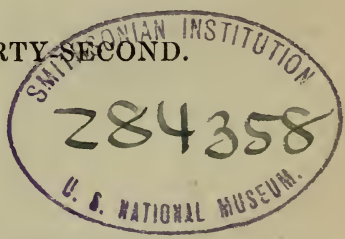
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Quod si cui mortalium cordi et curæ sit non tantum inventis hæerere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales,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

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- At p. 30, line 22, *for substneces read substances.*
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line 30, *for Guibon read Guybon.*
46, last line, *for Ketospondylian read Tretospondylian.*
59, line 2, *for carbonarius read anglicus.*
124, figure, the bracket of the "Laminated series" should include only
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1. *On the GRANITIC, GRANITOID, and ASSOCIATED METAMORPHIC ROCKS of the LAKE-DISTRICT.* Parts III.—V. By J. CLIFTON WARD, Esq., Assoc. R.S.M., F.G.S., of the Geological Survey of England and Wales. (Read December 1, 1875.)

[PLATES I. & II.]

PART III.—*On the Skiddaw Granite and its associated Metamorphic Rocks.*

[PLATE I.]

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Q. J. G. S. No. 125.

Introduction.

The Skiddaw Granite occurs over several detached areas of small extent in the mountain tract on the north side of Skiddaw and Blencathra, much of which is known as Skiddaw Forest, the birth-place of the river Caldew. The alteration in the surrounding Skiddaw Slate extends in every direction for two or three miles from the central mass, and is necessarily somewhat varied in character by the changeable nature of the slate, which not unfrequently contains beds of a sandy or even gritty texture. This last fact must be carefully borne in mind when we consider the metamorphism which has been effected.

As in the last part of this memoir, the subject shall be dealt with under the three heads of:—I. Examination in the field. II. Microscopical Examination. III. Chemical Examination.

In an Appendix short notices are given of similar researches on these and kindred rocks.

I. Examination in the Field.

1. *Unaltered Slate.*—The general character of the unaltered clay-slate is that of a bluish grey cleaved rock, seldom forming slates of any value, but generally weathering into small flakes and chips or into pencil-like fragments. The sandy or gritty beds are usually uncleaved—but are very inconstant in character, and over the area in question do not form beds of any thickness.

2. *First Stage of Alteration: Chiestolite Slate.*—On approaching the Skiddaw-granite area from the south, as on walking up the valley between Skiddaw and Blencathra, the first trace of alteration met with is the appearance of small faint spots on the cleaved surfaces of the slate. These increase in number and size; and many of them, becoming more definite, assume the form of crystals of chiestolite, which are soon found to traverse the slate in every direction, so that very various sections of their rhombic form are displayed, frequently showing a dark centre. The band of the chiestolite slate is seldom more than a quarter of a mile in width.

3. *Second Stage of Alteration: Spotted Schist (Knotenschiefer).*—The slate just described passes gradually into a rock of a general schistose character. It becomes more massive and less cleaved, the planes of cleavage being replaced by those of an imperfect foliation, which retain, however, the same general strike and dip, though they are frequently contorted.

The foliation seems to be due to the development of innumerable little spots, mostly of a rectangular or oblong form, lying with their longer axes in the planes of foliation; and they give the rock a general dark and spotted appearance. Large crystals of chiestolite and andalusite* frequently traverse the mass; and in many parts minute spangles of mica appear.

* It will be borne in mind that chiestolite is but a variety of andalusite, and the latter term may sometimes be used to include both.

This rock, misnamed Hornblende Slate, is frequently well jointed, and has furnished a great many boulders which have been transported southwards out of the tract of Skiddaw Forest. Its texture has also favoured its use for making sets of musical stones, several of which may be seen in Keswick.

4. *Third Stage of Alteration: Mica-schist.*—The spotted schist, becoming increasingly micaceous, passes over into mica-schist, which, however, is seldom well and typically developed, except close round the margin of the granite. It generally retains more or less of the spotty character, the spots becoming more and more faint, while sometimes crystals of chialstolite also occur.

The general colour of this schist is a light grey, passing into bluish grey. The foliations are wonderfully contorted, as may be especially well seen near the granite, at the junction of Grainsgill Beck with the river Caldew. This rock also weathers in places into large blocks, which often lie thickly strewn upon the mountain-slopes; but in other parts it readily crumbles away, forming a sandy wash.

5. *Granite and its Junctions with the Altered Rocks.*—The granite, around which these altered rocks lie, occurs in three detached masses, a small patch exposed in Sinen Gill (101 S.E.), a larger in the upper course of the Caldew, and a third a little lower down the same river, and extending northwards to the foot of Brandy Gill (101 N.E.). There is a fourth small area of granite at the head of Brandy Gill; but it is only poorly developed, and is much decomposed by weathering. It is surrounded by other rocks than Skiddaw slates, and will therefore be dealt with elsewhere.

The Sinen-Gill and *upper* Caldew granites are precisely similar in character, consisting of white felspar and dark mica; and the Brandy-Gill rock differs but slightly, and that principally on the north, where it borders on rocks which do not belong to the Skiddaw Series.

In almost every case observed the junction between the schist and the granite is well marked. Occasionally the schist at the point of junction is the dark and spotted rock, in which case the line of division between the two is very clear; and in no instance is there any difficulty in drawing a geological boundary to these three granitic masses. Sometimes close to the granite the rock becomes a little gneissic; but there is no general passage from mica-schist into gneiss and from gneiss into granite.

II. *Microscopical Examination.*

The microscopic structure of the chialstolite slate and spotted schists has been figured in the Official Survey Memoir on 101 S.E.; but the accompanying illustrations in Plate I. will, I think, throw additional light on the minute structure of these rocks. As in the preceding section of the memoir, one figure shows the actual junction of the granite and metamorphic rock.

1. *Chialstolite Slate.* (Plate I. fig. 1.)—The example figured is a fairly typical specimen of chialstolite slate. In many parts the non-crystalline character of the base is clearly seen, the various particles

of which the rock is composed standing out with sufficient distinctness; but in other parts the granular structure is more or less obscured by a wavy and indistinct meshwork of greenish and brown matter, among which small mica particles are pretty generally diffused.

The crystals of chiastolite are variously developed and are cut in every direction, thus yielding many different forms (see figure), the sections being longitudinal, transverse, or oblique to the principal axis. They invariably contain small particles of carbon, grouped mostly, and often exclusively, at the centre; and associated with these and also occurring in the base, are short black bars, probably of pyrites.

The crystal-sections have a narrow edging with a netted appearance, which appears as a minute coloured mosaic in polarized light, while under the same conditions the interior is either coloured or dark in spaces separated from one another by minute canals. Sometimes, as in the case of the crystal the pointed end of which is seen at the bottom of the figure, when the interior appears dark under crossed prisms, the margins and canals stand out brightly illuminated. In ordinary light the interior has a general light-brown tint between the canals.

In the figure it would almost seem as if the long crystal had been broken and its parts severed by the formation of the central lozenge-shaped one; and it is curious to observe how markedly wavy the base is at the upper end of one of the long fragments. There also occur a few very minute scattered prisms of a mineral which may be andalusite, showing mostly red and green colours in polarized light.

2. *Spotted Schist (Knotenschiefer)*. (Plate I. figs. 2, 3, & 4.)—The chief points to be noted in the microscopic examination of this rock are the great number of the rectangular spots and the crystalline nature of the base. From fig. 2 an idea may be gathered of the distribution of the spots, frequently much along the planes of cleavage, which now become more or less distinct planes of foliation. Sometimes the spots are long and narrow; but the more general form is rectangular or oblong. When viewed with polarized light, most of them distinctly exhibit shades of colour arranged in the form of a cross, as shown in fig. 3; and there seems to be little doubt that the spots are undeveloped chiastolite crystals. Particles of carbon (?) frequently occur in connexion with them as well as in the base, associated with bars of pyrites. In some specimens the numerous decomposing pyrite particles are very evident upon the weathered outside as well as under the microscope. The base around these spots is made up of very minute prisms, showing red and green colours under polarized light, and frequently taking a flowing arrangement (fig. 4), whilst mingled with them are numerous flakes of mica, black bars and dark patches, and some quartz. The prisms, which appear to be rhombic and show no dichroism, are possibly andalusite. The light-yellowish parts near the upper edges of figs. 3 and 4 are quartz, and contain some few liquid-cavities with vacuities. Fine brown cracks frequently traverse the mass.

3. *Mica-schist*. (Plate I. fig. 5, right-hand side.)—The passage from

the spotted to the mica-schist takes place by the increase of mica and quartz and the disappearance in great part of the andalusite and chialstolite. In the most fully developed mica-schist the whole rock consists of quartz and two micas, brown and white; but in most cases there are either traces left of the rectangular spots, often very faint, or sometimes even of well-developed crystals of chialstolite or andalusite. Occasionally, also a little hornblende appears to be present; but this mineral is by no means a constant or characteristic one in any of the rocks of this metamorphic series.

In fig. 5 is shown the junction of the granite and schist, the former appearing white in the specimen, and the latter being a dark micaeous schist. The junction is well defined, microscopically as well as lithologically, the crystalline particles of mica and quartz in the schist being small as compared with those of the same minerals in the granite. Crystals of felspar in the schist seem also comparatively rare. In the figure the variously clouded patches are mostly quartz, and some crystals of triclinic felspar occur on the left-hand side: small plates of mica are also present.

From the above descriptions it will be seen that, the mineral hornblende being scarce, the old name of hornblende slate is false when applied to the schistose rock; and I think there can be no question that it is an andalusite schist, probably the equivalent of the German Knotenschiefer.

III. Chemical Examination.

Having noticed the appearance and bearing of these rocks in the field, and examined their microscopic structure, we turn to their chemical composition. The following analyses have been made for me by Mr. John Hughes, F.C.S.; and I prefix an analysis of Welsh slate, after Haughton, to compare with A.

	Welsh Roofing Slate. Haughton.	A. Chialstolite Slate, How Gill, Skiddaw.	B. Spotted Schist, Skiddaw Forest.	C. Mica Schist (close to granite), Sinon Gill.	D. Skiddaw Granite, White Gill.
Silica	60.50	65.725	54.448	53.174	75.223
Alumina	19.70	14.182	23.930	24.460	11.140
Lime	1.12	1.176	1.288	1.512	1.624
Magnesia	2.20	2.342	2.379	1.946	1.081
Potash	3.18	3.261	3.010	5.037	4.516
Soda	2.20	1.981	2.086	2.930	3.996
Ferrous oxide	7.83	7.306	8.883	8.634	1.771
Ferric oxide .....	...	trace	trace	.246	trace
Bisulphide of iron .....	...	trace	1.801		
Phosphoric acid .....	...	trace	.085	.128	.149
Sulphuric acid .....	...	.294	trace	trace	trace
Carbonic acid .....	...	trace	trace	trace	trace
Loss on ignition, and water	3.30	3.733	2.090	1.933	.500
		100.000	100.000	100.000	100.000

In selecting the specimens for analysis, I have endeavoured as far as possible to take samples which should be fairly representative of the rocks.

The correspondence, in chemical composition, between the spotted and mica-schist is exceedingly close, although the specimens themselves were very different in appearance; while the analyses of these rocks differ considerably from those of the chialstolite slate and the granite. Indeed, chemically the chialstolite slate more nearly approaches the granite than do the intermediate rocks, B and C. The large proportion of alumina in B and C accounts for the great development, especially in B, of the little concretionary spots, in which the excess of alumina would appear to be secreted. Carius gives a set of analyses of spotted schist which show a higher percentage of silica than do either B or C (see Appendix, p. 9).

Now there can be no doubt whatever about the fact of the chialstolite slate passing into the spotted schist; and it is somewhat surprising, at first sight, to see such a manifest decrease in the percentage of silica and increase in that of alumina. But the analyses of clay slate are very variable, and it is quite possible that another sample of a similar rock from the same neighbourhood would present a closer correspondence in chemical composition than does A to B, more nearly resembling the Welsh slate.

The chief difference, chemically, between the metamorphic rocks A, B, C, and the granite D, is that the latter shows a very marked increase in the percentage of silica and a decrease in that of alumina. The question therefore arises, Is it possible to consider the granite in this case the extreme term of metamorphism of these rocks? Prof. Fuchs, in describing a similar series of metamorphic rocks occurring in the French Pyrenees*, shows that, in the extreme terms of the typical mica-schist, gneiss, and granite, the silica and alkalis are increased and the alkaline earths and iron are decreased. But at the same time he states that the increase in silica seems to have been independent of the metamorphism, and mentions unaltered clay slates traversed by white quartz veins. It seems, however, very hard to make this distinction; for the formation of quartz veins implies metamorphic action produced by heated waters carrying silica in solution, and this action probably effected under great pressure. Indeed the whole series of changes, from the unaltered clay slate to the mica-schist, is one pointing strongly to aqueous action under great pressure—in other words, to a very moist heat. It is quite conceivable that, under such circumstances, those rocks most deeply buried would become most highly silicated; and therefore it will not do to say, in *all* cases, that a rock A could not have been converted into another, D, *because* of the much lower percentage of silica in A than D; but, at the same time, when two rocks such as our C and D are found *close* to one another, it seems highly improbable that D has been produced by metamorphism out of the surrounding rock C.

When, therefore, all the evidence in this case is taken into

* Leonhard's Jahrbuch, 1870, p. 717.

account, it seems to me most reasonable to infer that the granite of Skiddaw, which we see exposed at the surface, was *not* formed by the extreme metamorphism of the rocks *immediately* surrounding it. Had this been the case, there would probably have been a more gradual passage, a transition from mica-schist into gneiss, and from gneiss into granite, and the chemical composition of the junction rocks would not have differed by so much as 22 per cent. of silica. At the same time, as just now hinted, it is by no means improbable that the granite was formed out of rocks of a similar class, at a somewhat greater depth; and the granite thus formed, and eating its way upwards, would probably in great measure absorb into itself the rocks immediately around. In connexion with this probable partially intrusive nature of the granite, the much-contorted character of the mica-schist close around it may be noted.

A further examination of the analyses shows that the last item mentioned in each case represents both water and carbon, thus:—

	A	B	C	D
Water	1.698	1.298	1.216	0.397
Carbonaceous matter ..	2.035	0.792	0.717	0.103
	<hr/>	<hr/>	<hr/>	<hr/>
	3.733	2.090	1.933	0.500

We have already seen that microscopical examination shows the presence of carbon in considerable quantity in connexion with the crystals of chiastolite; and it decreases in amount through the various terms of the series; the same seems to be the case with the proportion of water.

It is interesting to note that the proportion of phosphoric acid increases from A to D, just as, in Part II., we saw it increase among the more highly altered members of the volcanic series, accompanied by a *decrease* of carbonic acid; but the percentage of phosphoric acid in the specimens of slate analyzed (see also Part IV.) scarcely seems to warrant the idea that what occurs among the volcanic rocks was solely derived from these underlying slates.

Summary.

1. The spotted rock hitherto called hornblende slate, and well developed in the tract known as Skiddaw Forest, may be conveniently termed spotted (or andalusite) schist (the indefinite Knotenschiefer of the Germans).

2. There is a complete passage in the field from unaltered clay-slate, through chiastolite slate and spotted schist, to mica-schist.

3. The junction between the mica-schist and the granite is well defined, and there is no general transition from mica-schist into gneiss (proper) and from gneiss into granite.

4. Alteration of the clay slate begins by the formation of small spots, which become developed into chiastolite and andalusite.

5. The chiastolite *slate* passes into spotted *schist* by the great increase of the small oblong or rectangular spots arranged along

planes of foliation ; and mica appears, often in considerable quantity, probably formed from some of the andalusite or rectangular spots.

6. The spotted schist passes into mica-schist, consisting of quartz and brown and white mica, but frequently retains, to the last, faint spots, and occasionally chialstolite crystals. The planes of foliation in the mica-schist are very much contorted all round the granite margin.

7. When viewed *microscopically*, the chialstolite slate is found to contain in many parts small crystals, besides the large ones of chialstolite, and the spots, which last are often plainly seen to be but undeveloped chialstolite.

8. In the spotted schist the chief difference, microscopically, is the increase in number of the spots and of the minute crystals in the base, while mica begins to appear pretty plentifully (taking the place of some of the andalusite), and there is some quartz.

9. Lastly, in the mica-schist the andalusite and the spots give way more and more to mica and quartz.

10. Chemically, the altered rocks differ chiefly from the granite in containing far less silica and much more alumina and ferrous oxide. The analyses of the spotted and mica-schists are very nearly identical ; that of the chialstolite slate shows more silica and less alumina, but is in other respects similar to the analyses of the schists, though it contains more carbon.

11. On the whole, the evidence seems to be *against* regarding the granite, now exposed, as the result of the extreme metamorphism of the Skiddaw slates *immediately* around it ; but whether it may not have resulted from the metamorphism of underlying parts of the same series is an open question. The great contortion of the mica-schist may be in part due to the, at any rate *partially*, intrusive character of the granite.

Appendix.

The following papers by foreign authors have been written on rocks similar to those just described :—

NAUMANN, "Knotenschiefer," Erläuter. z. geogn. Karte v. Sachsen, 1838, No. ii. p. 264, and 1845, No. v. p. 50.

KERSTEN, "Knotenschiefer," Journ. f. prakt. Chemie, vol. xxxi. p. 108.

DUCHOCHER, "Études sur le métamorphisme des roches," Bullet. de la Soc. géol. de France, 1846, vol. iii. p. 546.

CARIUS, "Thonschiefer-Metamorphose bei Eichgrün," Leonh. u. Br. Jahrb. 1856, p. 595.

MÜLLER. "Knotenschiefer," Berg- u. hüttenm. Zeitung, 1858, p. 107.

JERMEEJEFF, PRM., "Ueber russische Andalusite," Verhdl. d. k. Ges. für die ges. Mineral. St. Petersburg, 1864, pp. 135-147. Leonh. Jahrb. 1866, p. 724.

KENNGOTT, Elemente der Petrographie (1868), p. 207.

FUCHS, "Die alten Sediment-Formationen und ihre Metamorphose in den französischen Pyrenäen," Leonh. Jahrb. 1870, p. 717.

For microscopic descriptions of the minerals andalusite and chialstolite, see also :—

ZIRKEL, Mikroskopische Beschaffenheit.

ROSENBUSCH, Mikroskopische Physiographie.

The following are the results at which Prof. Fuchs arrives in the memoir quoted, which deals with a set of rocks apparently very similar to those around Skiddaw :—

While the metamorphism of the clay slate generally increases as the granite is approached, yet do alternations occur of beds in all stages of metamorphism.

The metamorphism begins with the appearance of little specks (concretionary), which pass into andalusite and chiastolite; and the rest of the rock-mass passes by degrees into an indistinct mixture of mica and quartz with some felspar (mica-schist and gneiss).

The andalusite and concretions are still met with in the mica-schist and gneiss, but are at last changed by pseudomorphism into mica.

The cause of these mineral changes is, first of all, molecular arrangement; and afterwards an interchange of chemical constituents comes in to help. When the clay slate is changed into mica-schist and gneiss, the superfluous alumina goes to form the concretions and the andalusite. The alkaline earths and iron are decreased in quantity, but the alkalis and silica are increased.

There is a perfect petrographical passage in many places from the gneiss into the granite. The organic matter of the clay slate gradually disappears during the process of metamorphism; but traces of it can be found in all stages of the alteration and even in the granite itself.

The elaborate memoir by Durocher upon metamorphism, quoted above, tends as follows :—

For the idea of semifusion he substitutes that of a flow of secular heat emanating from below and from centres of plutonic action which perhaps did not even attain to dull red heat. Two kinds of metamorphism are distinguished—that resulting from a movement of the particles composing stratified beds, and that produced by the introduction of a foreign body playing the part of a cement and penetrating to the interior of the rocks, as carbon does to iron. Generally the igneous rocks develop in the adjacent beds just those minerals of which they are themselves composed.

Carius describes the metamorphism of clay slate around granite masses, near Eichgrün. At a certain distance from the granite the rock is full of small concretions (spotted schist), and becomes more and more micaceous the nearer the granitic mass is approached. He gives the following analyses of six specimens of these rocks :—

	1.	2.	3.	4.	5.	6.
Silica	59·385	60·028	60·605	63·174	60·005	61·387
Alumina	22·069	19·113	24·055	19·288	24·104	20·803
Iron oxide	6·816	7·373	5·687	4·935	6·436	6·606
Manganic oxide	0·273	0·141	0·280	0·537	0·137	0·246
Lime	0·236	1·165	0·412	0·388	0·173	0·903
Magnesia	3·608	2·186	1·781	1·599	1·872	2·105
Soda	2·109	3·198	0·776	1·829	2·087	3·262
Potash	3·849	3·785	3·648	4·193	2·797	2·966
Water	3·471	3·993	3·305	3·962	2·752	1·476
	101·816	100·982	100·349	99·905	100·363	99·754

Of these analyses, No. 1 is of unmetamorphosed slate, Nos. 2-5 contain the small concretions and mica, gradually increasing in the number and size of its flakes, and No. 6 shows the composition of *Cornubianite*, an extremely hard and crystalline metamorphic rock. The author observes that these analyses prove the metamorphism not to consist in an increase or loss of chemical elements, but rather in a chemical or mechanical change among those previously existing in the rock, and regards the cause of this change, whether the direct action of the granite or watery influence alone, as still an open question.

Kennigott alludes to Knotenschiefer, in his 'Elements of Petrography,' as a rock of an uncertain character to which various names have been given, such as Fleck-, Frucht-, or Garbenschiefer, according to the appearance of the small spots, and which should be definitely named when recognized minerals such as chiastolite &c. are present.

The metamorphosed Skiddaw slates have been thus described by various observers :—

In 1820 Jonathan Otley, whose name will always be held in reverence in the Lake-district, first separated the Skiddaw slates as a group from the other neighbouring formations*, and noticed the "mica slate," the "whintin" (=spotted schist), and the "chiastolite slate" developed around the granite. (See Otley's 'Guide to the Lakes.')

In 1824 and following years Prof. Sedgwick carried on his untiring and thorough investigation of the district. In 1832 he thus writes of the Skiddaw group where metamorphosed † :—“(1) Skiddaw slate with interspersed crystals of chiastolite, alternating with and passing into the preceding group (unaltered Skiddaw slates). (2) A similar slate with numerous crystals of chiastolite, passing in the descending order into a crystalline slate sometimes almost composed of matted crystals of chiastolite. (3) Mica-slate spotted with chiastolite. (4) Quartzose and micaceous slates sometimes passing into the character of gneiss.”

The same author, in his 'Letters,' dated 1842, says “I believe that this beautiful mineral group is nothing more than the Skiddaw slate altered and mineralized by the long-continued action of subterranean heat. The granite, though a fused rock, may not have produced the whole of this change; but it is at least an indication of the kind of power by which the “metamorphic structure was brought about.”

Otley, in the article already quoted, first drew attention to the distinction between cleavage and stratification in connexion with these rocks; and Sedgwick, in 1835, gave a definition of cleavage.

Prof. Harkness, in 1858, alludes thus to the rocks in question :—“This Skiddaw slate (on the north side of the granite), as it approximates the granite of Skiddaw Forest, passes into chiastolite slate, chiastolite rock, and a pseudo-gneiss. On the south side of the gra-

* “Remarks on the Succession of Rocks in the District of the Lakes,” Phil. Mag. vol. lvi. p. 257 (from the Lonsdale Magazine, vol. i. p. 433).

† “On the Geological Relations of the Stratified and Unstratified groups of rocks composing the Cumbrian Mountains,” Proc. Geol. Soc. vol. i. p. 399.

nite the same phenomena occur; but on this side hornblende rock and actinolite rock also appear."

In 1858 Mr. J. G. Marshall* stated his conviction, as mentioned in Appendix to Part II., that all the Lake-district granites were "truly metamorphic rocks," the clay-slate and green-slate series having "been generally subjected to the metamorphic action of heat, pressure, and moisture."

Prof. Harkness again writes on the Skiddaw-slate series in 1863†; and Prof. Phillips, in his article on the geology of the district for Black's Guide, first published in 1846 and revised in 1865, speaks of the gneiss and mica-schist surrounding the granite, and adds:—"Above them appears a thick series of dark slaty rocks, very regularly laminated and full of black spots of hornblende. This rock is locally called '*whintin*,' and by geologists has been named '*hornblende slate*.'"

The "hornblende rock" and "hornblende slate" thus alluded to by Professors Harkness and Phillips are what, for reasons given in the preceding pages, I have called *spotted schist* (German *Knotenschiefer*).

Prof. Nicholson also mentions "chiastolite rock" resting "upon hornblendic gneiss and, in some cases, mica-schist"‡.

EXPLANATION OF PLATE I.

- Fig. 1. Chiastolite slate, How Gill, Skiddaw. $\times 6$.
 2. Spotted schist (*Knotenschiefer*), Skiddaw Forest. $\times 6$.
 3. The same as fig. 2, viewed with polarized light. $\times 20$.
 4. The same as fig. 2, viewed with polarized light; a portion of the base between the rectangular spots. $\times 50$.
 5. Junction of Skiddaw granite and spotted mica-schist. The granite is on the left, and the schist on the right. $\times 10$, polarized light.

These figures have been copied from drawings in water-colour made by the author direct from the microscope.

PART IV.—*On the Quartz-Felsite, Syenitic, and associated Metamorphic Rocks of the Lake-district.*

[PLATE II.]

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 - c. Hypersthenite of Mosedale Crags and Long Dale.

* "On the Geology of the Lake-district, in reference especially to the Metamorphic and Igneous Rocks," Brit. Assoc. Rep. for 1858, Trans. Sect. p. 84.

† Quart. Journ. Geol. Soc. vol. xix. p. 113.

‡ 'Essay on the Geology of Cumberland and Westmoreland,' 1868.

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1. Rocks of St. John's Vale and of Buttermere.
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Summary.

Appendix: Notices of papers on these rocks by other authors.

Introduction.

I now propose to describe the mode of occurrence of several masses of quartz felsite, syenitic granite, and other rocks, together with their metamorphic associates. Following the plan adopted in the two previous Parts, the appearance of these rocks in the open country will first be noticed, and be followed by the microscopical and chemical examinations. Although the several masses are detached from one another, it will, I think, be better to describe the rocks together, in each section, as noted above, rather than to treat of each mass separately in all its bearings. The same order of description being preserved, however, in each section, it will be possible, when desired, to take each rock separately under the various heads of examination, and read all that relates to it independently of the others.

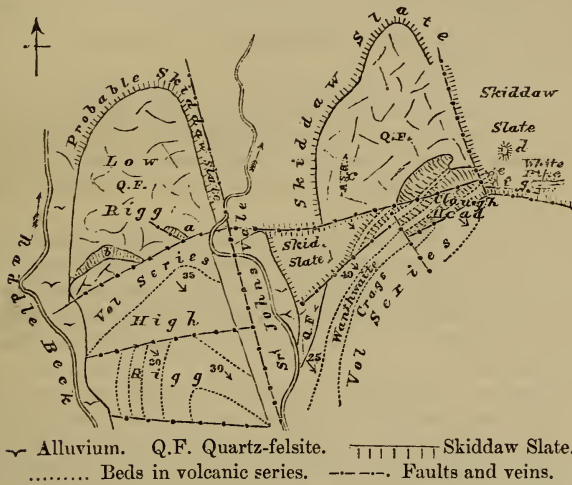
I. *Examination in the Field.*

1. *St.-John's Quartz Felsite and surrounding rocks.*—This rock occurs on either side of the lower end of the Vale of St. John, forming two masses, each about one mile long from north to south and a half to three quarters of a mile broad (Q.F. fig. 1). It is usually of a pale colour, though sometimes assuming a red tint, and consists mainly of quartz and felspar in a felsitic base. The quartz is crystallized. The felspar is orthoclase and oligoclase, the latter being much altered into a yellowish-green steatitic mineral. Mica is sparingly developed; and a small quantity of hornblende may perhaps occasionally be present. The rock not unfrequently contains large fragments, much altered; it is generally well jointed, as at Skundraw, and in some places shows lines of what appear to be former bedding.

Its distribution and appearance in the mass is very striking, except on the south. Each tract appears to be surrounded by Skiddaw Slate, although, the ground being much drift-covered, the slate is only seen at a few points, and at some of these shows little sign of alteration. The western tract is, I believe, faulted on the south against the volcanic rocks of High Rigg; and when looked at

from Wanthwaite Bank (a part of the eastern quartz-felsite tract) there may be noticed several well-marked features, apparently escarpments and dip-slopes, quite similar in strike and angle of dip to the well-scarped beds of High Rigg. When the ground is closely examined, Skiddaw Slate is found to run in among the quartz felsite in two places. One of these, just west of Bridge House, though only a short inlet (*a*, fig. 1), is quite in the line of the most marked

Fig. 1.—Sketch Map showing the Distribution of the Quartz Felsite of St. John's Vale and its Position with regard to the surrounding Rocks. (Scale 1 inch to a mile.)



transverse depression as seen from the other side of the valley. The other is a band of slate (*b*) which, in a much altered condition, may be traced from the fault near St. John's church, through and across the south-western corner of the felsite to Sikes, where both are hidden under alluvium. The appearance in this case is quite that of a bed conformable to the felsite above and below. Along the western side of this felsite tract there is a change in what appears like bedding-dip, to the N.N.E.

Again, when the eastern mass is looked at from the opposite or western side, indications of bedding-planes are also seen; and on the slope above Wanthwaite farm a bed of ash (*c*) appears with felsite above and below and apparently striking northwards, generally parallel to the margin of the felsitic mass. The southern margin of this eastern tract is also partly bounded by vein-faults; but between it and the crags of Wanthwaite and Clough Head, formed of volcanic rocks, occurs a small tract of, for the most part, highly altered slate, containing two or three bands of ash, bounded on the east by a probable north-and-south fault. It is very hard to distinguish

between some of the altered slate and some of these ash-intercalations, or between these and the partially developed felsite; some bands of *black shaly* slate, however, seem to have undergone but little alteration. Between Clough Head and White Pike, and forming the latter, are several small masses of partially developed quartz felsite (*d, e, f, g*), the slate generally passing into them all round; and much of the black slate is here converted into a very hard and flinty rock of the nature of hornstone.

Altogether the disposition and relation of these quartz-felsite masses, especially to the neighbouring volcanic rocks, rather suggest that they occupy the place of basement beds of that series, such beds probably presenting alternations of Skiddaw Slate with volcanic deposits. It will be seen in the sequel how far such a surmise, derived from field-evidence, is supported by the results of microscopic and chemical research.

A third small area of quartz felsite is exposed beneath the volcanic rocks of Wanthwaite Crag; and its upper boundary conforms so precisely to the strike of the overlying strata as to suggest that it also represents the lower part of the series altered *in situ*, the character of the beds above resembling those generally occurring near the base.

2. *Crag-Bridge Quartz Felsite*.—A similar quartz felsite, though occupying a much smaller tract than those of the Vale of St. John, occurs at Crag Bridge, Rosgill, near Shap; and here again the Skiddaw Slate is much altered immediately around the junction, and in some places may be seen to dovetail into the felsite in the most decided manner.

3. *Buttermere and Ennerdale Syenitic Granite, and surrounding rocks*.—This large mass of syenite and syenitic granite extends almost uninterruptedly for a distance of nine miles, from Buttermere on the north, to Wastwater on the south, forming for more than half the distance the boundary between the volcanic series on the south-east, and the Skiddaw Slate on the north-west. It is generally of a reddish tinge; and the hornblende and mica are often sparingly distributed, though occasionally one or the other is found in greater quantity. In the south, where detached masses occur surrounded by the volcanic series, and in some other parts, the rock should rather be called a felstone or sometimes a granulite, as, for example, along the northern shores of the western half of Wastwater.

The eastern boundary, from Red Pike, Buttermere, across the Ennerdale valley, to below Haycock, runs remarkably parallel with the outcrop of the various beds of the volcanic series, and appears in places to be faulted with them; this will be seen by a reference to the accompanying figure (fig. 2). In addition to this it should be noted that in several spots beneath Red Pike the syenite contains bands showing distinct lines of bedding, or, in one case, a markedly brecciated structure very like some of the beds of volcanic ash.

The Skiddaw Slate has experienced the same kind of alteration in this case as around the St.-John's quartz felsite, only that it frequently extends for much greater distances; but in a few cases,

Fig. 2.—Sketch Map showing a part of the Boundary of the Buttermere and Ennerdale Syenitic Granite, and its Relation to the neighbouring Rocks. (Scale 1 inch to a mile.)



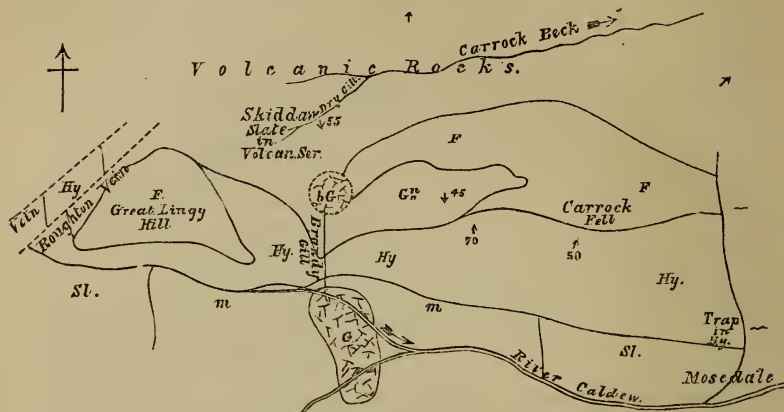
S. Syenitic granite. The rest as in fig. 1.

even here, unaltered black slate occurs close to the junction. Near Scale Force the altered slate has quite a streaky appearance outside; and on the summit of Red Pike, where only a small exposure occurs, it is very hard and massive, approximating to the syenitic rock. On either side of Ennerdale the slate is equally hard and flint-like along the junction and for some distance from it.

The volcanic rocks in its neighbourhood are generally much altered, being rendered very compact and flint-like; but it is often difficult, among these rocks in connexion with the syenite, to separate metamorphic phases from those which are probably not strictly dependent upon it; but in no case have I seen any thing like the series of changes described in Part II. as occurring around the granites of Eskdale and Shap; there are none of the purplish porphyritic rocks so generally found around these granites.

4. *Carrock-Fell Rocks*.—It will be seen by the accompanying figure (fig. 3) that the various igneous masses of Carrock Fell and its

Fig. 3.—*Sketch Map showing the Distribution of the Carrock Rocks.*
(Scale 1 inch to a mile.)



— Alluvium. F. Spherulitic felsite. Gn. Diorite. Hy. Hypersthenite.
G. Granite. bG. Bastard granite. m. Mica-schist. Sl. Skiddaw Slate.

neighbourhood dovetail more or less into each other along an east-and-west strike.

4 a. *Spherulitic Felsite of Carrock Fell and Great Lingy Hill*.—The colour of this rock varies from a pale reddish tint to a brownish-grey and grey, its colour generally serving to distinguish it from the other rocks having the same general range. There is nothing, lithologically, to indicate the spherulitic nature of much of this rock; but this character, as hereafter shown, is clearly revealed by microscopic examination. Its appearance is that of a rather coarse-grained felsite, with scattered greenish spots, and minute, porphyritically imbedded felspar crystals.

The best exposure of this rock is on the summit of Carrock Fell and in the crags just east of the summit. In some parts it has quite the appearance of passing into a trap of much the same nature as many of the contemporaneous beds of the district. A good example of this occurs on the Pike, just east of the Stone Circle.

The felsite graduates on the west and south of Carrock-Fell summit into diorite (?) on the one hand and hypersthenite on the other.

4 b. *Diorite (?) of Miton Hill and Round Knott*.—This rock has a somewhat limited extension, though both felsite and hypersthenite seem to pass over into it, occasionally, in other parts than the area given as its particular range.

Lithologically it is a dark green, highly crystalline compound of felspar and hornblende (?), becoming coarse-grained in the south,

and passing into hypersthenite—and more compact and reddish in the north, passing into the felsite of Rae Crags and Carrock Fell.

At Round Knott this rock contains most distinct lines of bedding, so that several dips could be taken, the general inclination corresponding to that prevailing among alternations of volcanic rocks and Skiddaw Slate in Dry Gill to the north-west.

4c. Hypersthenite of Mosedale Crags and Lang Dale.—Lithologically, this rock varies a good deal in character. When most fully developed it is a very coarsely crystalline mixture of hypersthene and darkish felspar, the hypersthene crystals being sometimes an inch or more in length. The felspar, in such a case, weathers most easily, and the hypersthene stands out prominently, producing a very rough-looking exterior. Occasionally, as at White Crags, the felspar is of a pale or white colour, and the hypersthene occurs generally in smaller crystals than in the rock just described; so that the aspect varies from a white or grey coarse-grained crystalline rock to a dark and more finely grained one.

At several parts along the strike of this rock, and especially a little south of Carrock-Fell summit, the coarsely crystalline hypersthenite presents a most marked appearance of bedding. Alternating with very coarsely crystalline layers are others of very fine grain, the aspect of the rock from a little distance quite resembling the bedding among the volcanic series. Moreover the dip of this bedding is tolerably constant along a line of strike answering to the strike of the volcanic beds on the north, the dip being in this case northwards at angles of from 50° to 70° . Again, at the crags just north of Mosedale, there are most undoubted cases of beds of contemporaneous trap alternating for short distances with hypersthenite and passing into it along the east-and-west line of strike.

It is somewhat doubtful whether or not the southern boundary of this rock with the Skiddaw Slate is a natural or a faulted one; most probably it is a faulted boundary, being very straight, for the most part very definite, and corresponding with a probable fault further to the east, on the other side of the valley. The slate, however, is much altered along the line of junction.

All three of these rocks become somewhat changed in character on approaching Brandy Gill, in and parallel with which there run several strong mineral veins. At the head of the Gill is a small area of bastard or half-developed granite. Below this it would seem that the dioritic and hypersthenic bands approach or cross the Gill, becoming at the same time markedly micaceous. At the foot of the Gill is mica-schist (altered Skiddaw Slate) bordering a very quartzo-micaceous granite.

II. *Microscopical Examination.*

The microscopic structure of the St.-John's quartz felsite and of the Ennerdale syenitic granite has been figured in the Survey Memoir on the Keswick district, pl. i. figs. 5 & 6. In the Plate accompanying the present paper I have given their structure as

more highly magnified, in order that comparisons may be made with that of the altered slate in their neighbourhood.

1. *St.-John's Quartz Felsite and altered Skiddaw Slate.*—In my Memoir on the Keswick district I have described the microscopic structure of the various stages of altered slate around the quartz felsite, but no figures are given. The chief characteristics are the following:—

Specimens of very decided slate, but with evident signs of alteration, show the following structure under a high power:—an irregular and patchy network of a yellowish-green mineral, sometimes crystallized in fan-shaped masses, faintly dichroic and more or less fibrous in appearance; mingled with this apparently chloritic or semi-micaceous mineral are an infinite number of minute quartz grains, while dark particles both of magnetite and carbonaceous matter are diffused throughout.

In the next stage of alteration, represented in fig. 1, Pl. II., the base has a structure which is between granular and felsitic, though more closely allied to the latter. In this base are many crystalline grains of quartz, much larger than any occurring in the previous stage; and imperfectly formed felspar crystals are here and there apparent. The yellowish-green mineral frequently occurs in larger portions, and puts on in many cases more the appearance of mica than in the last example. The quartz contains exceedingly minute liquid-cavities, occasional grains of magnetite, and small portions of the greenish mineral.

Lastly, the rock assumes its fully crystalline structure (fig. 2): the felsitic base contains numerous crystals of felspar, while those of quartz are developed in greater abundance and are generally of larger size than in the previous stage, the liquid-cavities being also larger. Mica is distinctly apparent, generally of a greenish colour.

2. *Crag-Bridge Quartz Felsite.*—In the specimens examined the base of this rock appears somewhat intermediate between that of altered Skiddaw Slate and one truly felsitic, being composed largely of quartz in small grains, and a great quantity of the yellowish-green chloritic mineral frequently crystallized in radiate and fan-shaped groups. Crystallized felspar seems rare, while mica is present in long greenish flakes, and crystals of quartz are here and there porphyritically imbedded. Besides these minerals a little hornblende may also be present. This microscopic character of the rock agrees with what might be inferred from its lithological appearance, being a less decided quartz felsite than that of St. John's Vale, and more resembling some of the minor patches.

3. *Buttermere and Ennerdale Syenitic Granite, and altered Skiddaw Slate.*—Figs. 3 and 4 (Pl. II.) represent the highly magnified microscopic structure of specimens of altered Skiddaw Slate from Red Pike and from near Scale Force, respectively. As before, we have the yellowish-green mineral in profusion, grains of quartz, sometimes assuming a more or less crystalline form, and particles of magnetite, together, probably, with some carbonaceous matter. In the example from near Scale Force the green mineral is frequently

arranged along bands, and the quartz grains are of various degrees of fineness between them. The quartz contains great numbers of liquid-cavities; one of them in fig. 4 is enlarged three times the rest of the figure; and the small contained vacuity in this, as in many other cases, keeps up a continual active movement to all parts of the cavity, never going out of focus in any position.

Fig. 5. represents the structure of the syenitic granite near its border, at Scale Force. The quartz is generally not crystallized, but interstitial and full of minute liquid-cavities; the base consists almost wholly of felspar crystals, both plagioclase and orthoclase, having a finely dotted appearance caused by innumerable very minute cavities. Mica and a chloritic mineral occur, the former scantily; the latter, though very soft, is frequently taken for hornblende. Indeed, although hornblende does occur in some parts of this rock, its presence *generally* is more than doubtful, especially in an unaltered form*; and therefore the term *syenite*, usually applied to this mass, or even that of syenitic granite, is scarcely an exact one. Although varying much in its character, yet, as it is distinct from true granite on the one hand and from true quartz felsite on the other, some distinctive name is needed.

The somewhat doubtful green mineral is frequently accompanied by patches of a black substance or iron-staining; and it seems probable that this is in most cases due to a decomposition of the mineral and peroxidation of the contained iron, the mineral thus resembling chlorophæite. At any rate it seems certain that the green mineral occurring so abundantly in the altered slate and almost universally in the syenitic granite, is one and the same, or different phases of development of the same group, that of the chlorites or hydrous micas. Generally speaking, in the crystalline rock, this greenish mineral occurs in larger flakes than in the altered rocks. Thus, in the latter we have quartz and a hydrous mica in some form, and in the former, quartz, both hydrous and anhydrous mica †, and felspar. The bearing of this will be considered hereafter.

The microscopic structure of the Buttermere and Ennerdale rock necessarily varies somewhat over so wide a spread, though the characters given above and the figure (fig. 5, Pl. II.) contained in this paper and that in the Survey Memoir (pl. i. fig. 6) represent the prevailing structure. Sometimes, where the syenitic granite adjoins the beds of the volcanic series, the transition rock is a hornblendic felsite, collections of small hornblende crystals occurring in a felsitic base.

In some parts the quartz is much diminished in quantity, and the soft green mineral is very abundant; this gives the rock a dark tinge.

4. *Carrock-Fell Rocks*.—We have already seen that the field-examination led to the division of the Carrock-Fell rocks into three

* Prof. Phillips remarks of this rock, "Rarely distinct hornblende is observable" (Black's 'Guide to the Lakes').

† The ordinary micas, it will be remembered, contain small quantities of water, but far less than the chlorite group.

groups, separated from one another by uncertain lines. We shall now see that the microscopic examination, made after the field-work was completed, fully confirms this.

4 a. *Spherulitic Felsite* (Carrock Fell, Rae Crags, Great Lingy Hill).—Specimens taken from various parts, along the line of strike of this rock, all show the same *general* microscopic structure, which is as follows*.

In plain light the base has a felsitic appearance but with indications of a radiate structure from numerous points, while scattered abundantly over this generally pale and hazy base are long greenish and dichroic fibres, and irregular patches and streaks of a green and greenish-brown mineral, which is apparently converted in many parts into a dark brown or black product. Occasionally a few small grains of quartz may be distinguished apart from the felsitic base, and crystals of felspar occur porphyritically imbedded.

In polarized light, between crossed Nicols, the radiate spherulitic structure of the base comes out admirably, a dark cross rotating with the turning of either prism. The spherulites have invariably a radiated and no concentric structure; and their margins are very seldom definite, but interfere with each other or become blended with the general felsitic base (fig. 6, Pl. II.). Their average size is about $\frac{1}{40}$ of an inch in diameter. Under crossed Nicols a good many particles of free quartz may be detected in the base, which exhibits the usual felsitic reaction on rotating either prism. The felspar crystals seem to be mostly orthoclase in some specimens, while plagioclase abounds in others. The green fibres appear to be hornblende; but very little of the greenish mineral seems to be in an unaltered state.

The rock, or parts of the rock, on Great Lingy Hill, are *less* spherulitic and more crystalline than that of Carrock summit; plagioclase crystals are numerous, and free quartz abounds, while a highly reticulated felsitic structure appears between the crystalline portions, apparently the remains of the spherulites.

A specimen from Rae Crags is intermediate between this last and the Carrock-summit rock. It is more crystalline than the latter, and more distinctly spherulitic than the former.

The example of contemporaneous trap-like rock mentioned as occurring on Pike, Carrock Fell, has the following microscopic structure. In ordinary light, numerous green dichroic fibres and particles appear scattered on a hazy felsitic ground; but with a high power ($\frac{1}{4}$ inch) some ghosts of small crystalline needles appear. Between crossed Nicols the base at once assumes a semicrystalline appearance, many small white prisms upon a felsitic ground, with scattered particles of the altered green mineral. I could, however, detect no trace of the development of a spherulitic structure. Altogether I am strongly inclined to think that the microscopic examination tends to confirm the suggestion of its contemporaneous trap-like origin derived from its outward aspect and I therefore

* Only the *general* structure of each group will be here described, all details being reserved for Survey publication.

regard the rock as part of an original lava-flow, with the minutely crystalline structure so common in that class of rock in this country. Whether the spherulitic felsite may be a further step in the alteration of somewhat similar beds, shall be considered when the other two divisions of the Carrock rocks have been described.

4 b. *Diorite* (?), altered dolerite (Round Knott and Miton Hill).—This generally fine-grained, dark, crystalline rock, presents a beautiful appearance under the microscope. Even specimens taken from that part of the rock at Round Knott which shows traces of bedding, have a fine crystalline microscopic structure, consisting of felspar, mostly plagioclase, a hornblendic mineral, and some nearly unaltered augite, and more or less quartz, probably of secondary formation. But, from the manner of occurrence of the green hornblendic mineral, and the indications of partially altered augite, one would be inclined to suspect that the rock may be an extremely altered one, belonging, in parts at any rate, to the doleritic class*.

Looking at its microscopic structure alone, one would but little expect to find such a rock having well-marked lines of bedding.

4 c. *Hypersthenite* (altered dolerite?), south of Carrock-Fell summit, crags above and north of Mosedale Village, Lang Dale, and Balliway Rigg.—This rock presents the following general microscopic characters. A coarsely crystalline compound of plagioclase felspar and hypersthene, with scattered grains of titaniferous iron oxide, and more or less quartz. The dark-green, coarsely crystalline varieties of the rock show little or no quartz; but the white or grey varieties (lighter-coloured felspar) contain a good deal, occupying spaces between the other minerals. The hypersthene may be replaced by a hornblendic mineral or may occur in conjunction with it. Fig. 7 (Pl. II.) represents the microscopic structure of the white variety from White Crags (an analysis of which is given in this paper) as viewed by polarized light. The quartz is seen in triangular and other spaces between the banded plagioclase crystals; and part of an altered crystal of hypersthene is shown with patches of the black iron oxide.

Mention has been made of the apparent stratification in this rock, immediately south of Carrock Fell and Round Knott. The coarse bands are, microscopically, a crystalline mixture of plagioclase and hypersthene; but the fine-grained bands, which alternate with the former, show a very different microscopic structure. This I have endeavoured to reproduce in fig. 8, as seen in polarized light, between crossed Nicols. In ordinary light a great number of well-defined grains, clear and transparent, are seen to be closely touching one another or parted by a green dichroic mineral, and minute particles of magnetite to be scattered plentifully throughout. Between crossed Nicols, the clear grains are seen to consist of partly crystallized felspar and quartz, besides which there occur some crystals of plagioclase of a larger size; and the green mineral seems to be in part hypersthene, and in part, probably, hornblende and

* This was Mr. Allport's opinion when he kindly glanced through these slides.

altered augite; but both are a great deal changed. The divisions which appear so frequently to traverse the small clear spaces appear only in polarized light. This kind of crypto-crystalline structure is akin to that described in Part II. of this Memoir as occurring in a highly altered volcanic rock close to the granite.

These fine-grained *bedded* portions are quite distinct from irregular segregations, some of which occur in the coarse-grained hypersthenite lower down the same hill-side. These last are of irregular form, often more or less circular, of a whitish tint, and fine-grained. Microscopic examination shows them to consist of a compound of well-developed felspar crystals, a green hornblende-looking mineral, and quartz.

III. Chemical Examination.

1. *Rocks of St. John's Vale and of Buttermere.*—The following are analyses of carefully selected specimens of (A) altered Skiddaw Slate from the summit of Red Pike, (B) St.-John's quartz felsite, (C) Buttermere syenitic granite. (See figs. 3, 2, and 5, Plate II.)

	A. Skidd. Slate of Red Pike.	B. Quartz felsite of St. John's.	C. Syenitic granite of Buttermere.	D. Mean of two Skidd. Slate analyses.	E. Coarse ash (altered).
Silica	54.480	67.180	71.442	60.102	68.421
Alumina	20.720	16.650	15.340	17.451	15.855
Lime	1.624	2.352	1.064	1.400	2.016
Magnesia	1.946	1.549	.720	2.144	.792
Potash	3.203	2.914	4.439	3.232	3.338
Soda	6.217	4.032	3.951	4.099	5.627
Ferrous oxide ..	8.188	2.151	1.107	7.747	2.855
Ferric oxide ..	.988	.559	1.230	.494	.172
Phosphoric acid.	.569	.179	.118	.284	.204
Sulphuric acid..	trace	trace	trace	.147	
Carbonic acid ..	trace	.885	trace	trace	trace
Loss on ignition	2.065	1.549	.589	2.899	.720
	100.000	100.000	100.000	99.999	100.000

In the fourth column is the mean of two extreme analyses of Skiddaw Slate, that of A and that of the How-Gill slate brought forward in Part III. The result is a very near approximation to Houghton's analysis of Welsh roofing-slate (see page 5, Part III). In the fifth column I have reinserted an analysis of coarse altered ash, brought forward in Part II. of this memoir*.

The question now arises, Have we any evidence, in chemical composition, to enable us to decide whether the quartz felsite of St. John's or the syenitic granite of Buttermere has been formed deep

* Quart. Journ. Geol. Soc. vol. xxxi. p. 597.

beneath the rocks in connexion with which it now occurs, and intruded into its present position, or by metamorphism *in situ*? If A, or even D, be contrasted with C, the difference in composition is at once seen to be striking, especially with regard to the relative proportions of silica and of ferrous oxide. On the other hand, when C is contrasted with E, the general correspondence is well marked. The same applies also to B—a considerable divergence between it and A or D, and a marked correspondence between it and E. Hence we may infer that, in so far as these few analyses represent the average composition of the rocks, it is quite possible that both the quartz felsite and the syenitic granite may be due to the extreme metamorphism *in situ* of beds of the volcanic series. And, further, the presence of bands of Skiddaw slate, interstratified with volcanic ash or trap, might tend to modify the result, some bands of slate (probably the black shaly bands) not yielding themselves readily to the change, and therefore remaining as such, and others, more highly silicated, such as the example from How Gill, becoming likewise transformed into the crystalline rock, though, perhaps, less decidedly so. We have already seen what evidence there is in the field to support the view that these felsitic and syenitic rocks represent or take the place of beds of the volcanic and Skiddaw series; and I am inclined to think that the evidence of chemical composition goes some way towards strengthening that view.

That these masses of St. John's and of Buttermere were probably consolidated at a very considerable depth has already been shown in the first part of this memoir, when dealing with the evidence of the liquid-cavities in the quartz; and it becomes a question how far metamorphism, carried on thus deeply, may be accompanied by an introduction of an additional amount of silica from below.

Finally, I would by no means wish to assert that *no* part of the masses in question is intrusive. With regard to that of St. John's, occupying only a small area, it may perhaps be so, any intrusive appearance which the rock may now have being probably the result of the subsequent faulting (see map, fig. 1, p. 13). But in the case of so large an area as that of the Buttermere and Ennerdale rocks, it is most probable that, even if we suppose the whole mass to be due to the metamorphism of beds of the volcanic and Skiddaw series, some measure of intrusion among and absorption of overlying beds may have taken place over certain tracts.

The comparatively large percentage due to "loss on ignition" in A and B represents carbon and water in the following proportions:—

	A.	B.
Water	1·704	·752
Carbonaceous matter	·361	·797
	<hr/>	<hr/>
	2·065	1·549

2. *Rocks of Carrock Fell.*—I have had analyses made of typical samples of (F) spherulitic felsite of Carrock Fell, and (G) hyper-

sthenite of White Craggs. The figures 6 and 7 in Plate II. are from slices of these samples.

	F. Carrock- Fell summit.	G. White Craggs.	H. Contemp. trap.
Silica	69·044	56·656	59·511
Alumina	11·660	16·129	17·460
Lime	1·456	7·068	5·376
Magnesia	·540	2·306	1·801
Potash	3·570	1·293	3·705
Soda	9·673	8·296	3·093
Ferrous oxide	1·449	6·590	4·926
Ferric oxide	2·030	·549	1·271
Bisulphide of iron	·	·	·604
Phosphoric acid	trace	·153	·115
Carbonic acid	trace	trace	1·569
Sulphur	·137	·356	·086
Loss on ignition	·441	·604	·483
	100·000	100·000	100·000

In the third column I have placed an analysis, H, of one of the contemporaneous traps of the district, to contrast with G.

When I first entered upon the examination of the Carrock district I fully expected to find a group of unmistakably intrusive rocks; but, as already detailed, I soon found evidence, in the strike of the various rocks above described, in the appearance of apparent dips, and in the existence of included portions of contemporaneous trap, to lead me to suspect that here also might be a case of the extreme metamorphism of rocks *in situ*. When we come to consider what the rocks may be which have possibly been thus altered, we find that the bands of felsite, diorite(?), and hypersthenite occupy a tract of country at the junction of the Skiddaw-slate series with the volcanic series. The volcanic rocks immediately eastwards, upon the other side of the valley, consist of a thick series of lavas, very similar to those of Eycott Hill to the south-east. The country to the north is formed of both ash and lava, the former much altered, and *exceedingly* weathered, and containing some bands of Skiddaw Slate about Dry Gill, dipping *southward*, as if under the rocks of Carrock. Hence these rocks, if they really represent any beds of the volcanic series, may occupy the place of the lowest series of traps and ashes, originally lying in a synclinal, and being the equivalents of the series immediately north and north-west, and east and south-east. Afterwards, on looking over the literature of the area in question, I found that Prof. Sedgwick had written thus of the hypersthenic rock:—"When on the spot, I considered it only as an instance of one of the porphyries near the base of the middle

division (green slate and porphyry) in an unusual state of crystallization" (see Appendix, p. 26).

If the analysis just given be now considered, we shall see how far this old view of Sedgwick's is rendered probable. Unfortunately I have not at present analyses of the lavas of Eycott Hill, which seem to be of a generally more basic character than the one chosen as representative of the more southern contemporaneous traps. However, if G and H be contrasted, the likeness in composition is sufficiently evident; and I doubt not that an analysis of the porphyritic dolerite (contemporaneous) of Eycott Hill and the country to the north would correspond still more closely with G. On the other hand, if F be compared with E (p. 22), representing an ashy and more highly silicated member of the volcanic series, considerable correspondence is again found to prevail. When these facts are taken into account, together with those previously brought forward, it seems, I think, in the highest degree probable that these various masses represent neither truly intrusive rocks nor old centres or foci of volcanic eruption, but rather a series of interbedded volcanic rocks of somewhat varying composition which have been metamorphosed *in situ*, the result being masses of felsite, diorite, and hypersthenite—the first the product of the 'most highly silicated beds, and the latter two of the less silicated and augitic lavas. If this be the case, the names given above to these masses must be regarded as correct only in a limited sense, as suggesting that these old volcanic beds have been so metamorphosed as to take on felsitic, dioritic, or hypersthenitic characters, these characters being by no means persistent and universal over large areas. Owing to the depth at which the metamorphism took place, the rocks have probably been partly silicated from below; and certainly much of the quartz is of secondary formation.

Summary.

1. The quartz felsite of St. John's Vale and the syenitic granite of Buttermere and Ennerdale lie, for the most part, at the junction of the volcanic and Skiddaw series, and seem, by their line of strike and by the occasional presence of bands of slate or volcanic rock enclosed within or running through them, to represent the transition beds between the two series metamorphosed in great measure *in situ*.

2. Microscopic examination seems to prove the occasional passage of *certain parts* of the Skiddaw Slate into quartz felsite (Pl. II. figs. 1 & 2).

3. The chemical examination, so far as it goes, shows the possibility of these rocks being formed by metamorphism out of the volcanic series and included beds of Skiddaw Slate.

4. Evidence gathered in the field, and microscopic and chemical examination, all seem to suggest that the rocks of Carrook Fell &c. represent the base of the volcanic series, consisting largely of contemporaneous traps thrown into a synclinal the axis of which ranges generally east and west, and metamorphosed into rocks of greatly varying character.

5. All the instances of metamorphism brought forward in this part were produced at great depths; and the rocks may have been considerably silicated from below.

6. Although all these various masses treated of were probably formed in the main by the metamorphism of beds *in situ*, it is probable that some parts of the resulting magma became occasionally intrusive among and absorptive of higher beds.

APPENDIX.

Notices of papers on these Rocks by other Authors.

But little more than a bare mention is made by Otley, in his 'Guide,' of the various rocks treated of in this part.

Prof. Sedgwick described them in his 'Letters' (1842). He notes the occurrence of the St.-John's rock in two principal masses, and remarks:—"When the largest mass was protruded, it bore upon its surface an enormous fragment of Skiddaw slate, which was thus elevated far above its natural level, mineralized by heat, and jammed against the base of Wanthwaite crag." (This supposed enormous fragment represents the area occupied by the alternations of slate and volcanic rocks at Clough Head, on the south of the eastern quartz-felsite mass.)

After describing the distribution of the syenite of Ennerdale and Buttermere, Prof. Sedgwick alludes to the alteration immediately around it, remarking that in some places "the black slates are so changed that they can hardly be distinguished from the porphyries of the middle division" (volcanic series). Again—"In some places the formations are in almost inextricable confusion, the slate rocks in one place abutting on the syenite, in another supporting it, and in a third resting upon it. A great mass of the Skiddaw Slate has been caught up by the syenite, carried to the top of Red Pike, and wedged against the green porphyries of High Stile." Finally, he adds:—"In no one case, however, has this syenite in mass penetrated the green slates or passed over them."

The same author notices the "almost endless varieties of structure" exhibited by the syenite of Carrock Fell, its crystals of hypersthene and great quantities of titaniferous oxide of iron disseminated through the mass, remarking:—"when on the spot I considered it only as an instance of one of the porphyries near the base of the middle division (green slate and porphyry) in an unusual state of crystallization."

Mr. J. G. Marshall, in his paper "On the Geology of the Lake-district" &c.*, includes all the syenites with the granites as metamorphic, being, he thinks, "but altered beds of slate rock *in situ*."

Prof. Harkness, in 1863, alluded to the Carrock-Fell syenite †.

Dr. Nicholson, in 1869, contributed a paper ‡ entitled "Notes on certain of the Intrusive Igneous Rocks of the Lake District." He

* Brit. Assoc. Rep. for 1858, Trans. Sect. p. 84.

† "On the Skiddaw Slate Series," Quart. Journ. Geol. Soc. vol. xix. p. 113.

‡ Quart. Journ. Geol. Soc. vol. xxv. p. 435.

notes the regular jointage of the quartz-felsite (called syenite) of St. John's, and its resemblance to bedding in the quarry nearest Threlkeld, and describes the rock in general. The metamorphism of the Skiddaw Slate in the Ennerdale district, around the syenite, is contrasted with the less amount of change occurring along the junction near Buttermere. The strike of the Carrock-Hill porphyry is noticed as similar to that of the bedded trap. In conclusion, the author is disposed "to look upon the igneous masses in question as the roots of the ancient vents from which were derived the alternating ashes and traps which together compose almost the whole of the green-slate series. Whether they are to be regarded as being produced by an alteration and fusion of the Skiddaw slates *in situ* is another question, and one which is at present incapable of solution. Phenomena, however, are not wanting which would appear to favour this view."

Prof. Phillips, in his article in Black's 'Guide,' speaks of the "principal mass" of "the syenitic and porphyritic rocks of the Vale of St. John" having "been forced up amongst the brecciated slates." The Ennerdale and Buttermere syenitic masses, he states, are "evidently irruptive," and "have been forced through, and perhaps have spread over the middle slates" (volcanic series). The same conclusion is also drawn in the case of the "syenites and porphyries round Carrock Fell and High Pike."

EXPLANATION OF PLATE II.

- Fig. 1. Altered Skiddaw Slate passing into quartz felsite, Clough Head, St. John's Vale. Magnified 30 times.
2. Quartz felsite of St. John's Vale. Magnified 30 times.
 3. Altered Skiddaw Slate, summit of Red Pike. Magnified 70 times.
 4. Altered Skiddaw Slate, near Scale Force, Buttermere. Magnified 70 times. The somewhat oval liquid-cavity in the large quartz space is magnified 210 times.
 5. Syenitic granite, Scale Force, Buttermere. Magnified 30 times.
 6. Spherulitic felsite, Carrock-Fell summit. Magnified 10 times, polarized light.
 7. Hypersthenite, White Crags, Carrock. Magnified 10 times, polarized light.
 8. Fine-grained band in coarsely crystalline hypersthenite; these bands dip regularly into the mountain-side, like ordinary bedded deposits. Magnified 10 times, polarized light.

The above figures were drawn in water-colours, direct from the microscope, by the author.

PART V.—General Summary.

CONTENTS.

Leading Results of the several parts—Considerations relating to Metamorphism.

1. Granite at various depths.
2. How far Granite may be an ultimate universal product of Metamorphism.
3. Distribution of Metamorphism.
4. Classes of Metamorphism.

Leading Results of the several Parts.—In the four preceding parts of this memoir I have endeavoured to bring forward all the principal facts bearing upon the origin of the Plutonic rocks of the district, and the degree of alteration to which the surrounding rocks have been subjected.

In Part I. the evidence of the liquid-cavities in the quartz of the granitic and granitoid rocks was considered, the general conclusion being that the granites, syenitic granites, and quartz felsites were all consolidated at very considerable depths, under great pressure, this pressure being much greater than could be due to the thickness of overlying rocks, and therefore exerted mainly from below and laterally, and resulting in the work of upheaval and contortion of the overlying strata. The period at which the principal formation of these granitic and granitoid rocks took place was considered to be that of the Old Red; and the work of elevation, consequent on the great surplus of upward and lateral pressure, was accompanied by an enormous denudation of rocks at the surface during the greater part of Old Red times.

In the subsequent divisions of this memoir, the mode of origin of these various masses was discussed. In Part II. the granites of Eskdale and Shap were dealt with, and it was shown to be at least probable, from evidence gathered in the field, and by microscopic and chemical examination, that these granites had been formed by the extreme metamorphism of rocks of the volcanic series, while at the same time the *partially* intrusive character of the Shap granite was suggested by various considerations.

Part III. discussed the origin of the Skiddaw granite from points of view furnished by field, microscopic, and chemical investigation. The gradual transition from unaltered Skiddaw Slate to mica-schist was proved under these three heads, while at the same time the abrupt passage from the mica-schist to the granite appeared to negative the idea of the next step, into granite, necessarily following in this case.

In Part IV. the quartz felsite of St. John's and the syenitic granite of Buttermere and Ennerdale were examined as to their origin; and there was found to be much evidence in favour of their representing transition beds between the volcanic series and Skiddaw Slates, metamorphosed *in situ*.

The interesting rocks of Carrock Fell were then considered, and field, microscopic, and chemical evidence were all thought to lead to the inference that these masses of felsitic, dioritic (?), and hypersthenitic rocks were due to the metamorphism *in situ* of the beds forming the lower part of the volcanic series.

Such, then, are the leading results of this inquiry; and it now only remains to point out several considerations relating to metamorphism to which the geological facts of this district seem to lead.

1. *Granite at various depths.*—Granite, it appears, may be formed and undergo consolidation at very different depths, and under varying circumstances. If the agents (pressure and moist heat) acting in the formation of granite work tolerably near the surface or

beneath some line of weakness in the overlying rocks, then the great pressure (one of these agents) under which granitic rocks seem invariably to be formed, is likely to relieve itself in volcanic outbursts, and the granite may be said to be *directly* the root of the volcano. But if, on the other hand, these agents are at work at very great depths beneath the surface, the pressure under which the granite may be formed, although very intense in its degree, and far exceeding that due to the superincumbent rocks alone, being unable to open direct connexion with the surface, is spent in the work of elevation and contortion of the overlying rocks. Then, if this work of contortion and fracturing of the rocks above open out great lines of weakness, or produce indirectly, by concomitant denudation taking place at the surface on a large scale, a decrease in the thickness of deposits overlying the granite, this last may then become eruptive, and volcanic outbursts take place at the surface. Hence it would follow, as is found to be the case, that volcanic phenomena succeed or accompany the elevation of large tracts, and occur in connexion with areas of depression.

It would therefore be in the highest degree unwise to suppose that every granitic mass has been the root and origin of some past series of volcanic phenomena; for it may represent (1) a mass so deeply formed that, notwithstanding all the elevation and contortion produced by the intense pressure, no point of sufficient weakness was found whereby relief might be obtained and a volcanic centre be established, (2) a mass which, though very deeply formed, was yet able to penetrate upwards for a certain distance along some area or line of weakness, though its final point of consolidation was still far below the surface, with which it for ever remained unconnected by any volcanic neck; or (3) it may actually represent the very foundation of a true volcanic neck.

The granite of most deeply-seated formation will thus be more usually surrounded by widely metamorphosed and contorted rocks, of which, indeed, the granite itself may generally be considered but a part, whereas the granite directly connected, at a moderate depth, with volcanic phenomena will bear more clearly the marks of an intrusive character. Although all volcanic phenomena may have so deep-seated an origin that they are invariably connected with a granitic magma, it of course does not follow that all consolidated granitic masses must necessarily have been at one time connected with volcanoes. If this view be true, then, in order for the production of the several classes of volcanic rocks, either (A) that so-called granitic magma must vary considerably in its composition over different areas, and at different periods over the same area, or (B) this magma must become variously changed on passing upwards through and among rocks of different composition and character. In the case, however, of a single vent erupting both basic and acidic material at different periods, we must suppose, in the latter alternative (B), that the eruptions had their chief source at somewhat different depths along the same line, where the surrounding rocks by which the character of the magma might be influenced were

likewise different. It is, indeed, hard to suppose that the matter forming the root of a volcano could exist in a state of igneous fusion without at the same time absorbing into itself portions of the surrounding rocks in various degrees, thus having its character more or less modified.

In this connexion it is well to remember that a granitic mass formed by metamorphism of rocks *in situ* is almost sure to become an intrusive mass *at some part*, even among rocks of a similar kind to that out of which it has been formed.

2. *How far Granite may be an ultimate universal product of Metamorphism.*—It has been seen that in the Lake-district there is one group of rocks (the volcanic) which in many of its members (especially the ashes) approaches the granites very nearly in chemical composition, while there is another (the Skiddaw Slate) which generally differs more widely, though having some parts much more highly silicated than others. Now what is true of the rocks of this limited district is true also of rocks in general; and we might be inclined to say decidedly that the latter group could not be metamorphosed into granite, while the former might be. But metamorphic action is varied; and although a simple melting down of clay-slate might never produce granite, yet a moist fusion, accompanied by elementary substances, brought upwards from still greater depths, might effect a great transformation. We know, indeed, that our slate-rocks are often abundantly seamed with veins of quartz, which mineral must have arisen from below in a state of solution, as is evidenced by its now containing myriads of liquid cavities. Now, just as silica has permeated these slightly altered rocks, so we may suppose silica to permeate, probably in still greater quantities, those rocks more highly altered at a greater depth, and the masses in a state of aqueo-igneous fusion at a greater depth still. Hence a rock of the composition of slate may be converted into granite by undergoing a change in the arrangement of the elements preexisting in it, *together with* the addition from below of some of those elements which were lacking in the original slate. In this sense, for example, the Skiddaw granite might be metamorphic in its origin, though possibly formed out of lower beds than those among which it now lies, and with the addition from below of an additional quantity of silica.

All writers on metamorphism have agreed that there are but three ways in which it can be effected—(1) change in the mechanical arrangement of the particles, (2) change in the arrangement of the chemical elements, (3) withdrawal or addition of some of these elements.

3. *Distribution of Metamorphism.*—There is, perhaps, no more striking geological fact than the manner in which, over highly metamorphosed areas, beds or tracts of rock showing little alteration alternate with others most intensely metamorphosed. I believe that the study of alterations effected in such a series of rocks as the "volcanic" in the Lake-district throws light upon this point. In this case there are frequent alternations of beds of very different

degrees of fineness or coarseness of material, and many alternations of various chemical composition. The changes produced have been sometimes purely mechanical—such as the compression of ashy particles into a very solid rock, or the elongation and fresh arrangement of such particles produced in the process of cleavage by intense lateral pressure. But, besides these, other and far greater changes have taken place, variously in different beds, by that most powerful of all agents, water, acting in a more or less heated condition and under pressure. The amount of alteration which has taken place in the beds by atomic or molecular rearrangement, and the addition or withdrawal of chemical elements, is most surprising; and the microscopic study of the rocks brings this fact out in a most striking manner. No trace of the original structure is left in many a rock which outwardly presents no special signs of intense metamorphism. Slice after slice may be cut and examined, and yet, perhaps, not a single fragment of the most prominent mineral be found in a wholly unaltered condition. And if this is the case among the less outwardly metamorphosed beds—if water at a comparatively low temperature, though acting perhaps through vast periods of time, be competent to produce such striking internal changes, what may not result from that far more intensely acting metamorphism, of the same class, which has completely obliterated all signs of former external structure? For it is a fact well worthy of careful notice, that this original external structure (whether of bedding or fragmental) very long survives the destruction of internal structure; and, from the mere outside appearance of many a rock, none would have the faintest idea of the enormous amount of change in its internal and microscopic structure.

Now, if we consider for a moment the action of metamorphism upon a series of rocks formed of alternating beds of (1) moderately fine-grained ash, (2) compact basaltic lava, (3) coarse brecciated ash, (4) fine stratified volcanic dust of a general felspathic character, (5) thin vesicular lava, (6) very fine-grained unstratified volcanic dust, (7) volcanic breccia, we may form a fair idea of what might be called *selective* metamorphism. The above-named deposits might be thus changed into:—1, a hard flinty-looking felstone roughly cleaved; 2, a rock with scarcely a trace of unaltered augite, but full of chlorite, with quartz filling up spaces, and *original* crystalline structure almost or wholly obliterated; 3, a ringing, white-weathering felstone, perfectly structureless inside, but revealing the outline of fragments on the exterior; 4, a felstone-like banded rock, exceedingly trap-like within, and containing imperfectly formed crystals of felspar; 5, an amygdaloidal rock, charged throughout with added material; 6, apparently a fine-grained trap; 7, a massive rock, seeming to be composed of all sorts of metamorphic rocks welded together. It is more than probable that in such a series No. 6 would be mistaken for a bed of contemporaneous trap (lava), of which 5 was the vesicular base, while 4 might be taken to be a contemporaneous *felstone* trap. If these various beds were of some thickness, and had an extended range, the errors supposed

above would be all the more likely to occur, the regularity of metamorphic selection along bands masking the very existence of great metamorphism. This selective metamorphism, in whatever kinds of rock it shows itself, will be much facilitated by the fact that very generally the *strike* of the rocks corresponds with the main axis of metamorphism, both being the result of lateral pressure acting at right angles. It is important to remember that in the case of such a series of beds as that just now supposed, while all may have been subjected to the same general amount of metamorphic action, some will show that metamorphism outwardly far more than others, while at the same time the various beds may have been changed in different ways according to their texture and composition.

4. *Classes of Metamorphism.*—In conclusion, it may be as well just to summarize the principal conditions under which rocks occur with regard to metamorphism.

(1) That state in which *igneous fusion* is the most important or conspicuous element. This is seen in the case of lava flowing from a volcanic vent. The presence of water, however, is distinctly recognized; and its sudden expansion into vapour with explosive violence is acknowledged as the chief agent in those paroxysmal eruptions which have sometimes resulted in the formation of crater-lakes of great size.

(2) A state of *aqueo-igneous fusion*, occurring at a much greater depth than the last, and reaching only a dull red heat as a maximum. In this state we have every reason to suppose the granitic magma to be which may now be solidifying at various remote spots beneath our feet. The metamorphism due to moist heat under pressure, at a temperature not exceeding 400° C., may show itself in the complete changing of the mineralogical and physical aspects of a rock, and in the production of such anhydrous silicates as felspar, augite, &c., which when produced in the dry way require a very much higher temperature for their formation (Daubrée*). Thus, while granite may be solidifying at a certain spot, the rocks all around may become granitoid and porphyritic.

(3) A state in which the rocks are permeated by water at a considerably lower temperature than 400° C. The metamorphism in this case, though not so generally conspicuous, is still highly important. Thus, the water with diminished temperature can now decompose those very felspar crystals which at a higher temperature it could give rise to; and minor changes innumerable may take place throughout the rock subject to it.

DISCUSSION.

Mr. RUTLEY partly agreed with the author in his views as to metamorphism, which seemed to him to be to a great extent a bathymetrical question. Granite had no doubt in many instances been formed from other rocks subjected to great heat accompanied

* This author has shown that the action of water-vapour is similar to that of liquid water.

by pressure. The nature of felsitic matter was not, in his opinion, well understood. In many instances it is exceedingly difficult to distinguish between mica and hornblende, hornblende and mica plates of microscopic size being much alike under certain circumstances. He had never seen lines of bedding in hypersthenite as described by the author. Quartz-porphyry and rocks of that description were merely varieties of granite. The felsitic dykes occurring in the Upper Silurians of the Lake-district nearly all contain magnesian mica. He thought it a curious fact that, although the Carboniferous Limestone must at one time have overlain a great part of the Silurian rocks of the Lake-district, there are no traces of the typical doleritic dykes of the Carboniferous Limestone in the latter rocks, through which, however, the dykes must in the first instance have passed; and it would be interesting to ascertain what was the mineral constitution of basalt dykes of Carboniferous age where they passed through underlying sub-Carboniferous rocks. The spots in the specimens described by the author as "Spotted Slate" appear to be crystals.

Prof. HUGHES drew attention to a paper by Mr. Marshall on the metamorphism of the Lake-district, which he considered correct in principle, though in the application the author might be often wrong. He thought that we should be cautious not to attach too great importance to the apparent dip of metamorphic rocks to or from a granitic boss or ridge, as the phenomena might be produced during movements at any period subsequent to the consolidation of the granite by the greater compressibility of the surrounding rocks as compared with the granite, the extreme of this action producing the protrusion of solid granite, also that the withdrawal of a large amount of matter from below to furnish the materials of the volcanic ejectamenta must cause extensive sinkings of the area from below which this matter was withdrawn. He gave examples, on a small scale, of what Mr. Ward had termed selective metamorphism, and showed that, in the case of the Whin Sill, it seemed to affect most the more siliceous rocks. He also referred to examples of certain mica-trap dykes on the borders of the Lake-district, the mode of occurrence of which suggested that they were due to the alteration of the Silurian rock in place along lines of joints.

Mr. JUDD maintained that the relations of the igneous to the stratified rocks of the Lake-district, which had been rendered so clear by the author's surveys, were perfectly consistent with a totally different conclusion from that at which he had arrived; and he doubted whether the chemical analyses cited in the paper could really be regarded as bearing out the author's views. With respect to the application to the district of Mr. Sorby's deductions from the study of liquid-cavities in the crystals of igneous rocks, he argued that (as many of the necessary data employed in the solution of the problem were confessedly only the rudest approximations instead of actual values) but little importance could be attached to the results arrived at.

Mr. HICKS remarked that, in the Cambrian series, rocks which had

been subjected to the conditions of heat and pressure existing at a depth of 50,000 feet are found not to be sensibly altered, whilst in the same rocks the passage of a trap dyke caused a considerable change in the mineral ingredients in its neighbourhood. The volcanic rocks described by the author were produced, Mr. Hicks thought, in Silurian times.

Mr. WARD replied as follows :

To Mr. Ruttley.—That the passage of the hypersthene into the felsite, though most decidedly gradual in some parts, was frequently tolerably abrupt.

To Prof. Hughes.—That Mr. Marshall's views as to metamorphism were carried much too far, inasmuch as he considered the whole volcanic series to represent beds of an ordinary sedimentary origin highly metamorphosed.

To Mr. Judd.—That the author had always endeavoured to be especially on his guard against mistaking lines of viscosity in volcanic lavas and other rocks for indications of former bedding. He defended the use of chemical analyses, when care was taken to insure the analysis of truly typical and well-selected specimens, adding that, although the results might not go for much when taken alone, yet they were of some value if united with other lines of research on the same rocks, such as microscopic and field examination. With reference to deductions drawn from the examination of liquid-cavities in the quartz of the granites, the author mentioned that Mr. Sorby had expressed considerable surprise and satisfaction at the general agreement of the author's results with those he had published many years since on various granites other than those of the Lake-country, and that a German physicist had arrived at parallel results by an entirely different method of examination. With regard to Mr. Judd's suggestion, that all or much of the Lower Old Red may once have been present in the Lake-district, thus adding to the thickness of rocks above the granite of Skiddaw &c., Mr. Ward remarked that he would leave the Society to judge whether we should consider that at the close of the Upper Silurian some 20,000 feet of strata of Old Red age were deposited and then denuded, *or*, considering there is *no* trace of these Lower Old Red strata in the district, whether at the close of the Upper Silurian, when the Skiddaw Slates were covered by some 20,000 feet of strata, that vast denudation alone took place, which bared the rocks round Skiddaw, and was succeeded by the deposition of only the uppermost beds of the Old Red.

To Mr. Hicks.—That he was of opinion that it was rather too strong a statement to make, that because certain beds buried—as Mr. Hicks affirmed—under 50,000 feet of strata were not much metamorphosed, therefore no granite could be formed at a less depth than this; he believed that the Lake-district work completely confuted such a statement.



Fig. 1.
x 6

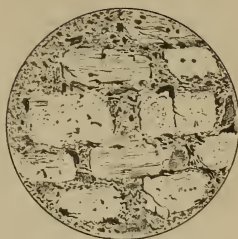


Fig. 2.
x 6



Fig. 3.
x 20

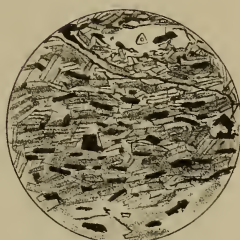


Fig. 4.
x 50



Fig. 5.
x 10

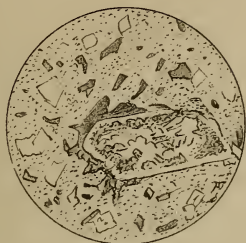


Fig. 1.
x 30



Fig. 2.
x 30



Fig. 3.
x 70



Fig. 4.
x 70



Fig. 5.
x 30



Fig. 6.
x 10



Fig. 7.
x 10



Fig. 8.
x 10

2. NOTES on the PALÆOZOIC ECHINI. By WALTER KEEPING, Esq., of the Woodwardian Museum, Scholar of Christ's College, Cambridge. (Read June 9, 1875.)

(Communicated by Professor T. McK. Hughes.)

[PLATE III.]

THE interest excited by the discovery, in 1869, of that remarkable flexible Echinoderm, *Asthenosoma* or *Calveria*, in the deep Atlantic, is increased by the fact noticed by Mr. J. Young* and other palæontologists, that certain other forms, whose day ended far back in geological time, also possessed the same overlapping plates and consequent flexibility. This structure was first described by Prof. J. Hall in *Lepidechinus*, and has since been noticed by Meek and Worthen in another American genus, *Lepidesthes*, and by Mr. Young in the scattered plates of *Archæocidaris* from our own Carboniferous rocks. This character I have also detected in other genera of the same group of Perischoechinidæ from Co. Wexford, Ireland.

It is worthy of note that whereas in the more modern (Cretaceous and Recent) group of flexible *Echini* (Echinothuridæ) the interambulacral plates imbricate from above downwards, and the ambulacral from below upwards, in these Palæozoic forms (Perischoechinidæ) the opposite arrangement obtains.

1. PERISCHODOMUS. Pl. III. figs. 1-5.

Since the first notice of the genus *Perischodomus* by Prof. McCoy, in the 'Annals of Natural History,' vol. iii. (1849) p. 251, this specimen, which is one of McCoy's two types, seems to have been lost sight of by palæontologists; for we find Mr. Etheridge, Jun., observing † that "very little is known regarding this genus," and Meek and Worthen say ‡ "only a single very imperfect specimen of it has, we believe, yet been found."

McCoy's diagnosis of this genus is:—"Spheroidal, depressed, sub-pentagonal; ambulacra narrow, of two rows of small plates, most usually of a transversely elongate pentagonal figure, and each pierced by one pair of simple pores; interambulacra wide, of five rows of plates very irregular in size and shape, all the plates covered with small equal granules or secondary tubercles, while the rows on each side adjoining the ambulacra alone bear the small smooth primary spines, one on each, the supporting tubercle being small, mammillated, perforated but not crenulated, surrounded by a double ring, and situated not in the centre but near the ambulacral edge, a little above the middle; ovarian plates pierced each with 6 foramina; mouth and anus small, both central."

To this must now be added:—interambulacral plates overlapping

* Geol. Mag. vol. x. p. 302.

† Quart. Journ. Geol. Soc. vol. xxx. p. 312.

‡ Pal. Illinois, vol. ii. p. 295.

from below upwards, and from the centres of the areas outwards; ambulacral from the dorsal side downwards.

The specimen which has disclosed this structure is a flattened, nearly perfect, dorsal half of *P. biserialis* (McCoy)*.

The interambulacral plates are convex and irregular in form, as shown in the figure given by McCoy†; but those of the median row are much more regular, being usually trapezoidal. The inferior overlapped surface of articulation in a well-exposed interambulacral plate is seen to be about half the breadth of the exposed part of the plate itself; it is not simply bevelled off flat, but is slightly hollowed to receive the corresponding *convex* surface of the plate below (fig. 3); on the contrary, in the lateral imbrication, the underlying overlapped surface is slightly convex (fig. 2).

The plates of the median range overlap those on each side of them as well as those above, like the summit tiles of a roof. Of the five ranges of interambulacral plates, two end suddenly at about the third plate from the apical disk, the last one being scarcely smaller than the rest in the range; the plates of the lateral ranges next above are larger than usual by way of compensation (fig. 4).

The ambulacral areas are slightly sunk, their plates overlapped on both sides by the interambulacral, and deeply interlocking with each other. Like the interambulacral plates they are irregular, in places club-shaped, the thick and thin ends alternating, in other places more regular (as in McCoy's figure); their surface is minutely granulated as in the interambulacral plates.

Of the apical disk (fig. 4), the five genital plates are preserved in this specimen. These are pentagonal in form, and are overlapped by the interambulacral plates. They are perforated by numerous pores—6 according to Prof. McCoy; but one plate has 8 distinct perforations, while another almost as obviously could not have possessed more than 6; so that in this genus we have the same remarkable irregularity as is observed by Messrs. Meek and Worthen in the genus *Melonites*‡.

Other small triangular plates are seen, which may possibly be the ocular plates; but I am unable to detect any perforations in them; moreover they are somewhat displaced, so as to be opposite the interambulacral plates; this displacement is shared by the other apical plates. If these are the ocular plates, it is singular that they should overlap the genital plates. Within the circle are seen other plates, two of which appear to be *in situ*; these may represent the *suranal* series of the *Saleniadae* and *Cidaridae*.

Two sets of spines were present in this species (*P. biserialis*). Prof. McCoy described the primary one as cylindrical and smooth "as far as seen." Only the secondary ones (fig. 5) are preserved on this specimen; and these, under the microscope, are seen to be delicate, needle-shaped, and coarsely ribbed. Length 3–5 mm.

In its general aspect, and in the complex nature of its imbrication, Prof. Hall's genus *Lepidochinus* approaches near to *Perischodomus*—so much so that we find Mr. Etheridge saying, "presuming for one

* Ann. & Mag. Nat. Hist. vol. iii. 1849, p. 254.

† Loc. cit. p. 253.

‡ Pal. Illinois, vol. ii. p. 228.

moment that that genus is ultimately proved to possess imbricating plates, the two genera *Lepidechinus* and *Perischodomus* may perhaps be considered identical"* . Still I think there is abundant difference between the two genera. The interambulacral plates in Prof. Hall's genus are far more numerous (as many as eleven ranges of plates); and these dwindle in size towards the summit; also, on the upper surface at least, well-developed tubercles are present on *all* the ranges of interambulacral plates † instead of being confined to the two lateral ranges.

The "imperfect specimens" mentioned by Messrs. Meek and Worthen as "doubtless belonging to *Lepidechinus*" ‡, would probably have been referred by them to *Perischodomus*, had they known of the imbricating character of the plates in this genus. *Lepidesthes* § is distinguished from this by its numerous (10) ranges of ambulacral plates; *Archæocidaris* by its large plates, *each* with a primary tubercle.

2. RHOECHINUS ||, nov. gen.

Test rather small, spheroidal (?), interambulacral areas consisting of five ranges of irregular plates, two of which disappear before reaching the apical pole; plates covered with small granules; no large tubercles. Ambulacral areas narrow, composed of two ranges of interlocking plates, each perforated by a pair of pores. The interambulacral plates imbricate from below upwards, and from the central range outwards; the ambulacral from above downwards.

This genus is nearly allied to *Perischodomus* and *Lepidechinus*, from both of which it is distinguished by the absence of primary tubercles.

R. IRREGULARIS (Keeping). Pl. III. figs. 6-8.

A small Urchin (diam. about 25 mm.), depressed at the poles. Interambulacral plates echinated, with little sharp granules (fig. 8). The median range is the first to disappear towards the poles, being only seen near the *equator* of the test; another range disappears at about two plates from the summit. Ambulacral areas sunk, narrow (2-3 mm.); plates transversely elongated, pentagonal, the pores situated about the centre of the plate. There are 4 or 5 ambulacral plates to one interambulacral.

Loc. Hook Head, Co. Wexford, Carboniferous Limestone.

3. PALECHINUS.

PALECHINUS? INTERMEDIUS (Keeping). Pl. III. figs. 9-11.

Test spheroidal; interambulacral areas with five (?) ranges of regular plates, outer ranges pentagonal, inner ranges hexagonal. Surface of the plates uniformly granulated with small tubercles

* Quart. Journ. Geol. Soc. vol. xxx. p. 313.

† Prof. Hall, Twentieth Report, State Cabinet, New York, t. ix. fig. 10.

‡ Pal. Ill. ii. p. 295. § *Loc. cit.* iii. p. 522. || ροά, a pomegranate.

surrounded by a smooth ring. Ambulacral areas as broad as one of the adjacent interambulacral plates (5 mm.); composed of two rows of plates, which are wedge-shaped, and granulated like the interambulacral; pores near the outer edges of the plates, bigeminal.

The interambulacral plates overlap from below upwards (?)^{*}; and the antero-lateral overlaps the postero-lateral edge †; the ambulacral plates overlap in the opposite direction. As a consequence of the alternating wedge-shaped ambulacral plates, only every other one makes an impression on the interambulacral plates, which are thus marked with 4–6 indentations.

Near to *P. gigas* (McCoy), from which it differs in the greater relative number of ambulacral plates, each of which has only two instead of four pores, and in the overlapping of the plates. This latter structure is not nearly so pronounced as in *Perischodonus*, and is, indeed, of a different type. In that genus the plates are thin and overlap like scales; here they are thick and bevelled off as a carpenter planes off his plank in joining (fig. 11); so that the test here could only have possessed a slight degree of mobility, and would scarcely be capable of “panting” ‡ like its modern representative *Calveria*. The specific name refers to the overlapping of the plates, which is interesting as being of a character intermediate between the simply opposed plates of ordinary *Echini* and those of *Perischodonus*.

Loc. Hook Head, Fethard.

PALÆCHINUS GIGAS (McCoy). Pl. III. figs. 12, 13.

In this species the ambulacral plates seem to be welded in pairs. They were described by Prof. McCoy § as each possessing two pairs of pores (fig. 12)—a character which M. Desor || suggests might separate it as a genus from *Palæchinus*; but its true nature is clearly shown by a specimen in a part of our collection arranged by Prof. McCoy himself, where the double character is indicated by a pair of median interlocking articular angles to each plate (fig. 13). This is the only example recorded of the fusion of the ambulacral plates in the Palæozoic *Echini*, a feature so common among recent Urchins.

PALÆCHINUS SPHÆRICUS (McCoy).

A specimen of this species shows a loose ocular plate with two pores, agreeing with those described by Mr. Baily ¶ in *P. ellipticus*.

* Since both poles are absent, I am unable to determine the direction of the imbrication; but we may presume that it was the same as in the other *Perischodoninae*.

† This character may be taken as generic; and Messrs. MEEK and WORTHEN suggest that it is of “even more than generic importance” (Pall. III. iii. p. 522). But since in every characteristic, except the bevelling of the plate, it agrees with *Palæchinus*, it is perhaps best to retain it in that genus till we obtain further evidence.

‡ The Depths of the Sea, by Prof. WYVILLE THOMSON, p. 156.

§ Carb. Foss. Ireland, pl. xxiv. f. 4, p. 172.

|| Desor, Synopsis des Echinides, p. 158.

¶ Royal Geol. Soc. Ireland, 1864.

4. ARCHÆOCIDARIS.

ARCHÆOCIDARIS URUI (Fleming). Pl. III. figs. 14-18.

A specimen found by Professor Hughes at Hafod-y-calch, Corwen, possessing sixteen large plates but slightly displaced from their natural position, indicates that this Urchin possessed as many as five ranges of interambulacral plates* in each area. These plates are very thin, and imbricate from the central ranges outwards (fig. 17) as in *Perischodomus*. The dorsal and ventral edges were more firmly united by a sort of hinge (fig. 16), the edge of one fitting into a groove in the other, as described by Mr. J. Young †, from which description it also follows that the ambulacral plates were overlapped by the contiguous interambulacral.

Part of an ambulacral range is preserved on one side, showing the plates to be very irregular and perforated by two large pores. A very good idea of the aspect of these plates may be got by imagining a couple of corallites cut from the Dudley chain coral, *Halysites catenulatus*. The only interambulacral plate which is contiguous to this series of plates is not pentagonal, but heptagonal, with rounded angles (fig. 15); this was explained by the discovery of a broadly wedge-shaped scale-like ambulacral plate (fig. 18), the head of the wedge being produced and rounded to fit into the space made by cutting off the angles of the interambulacral plates as above described. Such an arrangement would help to keep the plates in position during flexures of the test.

Associated with the plates and large thorny spines of this species the small secondary spines may nearly always be found. These resemble those of *Perischodomus* in appearance; they are tubular and coarsely ribbed, almost as coarsely as the larger spines, but possess no thorns upon them.

Opinions have differed widely as to the value of the group Perischoechinida in classification. By Prof. McCoy it was placed as a distinct order of the Echinodermata, while Pictet includes its members in the family Cidaridæ. But though no structure is known in them which is not represented in the Echinoidea, they are well distinguished from all the rest of the order by the greater number of ranges of interambulacral plates, and, so far as is yet known, also by the fact that when the plates of the test overlapped, this overlapping was in the opposite direction to that of the flexible Echini of the more modern group, and, again, by the greater number of pores in the apical series of plates, a character indicating other physiological variations ‡. They are equally well marked off in time—all the Perischoechinidæ having disappeared at the end of the Palæozoic period, before any of the modern types of *Echini* had appeared.

Prof. Wyville Thomson's remark in connexion with the Echino-

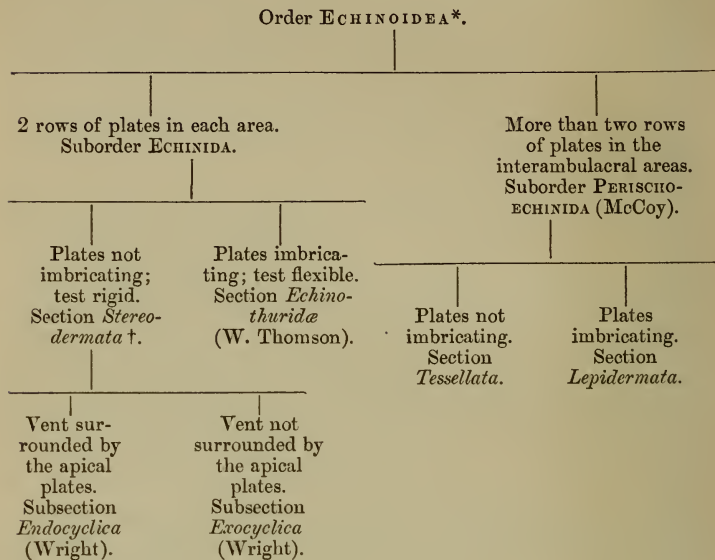
* *A. Wortheni* (Hall, Geol. Iowa, vol. ii. p. 700) has four rows of plates in each interambulacral area.

† Geol. Mag. vol. x. p. 302.

‡ Double genital pores occur in the genus *Cidaris* (Agassiz, Rev. Echin. p. 647).

thuridæ, that "they differ to the widest extent compatible with belonging to the same suborder," might, it seems to me, apply with greater force to the Perischoechinidæ. Such was Römer's opinion, who ranked them as a separate suborder.

I append the following classification of the Echinoidea.



APPENDIX.

Since writing the above I have had an opportunity of examining cursorily some specimens in the Jermyn-Street Museum. Amongst them is a giant *Echinus*, from the Carboniferous Limestone of Derbyshire, crushed and much disarranged. It covers an area of about $7\frac{1}{2}$ by $6\frac{1}{2}$ inches. Traces of the five ambulacra are seen converging to what is, I believe, the mouth, of which aperture no trace is now left.

The interambulacral plates are extremely numerous, mostly hexagonal, but some (the marginal rows) pentagonal; the plates have suffered much from weathering, so that only a few of them show that they were uniformly covered with small imperforate granules surrounded by a faint ring. There must have been from 10 to 15 ranges of these plates in each interambulacral area.

The ambulacral areas are very broad, and are composed of numerous very irregular plates, each perforated by a pair of pores. There are at least five rows of these plates; and certain appearances suggest that there may have been as many as 8 or 10 ranges, as in the

* For definition see Huxley 'Introduction to Classification of Animals,' p. 128.

† *στερεός*, stiff, fixed.

genus *Lepidesthes*. These ambulacral areas exactly resemble the figures of the American *Melonites* and *Oligoporus*; the plates are covered with granules similar to those of the interambulacral areas. Some of the interambulacral plates are distinctly overlapping; but in this character different plates vary very much, some of them showing no trace of it.

The thickness of the plates is great, being about equal to half the exposed surface in the case of the interambulacral plates.

Minute spines are profusely scattered over the whole surface of the specimen.

This fossil is, I believe, the first example recorded in Britain of that group of *Echini*, with numerous ranges of ambulacral plates, represented in America by the genera *Melonites*, *Oligoporus*, and *Lepidesthes*.

I hope soon to find time to give this specimen a more careful examination, and to determine its affinities.

EXPLANATION OF PLATE III.

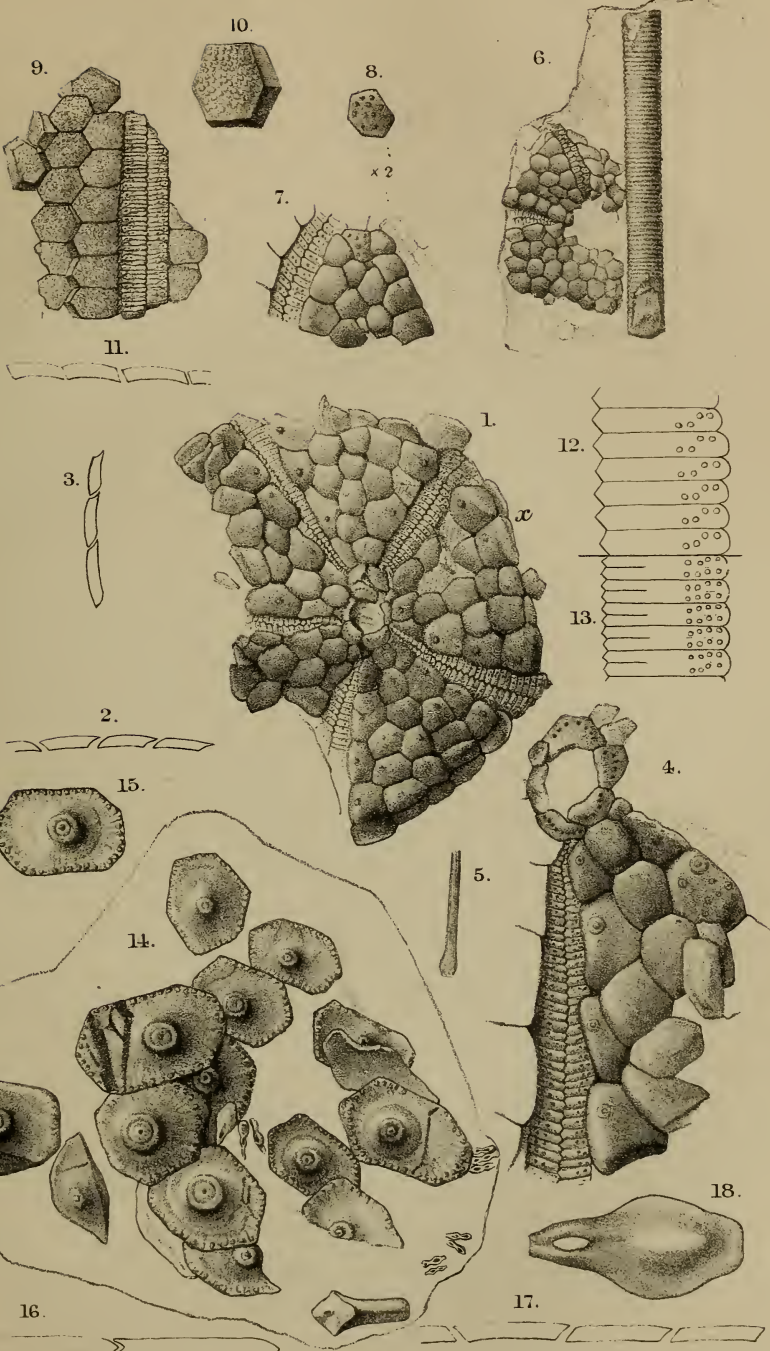
- Fig. 1. *Perischodonus biserialis* (M'Coy); nat. size. The overlapped surface of an interambulacral plate is exposed at *x*.
2. ———. Diagram to show the method of overlapping of the interambulacral plates from the central range outwards.
 3. ———. Diagram to show the method of overlapping of the interambulacral plates from pole to pole.
 4. ———. Apical disk and portion of corona, enlarged 2 diameters.
 5. ———. Secondary spine, enlarged 4 diameters.
 6. *Rhoechinus irregularis* (Keeping), nat. size.
 7. ———. Portion of fig. 6, enlarged 2 diameters.
 8. ———. An interambulacral plate, enlarged.
 9. *Palæchinus* (?) *intermedius* (Keeping), nat. size.
 10. ———. Interambulacral plate, showing its bevelled edges, twice nat. size.
 11. ———. Diagram to show the kind of overlapping of the interambulacral plates.
 12. *Palæchinus gigas* (M'Coy). Professor M'Coy's figure.
 13. ———. Corrected figure.
 14. *Archæocidaris Urvii* (Fleming), nat. size.
 15. ———. A heptagonal interambulacral plate of the same.
 16. ———. Diagram to show the method of articulation of the interambulacral plates from pole to pole.
 17. ———. Diagram to show the method of articulation of the interambulacral plates from the central range outwards.
 18. A peculiar ambulacral plate from fig. 14, enlarged.

DISCUSSION.

Mr. ETHERIDGE remarked that the genus established by the author in this paper was of particular interest as representing an American type, and it was of great importance in keeping up the correlation of the geology of Europe and America. He then commented at some length on the differences between the Palæozoic and more modern *Echini*. The type with flexible tests seemed never to have become extinct. In conclusion he expressed his approval of Mr. Keeping's proposed classification.

Prof. DUNCAN said that the analogies of the modern Echini with the Palæozoic are closer than is commonly imagined. The regular Echini of modern times do not always preserve the same number of plates in the ambulacral areas throughout. In modern forms the ambulacral pores run in straight series; in the older ones they are grouped obliquely. He remarked that some regular Echini have the plates jammed up and broken near the buccal orifice, so that if found separately their origin could not be determined.

Mr. KEEPING, in replying, stated that he had received great assistance from the paper by Mr. R. Etheridge, jun., in the Quarterly Journal. The fossil referred to as in the Jermyn-Street Museum had the ambulacral and interambulacral plates very numerous; no such form had hitherto been recorded in Britain. He did not think the modern flexible Echini were like the Palæozoic. As to the presence of crowded ambulacral plates in recent Echini, this was a character which he thought did not affect the classification now proposed.



3. *On a new MODIFICATION of DINOSAURIAN VERTEBRÆ.* By Prof. OWEN, C.B., F.R.S., F.G.S., &c. (Read November 17, 1875.)

[PLATES IV. & V.]

IN Dinosauria, after the character of "number of coalesced vertebræ with alternate disposition of their centrams and neural arches in the sacrum," that of "the complex development of the neural arch with par- and diapophyses in antecedent trunk-vertebræ" prevails; the modifications of the articular surfaces of the centrams are less constant.

Most commonly those surfaces, through the major part of the spinal column, are more or less flattened, the deviation from flatness being usually toward concavity on the hinder surface.

In this modification it is usual to find a few vertebræ at the fore part of the column with such concavity deepened to a cup and fitted to a ball on the fore end of the next centrum; such modification is termed "opisthocælian;" but I have not seen any example of a Dinosaur in which it prevailed throughout the dorsal region. In certain caudal vertebræ the deviation from flatness is toward concavity on both articular surfaces of the centrum; but I have not met with any instance in which the depth was such (as in the *Ichthyosaurus* e.g.) as to merit the term "amphicæulous;" and I know of no Dinosaur from the Lias upwards in which the dorsal vertebræ are so modified. The nearest approach is made by the vertebræ of the phytophagous Dinosaurian genera *Tapinocephalus* and *Pareiasaurus*; but it is so far from the true, or commonly understood, amphicælian character, that I venture to hope the Society will hold me justified in proposing another term for such vertebral modification.

Of the dorsal series of vertebræ in *Tapinocephalus Atherstonii*, Ow., the subject of Pl. IV. is a type. The centrum, $2\frac{1}{2}$ inches in length, is 5 inches in breadth, and $4\frac{3}{4}$ inches in height. Both articular surfaces deviate from flatness by a feeble concavity, a little more marked on the hinder one.

As at first wrought out of the matrix, which the petrified bone closely resembles in colour, no deviation from this common Dinosaurian character presented itself; and when, persisting in chiseling away whatever layer was doubtful, the defined central depression (fig. 1, *c'*) came into view, a doubt whether it was natural at first suggested itself. Similar thoroughness in exposing the veritable bony surface in other vertebræ, however, was attended with the same result. The small, central, subcircular pit, from 4 to 5 (rarely 6) lines in diameter, was repeated in each case. On the free surface of the anterior sacral, as on that of the posterior of four anchylosed sacrals of the Dinosaurian type, in *Tapinocephalus*, the foramen was relatively larger than in the dorso-lumbar series. The neural arch of the above fourth sacrals had been severed by fracture from an anchylosed fifth sacral; but the intervertebral space of the centrams had not been obliterated.

A vertical longitudinal section was then made of a dorsal centrum. A fine, close, cancellous texture prevailed, more compact at the periphery, with a slight enlargement of the cancelli toward the centre. The central pit or foramen led to a cylindrical canal 6 lines long, slightly expanding, and then rapidly contracting to a point (Pl. IV. fig. 1 *a, c'*), which met the apex of the opposite cone at the middle of the centrum. Each canal had admitted the original mud of the matrix to near the base of the cone; but that cavity contained crystals of spar, with matrix of a lighter colour than the rest. Some substance in the recent carcass had resisted further entry of the mud until the whole had hardened, and in the remaining cavities spar had slowly crystallized.

In developing from a similar almost intractable matrix the parts of the skeleton of another genus (*Pareiasaurus*, Ow.) of phytophagous Dinosaur, the dorso-lumbar vertebræ of a species (*Par. bombidens*) of somewhat smaller size than *Tapinocephalus Atherstonii* presented centrams proportionally longer to their breadth and height than in the representative of the latter genus. A centrum 3 inches 9 lines in breadth, and 3 inches 4 lines in height, has a length of 2 inches 8 lines along its lower part.

The articular surface of the centrum is subundulate, convex along a fourth of the periphery, concave at the centre, feebly so at both parts, and with the slight convexity continuing from the upper border to near the centre. The appearance of any pit here was so inappreciable that the tentative section of the first centrum so divided was made with little expectation of a repetition of the calenic-conical excavation. There it was, however (Pl. V. fig. 3, *c', c'*); its aperture or outlet a little wider relatively, the entering canal rather more constricted, the terminal cone with a somewhat dilated base, and an interval of the osseous texture, of two to four lines extent, separating the apices. Here also, the canal was filled by matrix, the cone by mixed discoloured matrix and spar.

Save as regards this central depression, the articular surfaces of the Pareiasaurian centrams, like those of *Tapinocephalus*, would be most correctly characterized as "amphiplatyan." But a vertebra of the same column of *Pareiasaurus bombidens*, of somewhat smaller size (Pl. V. figs. 4-7) deepened so regularly beyond the peripheral convexity of the articular surface of the centrum as to entitle it to be characterized as "amphicælian." From this character, which, in some cases is approached by the caudal vertebræ of amphiplatyan columns, I was at first disposed to view this vertebra as caudal, more especially as the lower border of both terminal surfaces was obliquely bevelled off, the anterior one (figs. 4 & 5, *hy*) in a great degree, and roughened as if for ligamentous or synchondrosal attachment of a hæm- or hypapophysis.

But with the foregoing characters were associated a wide neural canal (*ib.* fig. 6, *n*), a parapophysis near the lower part of the side of the centrum (*ib.* fig. 5, *p*), and the base of a diapophysis (*d*) outstanding from the basal part of the neurapophysis (*np*). These characters determine the vertebra to be cervical, and perhaps the an-

terior one, receiving the single occipital condyle by the somewhat deeper anterior concavity, and affording the subtriangular rough surface (figs. 4 & 5, *hy*) for the attachment of an atlanto-occipital "wedge-bone:" the smaller hinder surface (fig. 5, *hy'*) indicates a second smaller "wedge-bone" in the neck of *Pareiasaurus*. After securing five views of this vertebra, I made a longitudinal transverse section of the centrum, and, with the finely cancellous texture, exposed the pair of conical pits (fig 7, *c', c'*). The initial canal is feebly marked; the excavation is chiefly conical, the cones wider and shorter than in the succeeding vertebræ, and their apices separated by osseous tissue of a line in breadth.

In the above described and figured unossified tracts of the middle of the centrum in *Tapinocephalus* and *Pareiasaurus*, we have indications of a persistent trace of the primitive "chorda dorsalis." In the larger Dinosaur a beaded remnant would seem to traverse some proportion of the vertebral column, as in certain fishes*. It is a trace of a lower grade of vertebral structure, or stage of development of the centurms, and is interesting as being associated with a Dinosaurian type of probably Triassic age.

It recalls the more widely perforated, still less ossified, centurms of the vertebræ of Ganocephalous reptiles of the Carboniferous series, represented by *Parabatrachus*, *Hylonomus*, *Dendroperpeton*, &c., and thus strengthens the evidence of the post-Liassic age of the Karroo series given in the Quart. Journ. Geol. Soc. vol. xxiii. p. 140.

For the family of Dinosauria, represented by the genera *Tapinocephalus* and *Pareiasaurus*, I have proposed the name Tretospondylia.

In conclusion, I have to express my deep obligations to the late Andrew Geddes Bain, F.G.S., and to my friend Dr. Guibon Atherstone, F.G.S., for the fossil materials from Blinkwater and Gats Plaatz, South Africa, from which have been derived the above-described structures.

EXPLANATION OF THE PLATES.

PLATE IV.

Fig. 1. Anterior view of centrum, and anchylosed base of neural arch of a dorsal vertebra, of *Tapinocephalus Atherstonii*, Ow.

- 1a. Outline of section and plane of the articular surface of the centrum.
2. Side view of the same vertebra.

PLATE V.

Fig. 3. Longitudinal and vertical section of a dorsal centrum of *Pareiasaurus serridens*.

4. Anterior view of centrum, and anchylosed base of neural arch, of a cervical vertebra of *Pareiasaurus bombidens*, Ow.
5. Side view of the same vertebra.
6. Upper view of the same vertebra.
7. Longitudinal and transverse section of the centrum of the same vertebra. (The dotted lines show the lay of the surface as wrought out prior to the section.)

(All the figures are of the natural size.)

* *Scymnus*, *Mugil*, e. g., 'Anat. of Vertebrates,' 8vo, vol. i. pp. 32, 37, fig. 31.

DISCUSSION.

Prof. SEELEY wished to ask the author whether other specimens gave a better idea of these Dinosaurs. He thought that the Dinosauria and the Dicynodonts, in the structure of the pelvis and of the fore and hind limbs, resembled each other much more closely than any other two orders. He inquired whether this evidence did not break down the classificational value of the Dinosauria. The apertures seemed to him to be equivalent to the hollows in the vertebræ of birds, which are connected with the extension of the respiratory system throughout the body; and thus, as they occur in Dinosaurs and in Pterodactyles, they seem to aid in breaking down the demarkation between these groups. He also thought that he had observed the same structure in Dicynodonts. The specimens described by Prof. Owen appeared to him to open up some very broad philosophical questions.

Prof. OWEN said:—"The 'Philosophical Transactions' (1862), it is true, show that a Dicynodont had a sacrum of several vertebræ, as in the Dinosaurs. The structure of the hind limbs of Dicynodonts is not known; but that of the fore limbs shows a humerus perforated above the inner condyle, and three-jointed digits, save the pollex, which has two joints, in their pentadactyle fore paw. Besides this difference from Dinosaurs, the premaxillaries are confluent as one bone, with an edentulous trenchant border, evidently, like the corresponding border of the edentulous lower jaw, sheathed with a beak-like substance. The Dicynodonts in their pair of long upper tusks, and the Oudenodonts in their toothless jaws, further differ from Dinosaurs; and both agree in having vertebræ cupped as in *Ichthyosaurus*, a character which no Dinosaur of Liassic and later age presents. The ordinal terms *Dinosauria*, *Anomodontia*, *Pterosauria*, *Crocodylia*, so long as they are expressive of distinctive characters of the groups of Reptilia so associated, are useful instruments in gaining farther knowledge of the class. To extend any one of those terms to another group which may have a single character, added to those of class, in common with another, is to cast away the advantage of an ordinal term significant of actual knowledge of a sum of characters." He added that no Dicynodont, Oudenodont, or Endothiodont species of the order Anomodontia has hitherto been found in strata unquestionably so recent as those that have yielded species of Dinosauria, other than Ketospondylian.

Fig. 1.



Fig. 1^a

Fig. 2.

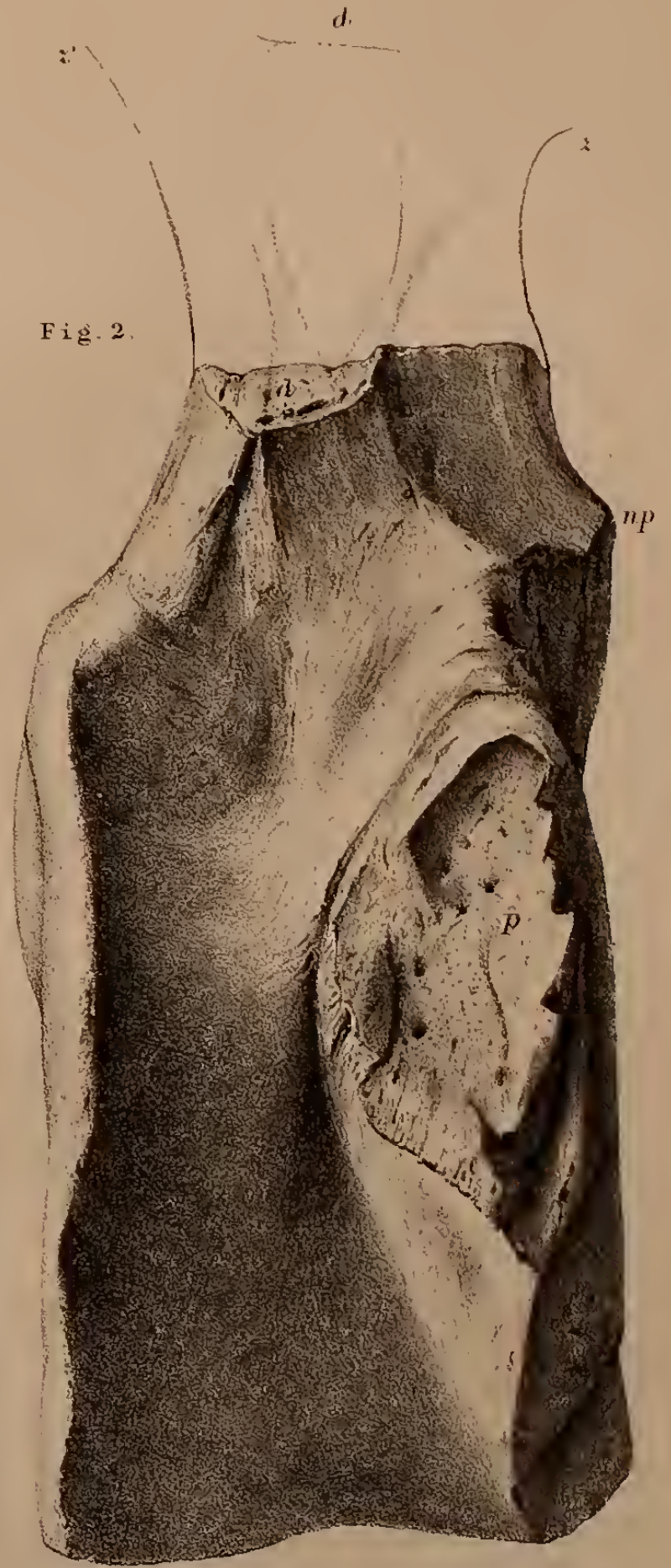


Fig. 7.

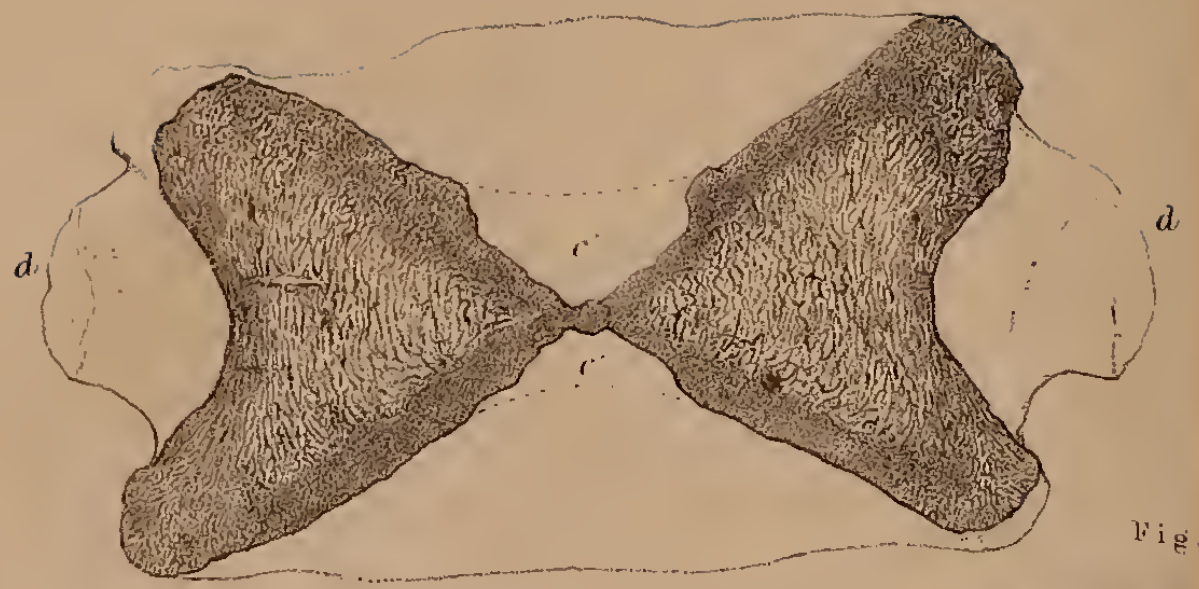


Fig. 1



Fig. 5.



Fig. 3.

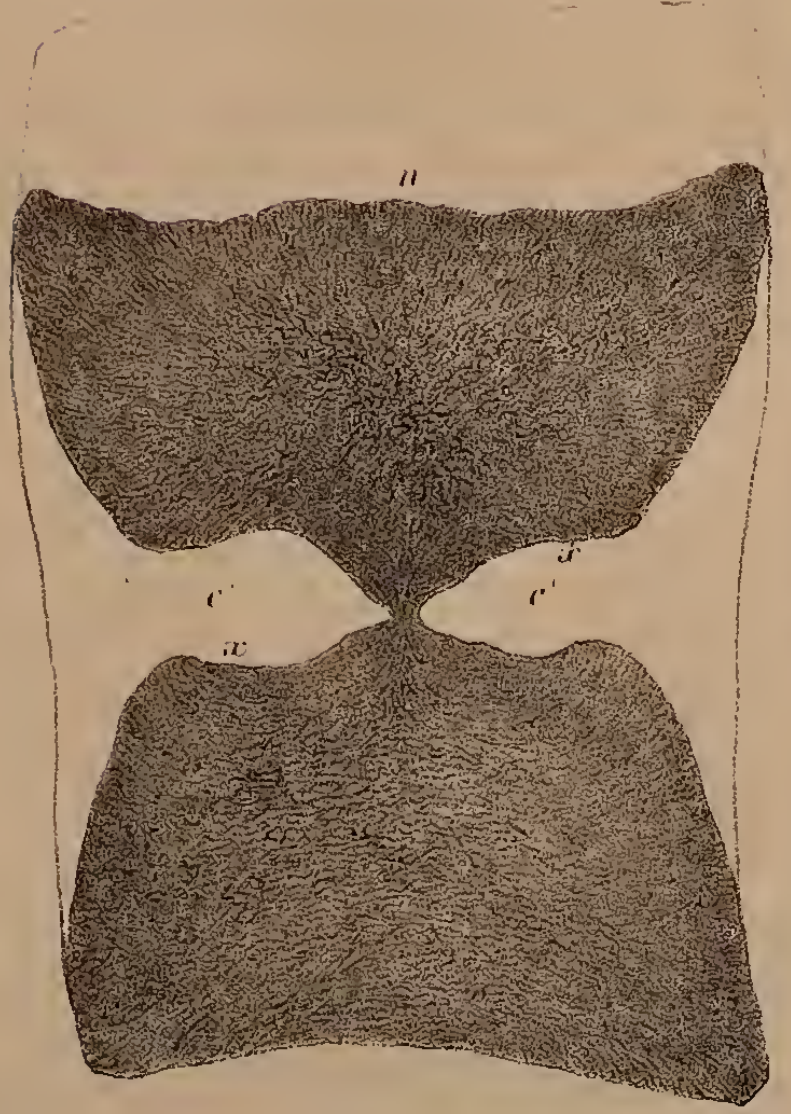


Fig. 6.



4. *On some NEW MACRUROUS CRUSTACEA from the KIMMERIDGE CLAY of the SUB-WEALDEN BORING, SUSSEX, and from BOULOGNE-SUR-MER.* By HENRY WOODWARD, Esq., F.R.S., F.G.S., of the British Museum. (Read November 3, 1875.)

[PLATE VI.]

IT has always appeared to me to be a point of special interest to geologists to record those forms found in a fossil state which have a considerable vertical range, and yet belong to genera existing at the present day. Among higher groups now living, we find the vertical range exceedingly small; but when we examine the Invertebrata, we meet with such genera as *Lingula*, *Pentacrinus*, and *Limulus* having an extremely high antiquity; but the higher forms of these types follow precisely the same general law, having a much more restricted range in time than the lower and humbler genera.

One of the Crustacea about to be described by me belongs to a very interesting group, the family of the Thalassinidæ.

Most if not all of the members of this family are fossorial in their habits, burrowing in the sand or mud with great rapidity and remaining concealed in their burrows, save their large claws, which have in many instances been caught and devoured by fishes, or have been cut off by the dredge, whilst the animal itself in its burrow escaped.

Of living British representatives we have four genera:—

1. *Callianassa*, Leach (1 species): *C. subterranea*, Leach.
2. *Gebia*, Leach (2 species): *G. stellata*, Leach; *G. deltura*, Leach.
3. *Axius*, Leach (1 species): *A. stirhynchus*, Leach.
4. *Calocaris*, Bell (1 species): *C. Macandreae*, Bell.

Formerly only one fossil species of this remarkable group of burrowing Crustaceans was known, the *Callianassa (Pagurus) Faujasii*, from the uppermost Chalk of Maestricht, first noticed in an admirable work by Faujas-Saint-Fond entitled ‘*Histoire Naturelle de la Montagne de St.-Pierre, Maestricht*,’ 1799 (p. 179, pl. 32. figs. 5 & 6), and subsequently described by Desmarest in 1822*, and by König in 1823†.

Another species was added in 1845, by Otto‡ from the Greensand§ of Triebitz in Bohemia and Kieslingswalde Glatz, Silesia, and named by him *Callianassa antiqua*.

In 1867 Dr Fritsch of Prague added five new species from the Chalk of Bohemia||, namely *C. Turtia*, *C. bohémica*, *C. brevis*, *C. elongata*, and *C. gracilis*.

* Brongniart et Desmarest, *Hist. Nat. des Crustacés*, Paris, 1822, 4to, p. 127, pl. 11, fig. 2.

† König, *Icones Foss. Sect. (Lond. 1823) Centuria 1. p. 2, pl. 2. fig. 20.*

‡ Otto in H. B. Geinitz's *Grundriss der Verstein.* p. 211, pl. 8. figs. 12 & 13 (Dresden, 1845).

§ “Greensand” = oberer Quadersandstein = U. Cretaceous.

|| Ueber die Callianassen der böhmischen Kreideformation (Prag, 1867), tabs. 1 & 2.

In 1868 I called attention to two new species of *Callianassa* at the Norwich Meeting of the British Association*—one, the *Callianassa neocomiensis*, from the Greensand of Colin Glen near Belfast, the other, *C. Batei*, from the Upper Marine series (Eocene), Hempstead, Isle of Wight.

I have now, by the kindness of Mr. Henry Willett, F.G.S., and the Committee of the Sub-Wealden Exploration, been favoured with portions of cores from the boring obtained at a depth of 1057 feet, containing, besides the fore limbs of a small macrurous Crustacean, to be presently described, three or four more or less perfect examples of a new species of *Callianassa*, and the oldest hitherto known of this remarkable type of fossorial Crustaceans (Pl. VI. figs. 1 & 2).

The fossil, which measures about 42 mm. in length, is seen in profile on several sections of cores, and indicates the horizontality of the beds penetrated. The parts of the fossil are all *in situ*, save the carapace, which has been displaced in each case.

The first pair of feet, which are longer than the entire body, have the penultimate joint, or manus, enormously developed (measuring 7 lines in length); the wrist is quadrate, broader than it is long; it decreases greatly in size from its broad articulation with the manus to its narrow proximal end, where it joins the arm (or "meros"), which is short and strongly curved, and is united by two very small and extremely slender joints (the "ischium" and "basos") to the cephalothorax.

The hands of the fore limbs are more equal in size than in the living species of *Callianassa*; but in other genera of Thalassinidæ, as for instance in *Axius*, the inequality is less marked. In the Eocene and Cretaceous species (already referred to) the disparity in the relative size of the hands is also somewhat diminished as compared with existing species. I am therefore not disposed to lay much stress upon this point.

The feet of the second pair are also didactyle; and the extremities of all the four pairs of smaller limbs are somewhat flattened and expanded, to assist in digging.

The carapace and the segments of the abdomen are smooth; the latter are somewhat quadrate in profile, not pointed; and the shelly covering of both is extremely thin, as in all the forms which habitually conceal themselves in foreign bodies—a peculiarity developed in the highest degree in the Paguridæ. The segments of the abdomen contract somewhat at each extremity as in other *Callianassæ*; and the caudal plates are oval.

I propose to designate this new species *Callianassa isochela*.

2. MECOCHIRUS PEYTONI, sp. nov. Pl. VI. fig. 3.

Kimmeridge Clay, Boulogne-sur-mer, and Sub-Wealden boring.

I should have hesitated to describe the fossil macruran represented by the two small fore limbs preserved in one of the cores for-

* Brit. Assoc. Report, Norwich, 1868, p. 72, pl. ii. figs. 4 & 5.

warded to me for examination by Mr. Henry Willett, F.G.S., had not my friend, Mr. John E. H. Peyton, F.G.S., of St. Leonards (who has devoted much attention to the question of the true geological horizon of the Sub-Wealden boring) gone over to Boulogne-sur-mer in September 1873, to examine the Kimmeridge Clay of that locality, where he not only obtained several specimens of *Lingula ovalis*, Sow. (new to that locality), but also a small but nearly perfect example of a Crustacean referable to the genus *Mecochirus*.

This genus (like *Callianassa*) early attracted the notice of geological writers. It was first described as a "Locust" by Knorr in 1755, then as an *Astacus* by Bajer in 1757, as a *Macrourites* by Schlothheim in 1820, and as a *Palæmon* by Krüger in 1823 & 1825. It was not, however, correctly defined and separated from other genera until 1827 (by Germar, in Keferstein's *Deutschl. Bd. iv. p. 102*), since when it has been repeatedly noticed and the species figured by Holl, Bronn, Münster, Mayer, Pearce, Quenstedt, M'Coy, Pictet, Oppel, and others.

The oldest species is the *Mecochirus olifex*, Quenstedt, from the Lower Lias of Dusslingen, near Tübingen, Württemberg*.

Next in ascending order is the *Mecochirus (Cancrinium) socialis*, of Meyer (1841) from the Kelloway group, Württemberg and Normandy.

To this species (*Mecochirus socialis*, Meyer, sp.) Dr. Albert Oppel has referred the *Mecochirus (Ammonicolax) Pearcei*, from the Oxford Clay of Christian Malford, near Chippenham, Wilts, which he considers a part of the Kelloway group.

I have not had the good fortune to see a specimen of Meyer's *M. socialis*; but, comparing his figures of that species with specimens of *M. Pearcei* in the British Museum (from the collection of Mr. William Cunningham, F.G.S.), and with other specimens obtained direct from Mr. William Buy (late of Sutton near Chippenham), I am satisfied the specimens from Wiltshire should still be retained as belonging to a distinct species as established by M'Coy in 1849 (*Ann. & Mag. Nat. Hist. series 2, vol. iv. p. 172*).

The remaining four species of *Mecochirus*, namely *M. longimanus*, Schloth., *M. Bajeri*, Germ., *M. brevimanus*, Münst., and *M. dubius*, Münst., are from the lithographic stone of Solenhofen, Bavaria.

Like other species of this remarkable genus, the fore limbs of *Mecochirus Peytoni* are equal to the length of the entire body. They measure 75 millims. in length, of which the terminal joint (dactylus) measures 18, the propodos 30, the carpus 5, the meros 18, and the ischium and basos 4 millims. The surface of the fore legs is very finely punctate.

The carapace, which is finely granulated, measures 30 millims from the rostrum to the posterior border, and 14 millims. in depth from the mesial dorsal line to the lower margin of the branchial region. The rostrum is somewhat produced.

The antennæ are not well preserved, but are long and slender.

* Württemb. naturw. Jahresh. 1850, Bd. vi. p. 186; Quenstedt, *der Jura*, 1856, p. 89, tab. 2. fig. 17.

The abdominal segments are 45 millims. in length and about 10 millims in depth (their epimeral borders are falcate); they are about 6 millims. in length each, and the caudal segment about 9 millims.

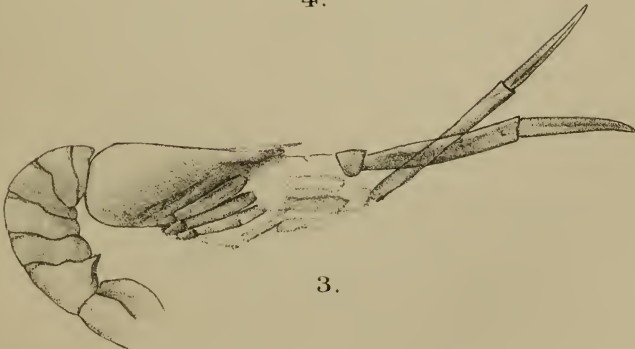
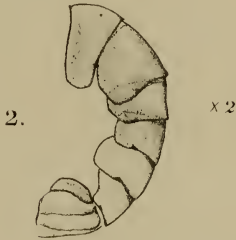
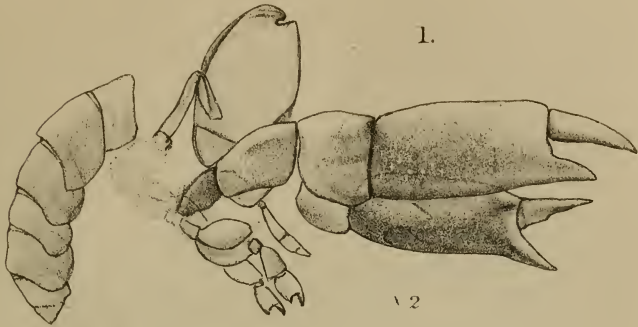
The smaller feet are not very clearly seen; but they measure about 25 millims. in length.

I believe the two fore limbs (Pl. VI. fig. 4) from the Sub-Wealden boring, though imperfect, may be referred to the same species, *M. Peytoni*; and in examining one of the specimens I was delighted to observe that it was associated (like that from Boulogne) with *Lingula ovalis*, Sow.

In size this species is intermediate between *Mecochirus socialis*, Meyer, sp., and *M. Pearcei*, M'Coy, being about 130 millims., the former being 60 millims. in total length (or less than half the size of *M. Peytoni*), the latter being 175 millims. long, and robust in proportion.

EXPLANATION OF PLATE VI.

- Fig. 1. A nearly entire specimen of *Callianassa isochele*, sp. nov.
 2. *Callianassa isochele*, sp. nov. Another specimen, showing the caudal series very well preserved. (Both figures twice nat. size.) From the Kimmeridge Clay of the Sub-Wealden boring, near Battle, Sussex.
 3. *Mecochirus Peytoni*, sp. nov. From the Kimmeridge Clay, Boulogne-sur-mer, associated with *Lingula ovalis* in the cliff-section; nat. size.
 4. Hands of *M. Peytoni*. From the Kimmeridge Clay, Sub-Wealden boring, near Battle, Sussex; nat. size.



5. *On a new FOSSIL CRAB from the TERTIARY of NEW ZEALAND, collected by Dr. HECTOR, F.R.S., F.G.S., Director of the Geological Survey of New Zealand. By HENRY WOODWARD, Esq., F.R.S., F.G.S., of the British Museum. With a Note by Dr. HECTOR. (Read November 3, 1875.)*

[PLATE VII.]

THE fine fossil Crab which I have now the pleasure to describe was obtained by my friend Dr. Hector, F.R.S., F.G.S., from the "passage-beds," Ototara series, Woodpecker Bay, Brighton, north-west coast of the South Island, New Zealand, considered by him to be probably equivalent in position to the very lowest Eocene, or the uppermost Cretaceous of Europe.

I have compared it with the various genera of fossil Crabs with which I am acquainted, and am of opinion that its nearest alliance is with the genus *Harpactocarcinus* of Alphonse Milne-Edwards*, from the Nummulitic series of France, Spain, and Italy. Of this genus Alphonse Milne-Edwards has described the following six species, namely:—

Harpactocarcinus, Alph. Milne-Edw.

- 1. *punctulatus*, Desm. M. Eocene, Barcelona and N. Italy.
- 2. *macrodactylus*, A. M.-Edw. " " "
- 3. *rotundatus*, A. M.-Edw. " " "
- 4. *ovalis*, A. M.-Edw. " " "
- 5. *Souverbiei*, A. M.-Edw. " Dax, S.W. of France.
- 6. *quadrilobatus*, Desm. " Dax; Perpignan; and Vicentin, N. Italy.

Of the above species the specimen from New Zealand most nearly approaches to *H. quadrilobatus*, Desm., in general proportions; but the carapace of the New-Zealand crab is much more tumid, and the relative proportions between the depth of the anterior and posterior halves of the carapace differ considerably. Thus, if an imaginary line be drawn transversely across each carapace from the epibranchial spine on the lateral border of each, we shall find the proportions to be as under:—

	Depth of anterior half.	Depth of posterior half.
<i>Harpactocarcinus quadrilobatus</i>	29	46
„ new species	35	40

The carapace of the New-Zealand crab is 83 millims. broad and 73 millims. in depth from the rostrum to the posterior border. If measured along the *curve* of the carapace, the depth is 83 millims.; but, owing to the curvature of the carapace this is less apparent.

The carapace is remarkably tumid, especially on the branchial

* Alph. Milne-Edwards, Hist. Crust. Podophth. fossiles, 1861-65. Family of Canceridæ, pp. 196-207.

and gastric regions; the surface of the posterior half of the carapace is very finely granulated; but the anterior half is nearly smooth. The rostrum is short and bicuspid, as in other *Harpactocarcini*; the orbits are shallow and rounded; the space between the orbits measures 15 millims.

The hepatic margin, at first partially obscured by matrix, now presents a nearly smoothly rounded border, a blunt and rounded denticle marking the lateral angles of the epibranchial border, as in *H. quadrilobatus*.

The divisions between the branchial, cardiac, and gastric regions are faintly indicated by a shallow undulation of the surface of the carapace, and a slightly roughened and incised line of short oblique markings on the sides of the gastric intumescence.

The external jaw-feet, or maxillipeds, are well preserved*. The endopodite is broad and straight-sided, and divided by a suture near its anterior third; the surface is marked by a longitudinal furrow; the exopodite is straight and narrow: both take their rise from a common basal joint.

The chelæ, or first pair of true limbs, are robust and, as is commonly the case among the Canceridæ, very unequal in size, the right being considerably larger than the left hand.

The ischium measures 8 millims. in length, the arm 31 millims.; these, with the short basal joint, are concealed beneath the carapace; the carpus is a short strong joint 26 millims. long, and having its distal end broadest (measuring 30 millims.) and armed at each angle with a stout short spine. Its proximal end contracts greatly at its articulation with the arm, giving it a triangular form. The length of the larger hand is 65 millims., breadth 30; length of the smaller hand 53 millims., breadth 21. The chelate ends of the limbs are considerably recurved, as in other Canceridæ.

The abdomen has nearly all flaked off; but a sufficient portion remains attached to the plastrosternum to show that the fossil crab was a female. In general form the plates of the plastrosternum agree with those of *Harpactocarcinus*. The four pairs of simple monodactylous feet are broken off short, but they present no characters dissimilar to those of other Cancerines.

I propose to name this interesting fossil *Harpactocarcinus tumidus*.

The presence of this Crab alone would sufficiently attest the near-shore character of this deposit at Woodpecker Bay; but, besides another specimen of *Harpactocarcinus tumidus* obtained from this deposit, a number of portions of chelæ of other Cancerine claws, with remains of an extinct gigantic Penguin, attest the correctness of this opinion.

For the present, however, I will refrain from generalizing on the exact horizon of this fossil from New Zealand as compared with the beds containing *Harpactocarcini* in Europe; but Dr. Hector has added a few remarks to my paper; and as he has visited the locality

* The entire underside has been carefully worked out by Mr. Barlow, the intelligent and able mason attached to the geological department of the British Museum.

and also obtained this and many other fossils therefrom, and worked out the geology of the district, I leave him to notice the geological facts of the case.

Note by Dr. HECTOR.

The locality where both the specimens of this fossil were obtained is a small bay on the exposed west coast of the South Island, where the shelter of the Seal-rocks affords a precarious landing-place for supplying stores to the gold-miners around Brighton. Northwards the coast is formed of granite for many miles; but the crystalline rocks at this place disappear under Upper Mesozoic and Lower Tertiary formations, which form the coast range, and expand southwards to a width of 15 miles, covering the important area of the Grey-River Coal-field.

The Seal-rocks belong to the upper part of the formations referred to, representing on the west coast the Ototara group of the north-east of Otago Province, a formation which is widely distributed throughout New Zealand, and nowhere, so far as I have seen, passes into the Tertiary strata of later date.

The Ototara group was referred to by Profs. E. Forbes and Rupert Jones*, who from fossils collected by Mr. Walter Mantell, considered it to possess mixed characters of the Upper Cretaceous and Eocene periods of Europe.

In the same formation Prof. Huxley, from a single bone brought also by Mr. Mantell, determined the former existence of a gigantic Penguin (*Palæudyptes antarcticus*†); and it is worthy of remark that not only have further remains of the skeleton of that bird been obtained in the Calcareous Sandstone at Ototara, but that a large part of a skeleton was extracted from the same stratum in the Seal-rocks with the first-found specimen of the Crustacean under notice, thus satisfactorily correlating the formations on the opposite sides of the island‡. Concerning the palæontological value of these Penguin remains Prof. Huxley makes the following important observations:—

“Whatever be the precise age of the fossil, it is not a little remarkable to find in strata of such antiquity the remains of a bird the whole of whose congeners are at present absolutely confined to the southern hemisphere, and therefore, in a broad sense, to the same great distributional area. If the strata be of Pliocene age, the fact is in accordance with the relations which have been observed between the recent and Pliocene faunæ of the Northern Hemisphere. On the other hand, the little that is at present known respecting the distribution of Birds in time is not inconsistent with the ascription of a far higher antiquity to a genus as closely allied as *Palæudyptes* to those which now exist” (*l. c.* p. 675).

The Ototara formation has, since the above was written, been examined in most distant parts of New Zealand; and though it varies in mineral aspect, it always maintains, at least in its upper part, the

* Quart. Journ. Geol. Soc. vol. vi. p. 329, 1850. † *Ibid.* vol. xv. p. 672, 1859.

‡ Hector, Trans. New-Zeal. Inst. vol. iv. p. 341.

Section from the Alps to Brighton, New Zealand.

W.



Details of Section.

Formations.

- IV. V. VI. ... {
a. Gravel sandstone.
b. Tough blue clay marls.
c. Calcareous and nummulitic.
d. Calcareous sandstone—Ototara group.
e. Gianconitic sandstone.
f. Chalk marls under Fucoidal limestone.
g. Leda marls—*Pecten pleuronectes*.
h. Greensand grits.
i. Dark tough clays.
k. Limonite sandstone and greensands, Saurian bones, Ammonites, &c.
l. Brown pitch coal.

Formations.

- IX. ... {
m. Upper conglomerates.
n. Bituminous coal (Dicotyledonous leaves).
X. {
o. Lower conglomerate,
p. Green sandstone and marlstone with *Tenuiopteris*
and the same fossils as at Rajamahal, India.
XI. {
q. Auriferous rocks of Reefston, green tufaceous sand-
stones and slates.
XII. XIII. *... {
s. Upper palaeozoic sandstones of the Alps.
XIV. * {
t. Madreporic limestones and quartzites with Trilobites
&c.
u. Schistose rocks along the west base of the Alps.
v. Granite in massive but generally isolated mountains.

* XIII. and XIV. are probably Carboniferous and Devonian.

character of a littoral or shallow-water calcareo-arenaceous deposit, rich in distinctive fossils associated with other forms that are common in the underlying formations. The stratigraphical position of the Ototara group, as the upper part of what for convenience of mapping, I have termed the Cretaceo-Tertiary formation, is shown in the following general schedule, in which the local names and subdivisions used in surveying have been suppressed, and a comparison attempted with European formations:—

		<i>Formation.</i>	<i>Physical Character.</i>	
Tertiary.	{	I. Recent and Postpliocene.	a. Fluviate and littoral.	} Moa period.
		II. Upper Pliocene.	Fluviatile, extended glaciers.	
			Fluviatile, oldest gold-drift.	
		III. Older Pliocene.	b. Marine, craglike and conglomerates.	
		IV. Upper Miocene.	a. Marine, argillaceous, concretionary.	
		V. Lower Miocene.	Marine, arenaceous, concretionary.	
		VI. Upper Eocene.	Marine calcareous.	
			b. Estuarine lignitiferous.	
		VII. Cretaceo-Tertiary.	a. OTOTARA group—calcareous sandstone.	} Saurians.
		VIII. Middle Cretaceous.	b. Chalk and marl.	
			a. Marine, ferruginous clays and green-sands.	
			b. Estuarine, gravels and <i>hydrous brown coal</i> ; chief SAURIAN BEDS.	
Mesozoic.	{	IX. Lower Cretaceous.	a. Fluviate grits and conglomerates; <i>anhydrous brown coal</i> .	
			b. Marine, grits, green and grey sandstone.	
		X. Jurassic.	Green sandstone and shales, with thin coal, <i>Pecopteris</i> , <i>Teniopteris</i> , &c.	
		XI. Liassic.	Red and blue marlstones.	
		XII. Trias.	Conglomerates and shales, plant-beds.	

About 320 specimens of fossil Mollusca and Echinodermata have been described from the first seven of the foregoing divisions, the collections having been made from 90 different localities*; and I have prepared the following Table to show the actual number of recent and extinct species, comparing the recent fauna with the Upper, Middle, and Lower Tertiary and Cretaceo-Tertiary formations, omitting those which are of doubtful specific identity or stratigraphical position.

Formations.	Univalves.		Bivalves.		Brachio-pods.		Echino-derms.		Totals.	
	R.	Ex.	R.	Ex.	R.	Ex.	R.	Ex.	R.	Ex.
Recent	285	...	134	...	9	...	26	...	454	...
II. III.	67	14	45	9	6	0	3	0	120	23
IV. V.	30	60	22	33	2	3	1	3	55	109
VI.	7	28	4	46	2	8	1	7	14	89
VII.	0	13	0	28	...	9	0	20	...	70
Extinct species, II.-VII. ....	...	87	...	71	...	10	...	26	...	194

* Catalogue of Tertiary Fossils in the Col. Museum, by F. W. Hutton, Assist. Geologist. New Zealand, 1873.

From the comparison which this Table affords with the recent fauna of the same area, the Otatara formation would seem to have no claim to a place among Eocene formations. This is confirmed by the occurrence of a few fossils of decidedly Cretaceous type, such as Saurian forms and fragments of the shell of *Inoceramus*, and the presence of many forms that are associated with decided Mesozoic fossils in the underlying strata. On the other hand, the occurrence of decidedly Tertiary fossils (among which is *Nautilus ziczac*, or a closely allied form), the gigantic Penguin bones, and the recent discovery of the bones of a Turtle, also from the Seal-rocks, indicate a fauna not dissimilar to that at present existing in adjoining areas to the north and south; so that any additional evidence bearing on this matter, such as is afforded by Mr. Woodward's determination of the affinities of this Crustacean, is an important contribution to New-Zealand palæontology.

The accompanying section (p. 54) explains the general sequence of the formations referred to in the foregoing paper on the west coast of the South Island, from Brighton to the Alps.

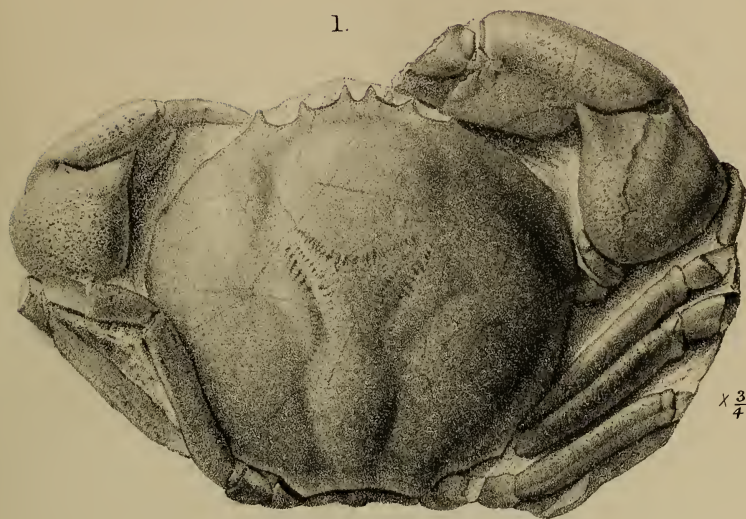
EXPLANATION OF PLATE VII.

Harpactocarcinus tumidus, H. Woodw. Three fourths nat. size.

- Fig. 1. Upperside of carapace.
2. Underside of carapace.

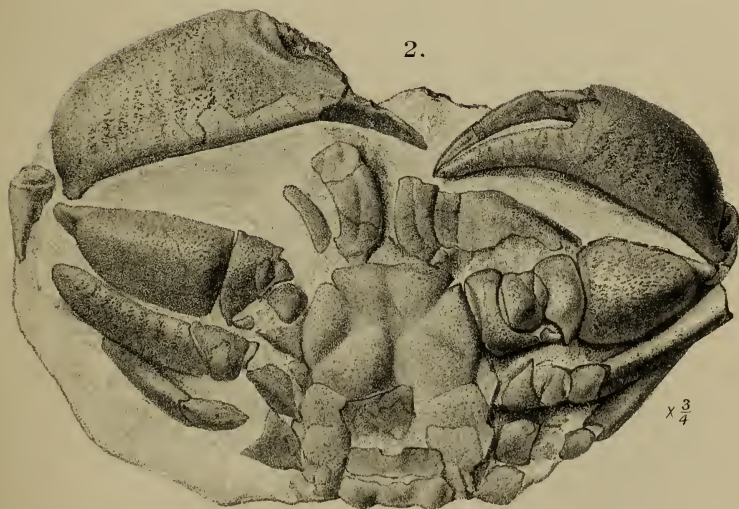
The specimen is preserved in the British Museum.

1.



$\times \frac{3}{4}$

2.



$\times \frac{3}{4}$

6. *On the DISCOVERY of a FOSSIL SCORPION in the BRITISH COAL-MEASURES.* By HENRY WOODWARD, Esq., F.R.S., F.G.S., of the British Museum. (Read November 3, 1875.)

[PLATE VIII.]

THE paucity of the remains of any class of terrestrial air-breathing animals preserved in a fossil state, has given to such organisms a special interest in the eyes of geologists, not only as marking the probable position of old land-surfaces, but also as giving us some slight indication of the climatal and zoological conditions of this, to us, otherwise *terra incognita*.

But this interest is greatly enhanced when such remains occur in strata of palæozoic age, in which evidences of land-dwelling animals are extremely rare. Indeed, but for our palæozoic coal-strata, we should have little left, save evidences of marine life, older than the Trias.

I have now the pleasure of announcing the discovery, in two distinct localities in England, of the remains of a fossil Scorpion in strata of Coal-measure age, and possibly in a third locality in Scotland.

So long ago as 1835, Count Sternberg published the discovery of a remarkable fossil Scorpion in the Coal formation at the village of Chomle, near Radnitz, Bohemia, afterwards named and described by Corda as *Cyclophthalmus senior* (Corda in 'Böhmischen Verhandlungen,' 1836, and 'Wiegmann's Archiv,' 1836, ii. p. 360).

This is the first authentic record of an Arachnide in the Coal-measures. It has been figured in the 'Transactions of the Royal Bohemian Museum;' and these figures were reproduced by the late Dr. Buckland in his 'Geology and Mineralogy' (1836, plate 46' and 46". fig. 13).

"This fossil Scorpion," writes Buckland, "differs from existing species less in general structure than in the position of the eyes. In the latter respect it approaches nearest to the genus *Androctonus*, which, like it, has twelve eyes, but differently disposed from those of the fossil species. From the nearly circular arrangement of these organs in the latter animal, it has been ranged under a new genus, *Cyclophthalmus*" (Buckland, *op. cit.* vol. i. p. 407).

This remarkable fossil remained unique until 1839, when Corda added a new genus of Pseudo-scorpions, also from the coal of Bohemia, which he named *Microlabis*.

No other Scorpion was noticed from the Coal-measures until 1868, when Messrs. Meek and Worthen, in their 'Palæontology of Illinois,' described a new form of this ancient family (from the lower part of the true Coal-measures of Mazon Creek, Morris, Grundy County, Illinois)* under the name of *Eoscorpium carbonarius*. This

* Geological Survey of Illinois (A. H. Worthen, Director), vol. iii. 1868 (Palæontology, by F. B. Meek and A. H. Worthen, p. 560, with woodcut).

form is considered by its describers to be near to the recent American species *Buthus hirsutus* from California, with which it accords well in its general proportions; but as neither the palpi nor the last three segments of the body are preserved, we fully agree in the conclusions of the learned authors as to the desirability of keeping it distinct generically.

The same locality in Illinois has yielded, in addition to many new and interesting forms of Crustacea, a new genus of Myriopods, named by Messrs. Meek and Worthen *Euphoberia*, with two species *E. armigera* and *E. major*, M. & W., two new Arachnides, named *Mazonia Woodiana*, M. & W., and *Architarbus rotundatus*, Scudder, and eight insects, determined by Mr. S. H. Scudder.

In April 1874 I visited an experimental sinking for coal on the estate of the Earl of Dartmouth at Sandwell Park near Birmingham, for the purpose of examining (on behalf of the British Museum) a large series of fossil plants of great interest, from the "Red Rocks" overlying the "Thick Coal."

My attention was specially called to an obscure specimen (discovered by Mr. Henry Johnson, C.E., the Secretary and Manager of the Sandwell-Park Colliery Co.) in black shale, which, to my surprise and pleasure, proved on examination to be the remains of a fossil Scorpion (Pl. VIII. fig. 1).

In November 1874 I received from Dr. D. R. Rankin, of Carluke, a single segment (preserved in the round) of an Articulate from the shale-beds of the upper limestone series of the Coal-measures near Carluke, which I am unable to assign to any other group of Articulate; and I believe it to be an abdominal segment of a Scorpion (figs. 5, 5a, 5b).

In August last, Mr. Edward Wilson of Nottingham (a most zealous and careful collector of geological specimens, and thoroughly acquainted with the geology of the country around Nottingham) forwarded me several specimens from the clay-ironstone nodules of the Coal-measures, Skegby New Colliery, near Mansfield. Two of these clay-ironstone nodules exhibit, now that they have been split open—one, the body-segments of a fossil Scorpion (fig. 2); and the other, one of its palpi (fig. 3). So interesting an addition to the already numerous forms of Arthropoda from the English Coal-measures deserves to be made known as widely as possible, that those geologists who live near workable coal-beds where the clay-ironstone nodules occur may be encouraged by these "finds" to make use of their hammers and their eyes to furnish us with more perfect remains of this ancient air-breather of the coal-period.

As the specimens of Scorpion from the coal are at present very imperfect, I will only point out that our Scorpion agrees best with an Indian form which I cannot very well distinguish from *Scorpio afer*; but I prefer to adopt Messrs. Meek and Worthen's genus *Eoscorpius* with the specific designation of *anglicus* for the fossil form, and to await the discovery of more perfect remains before venturing to define its characters more minutely.

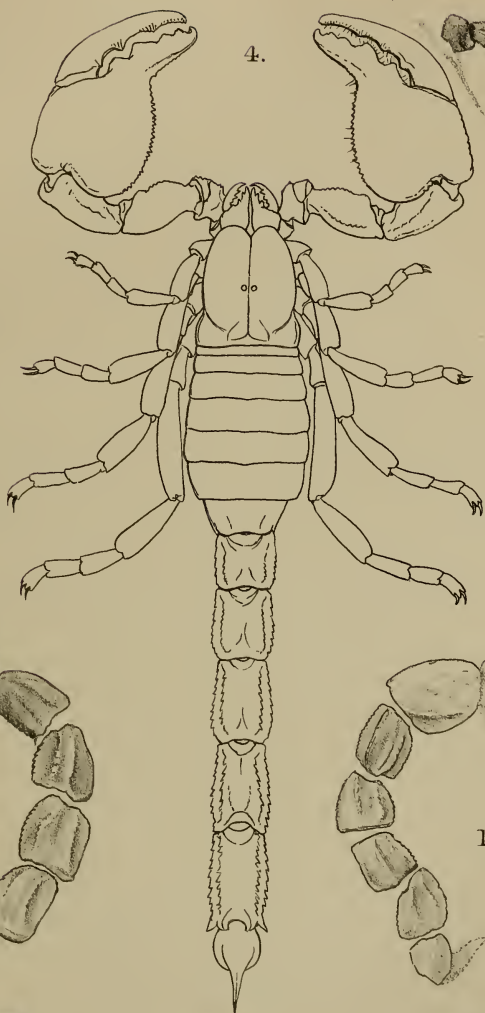


3^a



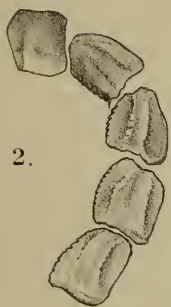
3.

x1/2.



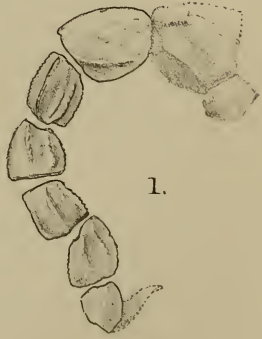
4.

x1/2



2.

x1/2



1.



5.



5^a



5^b

GH Ford & C.L. Griesbach.

Mintern Bros imp.

EXPLANATION OF PLATE VIII.

- Fig. 1. *Eoscorpium carbonarius*, sp. nov., from the Sandwell-Park Colliery.
2. The abdominal segments, from near Mansfield.
3. One of the chelate palpi, from near Mansfield, enlarged. 3*a*. The same, nat. size.
4. *Scorpio afer* (recent), nat. size.
5. Single articulation preserved in the round from the Coal-measures, Carlisle, Scotland; seen from above. 5*a*. The same, end view. 5*b*. The same, seen from below.

7. *On a remarkable fossil ORTHOPTEROUS INSECT from the COAL-MEASURES of SCOTLAND.* By HENRY WOODWARD, Esq., F.R.S., F.G.S., &c., British Museum. (Read November 3, 1875.)

[PLATE IX.]

THE clay-ironstone of Coalbrook Dale, Shropshire, has already yielded the wing of one most interesting form of fossil locust, the *Gryllacris* (*Corydalis*) *Brongniarti* (Pl. IX. fig. 2), figured and described in Mantell's 'Medals of Creation,' in Murchison's 'Siluria,' 4th edition, 1867, p. 300, woodcut 80, and, lastly, in the Geol. Mag. 1874, new series, Dec. ii. vol. i. pl. xiv. fig. 3; whilst the Coal-measures of Saarbruck and of Westphalia have yielded fossil remains of a *Gryllacris* and seven species of *Blattinæ*, or cockroaches, 4 *Termites* (white ants), 1 *Acridites*, 3 species of the Neuropterous genus *Dicthyoneura*; and from those of Grundy co., Illinois, U. S. A., 3 species of the genus *Miamia*, 1 of *Mylacris*, 1 of *Megathentomum*, 3 species of *Euphemerites*, and 1 doubtful species of *Mantis* have been described by Mr. S. H. Scudder, and from the Coal-measures of Cape Breton the genus *Haplophlebium* by the same author*.

Mr. Scudder has likewise described seven genera from more or less fragmentary remains in the Devonian rocks of New Brunswick †.

Dr. Anton Dohrn (Director of the Zoological Station at Naples) has described a new and most remarkable Neuropterous insect from the Permian (Todtliegende) of Birkenfeld, which he has named *Eugereon Bæckingii*, and regards as possibly belonging to an extinct order (DICTYOPTERA) ‡.

It has been my good fortune during the past year to have placed in my hands, through the kindness of Edward Charlesworth, Esq., F.G.S., a most interesting fossil insect from the Coal-measures of Scotland.

The insect in question has been preserved on the half of a clay-ironstone nodule, which had been split open for the purpose of examination; the fate of the corresponding half is unknown.

These clay-ironstone nodules have been known from the earliest times to contain fossil remains, and have in consequence been diligently examined; but as they occur in infinite numbers, and the geologists are few who devote themselves to their study, we know but little, after all, of the buried treasures they contain, and they too often pass into the smelting-furnaces unnoticed and unseen. In one clay-ironstone nodule larger than usual, Mr. George Maw, F.G.S., of Benthall Hall, near Broseley, obtained the entire and uncrushed skull of a Labyrinthodont, one of the most completely preserved of such remains ever found in the Coal. I had the good fortune to procure, through Mr. Hollier, of Dudley, in a small nodule,

* Geol. Mag. 1867, vol. iv. p. 386, pl. xvii. fig. 1.

† *Ibid.* 1868, vol. v. pp. 172, 216.

‡ Dr. Dohrn in 'Palæontographica,' 1866, Bd. xiii. p. 333, taf. xli., and *op. cit.* 1869, Bd. xvi. p. 129, taf. viii.

the nearly perfect remains of an Arachnide, *Eophrynus Prestvicii*, having both sides seen in the two halves of the same stone*. I allude to this in order to stimulate geologists in the neighbourhood of coal-fields to devote some time to splitting these nodules of the "pennystone" ironstone, feeling assured they will be well rewarded by finding king-crabs, Arachnides, Myriopods, insects, ferns, fruits, and other fossil remains, which may serve to enrich their own and the public museums, and increase our knowledge of the fauna and flora of the Carboniferous epoch.

Owing to the large expanse of surface covered by the fossil insect under consideration, only *two* of the four wings are well preserved; and of these two we have not the extremities, or the posterior border of the hinder wing.

The two best-preserved wings measure $2\frac{1}{4}$ inches in length and 1 inch and $1\frac{1}{4}$ inch respectively in breadth, the hind wing being the broadest, as is the case among the ORTHOPTERA generally.

The anterior margin of the fore wing is not well preserved; but a careful examination brings to light the characteristic strong longitudinal vein running parallel with the fore margin, so necessary for giving support to the wing in flight.

This is followed by a second equally straight vein.

The third vein is likewise parallel, but bifurcates near the extremity of the wing.

The fourth vein is much curved, and gives rise to six branches, three of which again bifurcate, and all bend outwards and backwards towards the hinder border of the wing. About 2 lines from the base of this strong fourth vein it unites with a fifth short vein at an acute angle, enclosing with the proximal border of the wing a triangular space. This triangular area is observable in all four wings, and appears to correspond exactly with a similar vein-area in the wing of *Gryllacris (Corydalis) Brongniarti* described by Mr. A. H. Swinton in the 'Geological Magazine,' 1874, Decade ii. vol. i. p. 337, pl. xiv. fig. 3, as "a vocal organ, and which in the LOCUSTIDÆ appears to be greatly developed, and to be furnished with a series of minute arches, which the insect causes to vibrate by moving one wing across the other, as the fiddle-bow is moved across the strings of the violin."

This shrill-vein is by no means always developed as an organ of sound in all the members of the Orthoptera; but few are without it in some measure.

The other veins of the wing take their rise from the centre of this triangular vein, and, branching into three and into two, terminate in the hinder border.

The venation of the hinder wing differs but little from that of the fore wing, save in its greater depth, and consequently in the prolongation backward of the hindermost veins. (See Pl. IX. fig. 1.)

The transverse veinlets which brace the principal veins together, have a general rectangular arrangement, dividing up the wing into a great number of chiefly square and oblong meshes.

* Geol. Mag. 1871, vol. viii. p. 385, pl. xl.

Of the body we see but little; a transverse band marks the probable division between the meso- and metathorax; and from the undisturbed position of the bases of the four wings we may conclude that the insect was not less than five lines in breadth across the thorax.

Immediately in front of the wings, and evidently *in situ*, is the prothorax, consisting of two dilated and rounded lobes, veined like the wings themselves, but rather more irregularly, and measuring 14 lines across and 6 lines in length. In the centre of these two rounded lobes, and extending 8 lines in advance of them, is what appears to be a slender frontal process, 3 lines long, behind which is the small head with its eyes, measuring 3 lines in breadth. In front and from one side of the prothorax, one leg is seen remaining *in situ*.

Compared with the ordinary Neuroptera, and even with Dr. Dohrn's *Eugereon Bœckingii*, we see that in the neuration of the wings there is a marked distinction; for whereas the cross veins in our fossil run nearly always at right angles to the longitudinal veins, leaving more or less quadrangular meshes, the wings in *Eugereon* and many other NEUROPTERA have the interspaces between the veins filled by polygonal meshes, especially in the hinder part of the wings. Nor does the arrangement of the main veins correspond.

Compared with modern ORTHOPTERA, we find that in the fossil there is a tendency to greater branching of the large longitudinal veins, and a more frequent branching of the transverse veinlets that brace them together; and that there is a less parallel disposition of the former.

Between this form and *Corydalis (Gryllacris) Brongniarti* (Pl. IX. fig. 2), from the Coal-measures, Coalbrook Dale, there is a marked similarity.

Having corresponded with Prof. J. O. Westwood, of Oxford, and also communicated with my esteemed colleague Charles O. Waterhouse, Esq., of the Zoological Department, I am confirmed by both these entomologists and also by R. McLachlan, Esq., F.L.S., in referring this remarkable fossil to the neighbourhood of the MANTIDÆ. In no other group do we meet with such a dilatation of the prothorax; and although the frontal process seems at first sight abnormal, nevertheless I find it, combined with the prothoracic dilatations, in the genus *Blepharis*, and notably in *B. domina*, from the White Nile. There is also a general agreement in the neuration of the wings, which leads me to rest satisfied in this determination. Nevertheless there are points of affinity with the NEUROPTERA which mark this insect, and which led Audouin to refer the Coalbrook-dale example to *Corydalis*, although Mr. A. H. Swinton has subsequently referred it to *Gryllacris**.

One great distinction between *Blepharis domina* and the fossil under consideration is, that in the latter the dilatations of the prothorax are tumid and rounded, whilst in the former they are perfectly flat and subtriangular.

* Geol. Mag. *loc. cit.*

Without following the example of Dr. Dohrn and proposing a new order for the fossil before us, I have no hesitation in placing it in a new genus, for which I would propose the name of *Lithomantis*, calling the species *L. carbonarius*.

The following is a list of the hitherto described fossil Insects and Arachnida found in the Palæozoic rocks:—

PERMIAN.

1. Eugereon Bœckingii, *Dohrn*. Birkenfield.

COAL-MEASURES.

ARACHNIDA.

I. *Scorpionidæ*.

- ✓ 1. Microlabis Sternbergi, *Corda*. Coal-measures, Bohemia.
- ✓ 2. Cyclophthalmus senior, *Corda*. Ditto, ditto.
- ✓ 3. Mazonia Woodiana, *M. & W.* Ditto, Illinois.
- ✓ 4. Eoscorpium carbonarius, *M. & W.* Ditto, ditto.
- ✓ 5. Eoscorpium anglicus, *H. Woodw.* Ditto, Sandwell-Park and Skegby Collieries.

II. *False Scorpions*.

- ✓ 6. Architarbus rotundatus, *Scudder*. Coal-measures, Illinois.
- ✓ 7. — subovalis, *H. Woodw.* Ditto, near Padiham, Lancashire.
- ✓ 8. Eophrynus Prestvicii, *H. Woodw.* Ditto, Coalbrook Dale and Dudley.

III. *Araneidæ*.

9. Aranea, sp. Coal-measures, Bohemia.
- ✓ 10. Protolycosa anthracophila, *Römer*. Ditto, Silesia.
- ✓ 11. Arthrolycosa antiqua, *Harger*. Ditto, Morris, Illinois.

MYRIPODA.

12. Xylobius sigillariæ, *Dawson*. Coal-measures, Glasgow, Huddersfield, and Nova Scotia.
13. Euphoberia armigera, *M. & W.* Ditto, Illinois, U.S., and Nova Scotia.
14. — Brownii, *H. W.* Ditto, Glasgow.
15. — major, *M. & W.* Ditto, Illinois, U.S.
16. — anthrax, *Salt.*, sp. (?). Ditto, Coalbrook Dale.
17. — ferox, *Salt.*, sp. Ditto, ditto.

COLEOPTERA.

18. Curculioides Ansticii, *Buckl.* Coal-measures, Coalbrook Dale.
19. Scarabæus, sp. Ditto, Saarbruck (a fossil fruit! *Römer*).
20. Troxites Germari, *F. Gold.* Ditto, Saarbruck.

ORTHOPTERA.

(Blattidæ.)

21. Blattina primæva, *F. Gold.* Coal-measures, Saarbruck. *Etoblattina primæva*
22. — Lebachensis, *F. Gold.* Ditto, ditto.
23. — gracilis, *F. Gold.* Ditto, ditto.
24. — anaglyptica, *German.* Ditto, Westphalia.
25. — anthracophila, *German.* Ditto, ditto.
26. — didyma, *German.* Ditto, Westphalia.
27. — flabellata, *German.* Ditto, ditto.
28. — venusta, *Lesqrx.* Ditto, Frog Bayou, Arkansas.

(Locustidæ.)

29. *Gryllacris lithanthraca*, *F. Gold.* Coal-measures, Saarbruck.
 30. — (Corydalis) *Brongniarti*, *Mant.* Ditto, Coalbrook-dale.
 31. *Acridites carbonatus*, *Germar.* Ditto, Westphalia.

(Mantidæ?)

- ✓ 32. *Lithomantis carbonarius*, *H. Woodw.* Coal-measures, Scotland.
 33. *Mantis*?, sp., *Scudder.* Ditto, Grundy Co., Illinois.

NEUROPTERA.

34. *Termes Heeri*, *F. Gold.* Coal-measures, Saarbruck.
 35. — *formosus*, *F. Gold.* Ditto, ditto.
 36. — *Decheni*, *F. Gold.* Ditto, ditto.
 37. — *affinis*, *F. Gold.* Ditto, ditto.
 38. *Dictyoneura anthracophila*, *F. Gold.* Coal-measures, Saarbruck.
 39. — *Humboldtiana*, *F. Gold.* Ditto, ditto.
 40. — *libelluloides*, *F. Gold.* Ditto, ditto.
 ✓ 41. *Miamia Bronsoni*, *Dana.* Ditto, Grundy Co., Illinois.
 ✓ 42. — *Danae*, *Scudder.* Ditto, ditto.
 ✓ 43. — (*Chrestotes*) *lapidea*, *Scudder.* Ditto, ditto.
 44. *Hemeristia occidentalis*, *Dana.* Ditto, ditto.
 45. *Mylacris anthracophila*, *Scudder* (in *Dana*).
 46. *Megathentomum pustulatum*, *Scudder.* Ditto, ditto.
 47. *Euphemerites simplex*, *Scudder.* Ditto, ditto.
 48. — *gigas*, *Scudder.* Ditto, ditto.
 49. — *affinis*, *Scudder.* Ditto, ditto.
 ✓ 50. *Haplophlebiium Barnesii*, *Scudder.* Ditto, Cape Breton.

LEPIDOPTERA?

51. *Tinea*, sp., *Fabricius.* Coal-measures.

DEVONIAN.

1. *Platphemera antiqua*, *Scudder.* Devonian, New Brunswick.
2. *Homothetus fossilis*, *Scudder.* Ditto, ditto.
3. *Lithentomum Harttii*, *Scudder.* Ditto, ditto.
4. *Xenoneura antiquorum*, *Scudder.* Ditto, ditto.
5. *Gerephemera simplex*, *Scudder.* Ditto, ditto.
6. *Dyscritus vetustus*, *Scudder.* Ditto, ditto.
7. *Archimylaeris acadicus*, *Scudder.* Ditto, ditto.

EXPLANATION OF PLATE IX.

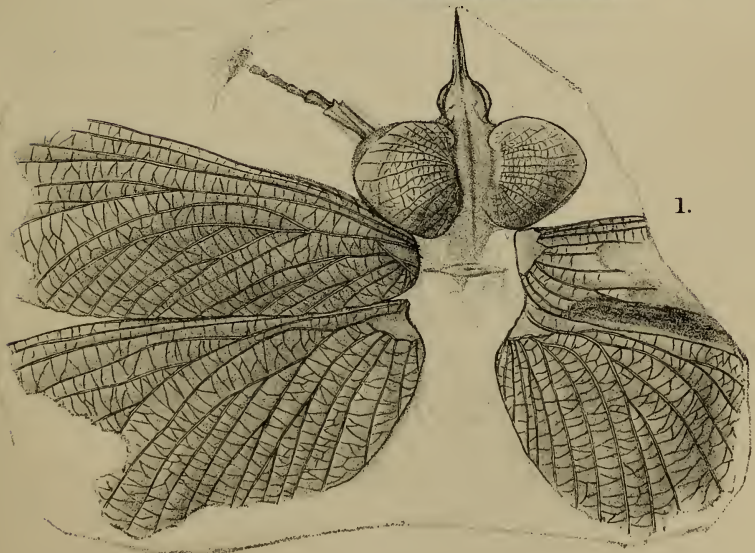
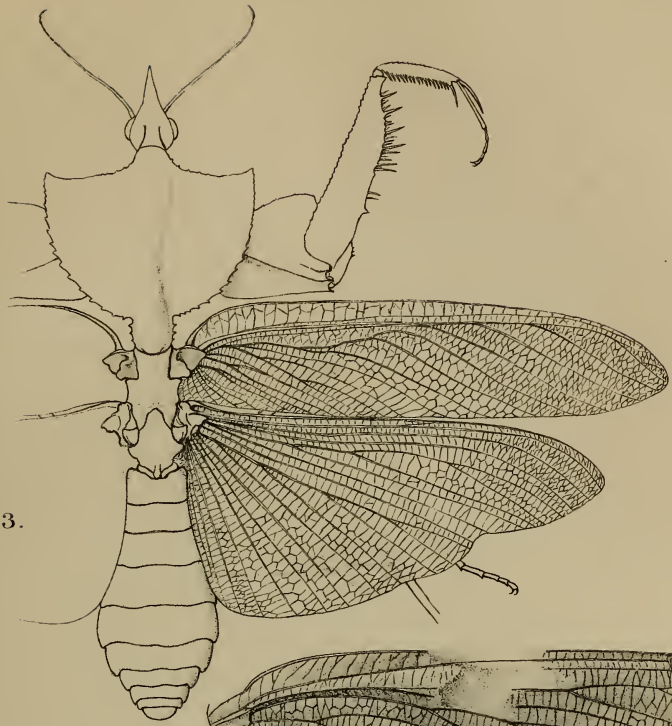
- Fig. 1. *Lithomantis carbonarius*, sp. nov.; nat. size. Coal-measures, Scotland.
 2. *Gryllacris* (*Corydalis*) *Brongniarti*; nat. size. Ditto, Coalbrook Dale.
 3. *Blepharis domina* (recent); nat. size. White Nile, Abyssinia.

DISCUSSION.

Mr. CHARLESWORTH inquired whether the presence of the few Cretaceous fossils found in the deposit which had furnished the New-Zealand Crab described might not be the result of the degradation of preexisting rocks.

Dr. HECTOR replied that, on stratigraphical grounds, this could not be the case.

Mr. CHARLESWORTH stated that he had been unable to ascertain the precise locality of the fossil Orthopteroous insect described, but that he was informed by the gentleman from whom he received it



that the nodule containing the specimen was picked up by a lady in Scotland.

Prof. MORRIS remarked that the New Zealand Crab was of especial interest. All the previously described species of *Harpactocarcinus* had been obtained from Nummulitic deposits in the south of Europe; and the same concurrence was observed in New Zealand. Similar phenomena occurred in Australia, where many species resembling European forms had been discovered by M'Coy.

Mr. ETHERIDGE said that one of Mr. Woodward's papers demonstrated the value of the Sub-Wealden boring. He had examined the cores, and had come to the conclusion that the Oxford Clay was reached at 500 feet; but in this he was mistaken, owing to his having wrongly identified the Ammonite discovered at that depth with *Ammonites jason*. The occurrence of the same species of Crustacean at Boulogne and in Sussex was of great interest, as marking the identity of the deposit in the two localities. *Lingula ovalis* occurred with other fossils throughout the Kimmeridge Clay of the boring.

Mr. WOODWARD thanked Mr. Charlesworth for his endeavours to ascertain the locality from which his *Lithomantis* was obtained, but remarked that, whatever this might be, there could be no doubt as to its geological horizon.

8. NOTES on the OCCURRENCE of *Eozoon* CANADENSE at CÔTE ST. PIERRE. By J. W. DAWSON, LL.D., F.R.S., F.G.S. (Read May 12, 1875.)

[PLATE X.]

CÔTE ST. PIERRE, in the Seigniorie of Petite Nation, on the river Ottawa, is the locality whence some of the most instructive specimens of *Eozoon* were obtained by the late Mr. Lowe, whose collections are referred to in papers presented to this Society by Sir W. E. Logan and the writer. Believing that a reexamination of this place would afford a good opportunity for collecting additional specimens, and for the study of the fossil *in situ*, as well as for testing the validity of objections recently raised to the animal nature of *Eozoon*, I made arrangements for visiting it in September last; and, through the kindness of Mr. Selwyn, Mr. T. C. Weston, of the Geological Survey, a skilful collector, and who has had much experience in preparing and examining specimens of *Eozoon*, was permitted to accompany me, and subsequently prepared slices and photographs of some of the specimens obtained.

The Lower Laurentian rocks of this region have been carefully mapped and described in the Reports of the Geological Survey, to which I may refer for their general description. The limestone, which has afforded *Eozoon* at Côte St. Pierre, is a thick bed belonging to the Grenville band of Sir W. E. Logan, and included between the two great belts of orthoclase gneiss (the third and fourth gneiss) which in this region constitute the upper beds of the Lower Laurentian. Its average thickness, according to the measurements of Sir William Logan, is 750 feet; but it varies from 1500 feet to 60 feet. Its outcrop has been traced in the country north of the Ottawa for at least 100 miles, along several anticlinal and synclinal folds*.

At Côte St. Pierre this limestone occurs on the flank of a hill of gneiss and stratified diorite, with a dip to the south-east at angles of 70° to 80°. The dip, however, is very inconstant, owing to the contortions of the beds.

The limestone is white and crystalline, and may be described as thin-bedded, since it presents a great number of layers of no great individual thickness, and differing in the coarseness of the crystallization and in the presence of dolomite, serpentine, and layers of gneissose matter in some of them. The specimens of *Eozoon* were found to be abundant in only one bed, not more than four feet in thickness, though occasional specimens and layers of fragments occur in other parts of the band. The exposures are in part natural weathered surfaces seen on a wooded bank, in part an opening made by Mr. Lowe to extract specimens of *Eozoon*, and a larger opening made, as we were informed, by parties in search of fibrous serpentine, or "rock-cotton," for economic purposes.

* See map in 'Geology of Canada,' 1863.

The sections seen in the artificial exposures may be tabulated as follows, though from the highly inclined position of the beds and the irregularity of the excavations, perfect accuracy was not attainable:—

Mr. Lowe's Excavation (order descending).

1. Limestone with serpentine and entire specimens of *Eozoon*—3 feet.
2. Coarse crystalline limestone, with layers containing fragments of *Eozoon*—4 feet.
3. Limestone with concretions and layers of serpentine, and a few specimens of *Eozoon*—several feet, to the bottom of the excavation.

Fisher's Excavation (order descending).

1. Laminated limestone with bands of serpentine—6 feet.
2. White laminated limestone traversed by small veins of chrysotile—8 feet.
3. Limestone with concretions and interrupted bands of serpentine and pyroxene, and fragments of *Eozoon*—10 feet. (Crystals and layers of dolomite occur in this and the preceding beds.)
4. Limestone with large concretions of serpentine, and in one layer fine-grained variety of *Eozoon* (var. *minor*)—20 feet.
5. Limestone with serpentine and perfect specimens of *Eozoon*. (This probably corresponds to Lowe's excavation)—12 feet.
6. Coarse-grained limestone and dolomite—several feet.
(After a break of several yards)
7. Limestone with masses of pyroxene and veins of chrysotile and some imperfect *Eozoon*.
(After a break of several yards)
8. Coarse-grained diorite, resting on a thick band of gneiss.

In front of Lowe's excavation, and apparently overlying the limestone exposed in it, is a narrow ledge of fine-grained gneiss; and beyond this other and probably overlying limestone appears, holding pyroxene and mica. The whole vertical thickness of the limestone exposed can scarcely exceed 150 feet; but this is probably only a small part of the development of the band at this place.

In the strike of the limestone to the south it appears to bend abruptly, or to be thrown by a fault, to the south-east, the gneiss and diorite coming forward into a line with it, and the limestone appearing in a little bare knoll in front of these. On the surface of this limestone were found some fine specimens of weathered *Eozoon*.

I examined carefully the relation of the bedded serpentine and the veins of chrysotile or fibrous serpentine to the limestone. The compact serpentine is evidently an original part of the deposit, occurring in layers and lenticular concretions. In some beds it shows no indication of the structure of *Eozoon*; but in others it fills the cavities of the fossils, and there are many regular layers of fragmental *Eozoon* of considerable thickness in which it fills the cells, while in other layers interstratified with these the fossil is associated with dolomite. I satisfied myself on this point not only on the ground, but also by taking away large specimens representing several thin layers, and treating them with dilute acid so as to bring out the structure. The following is a section of such a specimen, $5\frac{1}{2}$ inches in vertical thickness, treated with acid and examined with a lens:—

1. Limestone with crystals of dolomite and a few fragments of *Eozoon*.
2. Fine-grained limestone with granules of serpentine—the latter filling the chamberlets of fragments of *Eozoon* and small globigerine Foraminifera.
3. Limestone with dolomite and including a thin layer of serpentine as above.
4. Limestone and dolomite with grains of serpentine and fragments of supplemental skeleton of *Eozoon*.
5. Crystallized dolomite, holding a few fragments of *Eozoon* in the state of calcite.
6. Limestone with disseminated serpentine as above, chamberlets of *Eozoon* and fragments of its supplemental skeleton, also small groups of chamberlets, perhaps globigerine Foraminifera.

In other specimens a like thickness of rock presented a mass of fragments of supplemental skeleton with the canals injected with serpentine, and granules of the same filling the chambers.

The chrysotile veins, which are sometimes an inch or more in thickness, but branch off into the most minute fibres, are evidently altogether subsequent in origin to the bedded limestone and serpentine. They are undoubtedly of aqueous origin, and in their mode of occurrence strongly resemble the veins of fibrous gypsum penetrating the Lower Carboniferous marls of Nova Scotia. They cross the bedding in all directions, and pass through the structure of *Eozoon*, though sometimes running parallel to its laminae for short distances. They must have been introduced after the *Eozoon* was mineralized, and have evidently no connexion with its structure.

In the diagram (Pl. X. fig. 2) I have attempted to represent this relation; and I have no hesitation in stating that the assertion that these chrysotile veins are identical with or similar to the proper wall of *Eozoon* either in structure or distribution, is wholly without foundation, other than that which may arise from confounding dissimilar structures accidentally associated with each other.

Some slickensided joints lined with a lamellar and fibrous serpentine traverse the beds, and, as the chrysotile veins sometimes terminate in them, may be older than the latter. These also were observed to cross the masses of *Eozoon*.

Few disseminated minerals, other than those already mentioned, were observed in the *Eozoon* limestone. A few detached crystals of mica, pyroxene, and pyrite were found in the fragmental layers, and also a few rounded particles of quartz, probably grains of sand.

The perfect examples of *Eozoon*, at least those rendered evident by mineralization with serpentine, are confined to certain bands of limestone, and notably to one band—that originally opened by Mr. Lowe. In this bed the fossil occurs in patches of various sizes, some of them two feet or more in diameter, and bent or folded by the contortions of the strata; others are much smaller, down to a few inches. On the weathered surfaces the specimens mineralized with serpentine project, and exhibit their lamination in great perfection, resembling very closely the silicified *Stromatopora* of the Corniferous Limestone.

None of the specimens of *Eozoon* is of any great vertical thickness. The lower laminae are generally the best developed and with the thickest supplemental or intermediate skeleton. The upper

laminæ become thin-walled, though often very regular; and after about 100 laminæ at most, the superficial portions become acervuline for an inch or so and then terminate. In some specimens only a few regular laminæ are formed, succeeded by acervuline structures. A very fine and regular specimen in my collection has 100 laminæ in a thickness of $3\frac{1}{2}$ inches, giving a little more than a thirtieth of an inch for the average height of each lamina of sarcode and shell-wall.

In order to test the state of preservation of the canal system and nummuline layer, I treated a great number of specimens from different parts of the bed with a dilute acid. The result was, that in all the canal system could be detected in greater or less perfection in the thicker laminæ near the base of the forms, and in some through a great number of the laminæ. The structure of the nummuline layer was not so constantly preserved, its tubuli not being infiltrated in some parts, so that it appears as a structureless band, or fails altogether to be visible. In no instance could it be seen to pass into chrysotile, as recently affirmed by Messrs. Rowney and King*, although chrysotile veins often run very near to or across the walls. The nummuline layer is almost always distinctly limited by parallel surfaces, with its tubes at right angles, or nearly so, to these. The sort of chevron arrangement figured by Rowney and King in fig. 7 of their plate, in the number of the 'Annals of Natural History' for October 1874, I have never observed; and Mr. Weston, who has prepared and examined microscopically hundreds of specimens of *Eozoon*, was struck with the inaccuracy of the representations in this plate, and remarked on it the first time that I met him after he had seen the paper referred to. Figs. 2 and 3, Pl. X., relate to these points, and show the actual nature of the nummuline wall and its relation to the intermediate skeleton and chrysotile veins, as do also the figures recently published by Dr. Carpenter in his paper in the 'Annals'†.

By careful scrutiny of the beds we were enabled to detect two new forms of *Eozoon*, which may eventually prove to be distinct species, but which for the present may be regarded as varietal forms.

One of these, found *in situ* by Mr. Weston, is flat in form and very finely laminated, with thin walls except near the lower part, where there is some supplemental skeleton with finer and more curved canals than usual. The thin walls or laminæ of the ordinary skeleton are connected by very frequent vertical pillars or partitions, and are as numerous as thirty in half an inch, while the whole thickness of the specimen does not exceed an inch. It thus very closely resembles some of the Devonian and Silurian *Stromatopora*, especially when seen on the weathered surface. It may be named in the mean time variety *minor*.

The second occurs in more or less oval patches a few inches in diameter, limited by a sort of frame or border of compact serpentine, and presenting under the microscope an aggregation of small acervuline chamberlets, having the proper wall filled with unusually

* Ann. & Mag. of Nat. Hist. May 1874.

† *Ibid.* June 1874.

long parallel tubes, and with little development of supplemental or intermediate skeleton. The appearance of parallel tubulation running through and past several successive chamberlets was more conspicuous in these specimens than in the ordinary acervuline *Eozoon*, and the chamberlets themselves more cylindrical and tortuous. These specimens may either be portions of the acervuline superficial part of *Eozoon* broken off and separately preserved, or they may constitute a distinct varietal form. As the latter seems on the whole most probable, I would name this form variety *acervulina*.

These varieties are of much more rare occurrence than the ordinary type of *Eozoon*.

The ordinary specimens of *Eozoon* found at St. Pierre are mineralized with serpentine; but fragments imbedded in the dolomitic limestones have their canals filled with a transparent mineral which, from its optical character, is evidently dolomite, though the quantity obtained was not sufficient for any definite chemical test. Parts of the canals in these specimens were filled with calcite, as shown by its dissolving entirely away in a dilute acid. In one of the serpentinous specimens also I have observed that, while portions of the groups of canals, especially the basal portions, are filled with serpentine, the extremities of the canals and their finer branches present, under polarized light, the aspect of calcite; and that they are filled with this mineral is proved by these portions of the canal-filling being entirely removed when treated with dilute acid. It would thus appear that in these specimens, while the terminal parts of the canals have been filled with calcite, the basal portions have been occupied by serpentine. This is not, however, a new fact, as similar appearances have been already described both by Dr. Carpenter and the writer.

In one specimen I observed a portion of the fossil entirely replaced by serpentine, the walls of the skeleton being represented by a lighter-coloured serpentine than that filling the chambers, and still retaining traces of the canals. The walls thus replaced by serpentine could be clearly traced into connexion with the portions of those still existing as calcite. This shows that the serpentine, like the quartz in silicified shells and corals, has had the power of replacing the calcite of the fossils; and I believe that its partial action in this way accounts for some irregularities observed in the less perfectly preserved specimens. Nor is it improbable, as Dr. Hunt has already suggested, that some of the masses of serpentine and pyroxene on which specimens of *Eozoon* are based, may represent older and more perfectly mineralized masses of the fossil.

In some of the specimens of *Eozoon*, the superficial laminæ are apparently broken and displaced in such a manner as to suggest the idea that partial disintegration by the waves had taken place before they were finally buried. It is also observable that in some of the masses the compression to which they have been subjected has produced a microscopic faulting, which slightly displaces the laminæ.

One of the most interesting features of the St.-Pierre limestone,

not noticed by previous observers, is the occurrence of layers filled with little globose casts of chamberlets, single or attached in groups, and often exactly resembling the casts of *Globigerinæ* in greensand (Pl. X. figs. 4-10). On weathered surfaces they were often especially striking when examined with the lens. In some cases the chamberlets seem to have been merely lined with serpentine, so that they weather into hollow shells. The walls of these chamberlets have had the same tubulated structure as *Eozoon* (fig. 4); so that they are in their essential characters minute acervuline specimens of that species, and similar to those which I described in my paper of 1867* as occurring in the limestones of Long Lake and Wentworth, and also in the loganite filling the chambers of specimens of *Eozoon* from Burgess. Some of them are connected with each other by necks or processes, in the manner of the groups of chamberlets described by Gumbel as occurring in a limestone from Finland, examined by him. That they are organic I cannot doubt, and also that they have been distributed by currents over the surface of the layers along with fragments of *Eozoon*. Whether they are connected with that fossil or are specifically distinct may admit of more doubt. They may be merely minute portions detached from the acervuline surface of *Eozoon*, and possibly of the nature of reproductive buds. On the other hand, they may be distinct organisms growing in the manner of *Globigerina*. As this is at present uncertain, and as it is convenient to have some name for them, I propose to term them *Archæosphærinæ*, understanding by that name minute Foraminiferal organisms, having the form and mode of aggregation of *Globigerina*, but with the proper wall of *Eozoon*.

In slicing one of my specimens from Côte St. Pierre I have recently observed a very interesting peculiarity of structure, which deserves mention. It is an abnormal thickening of the calcareous wall in patches extending across the thickness of four or five lamellæ, the latter becoming slightly bent in approaching the thickened portion. This thickened portion is traversed by regularly placed parallel canals of large size, filled with dolomite, while the intervening calcite presents a very fine dendritic tubulation. The longitudinal axes of the canals lie nearly in the plane of the adjacent laminae. This structure reminds an observer of the *Cœnostroma* type of *Stromatopora*, and may be either an abnormal growth of *Eozoon*, consequent on some injury, or a parasitic mass of some Stromatoporoid organism finally overgrown by the *Eozoon*. The structure of the dolomite shows that it first incrustated the interior of the canals, and subsequently filled them—an appearance which I have also observed in some of the larger canals filled with serpentine, and which is very instructive as to their true nature.

From the above facts the true nature of *Eozoon* may, I think, be rendered evident to any geologist, however little he may have made the fossil Foraminifera a subject of study. The theories as to its origin may be summed up thus:—

1. The complicated theory of pseudomorphism and replacement,

* Quart. Journ. Geol. Soc. vol. xxiii. p. 260.

advocated by Messrs. Rowney and King, may be dismissed at once. Independently of the insuperable chemical difficulties which have been pointed out by Dr. Hunt*, and which he proposes to discuss more fully in his papers on Chemical Geology, now in the press, we have the further facts that no replacement of serpentine by calcite is indicated by the relations of these minerals to each other, while such replacement as does occur is in the other direction, or the change of calcite into serpentine, as evidenced by the state of preservation of some specimens of *Eozoon*, above referred to. Further, this theory fails to give any explanation of the specimens mineralized by pyroxene, dolomite, and calcite, or to account for the nummuline wall, except by attributing it to the alteration of chrysotile, which is inadmissible, as the veins of this mineral are newer than the walls supposed to have been derived from them.

2. Inasmuch as many apparently concretionary grains and lenticular masses of serpentine exist in the Laurentian limestones, it may be supposed possible that *Eozoon* is merely a modification of these concretionary forms. In this case, the filling of each lamina and chamberlet of *Eozoon* must be regarded as a separate concretion; and even if we could suppose some special cause to give regularity and uniformity to such concretions in some places and not in others, we still have unaccounted for the canals and tubuli, or the delicate threads of serpentine representing them. Further, we have to suppose that a tendency to this regular and complicated arrangement has affected in the same way minerals so diverse as serpentine, loganite, pyroxene, and dolomite.

3. The only remaining theory is that of infiltration by serpentine of cavities previously existing in the calcite. There is no chemical objection to this, inasmuch as we know of the infiltration of fossils in other formations by minerals akin to serpentine; and in these limestones the veins of fibrous serpentine have evidently been introduced by aqueous action subsequently to the production or fossilization of the *Eozoon*. Further, the white pyroxene of the Laurentian limestones, and the loganite and dolomite, are all known to have been produced by aqueous deposition. The only question remaining is, Whence came the original calcite skeleton with laminae, chambers, canals, and tubuli to be so infiltrated? The answer is given in the comparison with the tests of Foraminifera, originally proposed by the writer, and illustrated in so conclusive a manner by the researches of Dr. Carpenter.

I may add, in conclusion, that had geologists generally the opportunity of studying *Eozoon in situ*, in good exposures, like that at St. Pierre, they would much more fully understand and appreciate the arguments for its organic nature, than when they have had opportunities of examining only polished specimens and slices†. Its

* Trans. Royal Irish Academy, 1871.

† I have been sorry to find, from specimens in the cabinets of my friends, that some London dealers are in the habit of circulating specimens labelled "*Eozoon canadense*" which have no trace of the structures of the fossil, but are either badly preserved acervuline portions or merely ordinary serpentine marble. Such specimens can, of course, only mislead, and may produce much unnecessary scepticism.

Stromatoporoid masses, projecting from the weathered beds of limestone, would at once attract the attention of any collector; and the whole conditions of its occurrence, whether entire or in fragments, are precisely those of fossil corals in the Silurian limestones. Further, the symmetry and uniformity of its habit of growth are much more apparent when they can be studied in large specimens prepared by natural weathering or by treatment with an acid.

[*Note* (Oct. 30).—Messrs. Richardson and Weston, of the Geological Survey, have recently revisited the locality of *Eozoon* at Côte St. Pierre mentioned in the above paper, and have collected some additional specimens. One of these deserves notice, as illustrating the nature of *Archæosphærinæ*. It is a small or young small speci-

Figs. 1-4.—*Small weathered Specimen of Eozoon from Petite Nation.*

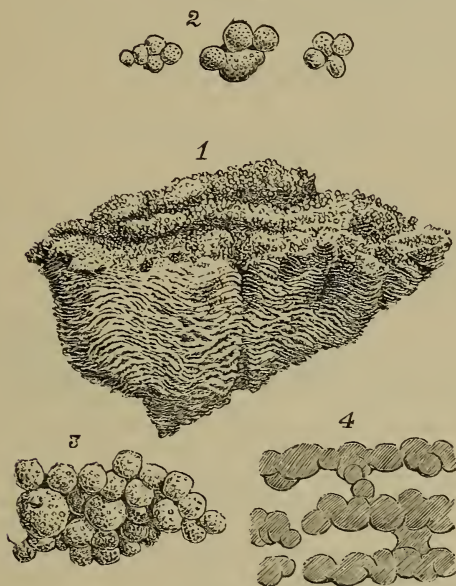


Fig. 1. Natural size; showing general form, and acervuline portion above and laminated portion below.

2. Enlarged casts of cells from upper part.

3. Enlarged casts of cells from the lower part of the acervuline portion.

4. Casts of sarcode layers from the laminated part; enlarged.

men, of a flattened oval form, $2\frac{1}{2}$ inches in its greatest diameter, and of no great thickness (fig. 1). It is a perfect cast in serpentine, and completely weathered out of the matrix, except a small portion of the upper surface, which was covered with limestone which I have carefully removed with a dilute acid. The serpentinous casts of the

chambers are in the lower part regularly laminated; but they are remarkable for their finely mammillated appearance, arising from their division into innumerable connected chamberlets resembling those of *Archæosphærina* (fig. 4). In the upper part the structure becomes acervuline, and the chamberlets rise into irregular prominences, which in the recent state must have been extremely friable, and, if broken up and scattered over the surfaces of beds, would not be distinguishable from the ordinary *Archæosphærinæ*. This specimen thus gives further probability to the view that the *Archæosphærinæ* may be for the most part detached chamberlets of *Eozoon*, perhaps dispersed in a living state and capable of acting as germs.]

EXPLANATION OF PLATE X.

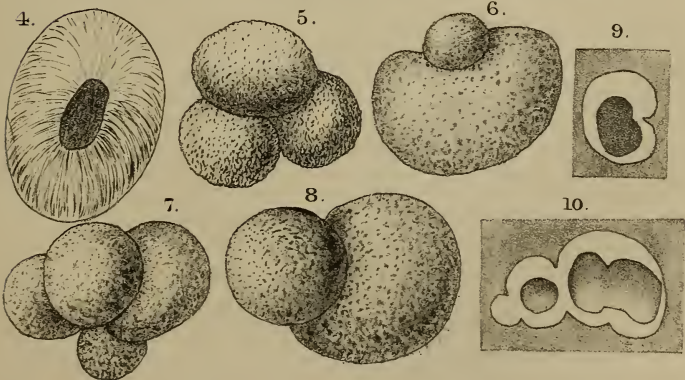
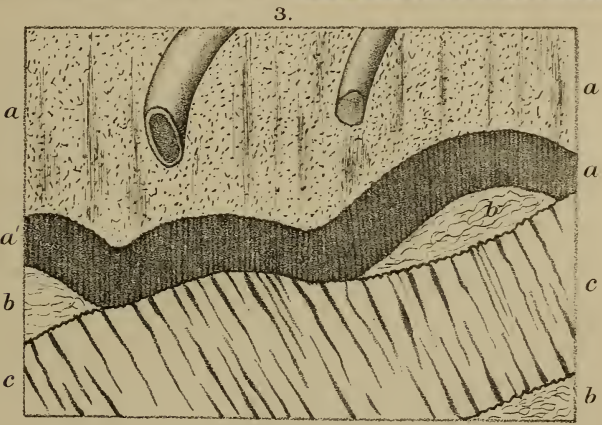
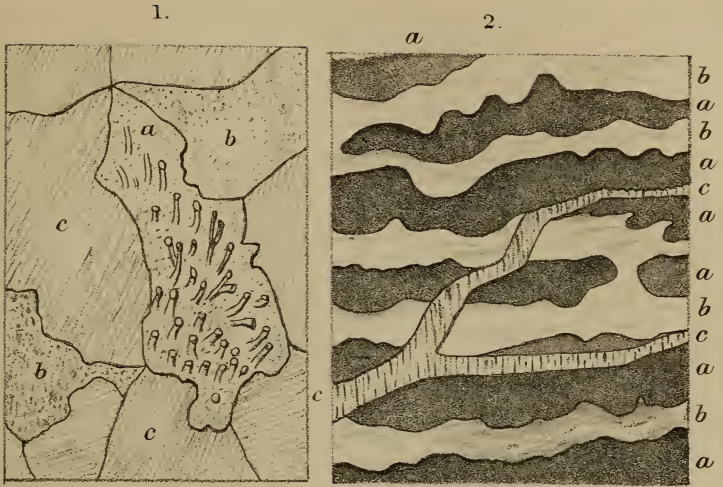
- Fig. 1. Fragments of skeleton of *Eozoon*, imbedded in dolomite limestone. (a) Fragment with canals. (b) Fragments not showing canals. (c) Dolomite. (Magnified 10 diameters.)
2. Laminated *Eozoon*, with vein of chrysotile. (a) Calcareous wall, slightly eroded with acid. (b) Serpentine filling chambers. (c) Chrysotile vein crossing the structures. (10 diam.)
3. Portion of a specimen similar to that in fig. 2; a very thin slice more highly magnified. (a) Intermediate skeleton with portions of two large canals. (a') Proper wall with fine tubulation. (b) Serpentine filling chambers. (c) Chrysotile vein traversing serpentine. (Magnified 90 diam.)
4. Small *Archæosphærina*, showing tubulated wall. (200 diam.)
- 5, 6, 7, 8. *Archæosphærinæ*, casts, as opaque objects, of some of the varieties. (75 diam.)
- 9 and 10. Similar specimens seen in section. (75 diam.)

The specimen represented in fig. 4 is from Long Lake; all the others are from Petite Nation.

DISCUSSION.

Prof. DUNCAN said that he thought the author had run the mineralogists rather hard. For his own part, when he first examined specimens of *Eozoon* he had come to the conclusion that they were ancient Foraminifera with Nummuline peculiarities; and since he had acquired a more intimate acquaintance with fibrous minerals and serpentines, he found himself more than ever confirmed in this view. The discovery of isolated masses was very interesting, seeing that, whether they were separated fragments or distinct organisms, they still showed the Nummuline structure. Prof. Duncan compared the habit of growth of *Eozoon* to that of the Nullipores, and suggested that it would be more philosophical to refer both the latter and the Foraminifera to Hæckel's group "Protista."

Mr. ETHERIDGE remarked upon the singular fact that whilst, as a general rule, we were disappointed in obtaining instructive sections of *Eozoon*, we had only to go to Dr. Carpenter to see sections which seemed to be convincing. He thought the difference of opinion that prevailed as to the nature of *Eozoon* was due mainly to the difficulty that certainly existed of procuring specimens to show the so-called tubuli and stolons. He stated that he had received from Jersey specimens which at the first glance he said were like



Eozoon; and on getting sections of these made, organic structure at any rate seemed to be present. He had specimens of *Stromatopora* so like *Eozoon* in external appearance, that Sir W. Logan on seeing them immediately mistook them for the latter.

Prof. RAMSAY said that he was pleased to find that there might be some relation between *Eozoon* and *Stromatopora*. For his own part he did not see how the structure described as *Eozoon* could have been formed, unless it was of organic origin.

Mr. EVANS remarked that, it seemed to him, one of the most interesting points of the paper consisted in the indication (he believed, for the first time) of the occurrence of possibly separate organisms associated with *Eozoon*. They apparently bore a close resemblance to *Globigerina*; and, considering the conditions of fossilization, their presence seemed to confirm the notion of the organic and indeed Foraminiferal origin of *Eozoon*.

9. GEOLOGICAL NOTES *from the State of New York.*

By T. G. B. LLOYD, Esq., C.E., F.G.S. (Read June 23, 1875.)

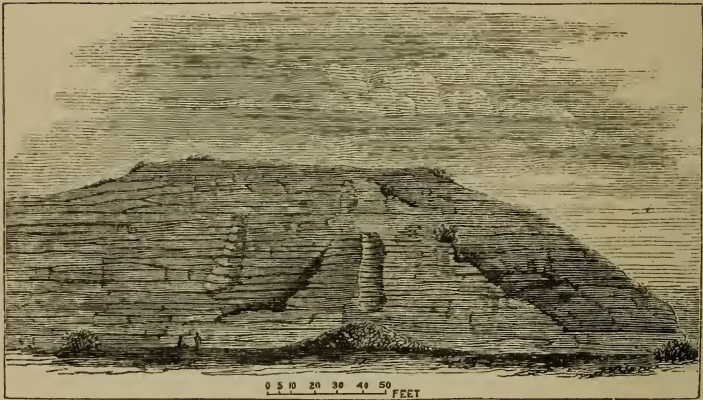
[Abstract.]

THE following notes of various geological facts occurring in the northern part of the State of New York were collected during a residence there some five or six years ago.

Grooves and Channellings, Black River, Watertown, Jefferson County.

The grooves and channellings which are seen cutting into the ledge of birdseye limestone at the base of the bank of sand, gravel, and boulders, pass obliquely across the bed of the river.

Fig. 1.—*View of the Pulpit Rock, near Oxbow, Jefferson Co., New York, showing remains of Giant's Kettles in Laurentian Granite.*



Further down stream, beyond the railroad bridge, the channellings were discontinued; but from the south side of the river they continued in a south-west direction to Lake Ontario, a distance of about 10 miles, according to Dr. Emmons.

Glacial Phenomena of the District around the village of Theresa, Jefferson Co.

The surfaces of the Potsdam Sandstone and of the Laurentian rocks, between Philadelphia on the south-east and the village of Redwood on the north-east of Theresa, are grooved and striated in a direction north-east and south-west, corresponding with the longer

axes of a number of small lakes which lie between Theresa and Redwood. Long parallel ridges, from 100 to 200 feet in width, of Laurentian gneiss are seen on the high ground between Philadelphia and Theresa, running in a direction about N.N.E. and S.S.W., with the strike of the beds. They rise some 40 or 50 feet above the surrounding plain, and are distant from each other about $\frac{1}{4}$ mile. The beds composing the ridges vary in dip from about 75° to 90° . The surfaces exhibit well-marked grooves and striæ. Hog's-backs of gneiss, with their steeper ends facing the south-west, rise here and there above the surface of the ground. A stiff, tenacious sandy clay ("Till;" D in table below), containing rounded boulders, chiefly of local origin, forms a capping to the ridges.

In the valley of Indian River, below the village of Theresa, the base of the cliff is grooved in a manner somewhat similar to that observed on Black River.

Tabular List of Beds.

- A. Light red dry sandstone (laminated); containing thin seams of carbonaceous matter, and rounded lumps of clay in layers.
- B. Dark brown and bluish-coloured sandy clays (laminated), containing occasional seams of light red *sand*, without boulders.
- B¹. Dark red unstratified clay without boulders.
- C. Beds of mainly unstratified gravel, clay, and sand, containing boulders.
- D. A tough sandy clay with rounded and some angular boulders (see Croskey's definition of boulder-clay). The bed-rock of sandstone or gneiss is rounded, smoothed, and grooved, and marked with fine parallel striæ.

The beds (A) occur at the head of the valley near Theresa, about $\frac{1}{2}$ mile south of the entrance of the gorge of Indian River. They were about 20 feet in thickness, and rested partly on the bed-rock of gneiss and on the surface of the bed B. The sand was laminated, and showed in places oblique-current action; besides the thin seams of carbonaceous matter, it contained seams of rounded nodules of clay, not concretionary. They varied in size from a walnut to a duck's egg; the clay composing them was like that of bed B.

It is probable that B and B¹ are only varieties of the same deposit. C and B only differ in the relative proportions of their constituents.

Summary of preceding Observations.

1. The persistent direction of the groovings and striations of the surface rocks over a considerable space.
2. The coincidence of the directions of the groovings &c. with the longer axes of most of the lakes of the district, and with the general course of Indian River.
3. The local character of the boulders.
4. The directions and forms of the parallel ridges and hog's-backs or roches moutonnées.

The ridges and troughs are quite distinct from the undulations in the Laurentian group so common in other parts of North America.

Giant's Kettle near Oxbow, Jefferson Co.

The cliff on the face of which the section of the kettle is exposed, has been named the Pulpit Rock, from the circumstance that the preachers of old used to hold forth from the interior of the kettle during their open-air meetings.

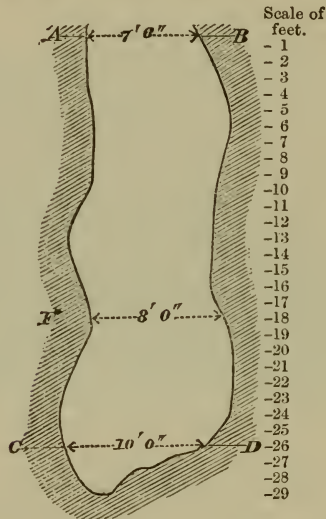
The drawing (fig. 1), for which I am indebted to the kindness of Mr. Ruddle, F.G.S., was made from a rough sketch taken on the spot.

The rock is of Laurentian granite, and is situated on the western side of a dry valley 450 feet wide. Its upper surface is about 70 feet above the road, and about 100 feet above the river Oswegatchie.

Besides the large kettle there were faint outlines of two others, situated at a higher level than the principal one.

Fig. 2 is a section through the centre of the kettle in a direction corresponding with the face of the rock. On the line C D it formed about three quarters of a circle; on A B it was nearly semicircular. A spiral groove ascended from right to left, as high as the

Fig. 2.—Section of Giant's Kettle in Laurentian Granite in the Pulpit Rock near Oxbow. (Scale $\frac{1}{16}$ inch to 1 foot.)



point F. The talus outside mainly consisted of the large mass of stones which formerly occupied the bottom of the kettle. Its resemblance to the kettles figured in Quart. Journ. Geol. Soc. vol. xxx. pp. 757, 759, figs. 4 & 5, will be apparent.

Flowerpot-shaped Blocks of Sandstone, Theresa, Jefferson Co.

The quarry from which the blocks were extracted was situated on a high cliff of Potsdam sandstone, overlooking the gorge of Indian

River. The beds of Potsdam sandstone passed from a fine-grained grit into a quartzite, the grains of which could not be distinguished without a lens. The upper surfaces of the beds were ripple-marked. At a depth of about 6 or 8 feet below the surface the peculiarly shaped blocks, or columns, were discovered. I observed a few lying about, which had been extracted by the quarrymen; one of the largest was 2 feet high, 2 feet in diameter at upper surface, and $1\frac{1}{2}$ foot on the lower surface. They were broken off at the lines separating the beds of sandstone. They corresponded exactly in texture and colour with the surrounding rock. On the edges of the blocks were thin layers of oxide of iron, easily detached by a blow. The surrounding rock was here and there streaked with the same substance. A short distance away from the quarry was a large mass of rock of a similar shape, and about 5 feet in diameter, which had apparently been dislodged from a hole close by it. There were no markings on the surface of the blocks. Prof. James Hall, of Albany, informed me that the true nature of the blocks was doubtful.

10. *The DRIFT of DEVON and CORNWALL, its ORIGIN, CORRELATION with that of the SOUTH-EAST of ENGLAND, and PLACE in the GLACIAL SERIES.* By THOMAS BELT, Esq., F.G.S. (Read November 3, 1875.)

[Abridged.]

1. INTRODUCTION.—If we separate the southern counties from the rest of England by a line following up the Thames to near Cirencester, then along the southern boundary of Gloucestershire to the Severn at the mouth of the Avon, we get an irregular strip of country, shaped somewhat like a fish, of which Kent forms the head, and Cornwall the tail. Excepting, perhaps, some of the hills of Somersetshire, this part of England appears to have been entirely free from the action of land-ice in the Glacial period; and there are no glaciated rock-surfaces, no true till, and no moraines. Along with, and, as I believe, in consequence of, this freedom from ice-action, there is also an utter absence of those fragmentary marine shells which, further north, are found in drift on both the eastern and western coasts, where the great streams of ice from the north, after crossing arms or channels of the sea, advanced upon the land—and the presence of which, as they are never found above heights to which the circumpolar ice reached, and for other reasons I have urged, is due, not to the submergence of the land beneath the ocean, but to portions of the ocean-bed having been carried up by the rising ice*.

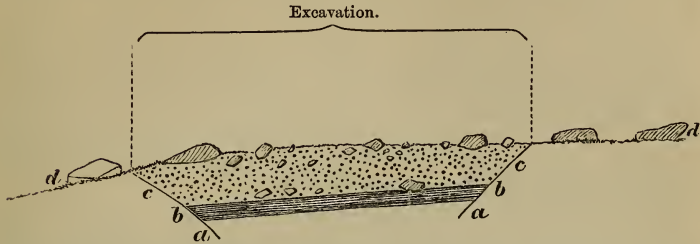
The purpose of the present paper is to describe the surface-geology of the counties of Devon and Cornwall, to examine the theories that have been proposed to account for the origin of the drift beds, to give my own views on the same question, and to support them by applying the theory to the drift beds of the whole of the south of England.

2. DRIFT BEDS OF DEVON AND CORNWALL.—The superficial deposits of Devon and Cornwall consist of two divisions:—*a. Upland deposits* (on the tops and sides of hills, mostly more than 300 feet above the present sea-level, and reaching up to about 1200 feet; these consist of gravels, clays, and transported boulders left in fragmentary patches, and evidently have had at one time a much greater extension); *b. Lowland deposits* (gravels, clays, and boulders spread out in more persistent and regular beds at low levels; they are most strongly developed in the valleys, but are not confined to them).

a. Upland deposits.—The whole of the surface of Dartmoor is sprinkled over with large blocks of granite, some of which are of enormous size. On the road from Tavistock to Princetown, about a mile west of Merriville bridge, one of the numerous excavations made in search of stream-tin exhibits the following section:—

* Nature, May 14 & 28, 1874.

Fig. 1.—Diagram Section of Excavation made in search of Stream-tin.



a. Soft decomposed granite. b. Stratified granite sand. c. Gravels and sand with boulders. d. Large blocks of granite lying on the surface.

Many other sections in the old stream-tin workings and in the banks of rivulets show a similar succession. If the blocks of granite had been left by the decomposition of softer portions of the bed-rock, they would have rested upon it. Neither can they have slipped down from the "tors" that crown many of the hills; for they are not confined to the slopes, but are spread out over the level ground as well, neither are they concentrated at the bottom of slopes, as they would have been by such an action. Here and there two or three, or even a dozen may be crowded together; but generally they are separated from each other.

Near to Okehampton, on the northern part of the moors, the bed-rock is composed of hardened shales and sandstones. The sides of the hills are covered with a stony clay, sometimes as much as 30 feet in thickness, containing many large angular blocks of stone, especially near to, and on, the surface. Amongst these, blocks of granite, that must have been brought at least two miles, are not unfrequent.

On the eastern side of Dartmoor, Mr. G. W. Ormerod has noticed beds of gravel reaching up to about 900 feet above the sea, and has given instances of many transported blocks of granite and Carboniferous rocks. Thus, to the east of Cranbrook Castle (1110 feet above the sea) and near Wooston Castle, large transported granitic blocks overlie the Carboniferous beds. On the Newton and Moreton-Hampstead Railway, fragments of granite are spread over the Carboniferous strata; and gravel formed of elvanic and Carboniferous rocks occurs at Riddy Hill, its nearest point of derivation being on the opposite side of the valley*. Mr. George Maw has described the occurrence at Petroclistow, near the centre of the county, of an isolated bed of gravel, composed almost entirely of the detritus of Dartmoor granite, twelve miles distant from the nearest granitic mass, and considers that it can only be accounted for by an amount of submergence covering the whole of the ridges†.

In one of the many able communications Mr. D. Mackintosh has made on the Glacial beds, he has advanced arguments to prove that

* Quart. Journ. Geol. Soc. vol. xxiii. p. 418.

† *Ibid.* vol. xx. p. 451.

the blocks of granite spread over Dartmoor must have been carried by currents of water and floating ice*. The experienced glacialist Mr. J. F. Campbell also believed that the denudation of the tors was due to floating ice †. Many miles to the east, on the Haldon Hills, gravels are found containing pebbles of granite and other crystalline rocks, mingled with chalk flints and chert. At Little Haldon Mr. Mackintosh found the gravels 10 feet thick, extending down the sides of the hill, proving that it had its present contour before they were deposited. The top of Little Haldon is about 800 feet above the sea; and the gravels extend over its summit.

Gravels with foreign pebbles are found on Straightway Hill, and on the summits of the hills surrounding the vale of Charmouth ‡. Mr. H. B. Woodward has kindly furnished me with much information respecting the drift-gravels that cover the Black-Down Hills, first described, I believe, by Dr. Buckland.

The bed-rocks belong to the Greensand formation; and on the tops of the hills, at heights of from 600 to 700 feet above the sea, occur patches of gravel with large, well-worn boulders of chert, large pebbles of quartz, rolled flints, and a few boulders of quartzite §. Mr. Woodward, in a letter to me, says:—"The occurrence of old pebbles in a clayey drift on the tops of the Greensand heights is the more important because, on the palæozoic rocks of Devonshire, it is often very difficult to decide between a drift gravel and the disintegrated conglomerates of the New Red series."

In Cornwall, upland gravels occur on Crousa Downs, near St. Keverne, and blocks of syenite are spread over the surface of them ||. On the isolated hill of St. Agnes, on the northern coast, Mr. Benedict Kitto has described gravels containing angular and waterworn stones covered by clay, and that again by rubble and rounded pebbles ¶.

When the nature of the evidence is fully understood, there is not likely to be any difference of opinion respecting the agent that transported the travelled blocks of Devon and Cornwall. The probability that they have been carried by floating ice is great, and is enhanced by the occurrence of rounded pebbles. These require for their formation the presence of water; and granting the existence of this up to the heights at which they are found, we may easily imagine that, in the Glacial Period, coast ice would form round the shores in winter, and float off pebbles and boulders in the spring.

b. Lowland deposits.—The Upland deposits are separated from those of lower levels by tracts over which no gravels are now found. They are distinguished from the Lowland deposits by evidence of tranquil deposition, whilst those in the lower grounds occur spread out in wide sheets, exhibiting many signs of sudden and tumultuous

* Geological Magazine, vol. iv. p. 399. † Frost and Fire, vol. ii. p. 220.

‡ Sir H. T. De la Beche, Report on the Geology of Cornwall, p. 395.

§ Mr. H. B. Woodward, Geological Magazine, 1874, p. 335.

|| Rev. E. Budge, Trans. Roy. Soc. Cornwall, vol. vi. p. 97; and Sir H. T. De la Beche, Report on the Geology of Cornwall, p. 396.

¶ Miners' Assoc. Cornwall and Devon, August, 1874.

formation. On the hills large stones are found scattered over the surface; in the Lowland deposits they occur at the bottom of the gravels. In Cornwall, the stream-tin is found at the bottom of the gravel, along with rocks of quartz of great size. In 1830, Mr. Joseph Carne urged that the occurrence of the stream-tin invariably at the bottom of the gravels proves that the whole of the materials had been in motion at once, and that these deposits furnish the strongest evidence of a sweeping inundation*.

In this view Mr. Carne followed Prof. Sedgwick, who, fifty years ago, had satisfied himself that the gravels had been spread out by a great débâcle†. Mr. Carne supported this theory with great ability, and referred to the fact that all the productive stream-tin works were situated in valleys opening to the south, whilst the richest tin veins are situated near the northern coast, and concluded that a deluge of water from the north had swept the tin into the southern valleys. Sir H. De la Beche fully concurred in this conclusion, and furnished additional arguments in its support. He says that any detritus that existed previously to the deposition of the stanniferous gravels appears to have been "fairly washed out by a mass of water rushing over the land, rolling and driving various loose materials before it, and allowing the tinstone, from its greater specific gravity, to be strewed along the bottom"‡.

In Devonshire, in every valley there is a repetition of the same facts—a scouring out of their upper reaches of all loose materials, which are spread out in great sheets towards their mouths. In the valleys of the Teign and its tributaries, there are some of the largest accumulations of gravel in Devonshire; and we have distinct evidence that it was not deposited during the excavation of the valleys, but that the latter were formed long before Miocene or præ-Miocene times; for at, and near, the junction of the Bovey river with the Teign are found the Bovey-Tracey lignites of Miocene age, lying in the valleys and covered by the lowland gravels. The Bovey-Tracey lignites have been bored through to a depth of 200 feet without the bottom of the old præ-Miocene valley being reached. The drift-beds extend up the sides of the valleys, and to the tops of the ranges bounding them.

3. THEORIES OF ORIGIN.—The facts to be explained, not only in Devon and Cornwall, but, as we shall see, over the whole of the south of England, are:—(1) gravels containing travelled boulders, on the sides and tops of hills up to about 1200 feet above the sea; (2) denudation of the surface-gravels from an intervening tract between the Upland and Lowland deposits; (3) in the lowlands, especially in the valleys within 100 feet above the level of the sea, a wide spreading-out of gravels that show signs of sudden and tumultuous deposition.

Subaërial denudation could not produce the hill-gravels containing rocks brought from a distance. Nor could the deposits lying on the

* Trans. Roy. Soc. Cornwall, vol. iv. p. 47.

† Annals of Philosophy, vol. ix. p. 241.

‡ Geology of Cornwall, pp. 396, 398, & 410.

sides of the valleys have been left there during their excavation ; for as we have seen, the configuration of the country dates back at least to early Tertiary times.

Water must have been present to form the gravels of Dartmoor up to about 1200 feet above the sea, and also to allow ice to transport the erratic blocks. Was the water that of the ocean, or of a great freshwater lake ? With respect to the area in question, there is this insuperable objection to the theory of marine submergence, that over the whole district no marine beaches, and not a single marine organism has been found, excepting within a few feet of the present sea-level. Nor can sea-shells have once existed in the deposits, and been since destroyed ; for mammalian remains and land and freshwater shells are preserved ; and any agency that would have obliterated the traces of the one, would not have spared the others.

After much study of this question, not only with regard to the part of the country now under consideration, but with reference to the erratic blocks and the stratified and terraced gravels of nearly the whole of Northern Europe, the only theory I can find that meets all the facts of the case and deals with all its difficulties, is:— (1) that at the height of the Glacial Period the bed of the Atlantic was occupied by ice flowing from the north-west, from the direction of Greenland, reaching the coast of Europe either at Brest or some other point further south, and damming back the whole of the drainage of northern Europe into an immense lake of fresh water, which, at its greatest extension, reached to a height of at least 1200 feet above the present level of the sea ; (2) that this lake was gradually lowered for some hundreds of feet, probably by the deepening of a channel of outlet, and then suddenly and completely drained by the breaking away of the ice-dam causing an enormous flood or débâcle ; (3) that the complete denudation of the detritus from the low grounds was prevented, and its outspread in great sheets caused, by the outflow of the waters being checked by the immense area drained through the single outlet of the British Channel.

In some Alpine lakes caused by glaciers, the waters periodically break away, and are again pent up by the readvance of the ice ; and so it is possible that a series of floods might be caused by the great Atlantic glacier. But I can find no evidence of more than one débâcle in the southern counties, and I am inclined to agree fully with the conclusion that Professor Sedgwick arrived at fifty years ago—that “ diluvial torrents have swept over the land, driving before them enormous masses of gravel,” and that “ all the diluvial detritus originated in the same system of causes, which, having produced their effects, were never repeated ”*. If, however, I were discussing the origin of the glacial beds north of the Thames, I should have to show that although there is evidence of only one sudden and tumultuous discharge of the waters, yet, after the débâcle so caused had occurred, they rose again, but were this time more quietly lowered.

Completely as this theory seems to explain the production and

* Annals of Philosophy, vol. ix. p. 248.

distribution of the surface deposits, I was not led to adopt it on that account alone, but because, in addition, I found abundant evidence that the ice from the north had moved down the bed of the Atlantic, and from the direction of Greenland as its chief gathering-point. Thus Newfoundland is glaciated from the north-east, and the ice advanced up the valley of the St. Lawrence, and forced the drainage from the great lakes to run into the basin of the Mississippi. Even so far westward as the Lake of the Woods, we learn from Mr. G. M. Dawson's elaborate and instructive report, that the ice moved persistently from the north-east*. The whole of Cape Cod is a great moraine, proving that the bed of the Atlantic was occupied by ice several degrees of latitude further south than is required on the European side of the basin to block up the English Channel.

In the Old World I found that the ice had advanced upon Siberia from the north, had overridden Iceland, the Hebrides, and the north of Scotland from the north-west, and at the extreme south-west of Ireland was 2000 feet thick. Mr. T. F. Jamieson has clearly shown that the ice that glaciated Caithness came from the north-west, and not from the south-east, as had been supposed by Mr. Croll. The Shetland Isles are too small to have borne local glaciers; yet we find from the interesting observations of Mr. C. W. Peach that they are hugely glaciated. On Lerwick he found the grooves and striæ pointing north and south, and that the drift had evidently come from the north. In North Uist he found great ruts and scorings pointing W.N.W. On reaching the top of Muckle Heog, 500 feet above the sea, he found the W.N.W. end vertical and polished down to at least 150 feet from the top. To what agent can we ascribe the glaciation of these islets, excepting an immense body of ice moving from the north-west †?

Greenland is now covered with ice; and this theory assumes that in the Glacial Period ice advanced from that direction, and flowed furthest down the deepest channel, which was the bed of the Atlantic. That

* Report on the Geology of the region in the vicinity of the 49th parallel, 1875. Map showing Glacial markings. I am indebted to Prof. Hall for information about Cape Cod.

† For Caithness see *Quart. Journ. Geol. Soc.* vol. xxii. p. 261; and for the Shetland Isles, *Geological Magazine*, 1865. So long ago as 1852, Dr. Robert Chambers, in a remarkably able paper read before the Royal Society of Edinburgh, and published in full in the '*Edinburgh Philosophical Journal*' for 1853, urged that the whole of the glaciation of Scotland could not have been produced by ice gathering on the mountain-chains, as they themselves had been overridden, and that the ice that had left the highest markings had flowed from the north-west. He argued that both the hills and valleys, including the lake-basins of Sutherland and Ross-shire were due to the erosion of the rocks by an immense body of ice that had moved down upon Scotland from the north-west. Mr. T. F. Jamieson, in his valuable papers on the Glacial Period, published in the *Journal* of this Society, has also mentioned many facts pointing to a flow of ice from this direction; but Mr. James Geikie, in the otherwise very complete account of the glacial phenomena of Scotland in his '*Great Ice Age*,' has not discussed this important question, though many of the facts mentioned by him, such as the blocking-up of the Clyde valley, would receive an easy solution by this theory.

ice from the north could have scored the eastern sides of the American hills, nearly at right angles to the slope of the continent, or have been forced up the valley of the St. Lawrence, before the ocean-depression was filled, seems as improbable as that it should flow along the ridges of the Alps, and not down the valleys. Doubtless the culmination of the Glacial Period was preceded and followed by both local and continental ice systems; but, in addition to these agencies, there is required, to explain the grander phenomena, the action of circumpolar ice filling the northern part of the Atlantic basin down to about latitude 39° on the American side, and about latitude 40° on the European side.

The main feature of the Glacial theory that I advocate is, that the glaciation of North-eastern America and North-western Europe was principally due, not to local and continental ice, but to that filling the northern part of the Atlantic basin, and blocking up the drainage of the continents as far as it extended. The theory requires no interglacial periods, no oscillations of the earth's surface; yet I know not of any fact in the composition and distribution of the glacial beds on either side of the Atlantic that does not find in it a natural and easy interpretation.

4. CORRESPONDENCE WITH THE DRIFT OF THE SOUTH-EAST OF ENGLAND.—It is clear that, if this theory is correct, evidence of the existence of the great lake and of its sudden and torrential discharge ought to be found over the whole of the vast area its waters once covered. I have found this evidence over much of Northern Europe, and in our own country, up the valley of the Severn, and over the whole of the eastern coast: but in this paper I confine myself to the south of England, as I thus avoid questions connected with the former presence of land ice, and with what many geologists consider evidence of marine submergence. I shall pass rapidly in review the surface geology of the rest of the southern counties.

Dorsetshire.—Upland deposits have been described on the Black Downs, to the S.W. of Dorchester, at Preston and Osmington, and in the Admiralty quarries on the top of the Isle of Portland*. The latter are remarkable, as they overlie remains of *Elephas primigenius* and *E. antiquus*. The raised beach with marine shells at Portland Bill is covered with the Lowland deposits, which appear to have been suddenly and tumultuously produced. Prof. Prestwich believes they were formed by the transient passage of a body of water sweeping the land detritus down to the shore-line, and to a certain distance beyond it—a conclusion identical with that arrived at by Sedgwick and De la Beche with regard to the Lowland deposits of Cornwall.

Hants and Wilts.—The superficial deposits of these counties have been admirably described by Mr. Codrington†. The gravels are not confined to the valleys, but cover the plateaux between them up to a height of 420 feet above the sea, and extend in width for a distance of 20 miles. At Milford Hill, near Salisbury, Upland gravels from

* Prof. Prestwich, Quart. Journ. Geol. Soc. vol. xxxi. p. 29.

† Quart. Journ. Geol. Soc. vol. xxvi. p. 528.

10 to 12 feet in depth contain palæolithic flint implements, which occur principally at the base of the deposit.

Sussex, Kent, and Surrey.—Sir Roderick Murchison very fully described the surface geology of these counties, and followed Sedgwick and De la Beche in ascribing the formation of the Lowland deposits to cataclysmal action. Of late years, however, the evidence that abounds of violent and tumultuous deposition has been almost ignored under the influence of the teachers of the theory of subaerial denudation.

In the distribution of the gravels between the escarpments of the North and South Downs there are two points to be explained—the complete denudation of many large tracts lying above 200 feet above the sea, and the outspread of the gravel in great sheets below that level and especially below 100 feet above the sea. To the former of these distinct yet complementary phenomena my attention was first drawn by Mr. J. H. Farrer, who pointed out to me from the top of Hawkhurst Down the remarkable absence of flints from between the chalk escarpment and the top of Leith Hill, and urged that if the Chalk that once covered the greensand slope had been removed by subaerial denudation, the flints would still have been left behind, and asked what force had cleared them away. In every county of the area to which this paper is confined there are Upland gravels, with transported stones, showing signs of gradual and tranquil deposition, and Lowland gravels affording evidence of sudden and tumultuous formation. Nowhere are there any marine remains or old sea-beaches, excepting near the present shore-line. In Cornwall and in Devon, as well as in Sussex and Surrey, independent observers, including the most illustrious of our geologists, have published their convictions that great currents of water poured across the country. I do not know what other geological conclusion has more evidence to support it. Yet because no acceptable theory has been advanced to account for the origin of such a tumultuous and overwhelming flood, the evidences of its occurrence have of late been neglected. Can we have a stronger argument of the necessity of a good theory of origin to enable us to appreciate the importance of the facts with which we have to deal?

5. CLASSIFICATION OF THE GLACIAL PHENOMENA.—I have in former papers * urged that Mr. Alfred Tylor's theory that the sea-level was greatly lowered in the Glacial period through the vast quantity of water that, in the form of ice, was piled up around the poles is borne out by much geological, physical, and biological evidence. Possibly a point of departure for the commencement of the Glacial period may be found in the first evidence of the lowering of the sea-level. Thus, in the Weybourne sands, the Portland-Bill marine beds, and the Bridlington Crag we have evidence of the sea rising to about the same level as it now does; and these deposits are clearly of older date than the overlying glacial beds.

The first stage of the Glacial Period, as thus defined, is marked by

* Naturalist in Nicaragua, p. 266; and Quarterly Journal of Science, Oct. 1874.

the older forest-beds and the immigration of the great mammalia, indicating that the sea had retired from the British Channel and the German Ocean. A great river appears to have run to the southwest through this now submerged area, on the banks of which and of its tributaries palæolithic man and the great mammalia lived, the latter frequenting low marshy tracks near to the streams, the former higher grounds more distant from them. That this river flowed southward, and not to the north, as supposed by Mr. Godwin-Austen, is indicated by the fact that the fauna is the same on the Somme and the Thames, which would scarcely have been the case if the Straits of Dover then formed the division between watersheds draining to the north and the south. This applies with particular force to the distribution of the hippopotamus. Its remains are found not only in all the southern parts of the area, but as far north as Yorkshire. There is evidence that the winters were more severe then than now; and it would have had no refuge from them to the north of Dover if the rivers there ran northwards; but if they drained into a great stream running southward as far the Bay of Biscay, it might easily have retreated down this in the autumn and reascended in the spring.

The presence of southern shells, such as *Cyrena fluminalis*, *Unio littoralis*, and *Paludina marginata*, in the old mammalian gravels both to the north and to the south of the Straits of Dover, is evidence nearly as strong that the streams in which they lived all belonged to the same watershed, and that the course of the main river was southward. For this great stream I propose the name of the Germanic River, as its principal drainage-area was the bed of the present German Ocean and the waters discharging into it.

The second stage of the Glacial Period is marked by the continued advance of the ice from the north, and, possibly, by the retreat of the southern fauna and the arrival of the Arctic mammals, whilst the woolly rhinoceros and the mammoth still roamed in summer over the area that had formerly been their winter retreat.

In the third stage the Atlantic Glacier reached the coast of Europe, and blocked up the English Channel and with it the drainage of the whole of Northern Europe, forming a great continental lake, over which floated icebergs carrying boulders from the Scandinavian mountains.

In the fourth stage the barrier of ice blocking up the English Channel was suddenly broken away, causing the tumultuous discharge of the waters of the great lake and the consequent outspread of the Lowland deposits, including the Middle Glacial sands and gravels Norfolk and Suffolk.

In the fifth stage the Atlantic glacier again advanced, and the great lake was reformed; but its discharge this time was more gradual. To this period belongs the formation of the Upper Boulder-clay of Norfolk and Suffolk, which I have not been able to satisfy myself is represented south of the Thames except by the "Trail" of Mr. Fisher; but some of the Upland deposits may belong to this and not to the third stage.

In the sixth and last stage, I consider that the Atlantic ice had

rapidly retired as far back as the extreme north of Scotland ; but the sea had not yet returned to its former level, and the British Isles were still joined to the continent. To it I assign the last great forest-period and the arrival of Neolithic man with the associated fauna from the continent.

Postscript.

January 17, 1876.—Since this paper was read before the Society I have again crossed Europe and examined the southern limits of the northern drift as far as the cliffs of glacial clay around the shores of the Sea of Azoff. I now attach much more importance to the second advance of the Atlantic glacier, and believe it marks the culmination of the Glacial Period. The restriction of the middle glacial sands and gravels to heights not exceeding, if reaching, 500 feet above the sea, leads me to think that the first great European lake drained around the hills of Brittany into the valley of the Loire, and that the principal distribution of the Scandinavian drift and the formation of most of the upland deposits belong to the period of the second great lake, when the *col* to the east of Brittany was also blocked up and the waters drained through the Black Sea to the Mediterranean, cutting out gradually a passage through the Dardanelles that had not before existed.

DISCUSSION.

Mr. HICKS stated that he had noticed that the glaciation at St. David's is from the north-west. He had already stated before the Society his opinion that there had been depressions proceeding from a point in the Atlantic, probably not far from the coast of South America, to the north-west and north-east ; and this might perhaps have something to do with causing a flow of ice from Greenland to the south-west in North America and to the south-east in Europe.

Rev. O. FISHER wished to know what would be the area of the great freshwater lake supposed to be produced by the damming action of the great Atlantic glacier.

Mr. BELT stated that the area blocked up by the ice would be about 400,000 square miles (2000×200), and would include all the region drained by the present northern rivers.

Prof. HUGHES wished to know why the waters could not drain off by way of the Black Sea, and why the advancing Atlantic glacier should be supposed to stop just at the western point of Cornwall. He could discover no evidence of there ever having been a lake such as the author described. The drift gravels were the result of all the agencies of denudation which had ever been at work ; and the boulders at the bottom of the low-ground drifts were probably due to the fall of *débris* from the summits. The boulders of the drift, if the author's theory were true, ought to consist of Greenland rocks, whereas they were really of local origin. With regard to the direction of glaciation in Britain and Northern Europe being from the north-west, he could not agree with the author. In many places

glaciation might be observed running in every direction ; and it was not fair to note only certain striæ, and neglect those which were not in favour of a foregone conclusion. He thought that Mr. Campbell had shown clearly that the glaciation of Ireland took place from the north-east.

Mr. MOGGRIDGE remarked that a very flat country extended across the continent of Europe from England to the Black Sea, and thought that in that direction there was no land sufficiently high to form the boundary of such a lake as that required by the author's theory.

Rev. T. G. BONNEY said that, in addition to the difficulties which Prof. Hughes had mentioned, four others at least occurred to him :— that the barrier to Mr. Belt's lake was defective between the highlands of Brittany and the Auvergne ; that the ice in its course from Greenland would have to cross a part of the Atlantic where the depth approached 2000 fathoms, which seemed to demand an inconceivable accumulation in that country ; that under such circumstances Wales, Scotland, and Scandinavia must have had their own ice-systems ; and that to reach Scandinavia (which certainly had its own ice-system), this great sheet must have crossed the Lofoten Islands, yet all the higher hills in these were remarkably sharp and broken. Further, in regard to what Mr. Belt had said about the lowering of the general level of the sea, it must be remembered that such an ice-cap would raise the level in the hemisphere where it occurred.

Mr. BELT, in reply, said that he did not want the ice to stop at Cornwall, but that his statement as to its limits was founded on observed marks of glaciation. He thought the absence of marine remains throughout the drifts of the northern plains of Europe was a highly important and suggestive fact. With regard to the glaciation of Ireland, he remarked that the ice flowing south-east from Greenland would strike against the high lands of Scotland and England, and be turned back over Ireland. The lowering of the sea was not absolutely required by the necessities of the paper ; but if the accumulation of ice took place simultaneously at both poles, the sea must necessarily be greatly lowered.

11. *On the CORRELATION of the DEPOSITS in CEFN and PONT-NEWYDD CAVES with the DRIFTS of the NORTH-WEST of ENGLAND and WALES.*
By D. MACKINTOSH, Esq., F.G.S. (Read June 23, 1875.)

IN the present state of Posttertiary geology it is of very great importance (as may be inferred from the Presidential address just published, May 1875) that some one should attempt to correlate the deposits in caves with the glacial drifts of the neighbourhood. I therefore venture to bring before the Society a brief statement of the results of observations lately made in and around the Cefn and Pont-newydd Caves, Denbighshire. These caves are situated near to each other in the face of a limestone escarpment, on the north bank of the river Elwy. The Pont-newydd cave has been described by Professor M'Kenny Hughes and the Rev. D. R. Thomas, in the *Journal of the Anthropological Institute* (vol. iii. p. 387), and by Mr. W. Boyd Dawkins, F.R.S., in his work on *Cave Hunting*. By these writers the cave-deposits are regarded as Postglacial. The best account of Cefn Cave, as it existed before the deposits were nearly all cleared out, is perhaps to be found in Mr. Joshua Trimmer's '*Practical Geology*,' published in 1841*, the following being the order of succession therein stated or implied:—

1. Sand, silt, and marl, with sea-shells in one or more places (uppermost).
2. Loam, with angular fragments of limestone and bones, filling the cavern nearly to the roof (*diluvium* of old authors).
3. Crust of stalagmite.
4. Loam, with smooth pebbles, bones, teeth, and fragments of wood (lowest).

Mr. Trimmer believed that the lowest of these deposits was introduced, before the glacial submergence, by the adjacent river while flowing at a considerably higher level than now. But that the river-channel must then have been excavated to a level as low, if not lower, than at present, is evident from the fact that the Upper Boulder-clay extends down to, and in some places runs under, the river-bed, in a manner showing that here (as elsewhere in the north-west of England and Wales) the river, since the glacial submergence, has been principally occupied in reexcavating its choked-up channel. Trimmer likewise believed that the deposit with sea-shells was introduced by the sea through a fissure in the roof of the cave.

From the nature and sequence of the deposits in Pont-newydd cave (a considerable portion of which has not yet been cleared out), compared with what I have seen of the remnants still visible in the Cefn cave, and from a further comparison of the facts thus obtained with accounts given by Mr. Trimmer, Mr. J. Price, M.A. (of Chester), Professor Hughes, Mr. Boyd Dawkins, &c., I have been led to regard the following as the sequence of the beds (order descending):—

* See also paper by Rev. E. Stanley, *Proc. Geol. Soc.* vol. i. p. 402.

1. Coarse sand charged with minute fragments of sea-shells, still found adhering to one side of a rising branch (ascended by steps) of the Cefn cave*. In the Pont-newydd cave a bed of very fine stoneless clay.
2. Clay, with angular and subangular fragments of limestone, a few polished fragments and pebbles of limestone, likewise a few pebbles of Denbighshire sandstone and grit, felstone, &c. This deposit (which contains bones of a number of the usual cave Mammalia) is horizontally continuous with the Upper Boulder-clay of the district (see sequel).
3. Stalagmitic crust, from less than an inch to 2 feet in thickness. Very little now left in the Cefn cave; apparently absent in the Pont-newydd cave.
4. Loam, with rounded and smoothed pebbles, bones, teeth, and fragments of bone and wood, in the Cefn cave. In the Pont-newydd cave a bed of extra-rounded pebbles, more or less cemented by stalagmitic matter.

The coarse sand in the uppermost bed (1) in no respect resembles the Upper Boulder-clay on the summit of the plateau above the cave; it is not what would result from a subaerial rearrangement of the clay; and the proportional number of fragments of shells is very much greater than that found in the clay †. It is therefore probable that the coarse sand was introduced by the sea through a fissure or fissures in the roof, as Trimmer supposed.

The clay (2) can be traced along the plain of Lancashire and Cheshire, the coast of Flintshire, and up the vale of Clwyd. It spreads over the gently rising ground between St. Asaph and the Cefn and Pont-newydd caves; and it may be seen all around the caves, in some places filling up hollows, in others covering plateaux, and in not a few instances clinging to the face of steep slopes, or even adhering to narrow rocky terraces or ledges. I have been familiar with this clay in Cheshire and Flintshire for four years, and have therefore little hesitation in asserting that traces of it, in an unmodified state, may be found at the entrances of both the Pont-newydd and Cefn caves—that in the interior of the Cefn cave, for a considerable distance from the entrance, there are indications of this clay having once filled the cave nearly, if not quite, to the roof—that in the interior of the Pont-newydd cave it maintains its unmodified character for a considerable distance from the entrance—and that in no part of these two caves has this clay been modified further than what may have resulted from the dropping of calcareous matter, from the temporary ponding back of water in the recesses or hollows, or from accumulation within the caves under conditions which may have differed from those without. The angular limestone fragments may have fallen from the roof or sides of the caves during the period of accumulation; or previously fallen fragments, along with the bones of animals, may have been washed up into the clay by the waves of the Upper-Boulder-clay sea. It ought not to be forgotten that in caves sea-waves are often possessed of very great force, and that they are capable of insinuating themselves into the remotest recesses.

* I had no difficulty in raking off large quantities with a hammer. It would appear to be present in at least one other branch of the cave.

† I could see none at all in the clay of the immediate neighbourhood of the cave, though they probably might be found, as I believe Prof. Hughes has collected them from the same clay in the Vale of Clwyd.

The stalagmitic crust (3) must have been accumulated during a period when conditions were favourable; and these conditions must have varied in different parts of the Cefn cave.

The bed under the stalagmite in the Cefn cave, with its representative in the Pont-newydd cave, is the most difficult to explain. I am unable to say whether it most resembles an accumulation of fine river-shingle or a raised beach. In the caves it does not occur at the height above the present sea-level of the more typical raised beaches. It is *not confined* to the caves, but may be seen at intervals along the sloping north bank of the Elwy. It may likewise be found in patches along the Elwy valley as far as the Vale of Clwyd, where it would *appear* to graduate into the middle gravel and sand which underlies the upper clay. However it may have originated, I cannot believe with Professor Hughes that, in the Pont-newydd cave, it was washed in through a swallow-hole, from the Boulder-clay of the neighbourhood, by a freshwater stream. The relative proportion of stones of different kinds is not nearly the same in the pebble-bed and in the Boulder-clay covering the surface of the ground at a higher level. In the pebble-bed nearly all the stones, so far as I could see, are Denbighshire sandstone or grit. In the Boulder-clay a large proportion of the pebbles are limestone. I could only see one felstone specimen in the pebble-bed (though others probably might be found). In the Boulder-clay felstone pebbles and boulders are far from being rare*. The pebble-bed is not confined to the cavern or the ground straight in front of it, as it would have been if deposited by a stream flowing out of the cavern; but it may be seen in a recess a short distance east of the mouth of the cavern, and, as I have already remarked, at intervals further east. Several examples of it may be found near the Cefn cave, clinging to the rocky slope. This bed could not have been accumulated before the glacial submergence, as it contains a few erratic pebbles †, which must have been transported by ice from regions far beyond the basin of the river Elwy.

Before endeavouring to offer a general explanation of the mode in which the various deposits were introduced into the Cefn and Pont-newydd caves, it may be necessary to state that the drift-deposits of the north-west of England and the borders of North Wales are separable into:—(1) a lower stony Boulder-clay (with glaciated stones), which to the south of the Mersey and in the eastern part of Wales can only be detected at intervals; (2) a middle sand and gravel (without any large boulders or glaciated stones, excepting a few among or near to the mountains), which extends almost continuously over very wide areas, and often attains a thickness of nearly 200 feet; (3) an upper Boulder- or brick-clay (with

* It likewise contains Eskdale granite.

† Professor Hughes mentions the occurrence of felstone in this bed in Pont-newydd cave. I saw a large boulder of very typical Arenig felstone, about half-way between Denbigh and Cefn; and I believe that a boulder which may be seen a short distance N.W. of the Cefn cave must have come from the same mountain.

glaciated stones and a few boulders), which is quite as persistent as the sand and gravel, but which has not yet been clearly traced to a height of more than a few hundred feet above the present sea-level. The first indicates a cold period, the second a comparatively mild period, and the third, I believe, a second cold period, though this has been disputed by Professor Hughes and Mr. Kinahan. Believing with Professor Ramsay that the great glacial submergence commenced before the ice-sheet or ice-sheets disappeared from the country, that the lower Boulder-clay (so far as it is of marine origin) was accumulated while the land was sinking, and that the sand and gravel formation was deposited while the land was rising—and likewise believing in an interglacial period, during the first part of which the land was still submerged, dry land prevailing during the second part, it follows that there must have been a second submergence, during which the upper Boulder-clay was deposited. It is possible that the pebble-bed in the Pont-newydd cave may have been deposited as the land was rising out of the interglacial or Middle-Sand-and-gravel sea, and that pebbles and loam may then have been introduced into the Cefn cave; but as the neighbourhood could not have been inhabited by land animals until after the emergence of the land, the bones, teeth, and fragments of wood which were found associated with the lowest deposit in the Cefn cave may have been washed in by rain through fissures in the roof. After the accumulation of the stalagmite, more bones must have been introduced, and the cave may have been temporarily inhabited by the hyæna. This state of things may have been brought to a close by the submergence of the cave beneath the waters of the Upper-Boulder-clay sea, which filled the cave nearly (if not, in many places, quite) to the roof. The sand with sea-shells may have been introduced through fissures in the roof while the plateau above the cave was gradually rising above the sea-level.

The above imperfect explanation is the best I can offer concerning the mode in which the different and very dissimilar deposits in the Cefn and Pont-newydd caves were accumulated.

P.S.—As may be learned from his paper read before the Anthropological Institute, Professor Hughes found Palæolithic flint implements and a human tooth, which he believed came from the bed I have called Upper Boulder-clay, in the Pont-newydd cave*.

* Since this paper was written, Professor Hughes has found a large fragment of felstone in the lowest bed of the Pont-newydd cave.

12. *Evidence of a CARNIVOROUS REPTILE (CYNODRACO MAJOR, OW.) about the size of a Lion, with Remarks thereon.* By Prof. OWEN, C.B., F.R.S., F.G.S., &c. (Read February 2, 1876.)

[PLATE XI.]

SEARCHING over the residuary, more or less shapeless blocks of matrix from the Karoo lacustrine deposits of South Africa, transmitted by their discoverer the late Andrew Geddes Bain, Esq., F.G.S., I came upon a lump about the size of one's fist, in which the sole indication of organic remains was a pair of mutilated canine-shaped teeth.

Part of the outer enamelled surface was exposed to view, and suggested that the block might contain a fragment of the upper jaw of a *Dicynodon*. On clearing away the matrix from the teeth, however, they presented a difference of shape from the tusks in that genus: the crown was narrow instead of round; the transverse section was a long oval (Pl. XI. fig. 3) with the small end pointed: when the whole of the outer side of the crown became exposed, the shape of the best-preserved canine (*ib.* fig. 2) resembled that in *Machairodus*, and most so that of *Machairodus latidens**. On carefully relieving the hinder trenchant margin of the tooth from the matrix, I was much interested in finding that it carried the resemblance to the canine of the extinct feline mammal to correspondence in the minute serration of that margin (*ib.* *ib.* *c'*).

A small part only of the non-enamelled base was preserved, the canines having been broken off a little above their exit from the socket; but the breadth of the broken base and the reduction of the pulp-cavity to a linear trace were indicative of a long and deeply implanted fang. Nevertheless it was evident that, in proportion to the antero-posterior diameter of the base of the enamelled crown, that part of the tooth was relatively longer than in *Machairodus latidens*: it differed also in the absence of the serrate border at the fore part of the crown (*ib.* *ib.* *c*). The only part of the skull preserved posterior to that supporting the upper canines was a portion of the lower jaw, of which the alveolar border of the right ramus extended one inch behind the right better-preserved upper canine. No trace of tooth could be detected in this border.

The symphyseal part of the lower jaw (fig. 5) extended forward about 2 inches in advance of the upper canines (*ib.* *c.* *c*). The animal had become fossilized with its mouth shut; and the upper canines descended along a laterally compressed part of the lower jaw, also as in *Machairodus*, one on each side, with their points projecting beyond the lower border of the jaw (fig. 1, *c.* *c*). The next thought was as to possible evidences of the teeth at the fore end of the lower jaw; but not until the extremely hard matrix had been ground down to the alveolar border were any such traces visible. The crowns of these teeth seemed to have been broken away prior to interment; but the bases of eight incisors and of two lower canines were exposed, in transverse sections at the level stated.

* British Fossil Mammals, 8vo, 1846, p. 180, fig. 69.

The lower canines (*ib.* fig. 5, *c'*, *c'*) had risen, as in *Machairodus*, immediately in front of the upper ones, and presented the same inferiority of size; but they are divided, in *Cynodraco*, by a toothless interval, or "diastema," from the lower incisors (*ib.* *i*, 1, 2, 3, 4). In this character, as in the number of incisors, the South-African Karoo fossil resembles the Marsupial genus *Didelphis*. The lower incisors are subequal, subcompressed, and elliptical in transverse section, at least at the base of the crown, with the long axis of the section directed from the fore to the hind part of the alveolar border; and they are close-set, as in carnivorous mammals. As in these, also, the dentine, in both canines and incisors, is of the hard unvascular kind, and the enamel as distinct in tissue and as thick.

The decrease in size is from the 1st to the 4th; but the degree shown in the fossil and fig. 5 may be due to section at different heights from the base.

Associated with this fossil, or from near the same locality, was a larger oblong block of the same matrix, with the ends of a long bone partially visible. Out of this block an entire humerus was developed (Pl. XI. figs. 6-9, half nat. size). It is of a left fore limb, in length 10 inches 6 lines, with some loss by abrasion of both articular extremities, the shaft showing well-marked developments for muscular attachments and other characters unusual or unknown in the Reptilian class.

The breadth of the distal end—the extension of strong ridges from both the outer (*e*, *e'*) and inner (*f*, *f'*) sides, just above the elbow-joint, indicative of strong supinators, flexors, and extensors of the forearm and paw—the modification of the articular surfaces of that end, better preserved than those above, for the combination of due attachment of two bones of the forearm with freedom of motion, not only in the bending and extending, but in rotating on each other, so that the paw could be turned "prone" and "supine," whereby its application as an instrument for seizing and lacerating is advantaged,—add to this the structure, hitherto known only in the Mammalian class and preeminently in the feline family, of a defence of the main artery and nerve of the forearm from compression during the action of the above-named muscles by a strong bridge of bone (*h*) spanning across them, furthermore the extensive and powerful ridge (*b*, *b'*) at the proximal half of the humerus for the attachment of arm-muscles, especially the deltoid,—the combination of these characteristics, which Cuvier dwells upon in contrasting the humerus of the feline and bovine mammals*, are here exemplified in a fossil homologue, from a formation of the Triassic or Permian division of geological time.

Extending, however, the comparison of the present humerus beyond the salient features above defined, the head of the bone (fig. 8) differs from that of the feline humerus in being broader transversely, instead of from before backward; the articular part is oblong and narrow, not hemispheroid nor nearly so convex; there is no elevation of an outer transverse tuberosity. The representative of the

* *Ossemens Fossiles*, vol. i. (4to, 1821) p. xlvii.

deltoid ridge (ib. *b*, *b'*), of similar basal extent to that in *Felis*, is more produced and is much thinner, extending as a broad plate of bone outward (radiad) and forward (thenad); it seems to be rather a development in those directions of the entire shaft than to be a superadded process of the shaft. The more rounded, thickened character which prevails through nearly the whole extent of the humerus of the feline as of most mammals, is here confined to a constriction barely an inch in extent between the subsidence of the deltoidal or delto-pectoral crest and the beginning of the neuro-arterial bridge (*h*) on the inner side, and of the supinator crest (*e*) on the outer side of the lower two fifths of the bone. The perforation itself (*k*) is more highly placed, is further from the articular surface for the ulna, than in *Felis*. The ulnar articulation or "trochlea" is less defined; the inner boundary ridge, so prominent in *Felis*, is here undeveloped. The convexity (fig. 6, *g*) for the radius, on the other hand, is relatively larger, and its ball advances further upon the fore part of the shaft, in the present fossil. In this, likewise, the anconal pit (fig. 7, *d*), so deep and well-defined by outer and inner ridges in *Felis*, is a mere wide and shallow triangular depression.

The delto-pectoral crest (*b*, *b'*) which seems to be a forward and inward production of the outer border of the proximal part of the humerus, is essentially a reptilian character of the bone. Its ordinary proportions in existing Saurians are shown in *Uromastix spinipes* (fig. 10, *b*, *b'*) and in *Monitor niloticus**; in Crocodiles the shortening of its base gives it more the character of a distinct process; in Pterodactyles its development is chiefly in transverse extent†; in *Cynodraco* the longitudinal extent prevails; in *Omosaurus* the development in both directions of the delto-pectoral crest is such as to have suggested the generic name of this Dinosaur. But the perforation or canal (*h*, *k*, fig. 6) is not present in any existing Reptile. There is, indeed, what may be loosely termed a "supracondyloid foramen" in several Reptilia. It is noticed in the osteology of the genus *Trionyx*; but its position in the humerus is defined:—"The bone is perforated from before backwards at the *outer* angle of the distal extremity"‡. The homologous supracondyloid foramen is shown in the humerus of the *Monitor niloticus*, in the under-cited monograph (Note *), in pl. xvii. fig. 6, at *e'*, where it perforates a low supinator crest. Its position in *Uromastix spinipes* is shown at *l* and *m* in figs. 10 and 11 (Plate XI.). Dr. Günther notes the homologous foramen in the humerus of *Testudo elephantopus* and its allies (*Testudo ephippium* e.g.), and describes it as "the canal on the *radial* edge of the bone, close to the elbow-joint, perforating the substance of the bone from the front to the hinder side"§.

* Monogr. on *Omosaurus*, pl. xvii. fig. 6, *b*, and fig. 6'.

† Monogr. on Cretaceous Pterodactyles, 4to, 1860, pl. iii. fig. 9, *b*.

‡ 'Descriptive Catalogue of the Osteological Series contained in the Museum of the Royal College of Surgeons of England,' 4to, 1853, p. 184, Nos. 942, 943.

§ Philos. Trans. 1875, p. 266, plate xlii.; "b, radial canal for blood-vessels," ib. p. 283.

Cuvier thus defines the supracondyloid canal in the Lion:—"Au-dessus du condyle interne, la ligne âpre est aussi percée d'un trou pour le passage de l'artère cubitale"* . But this is not the homologue of the commonly called "supracondyloid canal" in the humerus of certain Reptilia. The "internal condyle" of Cuvier and anthropotomy is the "ulnar condyle;" the "external condyle" is that which is termed "radial" in vertebrate anatomy. Thus the zootomist has to take into account, in the application of his science to Palæontology, of an "ulnar supracondyloid foramen," and a "radial supracondyloid foramen." There is, also, a third perforation of the distal end of the humerus distinct from both, which may be termed an "inter-condyloid foramen." It is that which is present in the humerus of the wolf † and some other mammals, but of which I have not found any example in recent or extinct Reptilia. While upon this comparison I am tempted further to remark that, in comparative anatomy, zootomy, or anatomy properly so called, the term "condyle" is restricted to portions of bone more or less convex, modified for the articulation of two bones, and usually covered with synovial cartilage. Anthropotomy, however, in reference to such portions of the distal articular surface of the human humerus, calls the radial condyle the "radial head," and the ulnar condyle the "ulnar trochlea," and restricts the term "condyle" to the tuberosities which project beyond and somewhat above the articular prominences, which, in the humerus, answer to the corresponding prominences rightly termed "condyles" in the femur ‡. I have found it useful, in comparisons of the humerus akin to those in the present paper, to call the anthropotomical condyles "epicondyles," as being parts projecting somewhat above, or proximad of, the true condyles, and to distinguish them as "entepicondyle" and "ectepicondyle" respectively. Thus the canal which gives passage to an artery and commonly a nerve at the distal end of the humerus in Felines, and most Marsupials, is an entepicondylar canal or foramen; and this it is which characterizes the humerus of *Cynodraco*. The canal which gives passage to a blood-vessel in the humerus of certain Chelonia and Lacertilia is an ectepicondylar canal; and its presence in no way affects the resemblance (I will not say affinity) to the feline Mammalia which the extinct *Cynodraco* presents in its humerus as in its dentition.

I am of opinion, though it is difficult to judge from the woodcuts of small and fragmentary humeri ascribed to *Dicynodon* by Prof. Huxley in the 'Memoirs of the Geological Survey of India,' that the "supracondyloid foramen" there indicated at *a*, figs A and B, p. 10, is not the homologue of the "supracondyloid foramen" which "occurs not unfrequently among Lacertian Reptiles," but that it differs not only in "form and proportions," but likewise in relative position, and that in *Dicynodon* it concurs with the pair of

* 'Leçons d'Anatomie comparée,' ed. 1835, vol. i. p. 384.

† 'British Fossil Mammals,' 8vo, 1846, p. 129, fig. 47, *a*.

‡ See for example, the instructive plate "77, left human humerus," p. 92, of the 'Anatomy Descriptive and Surgical,' 8vo, 1858, by Henry Gray, F.R.S.

long upper tusks in exemplifying Mammalian characters, not Lacer-
tarian ones. The same concurrence, not only with well-defined
canines, but likewise with equally well-defined incisors and molars,
has been observed by me in several species of extinct Reptilia from
the Karoo deposits of South Africa.

The earliest examples (*Galesaurus*, *Cynochampsa*) of such Reptilia
were made known through this Society by its 'Quarterly Journal,'
vol. xvi. (for the year 1859-60). Since that date I have had evi-
dences of the genera *Lycosaurus*, *Tigrisuchus*, *Cynosuchus*, *Nytho-
saurus*, *Scaloposaurus*, *Procolophon*, *Gorgonops*, as well as of the genus
Cynodraco, of one species of which the dental and humeral charac-
ters have supplied the chief subject of the present communication.

Most of the genera above mentioned are represented by more than
one species*: and both genera and species are classifiable in groups
characterized by modifications of the structure of the external bony
nostrils—as, for example, into the "tectinarian," "binarian," and
"mononarian" families, the skull in the latter presenting, in the
aspect and position of the single terminal nostril, a strikingly mam-
malian facies. For the name of these extinct carnivorous Saurians
I find it convenient, and believe it will be generally acceptable, to
form a distinct order of Reptilia under the denomination of *Therio-
dontia*, with the following characters:—"Dentition of the carnivo-
rous type; incisors defined by position and divided from the molars
by a large lanianiform canine on each side of both upper and lower
jaws, the lower canine crossing in front of the upper; no ectoptery-
goids; humerus with an entepicondylar foramen; digital formula of
fore foot 2, 3, 3, 3, 3 phalanges."

When we contrast the grand development and notable modifica-
tions of the extinct species of Reptilia with the poor scanty evidences
of the class still lingering on in life, we seem to be witnessing a
course of degeneration, of retrogradation, rather than of organic
progression in the course of time.

Although there be none now, there have been Saurians in which
the articular surfaces of certain vertebræ in the same column were
modified—as, e. g., of the anterior ones in great herbivorous Dino-
saur, for freer movements of the head, by means of an anterior ball
playing in a posterior cup, such as we now find in the Rhinoceros
and some other large mammalian herbivores. In another part of
the same vertebral column of these extinct reptiles we find a sacrum
not limited to two, but composed of five or six ankylosed vertebræ,
also as in these and many other mammals.

Again, some of these vegetarian Dinosaurs had masticatory teeth
of a complex structure † unknown in existing phytophagous Sauria,
but resembling those teeth of certain phytophagous mammals, e. g.
Megatherium ‡, *Mylodon* §. With the modification of a portion of the

* These will be characterized and the characters illustrated in the Plates of
the Catalogue of South-African Reptilia, on which I am now engaged by
direction of the Trustees of the British Museum.

† 'Odontography,' p. 250, pl. 71: 4to, 1840.

‡ Ibid. pl. 84.

§ Ibid. pl. 79.

dental tissue of each tooth, by retention in the dentine of sub-parallel vascular canals, is associated a downward development of the zygomatic arch, for extending the origin and augmenting the size and force of the masseteric masticatory muscles.

This structure, unknown in any existing Reptiles, but exemplified in *Iguanodon*, *Scelidosaurus*, *Pareiasaurus*, reappears, so to speak, in certain Mammalia, and here in members of the class which by their low position according to cerebral characters, with genital and concomitant modifications, show a near approach to the cold-blooded Ovipara: the Sloth and Kangaroo are examples.

But cranial characters of lack, as of gain, are not wanting in this comparative glance. The lingering evidence, in Reptiles, of vegetative repetition, as manifested by multiplied centres of ossification in the facial blastema, has disappeared. The ectopterygoid ceases to exist in both Theri- and Dicynodonts; that bone never reappears in the mammalian series.

In no existing Reptilia is the principle of differentiation of structure adapting particular teeth for special functions exemplified as in the extinct Theriodontia. Not until the discovery of members of this order of Reptilia could the anatomist specify "incisors," "molars," "canines," in the dental series, by characters of size, shape, and relative position, with the same certainty, or on as satisfactory grounds, as in the warm-blooded quadrupeds. With the carnivorous type of incisors, canines, and molars we now have evidence of an associated humeral structure unknown in any lacertian or other existing reptilian fore limb, but a structure reappearing in certain mammals and notably in the implacental group of Marsupialia and in the Ovo-viviparous Monotremes.

In one of the species of Saurians with what is now the mammalian type of humerus and of dentition, evidence, for which I am indebted to the Governor of the Cape of Good Hope, Sir Henry Barkly, K.C.B., has reached me of the bony structure of the fore paw, which again shows an advance towards the mammalian type. The pollex has two phalanges; the four other digits have each three phalanges. The slight difference in length in these fingers is due, as in a dog's paw, to difference of length in such phalanges, not to difference of number of these, not to excess in the third and fourth digits beyond the number three, which number rules in the fingers of all terrestrial mammals.

Reverting to the chief character of the Theriodont reptiles, a fact of some significance may be noted, viz. that the incisive formula of some of the species is repeated in the low marsupial order of mammals. *Didelphis*, e. g., has $i. \frac{5-5}{4-4}$, as in *Cynodraco*; *Thylacinus* and *Sarcophilus* have $i. \frac{4-4}{3-3}$, as in *Cynochampsa*. In no placental carnivore do the incisors exceed $\frac{3-3}{3-3}$.

In the class of cold-blooded, air-breathing, naked Ovipara, as known to zoology by existing species, the characters above specified, discussed, and compared are wanting. They would have been un-

known and unsuspected as reptilian ones by zootomists, save through the researches of the palæontologist.

If the gap in the animal series between the Mesozoic and human air-breathers had not been filled up otherwise than by reptiles, the remnant of that class which has survived and reached our times would have testified to total loss of such gains of organization as had enriched the ancestors or predecessors of modern tortoises, lizards, and crocodiles.

We now know that not one of these gains has been lost, but has been handed on and advanced through a higher type of Vertebrata, of which type we trace the dawn back to the period when Reptiles were at their best, grandest in bulk, most numerous in individuals, most varied in species, best endowed with kinds and powers of locomotion and with the instruments for obtaining and dealing with food.

Has the transference of structures from the reptilian to the mammalian type been a seeming one, delusive, due to accidental coincidence in animal species independently (thaumatogenously) created? or was the transference real, consequent on nomogeny or the incoming of species by secondary law, the mode of operation of which we have still to learn? Certain it is that the lost reptilian structures dealt with in the present paper are now manifested by quadrupeds with a higher condition of cerebral, circulatory, respiratory and tegumentary systems, the acquisition of which is not intelligible to the writer on either the Lamarckian or the Darwinian hypothesis.

EXPLANATION OF PLATE XI.

Cynodraco major.

Fig. 1. Nodule of Karoo clay-stone with fore part of skull, the upper canines exposed (*c, c*).

2. Side view of crown of right upper canine.
3. Transverse section of ditto at the dotted line *c*, fig. 2.
4. Portion of canine, magn. 2 diam., showing serrations of the trenchant hind border, *c*.
5. Upper view of fore end of mandible, showing transverse sections of the crown-base of the incisors (*i* 1, 2, 3, 4) and canines (*c'*), with the crowns of the upper canines (*c, c*).
6. Front (thenal) view of left humerus, half natural size.
7. Back (anconal) view of left humerus, half nat. size.
8. Proximal end, abraded, of left humerus, half nat. size.
9. Distal end, less abraded, of left humerus, half nat. size.
10. Front (thenal) view of left humerus of *Uromastix spinipes*, nat. size.
11. Back (anconal) view of left humerus of *Uromastix spinipes*, nat. size.

In the figures of the humerus, *a*, "head;" *b*, ectotuberosity, here the beginning of the delto-pectoral crest (*b b'*); *c*, entotuberosity, not well defined; *d*, olecranal depression; *e*, beginning of "supinator ridge," ending at *e'*, the ectepicondyle (the ridge is less developed in *Uromastix*); *f*, entepicondylar ridge; *f'*, entepicondyle; *l*, ulnar condyle; *g*, radial condyle; *h*, bridge defining *k*, the entepicondylar canal (fig. 6); *m*, bridge defining the ectepicondylar canal (figs. 10 and 11). All the figures of the natural size, save where otherwise expressed.

DISCUSSION.

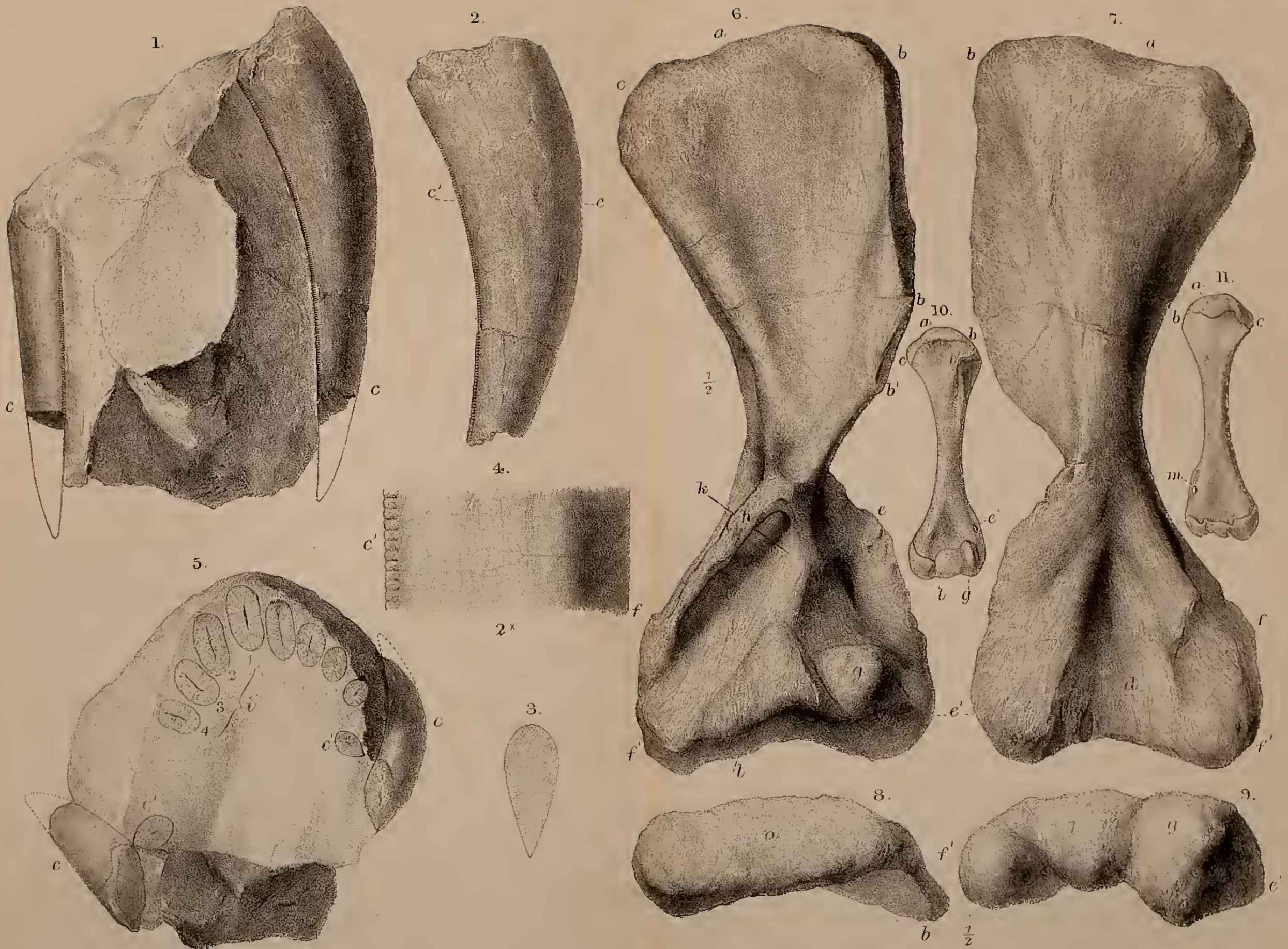
The PRESIDENT (Mr. Evans) remarked that Prof. Owen's paper was a most important and suggestive one, especially as regarded the views advanced respecting the connexion between these old Carnivorous reptiles and the Mammalian Carnivores.

Prof. SEELEY remarked upon the extraordinary characters presented by the creature described by the author, and expressed his regret at the want of additional materials, which might have thrown a further light upon the difficult and important questions raised in the paper. He thought that if all the forms referred to the Reptilia were to be regarded as belonging to that class, the latter would be rather difficult to define. The present representatives of the Reptilia are the Chelonia, Crocodilia, Lacertilia, and Ophidia; and any forms departing from these are not strictly Reptiles in the ordinary sense of the term. He thought the present fossil presented some Chelonian characters, but that in many Lizards we may find indications of a dentition similar to that of the fossil. He considered that there could be no doubt as to the connexion between Reptiles and Mammals, and that Prof. Huxley was wrong in his views as to the relationship between Birds and Reptiles. Every mammalian type has a reptilian brain in its earliest stages. The suggestion of the formation of a new order seemed to him to be founded upon certain points which could not be regarded as absolutely proved.

Prof. T. RUPERT JONES congratulated the Society on having been the medium of publication of the magnificent series of Fossil Reptiles characteristic of South Africa. He was sure that to Prof. Owen it must be a heartfelt pleasure to have been the immediate elucidator of these wonderful creatures of manifold and rare structures, brought out by his many years of continued labour on the collections made by Bain, Orpen, Atherston, and others. Together with the illustrated descriptions of Professor Huxley, his lucid and powerful expositions have made the history of these creatures known to the world; and they will prove a lasting monument of his persevering and elucidative work. Prof. Jones added a few words on the geological occurrence and distribution of the Dicynodont and associated Reptiles in the Karoo formation of South Africa, its lacustrine or estuarine origin, its enormous thickness, wide extent, and probable age as early Mesozoic.

Prof. DUNCAN maintained the necessity of accepting the Reptilian type as here understood by the author, and remarked that the embryonic forms of mammals are reptilian. The question seemed to him to be one of probabilities. The old beds contain the foreshadowings of higher forms of animals.

Prof. OWEN, in reply, stated that after thirty years of work on fossils he had arrived at the conclusion that the artificial line between the Palæozoic and Mesozoic series seems to need to be raised so as to include the Trias. The only fossil fish from the beds yielding the fossil described appeared to be Palæozoic. He justified the reference of the fossil to the Reptilia, and remarked that in no Reptile does the ramus of the lower jaw consist of one piece.



13. *On the Occurrence of the Genus ASTROCRINITES (Austin) in the Scotch CARBONIFEROUS LIMESTONE Series; with the Description of a New Species (A. ? BENNIEI), and Remarks on the Genus.* By R. ETHERIDGE, JUN., Esq., F.G.S. (Read February 2, 1876.)

[PLATES XII. & XIII.]

INTRODUCTION.—IN a paper entitled “Proposed Arrangement of the Echinodermata” &c.*, Messrs. Austin referred to a genus which they proposed to establish under the name of *Astracrinites*, in the following words:—“Another genus (*Astracrinites* of our MS.) offers so many affinities to the recent and fossil Echinodermata, that we consider it the most remarkable of all the known genera. By its being lobed it approaches to the *Lobistella*†; its ambulacra, spines, and arms mark it as allied to the *Echinites*, while the arrangement of its calcareous plates connects it with the LILIES of the ocean. In short, it possesses the lobes of a Starfish, the ambulacra and spines of a Sea-urchin, and the plates of a Crinoid. It is further remarkable by deviating from the quinary type so prevalent in the Echinodermata: the lobes and ambulacra of this new genus are each four in number.”

In the following year Messrs. Austin described this curious and aberrant form under the name of *Astracrinites tetragonus*. Their description is as follows‡:—

“Family ASTRACRINIDÆ,

“Consisting of the genera *Astracrinites* and *Aporocrinites*;

“Genus ASTROCRINITES, Austin.

“*Def.*—Dorso-central plate quadrangular, to which four pairs of elongated plates are attached, imparting a lobed shape to the fossil. In the retiring angles at the base of the four lobes are a like number of ambulacra. Mouth central. Anus lateral.

“*A. tetragonus*, Austin.

“*Def.*—The plates of this species agree with the generic definition. Each of the elongated plates has two or three rows of minute tubercles around its outer margin, apparently for the attachment of spines. The ambulacra have each a double row of pores placed centrally, with marginal tubercles. Near the centre of the dorso-central plate is an oval eminence, apparently analogous to the *madreporeiform tubercle* on the dorsal surface of the true Starfishes.”

In neither of these communications did the authors assign any locality to their fossil; but afterwards one of them, Fort-Major Austin, in a paper read before this Society, “Observations on the

* Ann. & Mag. Nat. Hist. 1842, x. p. 112.

† The *Lobistella* of Austin correspond to the *Cirrhigrada* of Forbes.

‡ *Op. cit.* 1843, xi. pp. 205, 206.

Cystidea of M. von Buch, and the Crinoidea generally," gave the horizon and locality as Carboniferous Limestone, Yorkshire*. The name *Astracrinites* has been rejected by Dr. H. G. Bronn, on account of its close resemblance to *Asterocrinites*, Münster; and he has proposed in its place that of *Zygocrinus*†. Dr. F. Römer observes that the four-rayed structure of this fossil more properly allies it with the Cystoidea than with the Blastoidea, which it otherwise considerably resembles‡.

Prof. de Koninck and M. le Hon § refer *Zygocrinus* to the Blastoidea, and state that the genus differs from *Pentremites* by the absence of ovarian apertures and the possession of separate openings for the mouth and anus.

Prof. Morris has altered Austin's name *Astracrinites* into *Astrocrinus*||, and does not recognize Bronn's name *Zygocrinus* in connexion with it. He gives Settle as the locality.

The late Prof. Pictet provisionally placed *Zygocrinus* in the Blastoidea, stating at the same time that its structure indicated a complete analogy with that of *Codaster* [*Codonaster*], M'Coy, except that it possesses four pseudambulacra, instead of five as in the latter ¶.

The substitution of generic names by various authors for trivial causes has given rise to endless confusion; and as I cannot perceive the desirability of adopting Dr. Bronn's substitution of *Zygocrinus* for Austin's *Astrocrinites*, I have much pleasure in restoring the latter, notwithstanding its resemblance to *Asterocrinites*, Münster, the difference being sufficiently well marked to prevent any confusion of the two names. A very eminent authority, Prof. A. Agassiz, thus writes on this subject**:—"We ought not to reject names differing so little as Moulinia, Moulinsia, Moulinsium, Cassidula, Cassidulus, simply because they are likely to be mistaken for one another; in our present condition, with an infinite number of genera, a difference, no matter how slight, should be sufficient reason for retaining the name instead of coining a new one, which is just as likely to fall into the same category, and resemble another name in a different department to as great an extent."

These quotations comprise all the published information I have been able to gather concerning the history of *Astrocrinites tetragonus*, Austin.

I have now the pleasure of bringing under the notice of the Society some small and highly interesting fossils lately discovered by Mr. James Bennie, during his duties as one of the fossil-collectors of the Scotch branch of H.M. Geological Survey. In doing so I have to thank Prof. Ramsay, F.R.S., Director General of the Survey, for permission, obtained through Prof. Geikie, F.R.S., to

* Quart. Journ. Geol. Soc. 1848, iv. p. 293.

† Index Pal. Nomenclator., 1848, p. 1381.

‡ Wiegmann's Archiv f. Naturg. 1851, p. 390.

§ Rech. sur les Crinoïdes du Terr. Carb. Belg., 1854, pp. 189 & 193.

¶ Cat. Brit. Foss. 2nd edit. (1854) p. 72.

|| Traité de Pal., 1857, iv. p. 295.

** Revision of the Echini, pts. 1 & 2 (1872), pp. 23, 24.

publish these notes otherwise than through the regular channel. The fossils in question, found by Mr. Bennie both in the Carboniferous series of the Lothians and Fife, are very closely allied, if not identical, with the genus *Astrocrinites*; but as they appear to differ in certain minor points from the typical species, I have considered the form to be an undescribed species, and have named it *A.? Benniei*, after Mr. Bennie, to whose acute observation we are indebted for the discovery of the specimens. Unfortunately the majority are much crushed, although a few are intact; and *in all*, the individual component parts retained in each specimen are in a fine state of preservation.

During my investigations into the structure of *A.? Benniei* I have been favoured by Fort-Major Austin with a drawing and a specimen of his *A. tetragonus*, and by Prof. T. McK. Hughes with the loan of specimens from the Cambridge Museum, which I recognized in the collection when visiting that Museum some time since. I take this opportunity of thanking both these gentlemen for their attention and kindness.

1. *Description of the Fossils.*

(a) *General Form.*—The body or calyx is *quadri-rotate*, with convex prominent lobes, three of which are alike and project more than the fourth, which varies considerably in its structure from the other three. The deep reentering angles between the lobes are occupied by the pseudambulacra. The dorsal surface, or that answering to the attached surface of a Crinoid, is convex, and covered by closely set tubercles, but without any sign of a point of attachment for a stem. The ventral surface is flattened, with a large central aperture, from which radiate the four pseudambulacra. On the non-symmetrical lobe, *and excentric, as compared with the ambulacral system*, is a second and pyriform aperture of complex structure.

(b) *Component Parts.*—It will perhaps be more intelligible if I describe the plates constituting *A.? Benniei* as those forming the three symmetrical lobes and those composing the unsymmetrical lobe. The minute size and crushed nature of the majority of the specimens, added to the very peculiar arrangement of their parts, make this anything but an easy task, which has, however, been lightened by the skill with which Mr. Bennie has sifted and washed samples of the disintegrated shale in which *A.? Benniei* occurs, and so obtained some, at least, of the plates in a free and separate condition. Immediately surrounding the central aperture, on the ventral surface, and in the angles between the ambulacra, are what I have, for the want of a better term, called the three "spearhead-shaped" plates (*a*, figs. 5 & 8), from their general resemblance to the head of a spear, having a small truncated base, constricted shaft, and expanded head. We have never succeeded in obtaining these little plates separate, but only in conjunction (*a*, fig. 8) with those next about to be described. These "spearhead" plates are succeeded in radial order by three larger pieces (*b*, figs. 1, 4, 5, & 8), thick, strongly arched, and convex, ornamented along the median

line or crest with several rows of peculiar tubercles (figs. 21 & 22). A few examples of these plates have been obtained by Mr. Bennie, in the manner previously explained, separate or united to their "spearhead" plates (*b*, fig. 8). So far these are the plates of the three symmetrical lobes visible on the ventral surface of the fossils; whilst the points of junction of the crested and tuberculated plates just mentioned with the succeeding pieces forming the dorsal surface are the most acute or prominently extended portions in the general periphery (*c*, fig. 1). These three crested plates, to the convexity of which the fossils owe much of their lobate character, are united with the truncated apices of four other plates, which enter into and chiefly form the dorsal surface, and with which they alternate. Two of these are arrowhead-shaped or forked plates, and alike (*e*, fig. 3; *b*, fig. 6; figs. 7 & 7*); whilst the other two appear to be different; but of their exact form I am not at present quite satisfied. A number of the forked plates have been picked out by Mr. Bennie (figs. 7 & 7*); they are slightly concave internally, with, on each side of the fork, two notched or angular shoulders (*b*, fig. 7*) and a central concave depression (*a*, fig. 7*), into which the apex of the pseudambulacrum fits. Each half or fork of the forked plates is convex (*c*, fig. 7); and the lateral union of every two contiguous halves gives rise to the lobes, which are continuations of those formed by the crested and tuberculated plates on the ventral surface (*b*, fig. 8). The closely packed tubercles on the dorsal surface usually hide the sutures between these forked plates; but they are visible in some specimens (*b*, fig. 3, *a*, fig. 6). As previously stated, I can with certainty only assert that two of these plates forming the dorsal surface have the form represented by fig. 7—the other two (*a*, fig. 10), bounding the pseudambulacra bordering the unsymmetrical lobe, being apparently different in form. In *A. tetragonus* the Messrs. Austin describe a dorsocentral plate; but I am again uncertain whether the present little fossils possess one, although in some specimens there are certain small grooves amongst the tubercles which appear to mark the outline of such a plate. If a dorsocentral plate is present, then it is to be seen in fig. 12, where lateral pressure has thrust it up out of its place (*a*, fig. 12).

Passing now to the fourth or unsymmetrical lobe, we meet with a much more complex structure, exceedingly well shown in fig. 5. The surface is much more flattened than that of either of the other three lobes (*b*, fig. 5), and occupied by an elongated pyriform aperture (fig. 5; *a*, fig. 20). On one side of the latter is an elongated plate (*c*, fig. 5; *b*, fig. 20), the ambulacral extremity of which has much the appearance of being half one of the "spearhead" plates (*a*, fig. 5). If this view is correct, the corresponding half on the other side (*c*, fig. 20) would occupy, during life, what is now a vacant space (*d*, fig. 5) merely filled with matrix. These two halves partly bound the excentric aperture, the remainder of the latter being excavated out of another plate (*e*, fig. 5; figs. 13 & 14; *d*, fig. 20), triangular or somewhat deltoid in form, and broader than long,

crossed by vertical scale-like ridges (fig. 13) instead of being ornamented with tubercles. It has a projecting lip (*f*, fig. 5; *e*, fig. 20), with a minute inward ridge (*g*, fig. 5). Following this plate round towards the dorsal surface, we find that its pointed extremity (*a*, figs. 13 & 14; *f*, fig. 20) is received into the reentering angle of yet another plate, which may be seen in the end view of a specimen represented in fig. 15 (*a*), passing on to the dorsal surface, with which it unites. Whether this (*a*, fig. 15) is a single plate or composed of two portions, I am in doubt. In some individuals it appears to be entire (*b*, fig. 12; *d*, fig. 11), whilst in others there is certainly a division down the centre from the reentering angle separating it into two halves (*a*, *a'*, figs. 15 & 16). In fig. 16 we have represented an internal view of the crushed hollow dorsal surface (with, at *b*, such a separation of the plate in question into two halves), the only remaining portion of the unsymmetrical lobe. The aperture-plate (*e*, fig. 5; *a*, fig. 15; *d*, fig. 20) presents, when viewed internally, some points of interest. The inward projecting ridge described as at *g* (fig. 5) is seen to be a portion of a minute circular cup-like depression (*b*, fig. 14), which leads inwards and downwards by a small channel or groove (*c*, fig. 14) towards the general cavity of the body. At the edge of the interior and vertical portion of the plate this channel appears to break up into two or three folds (*d*, fig. 14).

I have endeavoured in the foregoing description, with the aid of Mr. Sharman's truthful figures, to convey some idea of the plates composing this little organism, although it is difficult to convey to others a clear and comprehensive view of its structure, especially when we take into consideration its small size and usually crushed condition.

(c) *Pseudambulacra*.—The pseudambulacra are four in number (*a*, fig. 1), long, narrow, very slightly petaloid, and radiate outwards from the central aperture, one to each of the four concavities or interlobular spaces between the arched and convex lobes of the calyx. Each pseudambulacrum is more or less hexagonal in section, as indicated in fig. 18, which is a diagrammatic cross section of one. Mr. Bennie has succeeded in obtaining separated from the remainder of the organism (fig. 19). The component parts of the pseudambulacra are usually so closely fitted together that the plates can only be occasionally distinguished. The more or less nearly horizontal upper surface is traversed by a median (and for the size of the organism), deep longitudinal groove. The sides of each pseudambulacrum are bent down at a considerable angle, and in weathered specimens are seen to be formed by two series of small plates on each side. The pseudambulacral groove (*a*, fig. 17) gives off other, short, lateral, alternate grooves (*b*, fig. 17), which terminate in small and nearly round depressions (*c*, fig. 17) or sockets. Contiguous to each of these, and separated only by a small interspace, is another depression (*d*, fig. 17) somewhat more than halfway between the pseudambulacral groove and the margin, also connected by another groove (*f*, fig. 17) with a slit-like opening (or pore?) (*e*, fig. 17) between the side plates *g* and *h*.

The small spaces separating the inner contiguous sockets (*c* and *d*, fig. 17) are prominent, and give a longitudinal ridge-like appearance to both sides of the pseudambulacrum, better seen in the cross section (*c*, fig. 18). The slit-like opening (*e*, fig. 17) may represent the pore of the pore-plate in a *Pentremite*, when the smaller plate (*h*, fig. 17) would perhaps be identical with the supplementary pore-plate in the same genus; it appears, however, in the present organism to be itself sometimes pierced by a pore. On the underside of the pseudambulacrum, at the base or the end near the ventral aperture, is a peculiar projecting process (*e*, fig. 19).

(d) *Apertures*.—The ventral central aperture, when the spear-head-shaped plates (*a*, fig. 5) are in position, is in the form of a St. George's cross; but when these are removed it is seen as in fig. 4, much larger and quadrangular. The crushed condition and delicate nature of this part of the calyx in all these little fossils render it extremely difficult to form an absolutely correct idea as to what was the perfect state of the central aperture. I have not seen any evidence of supplementary pores surrounding the latter with which the pseudambulacral grooves communicate, similar to those discovered by Mr. Billings in the apex of *Pentremites conoideus*, Hall*.

The excentric aperture (fig. 5, & *a*, fig. 20) is pyriform and filled in, or perhaps covered by a plate very valve- or lid-like in character. It is a narrow elongate plate (*h*, fig. 5; *g*, fig. 20), slightly broader at the middle portion than at each extremity, the outer of which is split up into a series of small prolongations or fingers, resting on the margins of the aperture. In the figured specimen (fig. 5) the two terminal ones are the longest, whilst on the best-preserved side of the plate there are three lateral digitations; the former, or two terminal ones, rest one on each side of the previously mentioned ridge, running inwards towards a small cup-like depression (*g*, fig. 5; *b*, fig. 14).

(e) *Ornamentation*.—The dorsal surface and interradial lobes are ornamented with tubercles—those of the dorsal surface sharp and tooth-like (*a*, fig. 24), those of the plates short, conical, bluntly pointed, and impunctate, fluted down the sides, all set independently of one another, and with a plain smooth apex (figs. 21 & 22). The convex-crested plates on the ventral surface have usually each three or more rows of these tubercles well developed, the central row being the largest.

(f) *Spines*.—Adhering to one of the specimens by some particles of matrix, but not attached in place, is a microscopic spine (fig. 23).

(g) *Madreporiform Tubercle*.—I have quite failed to detect any body or projection of or on the surface which could for one moment be construed as representing this organ. It is true that on one of the specimens (*c*, fig. 3; *b*, fig. 24) obtained by Mr. Bennie at Carlops, there is a peculiar body, which I at first thought *might* be the "eminence on the dorsal surface" mentioned by Messrs. Austin in *A. tetragonus*, but was puzzled how to account for its pre-

* Pal. Fossils (Geol. Surv. Canada), ii. pt. 1, p. 103.

sence on only one individual out of the series of specimens in the Survey collection. When making the excellent drawings which accompany this paper, my friend and colleague, Mr. G. Sharman, noticed that the little body represented in the figure, although a good deal worn, possessed a spiral form—a fact which I had overlooked. It then struck me that this might be an accidentally adherent specimen of a somewhat common Carboniferous Foraminifer, *Valvulina*. For the sake of comparison, an enlarged figure of a species of *Valvulina* is also given (fig. 25); and it will be observed that the resemblance is very close. In some specimens the tubercles on the dorsocentral plate certainly appear to be somewhat worn off, or perhaps less developed than on other parts of the surface; but still in no way is there to be distinguished any resemblance to a Madreporiform tubercle, such as is described by Major Austin in his species.

2. *Affinities of A. ? Benniei with A. tetragonus, Austin.*

The specimen kindly forwarded to me by Fort-Major Austin, like those in the Cambridge Museum, is from limestone, and in a bad state of preservation; nevertheless in the former I can distinguish the two pieces which I have called the forked plates (*b*, fig. 6, fig. 7), and the three arched and crested plates bearing tubercles (*c*, fig. 1; *b*, fig. 5), although I cannot see the succeeding spear-head-shaped pieces (*a*, fig. 5). The dorsocentral plate has been accidentally removed in the specimen in question, leaving only its cavity (*a*, fig. 26). From a comparison of these with the specimen in our collection, showing the apparently displaced plate on the dorsal surface (*a*, fig. 12), I think it more than probable that this dorsocentral plate did exist in *A. ? Benniei*. The fourth or unsymmetrical lobe in this specimen of *A. tetragonus* is not well preserved, but appears to be generally constituted as in our species. Under these circumstances I think there can be very little doubt as to the close congeneric nature of these two fossils; for they coincide in the following points—the general tetroradial and lobate form, want of symmetry between all the lobes, presence of both a central and interradian aperture, possession of a tubercular ornamentation, absence of a stalk or column, and the arrangement of the pseudambulacra. On the other hand, as previously stated, I have quite failed to detect in *A. ? Benniei* any body resembling a madreporiform tubercle permanently attached; it is also smaller, less lobate, and apparently of more delicate construction than *A. tetragonus*.

3. *Systematic position of Astrocrinites.*

In their "Proposed Arrangement of the Echinodermata" &c., Messrs. Austin proposed a new family for the reception of their genus *Astracrinites** (then only known as a MS. name), the *Astracrinoides*, afterwards changed to *Astracrinidæ*†.

Their first class, the *Pinnastella* (= *Crinoidea* auct.), is divided

* Ann. & Mag. Nat. Hist. 1842, x. pp. 106-113.

† L. c. 1843, xi. p. 205.

into several orders, the first two of which are the *Cionacineti* (Austin), or those forms with a jointed flexible stalk, and the *Liberidæ* (Austin), the latter containing the family in question.

The following remarks are devoted to a consideration of the systematic position of *Astrocrinites? Benniei* with regard to the various orders of the Echinodermata as at present recognized. I believe I am correct in stating that throughout the Echinoidea, Asteroidea, and Blastoidea the quinqueradial arrangement is steadily maintained, and that in the Crinoidea, although the arms become much multiplied, they are primarily from five to ten in number. On the other hand, in the Cystoidea (e. g. *Apiocystites*, &c.) the radii are sometimes reduced to four; but although such is the case, they can hardly be compared to the radii of *A.? Benniei*; for in *Apiocystites* they are only recumbent arms, whereas in the latter they are pseudambulacra imbedded in the plates of the test. However, *A.? Benniei* so far corresponds with some Cystideans; but, on the other hand, there are not any organs similar to the pectinated rhombs of that Order.

The absence of a stem or column for attachment tends to separate this species from the Crinoidea, Blastoidea, and Cystoidea, although we know that in the adult condition some Crinoidea are free, and that certain Cystideans (*Agelacrinites* &c.) are asserted to be without any column; whilst in another, *Lepadocrinus*, there is evidence to show that it was free, or that its means of attachment were not of a permanent description.

A. tetragonus, Austin, has been described as possessing a madreporiform body, which, if it exists as described, would indicate Asteroid or Echinoid affinities; there is, however, no trace of such an organ in *A.? Benniei*. Furthermore, in the Asteroidea the skeleton is composed of a large number of small plates united by membrane; and when a second aperture in addition to the mouth is present, it is dorsal and nearly central. In the form under consideration the arrangement of the plates of the calyx is quite different from the foregoing; and both apertures, which are constant, are on the ventral surface.

It appears to me that the forked plates (figs. 7 & 7*) into which are received the apices of two of the pseudambulacra, correspond with the forked "radial" plates of the Blastoidea, although there is this curious divergence from the latter type:—If we take a Pentremite for example, any lobe-like projections existing in the general periphery are caused by the projection of that part of the radial plates into which are received the apices of the pseudambulacra (*a*, fig. 27), whereby the suture or union of each prong of the forked plates with its neighbour lies more or less in an angular concavity or re-entering angle (*b*, fig. 27); in *Astrocrinites* this arrangement is reversed, the pseudambulacra all lie in deep concavities between the convex and projecting lobes, so that in this case the line of union of the contiguous prongs of the forked plates lies on a convexity, instead of in a concavity as in the Pentremite.

Mr. Billings has pointed out that in the Pentremite the forked

plates, although called "radials," do not support the bases of the pseudambulacra as do those plates in the Crinoidea, but, on the contrary, these are situated at the apex of the *Pentremite*, the smaller extremity of each corresponding with the "apex of the ambulacrum of a Sea-urchin or of a Starfish. It also represents the tip of the arm of a Crinoid." Mr. Billings's deduction from this is, that the "forked plates do not belong to the radial but to the perisomatic system." In a similar manner the bases of the pseudambulacra in *Astrocrinites* are situated at the apex of the fossil, the tips being received in the "radial" or forked plates, occupying the position of the bases of the arms of a Crinoid*. The three convex arched plates (*b*, fig. 5) are probably analogous to the interradials in the Blastoidea (*a*, fig. 27), whilst for the truncated plate (figs. 13 & 14, *a*, & fig. 20) partly surrounding the excentric aperture it is more difficult to find a homologue. I would ask, Can it be compared to the fifth interradial plate of *Nucleocrinus* (which, according to Mr. Billings, "is truncated at its apex for the reception of the oro-anal orifice" †)? This oro-anal area of *Nucleocrinus*, Messrs. Meek and Worthen tell us, is wider and "often more prominent above . . . , and occupied by three large, elongated pieces, the middle one of which, the anal piece, is lanceolate in form, and, with the two interradials, fills all the large anal area down to the base" ‡.

I have not succeeded in finding any specimen with the central opening closed by small plates as in *Nucleocrinus* §, *Granatocrinus* ||, and some *Pentremite* ¶; nor are there any apertures to be seen analogous to those occurring at the apices of the deltoid or interradial plates of these genera, the ovarian orifices of some authors, the "respiratory spiracles" of Mr. Billings **. Finally, I believe that the peculiar lid or valve (*h*, fig. 5, *g*, fig. 20) covering the interradial aperture in *Astrocrinites* is analogous to that figured †† by Messrs. Meek and Worthen as covering the so-called anal aperture (the oro-anal of Billings) in *Granatocrinus Norwoodi* (Owen and Shumard), although in position it corresponds with the anal opening of *Codonaster*, McCoy, and *Codonites*, Meek and Worthen. Both these genera have been transferred by Mr. Billings to the *Cystoidea* ††.

The structure of the ambulacra appears to be to a great extent on the plan of the Blastoidea. Mr. Billings has described those of *Pentremites pyriformis* at some length. He says, "The median groove . . . sends off branches, right and left alternately, towards the sides of the ambulacrum. These branches do not run directly to the ambulacrum-pores. Each of them terminates at a point between the inner extremities of two of the pores. There is at this

* Geol. Surv. Canada, Pal. Foss. ii. pt. i. p. 112.

† *Op. cit.* p. 115.

‡ Illinois Geol. Rept. ii. p. 275.

§ Billings, *op. cit.* p. 117 and p. 114, f. 73.

|| Meek & Worthen, *l. c.* v. t. 9. f. 2 *a* & *b*.

¶ Billings, *op. cit.* p. 103.

** *Ibid.* †† *L. c.* t. 9. f. 2 *b*.

‡‡ See his views, American Journ. Sc. 1869, xlvi., 1870, xlix.; Ann. & Mag. Nat. Hist. 1870, v., 1871, vii.; Mem. Geol. Surv. Canada, Pal. Foss. ii. pt. i. p. 101.

point a small pit, which appears to be the socket of an appendage quite distinct from the pinnule. The groove does not reach the socket of the pinnule, which is situated further out, between two of the pores. On the other hand, a small groove runs from each pore, inward, and terminates at another socket, about halfway between the pore and the main median groove of the ambulacrum"*. If the description of the pseudambulacrum of *A? Benniei* be referred to (*ante*, p. 167) and fig. 17 examined, a close affinity to the foregoing will be recognized. The sockets at the termination of the short lateral grooves (*c*, fig. 17), I think, represent the small pits described by Mr. Billings in *P. pyriformis* as terminating the lateral grooves "at a point between the inner extremities of two of the pores." The socket (*d*, fig. 17), on the other hand, at the end of the groove (*f*, fig. 17), running inwards from each pore (*e*, fig. 17), is similar to those in *P. pyriformis*, "about halfway between the pore and the main median groove of the ambulacrum."

As previously stated, the Blastoid affinities of *Astrocrinites* (= *Zygoocrinus*) have been pointed out by Dr. F. Römer, Prof. de Koninck, M. le Hon, and the late Prof. Pictet. It is to this order that I would provisionally refer *Astrocrinites*, at any rate until further evidence, obtained from the examination of more perfect specimens than ours, can be adduced for or against such a reference.

4. *Affinities and Differences.*

With the Blastoidea *Astrocrinites* agrees (1) in the nature and function of certain of the plates of the calyx, (2) in the nature, arrangement, and mode of growth of the pseudambulacra, (3) in the possession of a central ventral aperture, around which the latter radiate, (4) in the presence of a second ventral aperture, excentric and interradial, closed by a valve or lid. On the other hand, this genus differs from the Blastoidea (1) in the quadriradiate arrangement of its parts, (2) its free and unattached habit, (3) the presence of the tubercular ornamentation; added to which the typical species has been described as possessing a madreporiform body, which ours does not.

5. *Localities and Geological Horizon.*

Astrocrinites? Benniei was first found by Mr. Bennie at Carlops Quarry, near Carlops, Peeblesshire, in shale overlying the No. 2 limestone of the Lower Carboniferous Limestone group of the Midlothian Carboniferous Series, where it occurs in considerable numbers. It was subsequently found plentifully in a bed of shale occupying the same geological horizon at Kidlaw, near Gifford, Haddingtonshire, and more sparingly at East Salton and Salton lime-works, chiefly as fragments; again at Skateraw and East Barnes, near Dunbar, in the same horizon, but usually in a fragmentary condition. A few individuals were found in the shale overlying the No. 2 limestone at Lampland, near Path-head, Haddingtonshire, and two fragments at Roscobie, Fifeshire, in shale connected with one of the lower

* *L. c.* p. 114.

limestones, probably either No. 1 or No. 2. The No. 2 limestone of the Midlothian Carboniferous Limestone series is probably the equivalent of the Hosie limestone of the west of Scotland.

P.S. Since this paper was written *A. ? Benniei* has also been met with at Cowdens Quarry, near Dumfermlino, Fife, in shale above the Linn limestone, probably the equivalent of the No. 1 limestone of the Midlothian Lower Carboniferous Limestone group. (Edinb. March 21, 1876.)

EXPLANATION OF PLATES XII. & XIII.

Astrocrinites ? Benniei (R. Eth. Jun.).

PLATE XII.

- Fig. 1. View of ventral surface, crushed: *a*, pseudambulacra; *b*, arched, convex, and crested plates ornamented with fluted tubercles (figs. 21 & 22); *c*, suture between *b* and half the succeeding forked plate (figs. 7 & 7*); *d*, central ventral aperture; *e*, position of the unsymmetrical lobe, broken away.
2. View of dorsal surface, crushed, covered with spike-like tubercles (*a*, fig. 2±): *a*, apices of two of the pseudambulacra.
 3. View of dorsal surface, somewhat distorted: *a*, pseudambulacrum; *b*, sutures between the forked plates *c*, *c'*; *c*, adherent Foraminifer? (see fig. 24, *b*); *d*, small encrinite ossicle adhering by matrix; *f*, base of the unsymmetrical lobe.
 4. Ventral surface, much weathered: *a*, central aperture; *b*, two convex crested plates; *b'*, position of the third convex crested plate, which has been removed; *b''*, position of the unsymmetrical lobe, which has also been removed; *c*, pseudambulacra.
 5. Ventral surface of a nearly perfect specimen: *a*, three spearhead plates projecting over the pseudambulacra (the sutures between them and the arched plates are well shown); *b*, convex crested plates, ornamented with the fluted tubercles (figs. 21 & 22); *c*, one of the plates bounding the excentric aperture (see *b*, fig. 20), probably representing half one of the spearhead plates *a*; *d*, space which would be occupied by the other half of this plate, with a small portion of the plate remaining (see *c*, fig. 20); *e*, the excentric-aperture plate (see figs. 13 & 14, and *d*, fig. 20); *f*, the projecting lip of this plate; *g*, inward process of the same; *h*, lid or valve covering the excentric aperture with its lateral digitations; *k*, three pseudambulacra; *l*, space which would be occupied by the fourth pseudambulacrum.
 6. Dorsal surface: *a*, sutures between the forked plates; *b*, *b*, the two forked plates; *c*, base of the unsymmetrical lobe.
 7. One of the forked plates, exterior view (see *b*, fig. 6): *a*, concavity into which the apex of the pseudambulacrum is received; *b*, crenulated ridge; *c*, convex halves of the forked plate.
 - 7*. Interior view of the same: *a*, same as in fig. 7; *b*, angular shoulders.
 8. Conjoined spearhead and convex crested plate, ornamented with fluted tubercles, a little laterally distorted: *a*, spearhead plate; *b*, convex crested plate.
 9. Side view of the same: the dotted line in both these figures shows position of suture between *a* and *b*.
 10. Side view of fig. 5: *a*, elongated plate, corresponding to half one of the forked plates. *b*, pseudambulacrum; *c*, excentric-aperture plate, side view; *d*, the lip-like projection of the same.

Fig. 11. Dorsal view of fig. 5: *a*, one of the pseudambulacra; *b*, position of the second pseudambulacrum; *c*, apex of the third pseudambulacrum; *d*, base of the unsymmetrical lobe.

PLATE XIII.

- Fig. 12. Dorsal view of a rather elongately lobed specimen: *a*, dorso-central plate pressed upwards; *b*, the base of the unsymmetrical lobe; *c, c, c*, the three symmetrical lobes.
13. Exterior view of the excentric-aperture plate: *a*, the pointed extremity received into the re-entering angle of the plate or plates.
 14. Interior view of the same: *a*, the pointed extremity; *b*, circular cup-like depression on which the apex of the lid appears to rest, placed at the end of the inward ridge seen at *g*, fig. 5; *c*, channel leading inwards from it; *d*, folds into which the channel appears to break up.
 15. End view of the unsymmetrical lobe: *a*, the excentric-aperture plate (figs. 13 & 14 &c.); *b b'*, the plate into which fits the excentric-aperture plate, with the suture apparently dividing it into two; *c*, lip of the excentric-aperture plate.
 16. Interior view of the dorsal surface of a crushed-down specimen: *a a'*, the plate or plates similar to *b b'* in fig. 15, crushed inwards; *b, b, b*, the three symmetrical lobes; *c, c*, hollows of the interlobular plates into which the apices of two of the pseudambulacra fit, similar to *a*, figs. 7 & 7*; *d, d*, position of the other two interlobular spaces in the perfect organism; *e*, interior of the dorsal surface, with a thin covering of matrix.
 17. Enlarged view of a portion of one of the pseudambulacra: *a*, ambulacral groove; *b*, alternate, lateral short groove; *c*, inner depression or socket at end of *b*; *d*, outer depression or socket at end of groove *f* proceeding inwards from the slit or opening *e*; *g*, lateral plate, probably equivalent to the pore-plate in *Pentremites*; *h*, supplementary plate, identical with the supplementary pore-plate in the same genus?
 18. Diagrammatic view of the cross section of a pseudambulacrum: *a*, ambulacral groove; *b*, more or less horizontal portion of the pseudambulacrum; *c*, ridge forming an interspace between the inner pair of sockets; *d*, exposed sides of the pseudambulacrum bent down at a considerable angle; *e*, concealed portion below the general surface of the organism.
 19. Side view of a pseudambulacrum: *a*, base; *b*, apex; *c*, exposed lateral portion; *d*, concealed lateral portion; *e*, inward process.
 20. The excentric aperture and plates surrounding it: *a*, the more or less pyriform aperture; *b* & *c*, the side plates which complete the aperture, and which probably correspond to one of the spearhead plates of the other lobes (*a*, fig. 3); the plate *c* is absent in the specimen, and its position is therefore only indicated; *d*, the excentric-aperture plate; *e*, its lip; *f*, pointed extremity of the plate which is received into the re-entering angle of *b b'*, fig. 15; *g*, lid or valve filling-in the aperture.
 - 21 & 22. Tubercles of the arched and crested plates (*b*, fig. 5, and figs 8 & 9)
 23. Microscopic spine attached by matrix to one of the specimens.
 24. Small body (*b*) adhering to dorsal surface of fig. 3, supposed to be a Foraminifer (*Valvulina*, sp.); *a*, tubercles of dorsal surface.
 25. Greatly enlarged view of a specimen of *Valvulina*, sp., for comparison with *b*, fig. 24.
 26. Dorsal surface of *A. tetragonus*, Austin, from a weathered specimen kindly presented to me by Major Austin: *a*, cavity left by the dorso-central plate, which has been accidentally removed; *b, b*, the two forked plates; *c*, the unsymmetrical lobe.
 27. *Pentremites cervinus*, Hall (Geol. Rept. State Iowa, 1858, i. pt. 2. t. 25. f. 11 a): *a, a*, two of the radial plates; *b*, suture between them.

N.B. All the parts figured are magnified, their true size varying from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch. Nos. 1 and 5, which are entire forms, are $\frac{1}{4}$ inch in diameter. The remainder are individual parts enlarged.



GSharman del. et lith.

R Etheridge Junr d'rexist.

M & N Hanhart imp.

ASTROCRINITES? BENNIEI.

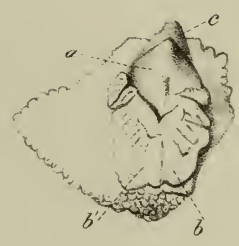
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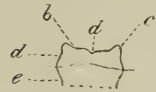
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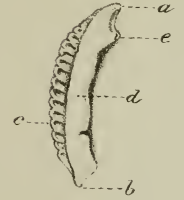
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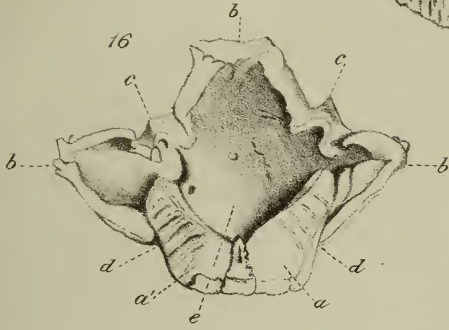
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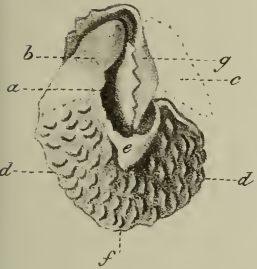
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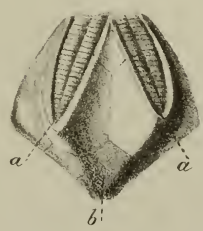
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G. Sharman del. et lith.

R. Etheridge Junr. direct.

M. & N. Hanhart imp.

ASTROCRINITES? BENNIEI.

DISCUSSION.

Prof. MORRIS complimented the author upon the care and labour he had bestowed in working out this genus from the fragmentary and minute specimens at his disposal. In the genera of Blastoidea, to which this form belongs, the plates of the calyx vary in number and form, as do also the orifices of the upper surface, in addition to which the normal number of the pseudambulacra appears to be only four, whilst in the other Blastoidea there are usually five. Occasionally, however, some Echinodermata present the abnormal condition of having only four rays. Besides the character of the rays, the genus is further distinguished by being stemless, in which character *Astrocrinites*, if rightly interpreted, bears the same relation to the stalked Blastoidea that *Marsupites* does to the Crinoidea.

14. *How ANGLESEY became an ISLAND.* By PROFESSOR A. C. RAMSAY, LL.D., F.R.S., V.P.G.S. (Read January 19, 1876.)

[PLATE XIV.]

THE structure of the low ground of Caernarvonshire within three or four miles of the Menai Straits in almost all respects resembles that of Anglesey, both in its geology and physical geography. The Menai Straits divide the two regions; but carboniferous rocks form the larger part of either shore, and the Straits may be considered simply as a long shallow valley, the bottom of which happens to lie beneath the level of the sea. The question thus arises, At what epoch and by what means was Anglesey separated from the mainland?

The whole of Anglesey is low; and only one steep escarpment, a minor one, occurs in the island—that of the Old Red Sandstone overlooking Traeth Dulas, which rises abruptly above the tidal flat of the Traeth to the height of about 250 feet. (See Map and Section Pl. XIV.).

The entire island may, indeed, be looked on as a gently undulating plain, the higher parts of which attain an average elevation of from 200 to 300 feet above the level of the sea; while most of its principal brooks and small rivers run north-east and south-west, in depressions with gently sloping sides; and only one inland valley, with the same trend, is of any marked importance, namely that of Malldraeth Marsh, in which the small coalfield lies. There are, however, a few exceptions to the average levels mentioned above—the summit of Holyhead mountain being 709 feet, and Garn, near Llanfairynghornwy, 558 feet above the sea, while the greatest elevation crossed by the sections of the Geological Survey (sheet No. 40) is only about 400 feet high.

On the opposite side of the Straits the same kind of low undulating scenery prevails for several miles inland, with the same kind of minor north-east valleys, one marked instance of which occurs in a long shallow and narrow valley in or alongside of which the Caernarvon and Bangor road runs for several miles.

The surface of the ground on both sides of the Straits is to a considerable extent composed of glacial detritus, with erratic boulders, large and small (from the north), gravel, sometimes sand, and clay from which any number of ice-scratched stones may be gathered from well-exposed sections, as, for example, in the boulder-clay coast cliff of the Mount at Beaumaris (which contains minute fragments of sea-shells), or anywhere else in similar cliffs round the shores of Anglesey, or inland in occasional pits and fresh cuttings on both sides of the Straits. Through these glacial accumulations the rocks of the country frequently appear, sometimes in barren tracts of considerable extent, sometimes in small isolated bosses of gneiss or grit, often covered with heath or furze, while the more fertile grounds

of the whole of Anglesey consist chiefly of glacial detritus, with here and there small alluvial meadows by the sides of the streams.

When freshly stripped of glacial *débris*, or even of a mere thin turfy soil, the underlying rocks are often found to be ice-smoothed and marked with glacial striae, running generally from about 30° to 40° west of south. The larger valleys of Malledraeth Marsh and the Menai Straits (with others of minor note) run in hollows in the same general direction.

This memoir is not the place in which to discuss the theory of the Glacial epoch; but for my general argument it is necessary to touch on one or two points connected therewith.

It is well known that in all mountain regions where glaciers exist, or have in past times existed, the disturbances of the earth's crust that produced the elevation of the mountains go back to periods long antecedent to the last great Glacial epoch. Thus the first great upheaval of the Alps is of præ-Miocene age, and the mountains of Scotland and Cumberland were mountains before Old-Red-Sandstone times, while the last great movement of the rocks of Wales is certainly older than the Permian epoch, and, probably, like the mountains of Cumberland, very much older.

There was therefore plenty of time, in what is now Wales, long before the beginning of the great Glacial episode, for the more ordinary agents of denudation to have formed deep valleys, down which, when that episode began, the growing glaciers might gravitate, deepening their channels as they pressed forward, and mamillating and striating the rocks over which they slid; for the great original valleys of the mountains were by no means entirely scooped out, but merely modified by the glaciers.

Thus, for example, it happens in Wales that all the striations in the valley of Dolgelly and the estuary of the Mawddach, in Merionethshire, follow the south-westerly trend of the valley, the glacier that filled it when at its greatest being fed by the snows of the slopes of Cader Idris and Aran Mowddwy and those of the tributary valleys of Afon Eden and the Mawddach, that joined it from the north, while from a central low watershed near the sources of the Wnion, another branch pressed north-easterly into and beyond the region now occupied by Bala lake.

The striated rocks exposed at low tide in the estuary of the Mawddach, and the islet-like heathy bosses of rock that stand out amid the marshy moss opposite Barmouth, are merely *roches moutonnées*, once buried deep beneath the glacier that pressed forward into Cardigan Bay.

In like manner all the western valleys of the Cambrian mountains of Merionethshire, from Barmouth to Diphwys west of Trawsfynydd, such as those of Afon Atro and Ardudwy, are marked by deep grooves and striations pointing more or less westward, according to the trend of the valleys. The broad flats and roughly hilly, but not mountainous, country of Cors-goch, Afon Eden, Trawsfynydd, and the ground bounded by the amphitheatre of scarp mountains formed by the Arenigs, the Manods, the Moelwyns, and the Cambrian steeps

of Graig-ddrwg were at the same time filled with deep accumulations of snow and ice, from which were discharged a radiating series of glaciers, one pressing southward to swell the ice-stream that filled the valley of what is now the estuary of the Mawddach, another through the Pass of Afon Trewern between Arenig Mawr and Arenig Bach eastward towards Bala and the valley of the Dee, whilst a third, swelled by all the snows of the Manods and the Moelwyns, flowed south-west, into what is now the broad flat of Traeth Bach, there to be joined by another great ice-stream which, partly descending from the high eastern slopes of Snowdon, filled Nant Gwynant, and debouched into the area now occupied by the marshy flat of Traeth Mawr. In all of these the directions of the striations necessarily conform to the trend of the valleys—easterly, southerly, or south-west, as the case may be.

I mention these specialities of striation partly to show that the Welsh group of mountains, as a whole, was not overridden by a great universal ice-sheet proceeding from the far north, as some have ventured to suppose. In the main, every large valley was filled by its own special glacier—a circumstance long ago stated in a broad way by Buckland, and definitely worked out by me for Caernarvonshire in my essay in the first volume of 'Peaks, Passes, and Glaciers,' afterwards republished in a little book. In North Wales, when the country was absolutely full of snow and ice, each great valley yet maintained its separate ice-flow. In such a case, however, there were many deviations consequent on under and upper ice-currents, the upper parts of glaciers diverging from the direction of the under-flow, and passing across what are now low watersheds, like that of Llyn Cawlyd, into neighbouring vales, such as that of the Conwy—a circumstance to which special attention has been called by the Reverend W. T. Kingsley, while engaged within the last few years in sounding the lakes of North Wales, with the view of proving them to be true rock-bound basins, in which he succeeded.

Such statements as these are preliminary to, and necessary for the understanding of, the main point of this paper, which I will now discuss.

On the north-west slopes of the Snowdonian range* (see Map, Pl. XIV.), great glaciers poured their ice-streams down the valleys of Llyniau Nant-y-llef to the west, and of Llanberis and Nant-ffrancon to the north-west and north; and these never quite reached the region now occupied by the Menai Straits, but, escaping from the higher bounding-walls of their valleys, spread out in the shape of broad fans on the north-western slopes of the minor hills that now overlook the Straits. This is proved by the northerly curve of the glacial striations at the mouth of the Pass of Llanberis, on the flatter area above the steep slopes of the slate-quarries by Llyn Peris and Llyn Padarn, and strongly hinted at by the long, smooth, grass-covered terraces of rock that pass from the opening of the valley of the Ogwen north-eastward along the seaward slope of Moel Wnion, and are still further continued

* I use the word *range* as a convenient term. There is no range of mountains in North Wales. Taken collectively they form a great group.

across the Aber valley towards Penmaen-mawr. These, when standing on or near them, are barely appreciable—but seen from Beaumaris across the Lavan sands, form unmistakable features in the landscape. I have often thought (though this is yet unproved) that the broad mound of glacial *débris* on which Penrhyn Castle stands may only be the relics of the terminal moraine, at a comparatively late period of the history of the large glacier that flowed down the valley of Nant-ffrancon and the Ogwen, fed by the snows of the Glyders, Foel-goch, Mynydd Perfedd, and Elidyr-fawr on one side, and by those of Carnedd Dafydd, Carnedd Llewelyn, and Foel-frâs on the other.

It thus appears that at this period the glaciers of Snowdonia did not cross the Menai Straits into what is now the island of Anglesey; and it is therefore clear that the north-east and south-west striations which mark the whole of that broad region must have been produced by some other power.

These striations point directly to the mountains of Cumberland, a country which, lying further north, was at one time buried so deeply under snow and ice, that almost all its mountains look simply like gigantic *roches moutonnées*; for Cumberland was far more intensely glaciated than the more southern region of Wales. From Cumberland a vast mass of ice flowed southward; and, reinforced by the ice-streams that came from the mountains of Carrick, in the south of Scotland, and perhaps even from the basin of the Clyde, it overspread the region now occupied by the shallow sea of Morecambe, Lancaster, and Liverpool bays, that lie between Cumberland and Anglesey (nowhere more than 30 fathoms deep), and pressing still further to the south-west, covered the whole of the low ground of Anglesey, and went to some unknown distance beyond. Furthermore, in my opinion, so great was the size and power of this ice-flow, that it hindered the glaciers of Llanberis and Nant-ffrancon from encroaching on the territory of Anglesey, and these simply joined the larger on-flowing glacier as minor tributary ice-streams. For this reason it happens that the glacial striations of Anglesey, as we might at first expect, *do not point towards the old glacier-valleys of Snowdonia that open on the Straits, but run at right angles to the courses of these comparatively minor glaciers.*

If we now turn to the rocks that form the banks of the Menai Straits, we find that they chiefly consist of nearly flat-lying Carboniferous strata (see Map and Section, Pl. XIV); and looking at the disposition of these strata from Traeth Melyn, opposite Caernarvon, to Llanfair-pwll-gwyngyll, in Anglesey, and on the opposite shore from Caernarvon to Bangor, there is reason to believe that from end to end they once filled the whole of the region now occupied by the Straits. The larger part of this region, as it now exists, is of Carboniferous Limestone age; but it by no means consists entirely of solid limestone. On the contrary, numerous bands of shale and friable sandstones and conglomerates are intermingled with the limestones, together with beds of soft red marl. On the coast opposite Caernarvon, the low cliffs are entirely formed of red marl overlying the

limestone; and on the Caernarvonshire coast for three miles north of the town, also overlying the limestone, there are soft shales of the Coal-measures, sometimes red and marly, and containing thin seams of coal.

In Anglesey, from three to four miles north-west of the Straits, lies the valley of Malldraeth Marsh, the rocks of which also consist of Carboniferous Limestone, Millstone grit, soft Coal-measure shales, with a little sandstone, beds of coal, and Permian strata; and this valley, nine miles in length, runs almost exactly parallel to the valley of the Menai Straits. Many years ago, at its north-eastern end, I saw deep glacial striations on the Millstone Grit, running straight down the shallow valley towards Caernarvon Bay.

Considering that the south-westerly trend of each of these valleys (and of others of minor note) corresponds with the general direction of the glacial striations of Anglesey, and therefore with the onward course of the great glacier that produced them, I have been led to the conclusion that both of the shallow valleys were scooped out in comparatively soft rocks by the grinding power of the vast glacier coming from the north-east, and that when in the course of time the climate ameliorated and the glacier disappeared the sea flowed in where part of the glacier had been, and Anglesey first became an island, the islets in the narrower and shallower part of the Straits at the Menai and tubular bridges being merely weathered *roches moutonnées*, once overridden by the moving glacier.

Malldraeth Marsh, as its name (the sodden sands) implies, is for the most part deeply buried under watery moss and alluvium; the river that traverses it is artificially banked and tidal for miles from its mouth; and if the alluvium that covers its surface, and the blown sands at its mouth were removed, it would again become, as it was in old times, an arm of the sea, a kind of low-banked fjord (like the Menai Straits), about nine miles in length, but, unlike the Straits, closed at its north-east end. Nowhere in the Straits is the water more than from 6 to 10 fathoms deep at high water; and around the islets near the bridges it varies from 3 to 7 fathoms. An elevation of the country of only 42 feet, would in time, by silting up and subsequent accumulation of alluvium, turn the north-eastern and south-western parts of the Straits on either side of the islets into valleys like that of Malldraeth Marsh.

There are some details connected with the partial submergence of North Wales during part of the Glacial epoch which it is needless to enter on with respect to this special subject. Anglesey was, after emergence, apparently joined to Caernarvonshire by an undulating plain of Boulder-clay; but by and by, through marine waste and subaerial drainage, this material was so much worn away that only the relics of it now remain in occasional cliffs and low banks on either side of the Straits. Then it was that at length Anglesey fairly became an island such as it now appears, though the long channel through which the waters of the Straits flow was ground out at a comparatively early part of the Glacial epoch.

Such I believe to have been the physical history of Anglesey

before, during, and after the Glacial epoch; and thus it was that Anglesey got separated from the mainland of North Wales by what is, after all, merely a long and broad glacial groove.

This with me is no hasty conclusion. Having at intervals been much in Anglesey, and occasionally living on the banks of the Straits for years, I wondered what might be their meaning. It is difficult or, perhaps, impossible to look at this long narrow channel without the idea entering the mind that at some unknown but comparatively recent time it may have formed part of the course of a large river flowing from some unknown land now submerged or destroyed by denudation; and this hypothesis possessed me so strongly for years, that, though always in doubt and in search of a better, it helped to blind me to any other. Last summer, however, while looking at the Straits, the whole truth of the case seemed suddenly to flash into my mind. The result I have given in this paper.

EXPLANATION OF PLATE XIV.

Geological Map of Anglesey and the adjacent parts of North Wales, with a contoured section of the form of the ground along the line A B.

Scale of Map, 12 miles to an inch.

Scale of Section, 4 miles to an inch.

DISCUSSION.

Mr. Hicks said he did not agree with Prof. Ramsay that the Menai Straits were formed by a glacier passing over the land. The hollow was made by the great changes which took place towards or at the close of the Palæozoic epoch. The great N.E. to S.W. faults on both sides of the Straits dropped the Carboniferous beds against the older and harder Palæozoic rocks, and a depression containing broken-up and soft beds was thereby formed at the close of the Palæozoic epoch. During the Glacial epoch the land here stood very much higher than at present, and the present hollow formed then a valley above sea-level. The separation of Anglesey from the main land occurred at a comparatively recent period, and is entirely due to the gradual encroachment of the sea over a gradually subsiding area. The subsidence which has taken place along the western coast, even in historic times, has been considerable in extent; and the sea is still continually encroaching on the land and along the lines of valleys.

Mr. J. F. CAMPBELL confirmed the author's views. He had found striæ high up on the Snowdonian range, in Ireland, and all over the British Islands, pointing in a direction towards Scandinavia, and thence towards the North Pole.

Mr. CHARLES MOORE remarked that the Mendips were upheaved before the formation of the New Red Sandstone, which lies unconformably upon the up-turned Coal-measures, and that the Carboni-

ferous strata of that region had been pounded and crushed, so as greatly to facilitate their removal by denuding agencies. He inquired whether Prof. Ramsay could define more closely the period of the upheaval near the Menai Straits.

Mr. HENRY WOODWARD remarked that since the Glacial period a considerable subsidence of Anglesey had taken place, and instanced, in support of this view, the finding of a jaw of *Elephas primigenius* associated with old forests at a great depth during the excavations for the enlargement of Holyhead Harbour. He thought that ice from Cumberland would suffice for the glaciation of the surface of Anglesey without going so far as the North Pole.

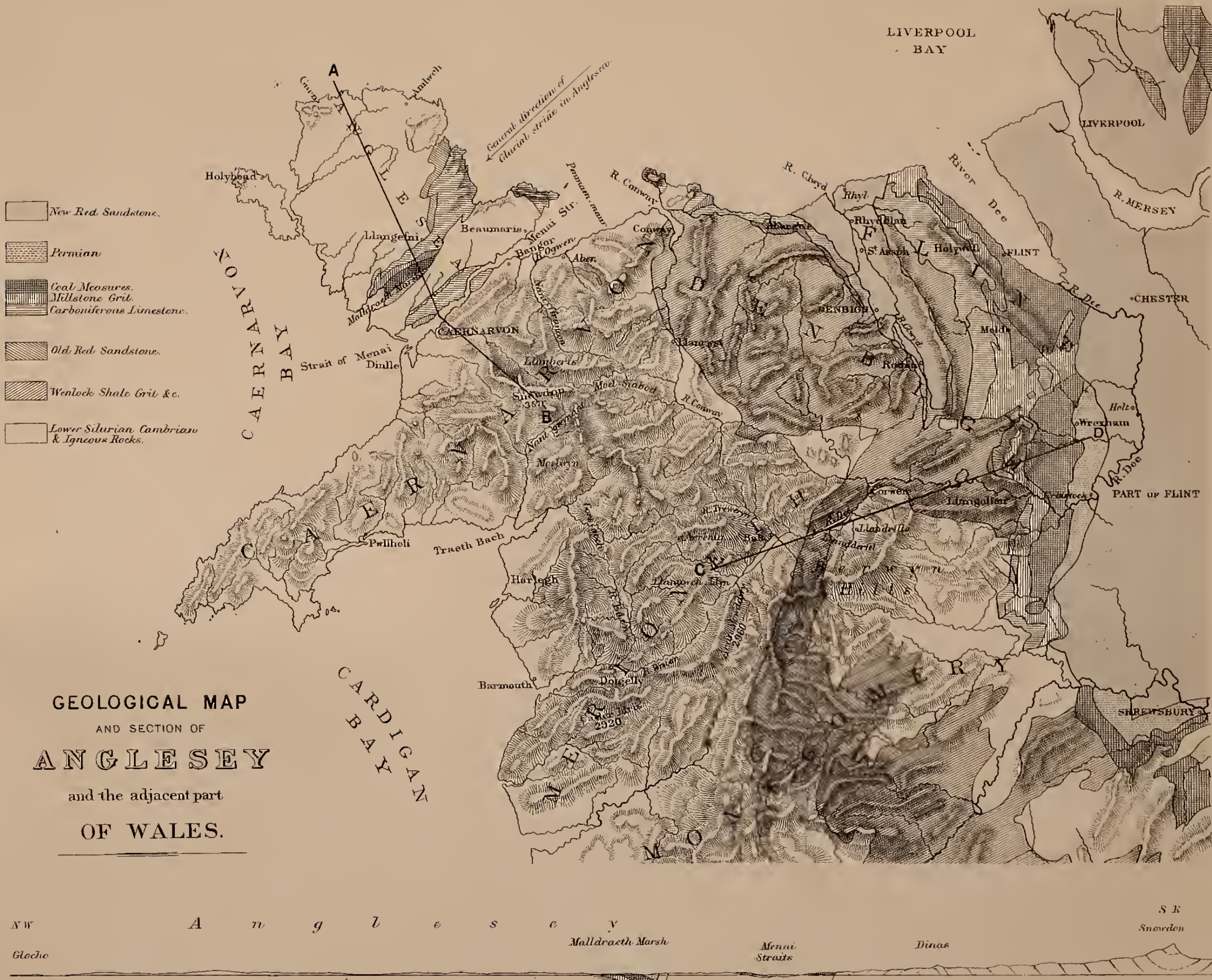
Mr. FORDHAM inquired why we should go to Cumberland for ice when Snowdon was so near. If there were ever a polar ice-sheet, the mountains of Cumberland and Wales, he thought, were not worth mentioning. He inquired whether there were any erratic blocks in Anglesey which might indicate the source of the ice by which it was glaciated, and also whether the Great Orme's Head was striated. He thought there was some reference to the Straits having been much shallower than at present within historic times.

Mr. DREW confirmed Prof Ramsay's views. The Straits are now margined by cliffs, owing probably to erosion subsequent to their formation.

Mr. JORDAN remarked that faults, as a rule, do not affect the surface.

The PRESIDENT (Mr. Evans) remarked that he understood Prof. Ramsay to maintain that the general features of the country were preexistent to the Glacial period, but that where there were softer rocks the ice cut through them, the hollows thus formed being afterwards often filled up and reexcavated by subaerial denudation.

The AUTHOR, in reply, stated that at the close of the Carboniferous period Anglesey was covered with Carboniferous strata, and that, although faults did occur in places, letting down portions of these rocks, these had nothing to do with the production of the Menai valley. The Millstone Grit and Coal-measures, not less than 1500 feet thick, originally lay over the Carboniferous Limestone of Menai Straits when the faults were produced. The ice came from the north-east and not from Wales; and the striations pointed directly towards Cumberland. The Great Orme's Head could hardly show any striæ, as its surface had been greatly affected by weathering. Many erratics occur near Beaumaris which are similar to the rocks of Cumberland or Galloway, and which may perhaps be identified with them.



GEOLOGICAL MAP
AND SECTION OF
ANGLESEY
and the adjacent part
OF WALES.

NW *A n g l e s e y* SE
 Gloche *Malltraeth Marsh* *Menai Straits* *Dinas* *Snowdon*

15. *On the presence of the FOREST-BED SERIES at KESSINGLAND and PAKEFIELD, in SUFFOLK, and its position beneath the CHILLESFORD CLAY.* By JOHN GUNN, Esq., M.A., F.G.S. (Read November 17, 1876.)

THE following remarks, together with the accompanying section and the Elephantine and Cervine remains exhibited from the soil of the forest-bed at Kessingland and Pakefield, are intended to be supplementary to a paper "On the Relative Position of the Forest-bed and the Chillesford Clay in Norfolk and Suffolk, and on the Real Position of the Forest-bed"*. I have but little to add to that paper and nothing in it to withdraw or alter. My object is to describe the rootlet-bed, part of the freshwater formation, which succeeded the Forest-bed, and to exhibit the Elephantine and Cervine remains as proofs that the soil of the Forest-bed lies beneath the Chillesford Clay.

As far back as 1868 Professor Huxley, then President, in discussing a paper by Mr. Prestwich on the Red Crag of Suffolk, observed that Mr. Gunn had stated as "a fact, and a very important fact," that he had seen the Forest-bed exposed on the beach at Easton Bavent, Kessingland, and Pakefield underlying the Chillesford Clays and Sands. This was opposed by Mr. Prestwich, who said he had seen the roots of trees in the Chillesford Clay, which he considered to be a proof that the Forest grew above it and upon it. It has also since been stated by others who have visited the spot, and have not been able to see the Forest-bed in consequence of its being covered with beach-sand and shingle, that Mr. Gunn's *ipse dixit* could not be accepted. I determined therefore to collect all the specimens I could, and carefully to note the beds from which they were derived. It would be foreign to my purpose to describe and particularize the specimens, which would fill a long paper; but it will suffice to say that they correspond with those from similar beds at Bacton and Cromer. If the reader will turn to the section (fig. 1), which is a general one of the cliffs, about three fourths of a mile in extent, I will indicate the beds from which they have been obtained.

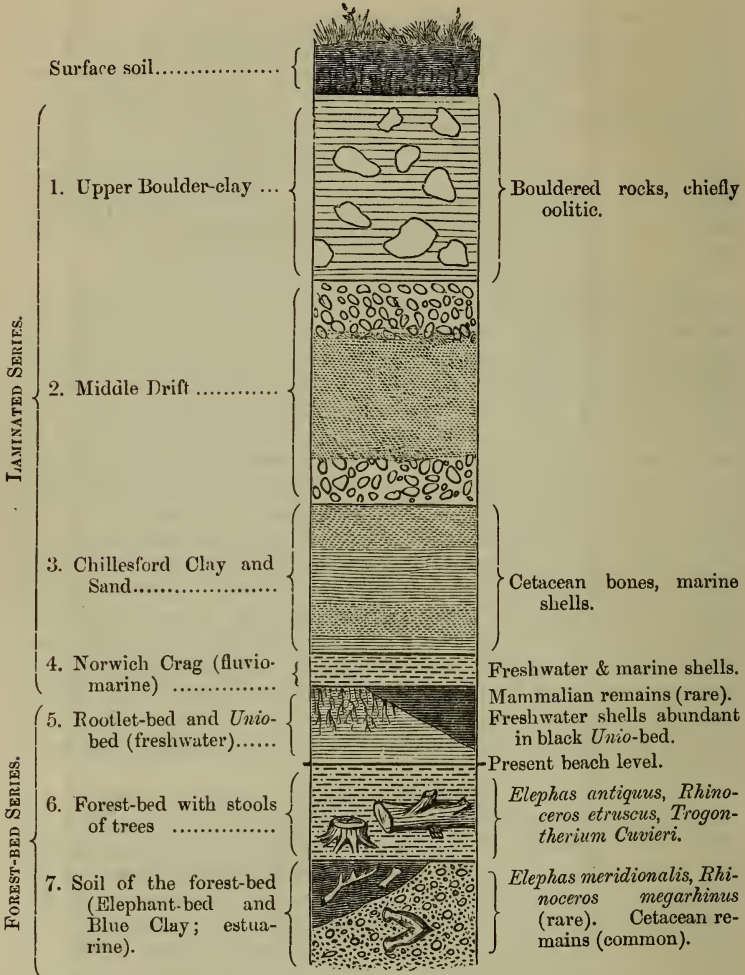
No. 7, at the foot of the cliff, represents the estuarine soil of the Forest-bed, on which the forest grew after this bed was raised above the level of the water. It consists of two parts, blue clay and gravel, the latter called the "elephant-bed," as described in my former paper; and from these two deposits every specimen exhibited has been obtained; the colours of the specimens mark their respective beds; or, if any be beach specimens, the matrix will do so equally. This bed ranges to the full extent of the Forest-bed; and its thickness has not been ascertained. It lies between high- and low-water mark; and the water rises so as to prevent one's searching with the spade.

No. 6 represents the Forest-bed, upon the soil last mentioned.

* Quart. Journ. Geol. Soc. vol. xxvi. p. 551 *et seqq.*

This I have seen here on one spot (a mere patch of a few yards length) which has escaped denudation. It is well developed, with blackened earth and large stools and stems of trees; but I did not find any mammalian remains in it; and Mr. Thomson, of Pake-

Fig. 1.—Section of Cliff at Kessingland and Pakefield.



field, whom I employed to collect specimens, says that he never found any except in No. 7, in which they abound for about three quarters of a mile. I mention this to show from what bed the specimens exhibited are taken, and not to affirm that they are confined to No. 7, because a fine molar of *Elephas antiquus* has been ob-

tained from the Forest-bed here; and the researches of Mr. Blake, F.G.S., of the Geological Survey, have proved that mammalian remains are to be found in No. 5.

No. 5 represents the freshwater beds, about 6 feet in thickness, formed on the subsidence of the Forest-bed. They consist in part of a black soil, only a few yards long, with freshwater shells, corresponding with those at Mundesley and Runton, commonly called *Unio*-beds. They consist in part also of the rootlet-bed, about 500 yards long, of green oozy clay, similar to that at Runton, pierced vertically with small roots, about the size of the little finger. This, Mr. Prestwich has pointed out as an indication of the presence of the Forest-bed (Quart. Journ. Geol. Soc. vol. xxvii. pp. 463, 464). With all submission to so high an authority, it appears to me to represent brushwood, which succeeded the true forest very extensively. The rootlets are very different from the grand roots which extend laterally from the stools of the forest-trees; and, besides, even these could not be expected to grow from such decidedly marine formations as the Chillesford Clays or Sands, which were continuously being submerged in deeper and deeper water, till the Westleton (or pebbly) beds and the Lower Boulder-clay were deposited without any break.

On the forest going down, this freshwater bed seems to have been formed; and the rootlets remain in it. At Happisburgh there appears to have been a hill, like that at Kessingland, which continued above water after the submersion of the lower land. On this hill hazelnuts and the bones of sheep or goats, now in the Norwich Museum, have been found; and a part of the sludge, as Dr. Falconer called it, was carted away at his suggestion; and a portion of it, full of the leaves of the willow, is now exhibited. This is evidently more recent than the Forest-bed, and probably of the same age as the rootlet-bed at Pakefield, Kessingland, and Runton.

No. 4 represents the Fluvio-marine deposits, about 2 feet thick, which succeeded the fresh water on the influx of the sea. Crag-shells have been seen here, but rarely. The Norwich fluvio-marine Crag most probably belongs to this division, which, at Bramerton, underlies the next-mentioned deposit. Here, as at other places, an interval of several miles may be interposed between beds of crag-shells, and yet the deposits are continuous and are stratigraphically the same. This remark applies equally to No. 3, next mentioned. The Chillesford Clay sometimes yields shells, as at Easton Bavent, and, slightly, at Aldeby; but at Bramerton, Brundall, Wroxham, Horstead, Coltishall, Hoveton, Barton Turf, Ludham, Burgh, near Aylsham, and other places it is destitute of them; and yet, from its mineral character, it can scarcely be mistaken. The fluvio-marine beds, both here and at Happisburgh, are cut short by the rise of the freshwater deposits, and are but partially and faintly represented. Owing to this cause, at Happisburgh the Lower Boulder-clay rests immediately upon the Forest-bed, without the intervention of any of the intermediate beds.

No. 3 represents the marine formations, and contains the Chillesford Sands and Clays, which are finely developed here, notwithstand-

ing that Messrs. Wood and Harmer, in their Palæontographical Monograph almost ignore them, except at the Pakefield-Lighthouse Gorge, near which they represent them as dipping down or truncated and not reappearing throughout the entire length of the coast. They average about 12 feet in thickness.

No. 2 has generally been regarded as the Middle Drift; but, from the admixture of occasional plots of pebbles, I am inclined to call it the Pebbly Bed, or Westleton Sands. The upper part is, perhaps, Middle Drift. It is about 15 feet thick.

No. 1 represents a grand display of the Upper Boulder-clay, averaging 15 feet; above is the warp and humus, 4 feet.

If I have erred in any respect, I trust I shall be corrected by the geological surveyors now at work in the neighbourhood.

DISCUSSION.

Mr. A. TYLOR inquired whether the lowest beds in Mr. Gunn's section represent the Antwerp Crag, as in this case the succeeding deposits would represent the other three Crags. Great quantities of fossil bones and teeth had been collected at Antwerp during the construction of the fortifications of that city.

M. CHARLESWORTH could not understand how the Norwich Crag can be above the Forest-bed. Remains of Mastodon have not been found in the Forest-bed; but they occur in the Norwich Crag.

Mr. GUNN said that it was now agreed at Norwich that the so-called Mammaliferous Crag is not really Mammaliferous, but that the mammalian remains found in it are derived from the Stony Bed resting immediately upon the Chalk. Dr. Falconer entertained the same opinion.

Mr. CHARLESWORTH stated that what he wanted was the evidence upon which the bed indicated in the section brought before the Society by Mr. Gunn was identified with the Norwich Crag.

Mr. GWYN JEFFREYS remarked that certain Arctic shells occur in the Chillesford Clay, and instanced particularly *Leda hyperborea*, a species which was obtained from a depth of 450 fathoms in the Norwegian Sea, and which he had found in 175 fathoms at the entrance to Baffin's Bay. The *Ledæ* are deep-water species; and the occurrence of *L. hyperborea* in the Chillesford Clay would seem to indicate that that deposit had been formed at a considerable depth, and afterwards upheaved.

Mr. WHITAKER stated that he had been with Mr. Blake along the coast to examine the lower beds referred to by Mr. Gunn. Mr. Blake had clearly established that in the case of these beds, which were only about 20 feet thick, different observers had given different names to the same things, and in fact had given names to conditions and not to beds. He was glad that Mr. Gunn had called the "Rootlet-bed" by that name, as it was certainly not a "Forest bed" though it had been so called. From the varying nature of the coast, and the fact that the sections were interrupted, he could easily understand the difficulty that had been experienced in establishing

the sequence of the deposits and their identity in different sections. He thought that the Forest-bed, the Chillesford beds, the "laminated beds" and the gravelly sands belonged to the same series. It is a question whether the so-called Norwich Crag of the coast is the same as that inland; Messrs. Wood and Harmer think that it is not. He would caution geologists against forming subdivisions among these beds, as they vary constantly. He thought it probable that the Norwich Crag is newer than the Red Crag, and that there is no break between the Crag and the Drift.

Prof. SEELEY stated that in 1863 he had been along the whole of the coast, in company with the late Prof. Sedgwick. The coast was then quite clear, and the beds could be traced all along. The Forest-bed was full of trees, with bones &c. lying about among their roots. East of Cromer a series of beds was shown different from those to the west. To the west of Cromer the Norwich Crag changed its character, being reduced to a thin calcareous band half an inch thick, in which shells such as usually occur in the Norwich Crag are to be met with. This thin bed rested immediately upon the Forest-bed, which was therefore below, but possibly in part contemporaneous with the Norwich Crag.

Mr. WOODWARD considered that Mr. Gunn had done great service to palæontology by the indefatigable zeal with which he had collected the mammalian remains from the soil of the Forest-bed. He considered that Mr. Gunn had conclusively proved the existence of the Forest-bed all along the coast; but in former times it must have extended far out into the German Ocean, as specimens of Mammoths' teeth and tusks have been dredged up in abundance by the trawlers off the Dogger bank, together with a nearly perfect skull of *Rhinoceros leptorhinus*. The Antwerp collection mentioned by Mr. Tylor belonged to the same series as the so-called Coprolite diggings; many of the shells were distinct from those of any of the Craggs. He quite agreed with Mr. Gunn that all the mammalian remains found in the Norwich Crag belonged to the Stony bed at the base, resting directly on the denuded surface of the Chalk.

Mr. CHARLESWORTH reiterated his question as to the evidence by which the bed marked Norwich Crag in the section exhibited by Mr. Gunn had been identified. He maintained that the newer beds of the Norwich Crag could only be identified by means of their characteristic shells; and he asked Mr. Gunn what evidence of this nature he had to adduce in support of his opinion that the deposit in question was Norwich Crag. He denied positively that the mammalian remains were only found in the Stony bed.

Prof. RAMSAY congratulated the author on having proved the existence of the Forest-bed, and expressed his gratification at seeing such local points of great geological interest so carefully worked out by observers residing on the spot.

The AUTHOR thanked Mr. Charlesworth and the President for discussing the question as to the identity of the Norwich Crag. He maintained that there had been a regular sequence of deepening conditions. At Easton Bavent the Chillesford Clay rested on Nor-

wich Crag; but he did not think that it was necessary that shells should be found in order to prove the nature of the latter bed: in fact he considered that far too much weight was laid upon conchological evidence in such matters, and far too little upon stratigraphical considerations. He differed from Mr. Prestwich with regard to the position of the Forest-bed, which no doubt extended far under the North Sea, perhaps even as far as Belgium, the beds in which country probably correspond with those of East Anglia. He stated that the Stony bed is not to be seen at Pakefield, because the Chalk upon which it immediately lies dips down at a high angle and passes at some depth below the Forest-bed.

16. *On the INFLUENCE of various Substances in ACCELERATING the PRECIPITATION of CLAY suspended in WATER.* By WILLIAM RAMSAY, Esq., Tutorial Assistant in Glasgow University Laboratory. *With a Note by* PROF. RAMSAY. (Read March 8, 1876.)

(Communicated by Prof. Ramsay, F.R.S., V.P.G.S.)

It has been noticed by several observers that clay suspended in water settles more quickly if the water is salt than if it is fresh. This fact is contrary to what would naturally be supposed—namely, that suspended matter should settle more easily in a liquid of low than in one of high specific gravity.

The earliest notice which I have been able to find relating to this subject, is a note by Skey in the 'Chemical News' for 1868, p. 160, in which he advances the following hypothesis to explain the phenomenon.

After taking notice of the fact that those salts which accelerate the precipitation of clay are too stable to be decomposed by mere contact with it, he suggests that such salts have a strong affinity for water compared with that of clay for water. They therefore tend to abstract water from the clay, and cause it to coagulate and settle. In corroboration of this he instances the fact that iron ferrocyanide is thrown down by numerous salts; that silica is precipitated from its solution in ammonia by chloride of ammonium; and that nitrate of baryta is precipitated by nitric acid.

In the 'Chemical News' for August, 1874, Durham advances an electric hypothesis; he supposes that clay, in falling through water, "generates electricity by friction, and, as water is a bad conductor, the difference in potential between the clay and the water remains for some time, hence they are mutually attracted; but when an acid or salt are added, the liquid becomes a good conductor, the potentials are equalized, and the clay falls."

Durham also states that in solutions of the same salt of different strengths, the rate of settling is in the order of the specific gravity of the solutions, and that clay remains longest suspended in the liquid of highest specific gravity.

Before reading either of these papers my attention was drawn to this subject by a communication from Mr. Peter Robertson to the Geological Society of Glasgow. It struck me that a probable solution of the question was to be found in the relative amounts of heat absorbed by various salts in passing into solution.

Does the rapidity of precipitation of clay in solutions of salts bear any relation to the absorption of heat by the salts in passing into the liquid state? In order to answer this question, some experiments were made which I shall now proceed to describe.

Some very fine clay was procured, which on being put into water broke up of its own accord into very minute particles. A number of solutions of different salts were prepared, and the specific gravi-

ties determined. A measured quantity of the muddy water was added to each solution, and the rates of settling compared with one another. It was found impossible to obtain any definite measure of the rates of settling; for neither by weighing the clay which had settled in a given time, nor by comparing one stratum of mud settling in one solution of salt with another stratum in another salt solution, could a reliable measure be obtained. It was always easy, however, to pronounce which was settling most quickly.

The results will be seen in the following Table. In each case one part of salt by weight was dissolved in four parts of water. The salts are arranged in the order of settling, those in which the clay subsided most quickly being placed first, with regular progression to the one which kept the mud longest in suspension.

Salt.	Reduction of temperature on dissolving.	Specific gravity of solution at 10° C.
Ammonium chloride	15·19 C.	1·0604
Ammonium nitrate	14·10	1·0863
Potassium chloride	11·81	1·1361
Sodium nitrate	9·46	1·1355
Barium chloride	4·50	1·1733
Magnesium sulphate	4·50	1·1035
Zinc sulphate	3·10	1·1258
Sodium chloride	2·10	1·1513
Lead nitrate	1·90	1·2099

It will be at once seen that those salts which absorb most heat on going into solution allow clay to deposit most easily.

In order to ascertain if the fluidity of the solution had any influence on the rate of settling, the rate of flow through a capillary tube, of the following six salts, was determined. The numbers are seconds, and are simply comparative. The temperature for all was 15° C.; and there was a constant pressure of one metre of water.

Salt.	Time of flow through a capillary tube. seconds.
Ammonium chloride	370·0
Ammonium nitrate	366·0
Potassium chloride	381·0
Sodium nitrate	456·0
Barium chloride	455·0
Sodium chloride	554·0
Water	380·0

The order holds good for several of the salts, but it is not constant enough to allow of the deduction of a general rule. A connexion appears, however, to subsist between the fluidity of the solutions and their absorption of heat on being dissolved. Water flows more rapidly through a capillary tube than any of the solutions, except

those of ammonium chloride and nitrate; and yet mud settles much more slowly in water than in any of the solutions.

Clay does not deposit so quickly in acid solutions as in solutions of salts. The order of settling for the four acids hydrochloric, nitric, sulphuric, and acetic acids of 16 per cent. was

1. Nitric acid.
2. Hydrochloric acid.
3. Acetic acid.
4. Sulphuric acid.

The difference between the rates in hydrochloric and acetic acids was slight, but still perceptible. Hydrochloric acid has a solvent action on the iron contained in the mud.

Mud deposits more rapidly in a solution of caustic soda than in a solution of potash; and as potassium hydrate evolves more heat on solution than sodium hydrate, the rule appears to hold in their case.

It appeared desirable to ascertain if the rate of deposition varied with the density of the solution. For this purpose four solutions of common salt were prepared, the strongest containing 100 grains dissolved in 500 cub. centims. of water; the second was half-strength, the third one quarter, and the fourth one eighth.

The specific gravities of the solutions were:—

Common salt.	sp. grav.
100 grams dissolved in 500 cub. centims. water.	1.1222
50 " " "	1.0631
25 " " "	1.0220
12.5 " " "	1.0122

The mud deposited in the order of their specific gravities; it precipitated most quickly from the strongest solution. It thus appears, that, although probably the specific gravity of the solution has some influence on the rate of settling, the real cause is most probably the absorption of heat; for the more salt passes into solution, the more heat is absorbed. This explanation is confirmed by the department of fine mud in water of different temperatures. It is well known that precipitates will settle more rapidly if the liquid in which they are suspended be boiled. This phenomenon is, I believe, usually attributed to the coagulation of the precipitate; and in some cases, for instance gelatinous precipitates, this undoubtedly happens; but in the case of finely divided precipitates I am disposed to attribute the settling to the absorption of heat by the water.

Experiments were made with a view to decide this point. The water, however, after being heated up to the required temperature, must be kept at that temperature by means of a heat equal on all sides, while the mud is depositing. This was done by means of water-baths, in which the beakers containing the water and mud were placed. In every case it was observed that the hotter the water the more rapidly the mud settled.

Perhaps I may be allowed to attempt a possible explanation of

these phenomena. It is generally agreed that the molecules of a fluid acquire, when heat is applied, a greater amplitude of vibration, but that the duration of each vibration remains constant. To take the simplest case, suppose a particle a vibrating in a horizontal plane, and that it performs each vibration in equal times, whether the amplitude of the vibration remain constant or not. Another particle b is descending at right angles to the plane of vibration of a . If the amplitude of the vibration of a be doubled, the particle b will have twice as great a chance of avoiding collision with a as before; for the particle a will traverse a given space in half the time it formerly took, leaving it vacant the other half. The particle b will therefore be at liberty to fall through this space for twice as long a time as was at its disposal before the amplitude of vibration was doubled.

Of course the problem is infinitely more complicated than the very rough and ready instance I have given; but I think it is simply an extension of the phenomenon, and can therefore be accounted for on the same principle.

Note by Prof. A. C. RAMSAY, F.R.S., F.G.S.

Though the author does not draw any geological inferences from the foregoing data, it is yet obvious that they have geological bearings. Thus, given equal amounts of mud in suspension in a salt lake or in the sea, and in a freshwater lake, the water of each being still, a greater quantity of sediment in a given time will be precipitated to the bottom in the salt water than in the fresh water, and the amount of salt in solution will relatively retard or hasten precipitation. But supposing mud in suspension to be carried into the sea by a river, the mixture of fresh and salt water, the current at its mouth, and the movements of the sea beyond that current, due to winds, tides, and ocean currents, will also affect the question to such an extent that under these circumstances no absolute rate of precipitation can be estimated in a given time, over a given area, for a given quantity of mud. Still salt water, as compared with fresh water, must under like circumstances have an effect—as, for example, in the case of the mud carried by rivers into the great lakes of America and into Hudson's Bay, or the mud carried into the salt lakes of Central Asia, and that carried into the large lakes of Switzerland and the north of Italy. Examples of fresh and salt lakes occurred in old geological times; take the case of the Swiss Miocene deposits for the first, and of the British Permian and Triassic (and some other areas) for the second; and the rates of deposition of mud in such instances may possibly have been modified by the freshness or saltiness of the water.

DISCUSSION.

Prof. HUGHES inquired whether the observations had been sufficiently carefully made to determine the amount of precipitation in

a given time. If particles put into heated water were not of the same temperature as the water, the gases would be driven off from them, and their place would be taken, on cooling, by water, which would hasten the deposition. He asked whether, in the case of the solutions, the difference of the specific gravity of the fluids might not somewhat similarly affect the air entangled in the particles.

Prof. MASKELYNE said that he thought this paper was hardly suited to the Geological Society, the question discussed in it being a purely physical one. Absolutely pure water is viscous; and judging by the influence of salts in solution in aiding precipitation and filtration in the laboratory, it would seem that this viscosity is impaired by salts dissolved in it. The results obtained might therefore be due to the different viscosities of the solutions employed.

Prof. RAMSAY remarked that at any rate the fact remained that the mud went down faster in salt water than in fresh; and that fact seemed to him to have important geological bearings.

Mr. EVANS expressed a hope that these experiments might be carried still further, as, although they were undoubtedly of a physical nature, their results appeared to be of considerable importance from a geological point of view. He suggested that experiments might be made with solutions which, having been already saturated with one salt, would yet dissolve another without undergoing any change of volume.

Mr. D. FORBES stated that the author's results seemed to him to be deserving of great confidence; his experiments had evidently been conducted with all due care.

Prof. MORRIS remarked that the subject was not a new one. Mr. D. Robertson studied it in 1873, and found that mud is less rapidly precipitated in weak than in strong saline solutions. The specific gravity of the matter in suspension must also be taken into consideration in such experiments.

The PRESIDENT (Prof. Duncan) did not feel quite sure that the results embodied in this paper would be found to have much practical bearing on geological questions. Very fine sediments take a long time to fall, and would probably be carried far out to sea. From his own observations he did not think that the greatest quantity of mud was precipitated at the mouths of rivers.

17. *Fossiliferous* CAMBRIAN SHALES near Caernarvon. By J. E. MARR, Esq., St. John's College, Cambridge. (Read March 8, 1876.)

(Communicated by Prof. T. Mc K. Hughes, F.G.S.)

THE shales under consideration extend from about three miles S.W. of Caernarvon to Bangor, being roughly parallel to the Menai Straits. They are faulted against Lower Cambrian to the east, and disappear against a dyke on the west. They are, as a rule, greyish black to bluish black in colour, most commonly tolerably sandy and micaceous; but in places, as where the fossils are found, they are chiefly clayey with hardly any admixture of sand.

The fossils were obtained from three places, all within a mile of Caernarvon and on the banks of the Sciont.

The first place is close to Pont Sciont, on the E. side of the river, where an arrow marks the dip in the Ordnance map. The shales here are bluish black, dipping at about 45° S.E., containing a large amount of iron oxide, from the decomposition of iron pyrites, which is itself found in nests and veins scattered through the mass of shales, but especially towards the top of the section; and the outer surfaces of the rock weather to a rusty or olive-brown hue.

The rock is of a splintery nature; and it is rather difficult to get large pieces. It has a concretionary structure all through, breaking up into lenticular pieces; and it is in the interior of these pieces that most of the fossils occur.

Most of the fossils came from the bottom of the section, and were scattered somewhat capriciously, so that one might work for two or three hours without finding a single specimen, and then suddenly come upon two or three. Graptolites are the most abundant fossils in this place. About 35 yards S.W. of the place from which the fossils were obtained runs a greenstone dyke, parallel to the bedding of the rock, and altering the shales to the distance of about four yards from the edge of the dyke. The shale, where altered, has a subconchoidal fracture, and a glazed porcellaneous appearance with slickensided and iridescent joint-surfaces. One Graptolite occurred here at the outer edge of the altered rock; but unfortunately it fell to pieces. On the other side of the dyke no rock is seen exposed; but about 50 yards further on another dyke is just visible, in weathered bosses, at the side of the road.

The second place where the fossils were found is on the S.W. side of the river, and a few hundred yards nearer to the mouth of the river than the preceding place. Here a series of sections is exhibited along the old framway from Caernarvon to Wantlle. The section where the fossils were found is the third from the tramway bridge over the river, and about opposite the letter "a" in the "road" of "Wantlle railroad." The shale at this place is very similar to that just described, but breaks up into larger masses. As the concretionary structure is not so strongly developed, Graptolites were

not so numerous here as in the first place ; but Phyllopod crustaceans appeared to predominate.

The last place is on the same side of the river as the first, but about three quarters of a mile higher up, close to the mill *below* Peblig Bridge, but on the opposite side of the river ; and the only two specimens found were got out of the material taken from a pit which was said to be sunk for the purpose of getting coal !

The rock here has quite a different texture from that of the formerly described rocks, being finely laminated and without the jointed and concretionary structure of the other rocks. It has a fine texture and greasy feel. In it occur veins of quartz &c., which show most beautiful instances of slickensides. The pieces in which the fossils occur were got from a depth of about 60 feet from the surface. Fossils seem to be scarcer here than at the other places. I only found two pieces, one having on it a tube, and the other a tube similar to the former on one side, and a Graptolite on the other.

On the whole the first place has afforded a much greater variety than the other two ; but as it was worked for a very much longer time, it is doubtful whether, with thorough search, the second would not yield a much more abundant fauna than it has hitherto done. The third place seems to be much less fossiliferous than the other two, the more so as, although I tried a fourth place about a quarter of a mile higher up the river than the third, and on the same bank, and although the shale was of exactly the same character as that of the third place, it did not yield a sign of any organism whatever.

The whole deposit is the more interesting as the only remains hitherto found are a single specimen of *Bellerophon perturbatus* below Penrhyn Park, near Bangor, some Graptolites and an obscure fragment of a Crustacean near Caernarvon, at the place first described in this paper. Cf. Prof. Ramsay's Memoir on the Geology of North Wales (Mem. Geol. Survey, vol. iii. p. 161).

The fossils seem to indicate that the deposit belongs to the upper part of the Arenig group.

APPENDIX. By HENRY HICKS, Esq., F.G.S.

IN the interesting series of fossils collected by Mr. Marr, and which have been placed in my hands for identification by Professor Hughes, I have been able to recognize the following forms :—a new *Caryocaris*, a new *Æglina*; *Trinucleus*, sp.; *Barrandea*, sp.; *Lingula*, sp.; *Discina*, sp.; *Obolella*, sp.; *Orthoceras caereesiense* (Hicks), *Didymograptus bifidus* (Hall), *D. indentus* (Hall), *D. Murchisoni* (Beck) and var. *furcillatus* (Lapw.). The specimens hitherto discovered are for the most part fragmentary; and hence identification of some of the species is difficult. I have therefore preferred in such cases to note the occurrence of the genus only. Others are undoubtedly new species or varieties, to which I propose to give names, though I do not think it would be advisable to figure or describe them fully until better specimens are found. Fortunately the species recognized enable us to make

out without any doubt the position of the beds in the series, and to correlate them with those in other districts.

As described in Mr. Marr's paper, the rocks have been faulted down against very much older beds, and the stratigraphical evidence of their position is wanting; we have therefore to rely almost entirely upon the fossils and some slight assistance which we are able to derive from lithological characters. The whole fauna, speaking generally, has an Arenig look about it; and even were no species capable of being clearly made out, I should have no hesitation in placing the beds in that group. It is, however, far more satisfactory to be able to point out, from evidence derived from other districts where the succession is perfectly clear, what the real position of the beds must be as proved by the contained fossils. At St. Davids the Graptolites *D. bifidus* and *D. indentus* are found only in the upper Arenig rocks, and *D. furcillatus* and *D. Murchisoni* in the Lower Llandcilo. According to Messrs. Hopkinson & Lapworth, this is also the position of these fossils in the neighbourhood of Shelve in Shropshire, and in Cumberland.

Another of the fossils, *Orthoceras caereesiense*, is also found in the Upper Arenig rocks at St. Davids; and the genus *Caryocaris* is only known to occur in the Skiddaw slates of Cumberland, associated with the same Graptolites as are found here. I think we are justified therefore in correlating these beds with the Upper Arenig rocks elsewhere.

In some respects the fauna would indicate a position intermediate between the Upper Arenig and Lower Llandcilo, a passage from the one into the other. However, on grounds mentioned in a former paper to the Society, viz. that no beds so low are anywhere exposed in the neighbourhood of Llandcilo, and that these were distinctly recognized in parts of North Wales by Prof. Sedgwick many years ago, and called the Arenig group by him, I feel it is but right that they should be included in that group.

The lithological evidence also tends to bear out in a marked degree the foregoing conclusions. From the fact that it was about this time that volcanic action commenced in Wales and Cumberland, the rocks in each of these areas assumed much the same character; specimens from St. Davids, Shelve, Cumberland, and near Caernarvon are all bluish-black micaceous shales, with little or no cleavage. In no other part perhaps in these early series have we this character so universally shown; and I attribute the cause to the admixture of a considerable amount of fine volcanic material with the ordinary sediment. Why these were not formed into slates, as the previous and succeeding beds, may have been from the presence of too little argillaceous in proportion to the amount of volcanic material; for they were subjected to the same amount of pressure as those in which the cleavage is now most marked. These beds are succeeded in the places mentioned by contemporaneous tuff beds, the first of which we have evidence in the British area. There can be no doubt in my opinion that a moderately deep sea prevailed over these areas at the time that these beds were

deposited, and that the volcanoes were submarine. The presence of fine sediment over so many parts in Britain, and in other regions in Western Europe proves also that there was no land of any extent near.

The immediately preceding and the succeeding sediments also are for the most part such only as would be formed in a moderately deep sea and away from shore. The fine argillaceous material, however, was undoubtedly the result of denudation, though in this case of distant land. Up to this time the sediments had been gradually changing from the rougher to the finer materials; and in the next group, wherever volcanic action was not taking place over these areas, the rocks heaped up were formed almost entirely by marine life, showing the presence then of a clear sea. Exception might perhaps be taken to this view on the evidence of the great grit bed in parts of Caernarvonshire, and also of the Stiper Stones in Shropshire. It must not be forgotten, however, that in each of these places very fine sediments directly overlie and underlie these quartzose sandstones, and quite conformably. My own opinion, already expressed in a former paper*, is that the grit bed and the Stiper Stones are parts of what was a shifting sandbank at a considerable distance from land, and in a sea of moderate depth.

The discovery of these fossils by Mr. Marr must be looked upon as of considerable importance, since it enables us to read the succession of these early Palæozoic rocks in Caernarvonshire in a much clearer manner than we have hitherto done, and it also carries the succession there a stage higher.

The following attempt at a comparison of the series which make up the Arenig group in Caernarvonshire and in Pembrokeshire may now be useful.

	<i>Pembrokeshire.</i>	<i>Caernarvonshire.</i>
Upper Arenig. {	a, Black shale followed by interbedded tuff.	a, Shales of Bangor and Caernarvon, and shales under and mixed up with the lower ash-beds in the Arenig mountains, and to the N.E. and N.W. of Portmadoc.
	b, Fine slates	b, Slates at Ty Obrey, and under the above near Arenig.
Middle Arenig.	Slates and flags	Grit bed at Ty Obrey &c.
Lower Arenig.	Slates and flags	Upper Tremadoc rocks near Portmadoc, and black slates under the grit bed near Arenig &c. †

* Quart. Journ. Geol. Soc. vol. xxxi. page 175.

† In addition to the evidence given in my former paper in regard to these beds, I have lately received from Mr. Homfray a good specimen of *Callograptus*, which was discovered by Mr. Ash in the neighbourhood of Portmadoc, in the lower part of the Upper Tremadoc rocks, and which appears to be identical with the species found at St. Davids.

A very short diagnosis of the two new species may be added, leaving the fuller descriptions until better specimens have been found.

CARYOCARIS MARRII, n. sp.

Carapace about $\frac{3}{4}$ inch long, more pointed than rounded anteriorly, subtruncate posteriorly; width at the broadest part about $\frac{1}{4}$ inch. Shell thick and horny-looking, probably similar in composition to the shell of a Trilobite. The surface is convex over about three quarters of its length, and is marked with at least three moderately deep furrows, bent considerably forwards, and which seem to divide it into lobes. The carapace has the appearance of being much narrower than in *C. Wrightii*.

ÆGLINA HUGHESII, n. sp.

Apparently not more than $\frac{1}{2}$ inch in length, sometimes much less. Head smooth, inflated, and convex, longer and wider than the tail. Glabella-furrows indistinct. Eyes small. Body-rings six: axis arched, very wide anteriorly, but tapering regularly backward. Tail triangular and strongly margined, axis raised and reaching nearly to the hinder margin. This is a very good species, and cannot well be confounded with any other British species. Its small size, very strongly marked tapering axis, and large inflated head, are good characteristics.

DISCUSSION.

Prof. RAMSAY was glad to find that the Upper Arenigs mark a passage, as, indeed, he had previously thought. He had never seen volcanic materials in that part of Caernarvonshire; but intrusive porphyries occur there. It seemed to him that the series was incomplete; there is no trace of the Tremadoc rocks and Lingula-flags near the Menai Straits, the Arenig beds lying unfaulted upon Cambrian in Caernarvonshire and quite unconformably in Anglesey. Certain ferruginous beds of the Arenig series which occur near the Menai Straits are found further south lying on Cambrian with no Tremadoc beds or Lingula-flags, and so also in Anglesey.

Mr. JUDD suggested that, in appealing to the case of the Scottish rocks as supporting his views concerning the unconformity between the Cambrian and Silurian formations, Professor Ramsay was reasoning in a circle, seeing that the so-called Cambrian rocks of Scotland had only been identified as such on the ground of their unconformable infraposition to the Silurian.

Prof. HUGHES remarked that the question seemed to be what is to be regarded as the base of the Arenig. The North-Wales district was evidently highly faulted, which gave rise to most of the difficulties. He objected to certain beds being classed as Cambrian without fossil evidence, and maintained that we have as yet no right to apply the term Laurentian to any rock on this side of the Atlantic.

Mr. Hicks, in reply, said he could not agree with Prof. Ramsay that there was a break in the series at this point, either in the south of Scotland, in Cumberland, in Shropshire, or in Wales. The faunas and the sediments in each of these places show that very similar conditions prevailed when the rocks were deposited. In nearly all, the conformity between the beds also is most clearly shown. These shales near Caernarvon, he thought, were undoubtedly dropped down against the older beds by two or more faults, and were not unconformable to the older rocks, as supposed by Prof. Ramsay. There is no evidence to show that any changes took place over this limited area at or before the time these beds were deposited which could have produced such an effect. The sections are acknowledged to be for the most part hidden by drift; there is no actual unconformity seen, and the whole is assumed on the strength of very imperfect data. There are no alterations in the sediments such as would indicate beach-conditions; and many of the beds are greatly metamorphosed, and their age in most cases doubtful. It seems, therefore, far more reasonable to suppose that the ground here is greatly faulted, and that, as in very many other areas, the absence of a series at any one or more places is due to some accidental cause, and not to an unconformity.

18. *On COLUMNAR, FISSILE, and SPHEROIDAL STRUCTURE.* By the Rev. T. G. BONNEY, M.A., F.G.S., Fellow and Tutor of St. John's College, Cambridge. (Read February 23, 1876.)

THE subject of the columnar jointing and spheroidal structure of rocks has of late received considerable attention, the most important papers on the subject being those by Professor James Thomson* and by Mr. R. Mallet†. The former explains the columnar structure by a contraction of the mass in cooling, and advances a novel theory to account for the cup-and-ball structure observed in cross-jointing, viz.—that the fracture commenced at the centre, owing to a longitudinal tensile stress, starting often from a “small [included] mass of stone different in texture and in hardness from the rest” of the rock, and proceeded outwards towards the periphery. The cause of this tensile stress he considers to be, probably, chemical action set up by infiltration of water, which has produced an expansion of the outside of the column, so that the outer part, growing longer, has strained and finally snapped the interior. The spheroidal structure, often manifested in decaying basalts, he considered not to be “an original concretionary structure, but due to decomposition penetrating from without inwards in blocks or fragments, into which the rock has been fissured.”

Mr. R. Mallet commences his paper by an ingenious mathematical demonstration of the cause of hexagonal fracture in the contracting body. He then passes on to consider the cup-and-ball structure. This he regards as a further product of contraction from loss of heat in a prism which is now cooling from the sides as well as from an end, so that the curved surface of the joint is always concave to the end which is losing heat; and he regards the spheroidal structure as the result of the residual forces of contraction which yet remain in the imperfectly cooled prismatic blocks into which the column is divided.

That columnar structure was due to contraction was clearly pointed out many years since by Mr. Scrope in his admirable work on the Auvergne‡; so that the confused statements in subsequent text-books of geology well deserve the severe comments of the above-named authors. With their explanation I fully concur; and the demonstration of Mr. R. Mallet seems to me unanswerable. I shall therefore pass rapidly over this part of the subject, merely calling attention to one or two points of interest in connexion with columnar structure. As, however, I entirely dissent from Professor J. Thomson's conclusions in the rest of his paper, and differ to some extent from those of Mr. Mallet, I venture to think there is yet room for a few remarks on the subject—one which I have for some time past lost no opportunity of studying.

* Report of Belfast Naturalists' Field Club, 1869-70.

† Phil. Mag. ser. 4, vol. 1. pp. 122, 201.

‡ Volcanoes of Central France, p. 92.

I shall begin by describing the various structures which may be observed in rocks, more especially volcanic, and then consider how far they can be explained by the theory of contraction, as stated by the above-named authors. The advantage of this method will be that we shall see more clearly what phenomena have to be explained. I shall consider the spheroidal structure apart from the others.

It is almost needless to remark that though columnar structure* appears to be most frequent in basalt, it is not confined to that rock; I have myself seen it in trachyte (district of Mont Dor, Auvergne), pitchstone (Arran), felstone (Cader Idris, &c.), phonolite (Roche Sannadoire &c., Auvergne). Nor is it confined to igneous rock. I have observed it in volcanic mud (beneath a bed of basalt in Tideswell Dale, Derbyshire), in coal at contact with basalt from Ayrshire (Geological Museum of Edinburgh) and from Yorkshire (Woodwardian Museum, Cambridge), in hæmatite iron-ore (*ib.*; the columns are about $\frac{1}{8}$ inch in diameter), and, though rather imperfect, in palagonite tuff (Iceland), and in a large quartz vein (Svolvær, Lofoten Islands). Ice also, when kept for some time very near a temperature of 32° Fahrenheit, as it is during a slow thaw or in those singular caverns termed *glacières*, in the Alps, also exhibits a beautifully regular columnar structure, which I can only attribute to a contraction of the mass, probably as it passes from the point of minimum density to the melting-point †.

Occasionally one set of parallel divisional planes is more strongly marked than the others, so that, while the majority of the columns retain the hexagonal type, an oblong form dominates, and a somewhat platy or bedded aspect is given to the rock-mass. I remember observing this especially in a trachyte in the ravine of the cascade of the Dore, on the Pic de Saney; and it is very conspicuous in the great mass of felsite which rises above Llyn-y-Gader (Cader Idris).

Columnar structure is rarely set up quite close to the exterior of the mass; there is usually an interval, varying from a few inches to several yards; this is either affected by some other form of jointing or is quite irregularly cracked.

Where the space intervening between the columnar part and the exterior is but small, as, for example, in "the Spindle," near St. Andrew's, Fife, and at Montiquey quarry, near Balmuto in the same county, it may be concluded that the mass soon began to lose heat very uniformly. Hence this structure is more likely to occur in intrusive masses (especially when the lava cooled at some depth like the above) than in streams of subaerial lava. In the latter also the columns often approach nearer to the under than to the upper surface. Thus the lava-stream of Royat is rudely columnar almost close to its base at the grotto of the Tirtaine, as is the stream from the eastern side of the Puy de Gravenoir, where it is exposed in a quarry on the east of the road from Clermont-Ferrand to Beaumont, while the upper part, still some yards thick, exhibits a far less

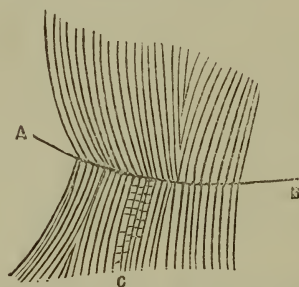
* As it may be considered to be now agreed that the sides of the prisms are normal to the surface of cooling, I shall not multiply instances to prove this.

† See 'Nature,' vol. i. p. 481, vol. iii. p. 288.

regular structure. The same may be observed in the prismatic lava at Torre del Greco (Naples), and at Fingal's Cave (Staffa).

The curved forms of the columns have been so fully discussed by Mr. Scrope and Mr. R. Mallet that I pass them by, merely stating that while some of the cases of slight flexure may be produced by a small motion of the lava-stream, after the formation of the columns, but before it has become perfectly solid, the majority must be due to changes in the form of the surface of what we may call breaking-tension in the cooling mass. It is extremely difficult to explain such complicated cases as the Clam-shell Cave (Staffa), Pouk Hill (Walsall), the Roche Sanadoire (Auvergne), and Jaujac (Ardèche); but we must remember that the surface of cooling must be closely related to the surface of the mass, and that partial denudation has often deprived us of the data for that part of the problem. Variation in the conductivity of the superincumbent materials might also produce some effect. Further complication has been sometimes introduced by large fissures, which appear to have opened out in the the mass somewhat anterior to its breaking into columns, and have allowed of a more rapid escape of heat from their surfaces. Thus columns will often be found to curve to a large, more or less horizontal joint (see fig. 1).

Fig. 1.—Columns of *Trachyte* curving to a joint (*Pic de Saucy, near Cascade of the Dore*).



A, B. Great joint. C. Minute cross-joints.

The structures more or less parallel to the surfaces of the mass, and consequently generally at right angles to the columnar, have next to be noticed. These may be roughly classified as (a) Fissile and Platy, (b) Tabular, (c) Curvitarular, (d) Cup-and-ball structure.

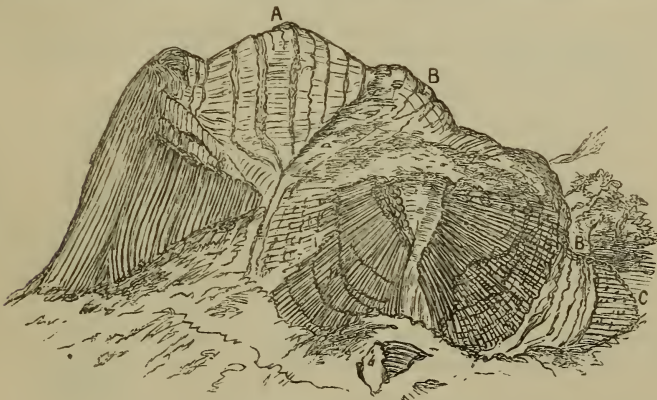
(a) *Fissile*.—A distinct tendency to a cleavage, at first sight closely resembling that of ordinary slates, is often visible in igneous rocks. A pitchstone on the north side of the hill of Dunfion (Arran) splits with tolerable ease in one direction. The great intrusive sheet of pitchstone on the Corriegills shore of the same island also has a distinctly fissile character, especially near the upper and lower surfaces, to which the structure is parallel. The same structure may be often observed near the surface of basalt dykes, as on this same shore; usually, however, it extends only for a few inches into

the mass. The outer part of the mass of basalt at the Spindle and Montiquey (mentioned above) exfoliates in rather thin plates; and the columns are, so to speak, enclosed in a fissile spheroidal shell a few inches thick.

The phenomenon is very conspicuous in some of the trachytic rocks of the Auvergne; those in the Cantal and Mont Dore are so fissile as to be used for roofing-slates. The well-known Roche Sanadoire and Roche Tuillièrè*, the latter of which is extensively quarried for the above purpose, are very remarkable instances of this structure, and throw much light upon its origin. I shall therefore describe them in some little detail. Near the highest part of the great Auvergne plateau, from which rise the groups of the Puy-de-Dôme volcanoes and the chain of the Pic de Sancy, and at the northern extremity of the latter, two rocky bluffs rise on either side of the deep cirque-like head of a wooded glen. That on the right bank of the valley is the Sanadoire, on the left La Tuillièrè. Both are phonolite; but the character of the rock†, and still more its structure, are different.

The Roche Sanadoire forms the extremity of a rather short spur from the Puy de l'Angle. On the southern side it is not very conspicuously columnar; but the rock, which is exposed in several abrupt crags, is divided into a vast number of small rather irregular prisms, with numerous cross joints. When, however, a view is gained of the precipitous western face, the columnar structure becomes more conspicuous, together with another set of divisional planes, which give a more fissile character to the rock. A reference

Fig. 2.—*Columnar and Fissile structures. Roche Sanadoire.*



A, C. Jointed columns. B. Fissile bands.

* Mr. R. Mallet (Phil. Mag. ser. 4, vol. 1. p. 218) calls the rock of La Tuillièrè basalt, and the fissile structure a "slaty cleavage" due to subsequent pressure. The rock is a phonolite, and has not the slightest resemblance to basalt; and the structure, I trust to show, is not a case of ordinary cleavage.

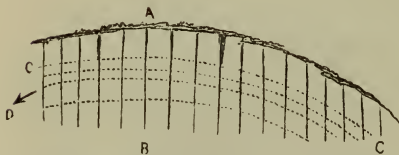
† For full account see 'Neues Jahrbuch für Mineralogie,' 1872, p. 351.
Q. J. G. S. No. 126.

to the annexed diagram (fig. 2), together with the following extract from my note-book may make this plain:—

“The columns are frequently rather rude and quadrangular in shape; in part, however, they are tolerably regular and hexagonal. They are bent in a most singular manner, so that those toward the outside curve round and roughly overarch an interior nearly vertical sheaf or boss. These columns are cut by numerous cross joints which run parallel to great curving divisional planes, and traverse their axes at a high angle. Thus the columns appear to be built up of slabs. The cross joints are commonly not at right angles to the axis, the inclination sometimes not exceeding 50° . In parts this platy structure becomes so conspicuous as almost to obliterate the prismatic; and a very singular effect is produced by this alternation of bands of ‘frilled’ and ‘crimped’ rock. The whole mass, whether distinctly columnar or not, has more or less of a fissile structure, which is of course most distinct where the columns are least so, and is (so far as I could see, and as one would expect) parallel to the great curving divisional planes. This description applies especially to the south-western part of the hill; when a view is obtained of the whole of the western face, as from the slopes on the opposite sides of the valley, the same complicated double structure will be seen continued throughout.”

Turning now to the Roche Tuillière, we find that its eastern face is divided into a number of large columns; these are very distinctly marked, and are cut by a great number of cross joints, which are not at right angles to the axis of the columns, but dip outwards. These joints also, when viewed from a distance, are seen not to traverse the face of the cliff horizontally, but to arch upward from its two extremities so as to become horizontal in the centre,

Fig. 3.—*Diagram of Columns and Cross joints (Roche Tuillière).*



A B. Vertical joints. C C. Direction of cross joints. D. Direction of southern end of cliff.

Fig. 4.—*Fissile structure. (Roche Tuillière).*



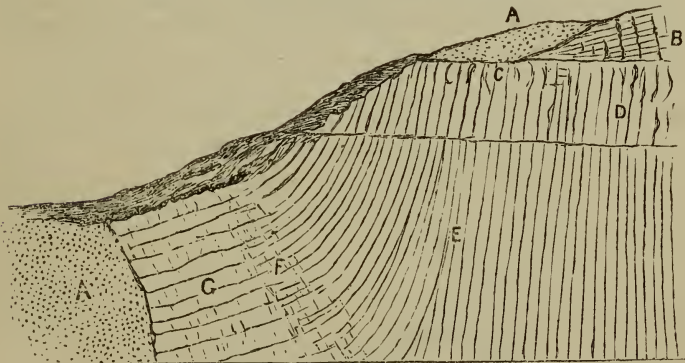
following very nearly the curve of its sky-line, which has no doubt been determined by the direction of these divisional planes. On climbing the steep wooded talus to the base of the columns their structure becomes more evident. In shape they are rather less

regular than their distant appearance would lead one to infer, as they vary from irregular quadrangular to hexagonal, the majority appearing to be pentagonal. They are often as much as 6 feet in diameter. The great cross joints cut the columns at distances from 2 to 5 feet apart; and the whole mass is traversed by a fissile structure curiously resembling that of a roughly cleaved slate, parallel to these joints. As the outward dip of these planes is some 20° , it produces a most unpleasant idea of instability upon the mind; for the columns look as if the least disturbance would cause them to slip forward. At the southern end of the cliff the columns are less distinct; and here the curve of the divisional planes makes a much higher angle with the horizon than elsewhere, becoming nearly vertical (see figs. 3 & 4).

From the above descriptions it will be evident that the fissile structure in these rocks cannot be a true cleavage; its explanation will be attempted presently.

(b) *Tabular Structure*.—In many igneous rocks the horizontal joints are so regularly and strongly defined as to produce a tabular or bedded structure. Instances of this may be seen in many granites, as, for example, at Pardenick Point, near the Land's End; in dolerite, in an intrusive mass under "the Castle," Burntisland (Fife); in the gabbro of the Gimlet rock, Pwlhelli, and of the Cuchullin Hills; and, though less perfectly, in some of the "traps" in the Lake-district. A case which I have more than once observed seems to suggest some connexion between this and the platy structure described above. An excellent example of it may be found in a quarry on the Gross Weilberg (Siebengebirge) (fig. 5). Here a mass of

Fig. 5.—Columns &c. (Gross Weilberg).



- A. Trachytic tuff. B. Closely jointed rude columns. C. Bent columns.
 D. Upper stage of quarry with good columns. E. Lower stage.
 F. Platy structure. G. The same in rude columns.

basalt is intruded into a trachytic tuff. The exterior of the mass at the top is for the space of 3 or 4 feet divided into rude quadran-

gular prisms, which are traversed by so many cross joints as to make the rock almost platy in structure; then, after a distance of about a yard, where the normal joints become rather more frequent and somewhat confused, a series of magnificent columns commences, which run with great regularity, and are singularly free from cross joints, the shafts often being unbroken for a distance of several yards. On approaching a contact with the tuff on the lower side of the mass a platy structure again sets in.

This tabular structure, it will be observed, is roughly parallel to the bounding surface of the mass, as is the bedding in the case noticed under Burntisland Castle. Intrusive dykes also sometimes show a tabular or roughly platy structure running parallel to their bounding surfaces.

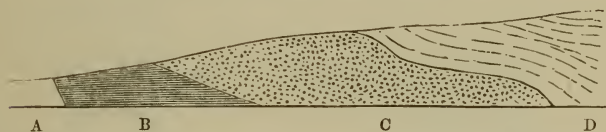
(c) *Curvitarbular Structure*.—I proceed next to describe a structure which I have not often noticed myself, and do not remember to have seen described by others—which, for the sake of a name, I may denominate curvitarbular jointing. As an example of it I will describe the basalt of the Plateau de Prudelle, above the valley of Villar (Auvergne), a sketch of which is engraved by Mr. Scrope, in plate vi. of his work on the Auvergne. This basalt crowns a rib or promontory of granite, resting on this or on a thin intervening bed of sandy (and ashy?) marl containing rolled felspar crystals and a few bits of scoriaceous basalt. Above the marl comes a rather irregular, hard, “ropy”-looking, brown band, probably only the baked crust of the marl, which is united irregularly to the base of the basalt flow. This is very rough, slaggy and scoriaceous, in places resembling an agglomerate of cinders, sometimes partly fused together, sometimes loose. This crust is about a foot thick, and passes rather suddenly into a somewhat slaggy-looking basalt, with a few elongated vesicles and occasional irregular vertical joints. This continues for about 2 feet; and then the curvitarbular structure sets in rather suddenly. The mass is traversed by a series of more or less

Fig. 6.—*Diagram of Curvitarbular structure (Plateau de la Prudelle).*



horizontal curving joints with their convexities upward; so that the whole is divided into a series of plano-convex, meniscoid, or concavo-convex blocks, in length perhaps about 2 to 4 feet, and in thickness 4 to 12 inches (fig. 6). This structure continues with but slight indications of any tendency to vertical master joints for some 35 feet; and then the basalt for the remaining space (perhaps about 4 yards) becomes rather suddenly rudely columnar*. How much has been removed by denudation from the top of the flow it is impossible to say. At the end of the spur there is evidence that its surface was uneven and a ridge already defined when the basalt flowed; for the tabular structure curves in both the longitudinal and transverse sections, so as to remain symmetrical with the surface of the ground. It is therefore evident that it is connected with the form of the surface of the rock. Close to the station of Rougeac (railway from Le Puy to Arvant) I saw a similar structure in a mass of basalt. A very rough sketch of this interesting section (jotted down from the railway-carriage window) is given below (fig. 7).

Fig. 7.—Section at Rougeac.



A. Basalt. B. Stratified volcanic ash. C. Agglomeratic volcanic ash.
D. Basalt, with curvilinear structure.

Here also the structure is affected by the form of the bounding surface; but in this case the convexities of the curves are turned downward.

(d) *Cup-and-ball Structure*.—The next structure to be noticed is that form of cross-jointing of columnar rock which goes by the name of cup-and-ball structure. Usually the columns are divided across, at variable distances, by plane cross joints at right angles to their axes. These sometimes, as in the Gross Oelberg and Weilberg (Siebengebirge), and at Murat (Département de Cantal, Auvergne), are as much as 15 or 20 feet apart; but commonly they are not more than a yard, and sometimes less. Occasionally, however, the joint-surface is not a plane, but more or less curved, so that the convex extremity of one segment fits into the concave extremity of the next. The form of this curve varies: sometimes its curvature is but slight, and it is continued down to the sides of the prism; at others the curvature is more marked, the outline of the ball being more nearly circular, and is not continued to the sides of the prism, a flat space

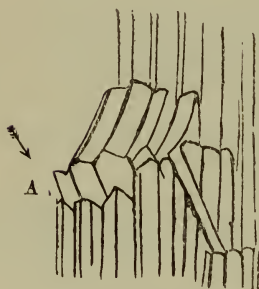
* Mr. Scrope (p. 106) describes this basalt as separated at some points into very regular prisms of five or six sides, which exfoliate by decomposition in slaty laminae at right angles to their axes. I do not remember to have seen this structure conspicuous in the part which I examined.

intervening between these and the curved boundary of the ball, which, as a rule, nowhere touches them.

These curves generally point in one direction, sometimes upward, sometimes downward; occasionally, however, cases may be noticed where they are differently directed in adjoining columns*. So far as I can remember, they are most frequent where the rock exhibits the spheroidal structure which I am about to describe; but before doing this I should wish to call attention to a curious form of cross-jointing which I observed in some of the basalt columns at the upper part of the hill of Bonnevie, Murat (fig. 8).

Here, in the upper part of the excavation opened for quarrying, a curious interruption to the regularity of the columns may be observed in the form of a sort of projection, like a part of a capital from which springs the base (curving till the old direction is

Fig. 8.—Cross joints at Bonnevie.



A. Plane of parallel joints.

Fig. 9.—Structure of Columns in the Lava at Royat.



resumed) of another column. A closer examination shows that this structure is connected with a series of cross joints, which cut the columns (here at angles of about 60°), and to whose plane the axes of the imperfect prisms forming the brackets are parallel. These joints are from 4'-6' apart; and the ordinary cross-jointing in the other parts of the hill seems rather regular.

A singular case of columnar and joint-structure occurs in the valley of the Tirtaine, near the grotto of the springs between Old and New Royat (Auvergne). Here the lava-stream, which is generally irregularly jointed, and sometimes (according to Mr. Scrope) spheroidal, is rudely columnar at its base (fig. 9). The columns are irregularly hexagonal, and about 18" in diameter. At first sight they seem cross-jointed at intervals of about 12" or 15";

* As is the case (pointed out by Mr. Scrope, *Geol. Mag.* Dec. 11, vol. ii. p. 412) in the columns in possession of our Society.

but on closer examination it becomes evident that this apparent division is caused by a change in the direction of the faces of the column, so that for a very short space, at this point, they are no longer vertical, but bend very slightly in or out. Nearly all these apparent bands curve a little upwards. Sometimes they correspond with actual cross joints; at others there may be very fine concealed cross joints; but in many there is not the slightest sign of any division at all. Still these bands indicate a tendency to division; for at a short distance the columns become less regular, and the real cross joints (still curving upwards) more numerous, so that the lava is first divided into irregular rectangular blocks, with curved upper and under surfaces, and then broken by irregular curving joints, which in a few cases approach the curvilinear structure already described; so that in one part the columnar, in another the curvilinear structure is dominant.

To proceed to the spheroidal structure. Professor J. Thomson regards it as the result of a process of exfoliation due to the action of the weather on a tolerably regular-shaped homogeneous mass. Though undoubtedly cuboidal blocks of rock have, for obvious reasons, a tendency to weather into rough spheroids, and though further action of the weather might occasionally produce concentric exfoliation in such spheroids, yet I trust to show that this explanation is wholly inadequate in the present case, although doubtless the weather has great effect in developing the structure. The examples which I am about to mention will, I think, establish these two propositions:—

(1) Spheroidal structure is to be seen in rocks which are not homogeneous and are not at all cuboidal in form.

(2) Spheroids may be found in columnar rock which have evidently formed inside a prism, the exterior of which was not broken by joints.

Spheroidal structure has been observed in plaster on a wall*. A very fine example of it in bedded shale is figured by Mr. Jukes in his 'Manual of Geology'†. I have seen it well developed (of an ellipsoidal form) in a lenticular fragment of shale caught up in basalt on the Fifeshire coast, near Elie. A very fine instance of it may be seen in volcanic ash near the village of Santa Lucia (Valle de Cordevole, Italian Tyrol). Here it is so conspicuous that the rock at a short distance might be readily mistaken for a decomposing basalt. Instances of it can also be found in the agglomeratic ash of the Binns, Burntisland (Fife). The annexed diagram (fig. 10) will show that here the structure is wholly independent of the form of the rock. Sometimes also it occurs where a distinct stratification may be observed, through the planes of which it cuts.

Again, perlite‡ obsidian and pitchstone is a true case of spheroidal

* Geol. Mag. vol. viii. p. 333. † Manual of Geology, p. 311 (ed. Geikie).

‡ I distinguish, of course, perlite from spherulitic structure. The best specimens which have come under my own notice have been from Hungary: for the opportunity of examining a very interesting example I am indebted to Mr. Judd's kindness.

roidal structure, though on a minute scale; and here examination of the rocks, both macroscopic and microscopic, proves that the structure is in no way connected with previously formed cubes, or capable of being explained by simple exfoliation during decomposition. But the following instances of its occurrence will, I think, show that no theory of mere decomposition is adequate to explain the facts.

The annexed diagram (fig. 11) is taken from a large spheroid ex-

Fig. 10.—*Spheroidal structure in Agglomerate (Burntisland).*



Fig. 11.—*Spheroid in Basalt near Murat.*



hibited in a mass of basalt by the roadside on the way from Murat to the bridge over the Alagnon (Auvergne). A glance at it will, I think, show that the curious prolongation of the outer layer is impossible to explain on any principle of weathering. I may add that this occurrence of an isolated spheroid or small group of spheroids in a mass which generally does not show the structure is by no means rare.

But I can produce yet stronger cases. A few kilometres from Le Puy on the Route de Brioude, close to where a road turns off to Polignac, is a mass of columnar basalt rather decomposed, part of which exhibits very well the spheroidal structure. Here spheroids may be seen, one above another, enclosed three or four at a time in a columnar shell without any dividing cross joints, so that they are just like Dutch cheeses packed in hexagonal cases (the interstices being filled up). The lid of the box has more or less fallen away, and exposed the contained spheroids (See fig. 12).

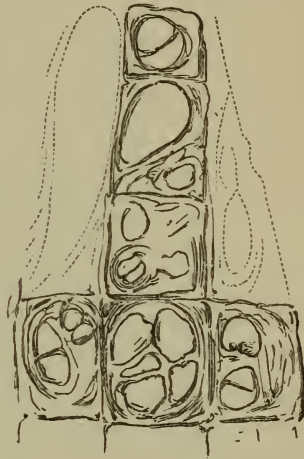
Again, a mass of trachyte, intrusive in trachytic ash, by the roadside on the flank of the Puy Gros (near the Roche Sanadoire mentioned above) showed structures bearing on this as well as other points of interest. The surface in contact with underlying tuff exhibited a platy structure for about three inches; then came a layer rudely spheroidal; above that were some irregularly vertical joints; two of these curved in opposite directions so as to enclose a

lenticular space. In this, two internal spheroids were exposed by the exfoliation of the face, which were not connected with any cross joints. In the adjoining mass four large, rude and very irregular spheroids were shown (the bounding surfaces being incomplete or with more than one centre). Similar instances of spheroids disconnected from the main joints may be seen in a quarry called Turner's Pit in the Rowley-Regis basalt, where also, in some cases, the nuclei of the spheroids are further subdivided, so that imperfect spheroids are enclosed by a spheroidal shell, like the twin kernels of a nut (fig. 13). It is therefore clear that, though the spheroids often do corre-

Fig. 12.—Spheroids in an unjointed column near Le Puy.



Fig. 13.—Complicated spheroidal structure (Rowley-Regis basalt).



spond with the spaces between cross joints in the column, there is no necessary connexion; both may be due to a somewhat similar cause; but the spheroid can exist without the cross joint, and *vice versa*.

Is it, then, possible to find any one cause which will explain these various divisional structures from the fissile to the spheroidal? I think that which has already been suggested (I may say proved) for some of them, *viz.* the contraction of a cooling mass, is capable of explaining all. Mr. Mallet has shown that if a mass of molten rock be cooling uniformly from a surface, it will, in consequence of the mathematical principle of least action, break into hexagonal prisms at right angles to the surface of cooling. By the same principle, if a cube were contracting in consequence of a uniform loss of heat from each of its sides, it would be more likely to rupture internally (supposing that the solidification of the exterior prevented diminution of volume) in spheroidal shells; for the more rapid loss of heat from the angles would tend to bring the isothermal surfaces within into a rudely spherical form; and then, when the strain

caused shells to be formed, they would be spherical, because the sphere is, for an equal volume, the figure of least area, and therefore of least resistance; and as its surface is at every point at right angles to the radius, there is no tangential component to the central force, and thus the whole of it is effective in rupturing. Thus a hexagon is the figure which will result from uniform contraction in two dimensions, a sphere from contraction in three dimensions.

But now, supposing that the contraction is mainly in one dimension, or, to put it otherwise, suppose that all the points lying in one surface in a body are in a state of uniform strain in one direction, naturally there would be a tendency to rupture along a surface at right angles to the strain. Suppose, for example, a number of tiles placed on a floor were subjected to strains perpendicular to the floor, they would naturally split parallel to it. Something analogous to this happens in the cooling of an igneous mass, where heat is lost from a surface (suppose the upper). The strains in a horizontal direction, due to contraction, are at once eased by the formation of joints, more or less regular; but if the loss of heat from the surface be rather rapid, there will be a strong normal strain, which will not be relieved thus, and so slabs or tabulæ will be broken off by a kind of exfoliation; and the more the adjacent particles in a straight line normal to the cooling surface differ in temperature, as will be the case in rapid cooling, the more frequent will these cross joints be. Thus the mass near the surface is generally platy or tabular.

The matter may be expressed, perhaps, rather more simply in another way. Suppose a body contracting uniformly towards a point within it, and its particles incapable of differential motion; then if rupture takes place, a series of spherical shells, concentric with this point, will be formed. Suppose now (the law remaining the same) this point be in the surface of the body; then it will break in concentric hemispherical shells. Suppose the point towards which contraction takes place be outside, still the body will break into segments of large concentric spheres whose curvature will become less and less as the point becomes more remote, the limit being, of course, a plane when the distance of the point is infinite. Read, for a force causing contraction to a point, loss of heat from a surface causing contraction, and the case remains the same. When heat was lost with tolerable uniformity throughout any part of the mass, spheroids both large and small would be formed; when it was lost from a more or less plane surface, but from certain points on it more than others (which is equivalent to what would happen when cooling had advanced a little distance within a lava-stream, owing to either superficial irregularities or surface-fissures), curved cross joints and curvilinear joints would be formed; and when cooling was taking place uniformly from all the points of a plane surface, then platy or tabular forms would result. It must also be remembered that the form of the exterior surface would greatly modify these results; for, speaking generally, all points of equal tension would lie in surfaces parallel to the exterior one, whatever it might be. Still, the principle of least action would cause a certain sym-

metry in the surface of rupture; and thus surfaces of revolution (such as spheroids, hyperboloids, &c.) would be generally produced.

There is thus a certain relation between the spheroids, the curved horizontal joints, and the great curving cross joints, such as are seen at the Roche Tuillière. Hence the fissile structure so well exhibited both here and at the Roche Sanadoire is not a *cleavage* structure in the ordinary* sense of the word; for it is the result of force acting in exactly the opposite direction, being the result of *tension*; whilst cleavage is due to compression—somewhat similar results being thus produced by forces with changed algebraic signs.

I consider the cup-and-ball joint structure a special case of the spheroidal; and the only point on which I feel some doubt is whether one should regard the division as beginning at the centre or at the exterior, or as to some extent independent,—namely, whether as a column cools tolerably uniformly, it tends by symmetry to divide into approximately equal lengths, and so spheroids are formed in the more plastic though warmer parts (the exterior shell being a little more rapidly chilled), and whether the cracks thus formed between two adjacent spheroids are continued toward the exterior, which then, being in a state of strain, is cracked horizontally at these points of weakness; or whether the exterior, cracking first, caused a line of weakness, which determined the commencement of a spheroid in the inner parts; or, as a third possibility, whether the two divisional surfaces are to some extent independent—the spheroids forming within in the more plastic part of the column, the cracks opening from without to the more solidified part, and the two surfaces of division running together at last so as to complete the separation.

Some independence in these surfaces of division seems to be indicated by the occurrence of distinctly formed spheroids in an unbroken column, and by the fact that the spheroids are occasionally again subdivided into segments which to some extent continue the same structure, two or even more of these being enclosed in a more regular spheroidal shell (see fig. 13). This independence, too, would explain the fact that the ends of columns pointing in the same direction show sometimes cups and sometimes balls. It is quite true that the divisional curves, if due to strain from contraction, should be concave to the surface of cooling, as Mr. Mallet has proved (and this, I have little doubt, is the case in the curvilinear structure); but, as Mr. Srope objects, and as my own experience has shown me, in the case of cup-and-ball structure in columns there is great uncertainty, adjacent columns showing at top, one a cup, the other a ball. If, however, the two fissures were formed to some extent independently (the curved one beginning at the interior, the plane one at the exterior), this would be likely to happen, though still the one or the other structure might predominate: the outside cracks would

* That it cannot be a true cleavage is shown (1) by the extreme improbability of this being produced in rocks which are not likely to have been subjected to great earth-movements and must have always been of rather a superficial character, and (2), in the cases quoted, by the impossibility of explaining the arrangement of the divisional planes on any theory of cleavage.

generally form at the points where the spheroid's surface was nearest to the outside of the column, because the shell would be rather weaker there.

The independence of the structures is to some extent confirmed by the fact that a thin plane lamina of rock sometimes exists between two spheroids in a column.

All the divisional structures, therefore, which can be observed in igneous rocks are, if the above considerations be admitted, to be referred to one and the same cause, viz. contraction of the mass while cooling. It is not, of course, denied that in some cases effects may have been produced by subsequent chemical or mechanical action (as the true cleavage in certain of the Welsh felstones); but it is contended that those above described are all the result of one and the same cause.

DISCUSSION.

Prof. RAMSAY inquired whether Mr. Bonney had observed the cup-and-ball structure in narrow dykes at right angles to the planes of cooling.

Mr. KOCH stated that he had tried many experiments bearing on the subject of prismatic and spheroidal structure. Slag at 1500° C., when suffered to run into water, has a perfectly smooth surface, and exhibits distinct prismatic structure. Fragments of ironstone placed on the sole of a furnace cracked off in shells, leaving spheres; and quartzite under similar circumstances flaked off in the same way.

Mr. JUDD noticed the interesting bearing of the numerous facts described in this paper on the theories concerning the production of columnar structures propounded by Prof. James Thomson and Mr. Robert Mallet. He, however, deprecated the introduction by the author of the question of the fissile structure of phonolites (which microscopic examination proved to be the result of peculiarities in the arrangement of the crystalline constituents of the rock) as having any relation to the structures resulting from contraction.

Mr. RUTLEY stated that one of the felstone dykes in the Lake-district showed spurious cleavage in the direction of the dyke.

Mr. MURPHY remarked that as the cooling commenced at the surface, the percolation of water between the first formed columns would aid in the production of the columnar structure lower down.

The AUTHOR, in reply to Mr. Judd, said that he did not regret having introduced the Auvergne phonolites into his paper, for he was convinced that their structure could not be explained by pressure; he considered that the intricacy of the arrangement shown by his diagrams negatived the supposition. Separation of the minerals, as described by Mr. Judd, would not necessarily be fatal to his theory; but in the case of the Roche Sanadoire, he had examined a section to see if it existed, and had not found it.

19. *On the so-called "GREENSTONES" of WESTERN CORNWALL.*

By J. ARTHUR PHILLIPS, Esq., F.G.S. &c. (Read February 23, 1876.)

IN a paper which I had the honour of reading before this Society in March 1874, I described and gave analyses of two varieties of Cornish Greenstone, both of which were characterized as being probably altered hornblende slates. In the present communication it is my intention to give the results of a chemical and microscopical examination of some of the more important of the so-called Greenstones of West Cornwall, reserving for a future occasion an account of those found east of the parish of St. Stephens.

PENZANCE DISTRICT.—The most extensive group of these rocks is probably that situated on the margin of Mount's Bay, in the vicinity of Penzance, and extending, with comparatively little interruption, from Penlee Point, about two and a half miles south-west of that town, to a mile east of the village of Gulval. From the latter locality to Marazion there does not appear to be any extensive exposure of rocks of this class, but they again make their appearance in considerable masses in the sea-cliff extending eastward from Marazion to Cuddan Point.

This district may be regarded as being to a certain extent classic ground, since the rocks which now occupy our attention have frequently been the subject of the investigations and speculations of the earlier geologists.

In a paper read by Prof. Sedgwick before the Cambridge Philosophical Society, March 20th, 1820, he says:—"In the cliffs between Penzance and Mousehole, we found the ordinary varieties of clay-slate, much intersected by contemporaneous veins of quartz. These rocks were succeeded by, and alternated with, beds of compact felspar, greenstone, hornblende rock, and the purple schist before mentioned, all resting conformably, and, on the great scale, exhibiting a slaty texture, although many of the hand specimens derived from them broke into irregular fragments"*.

Dr. J. Forbes, who wrote about the year 1822, remarks, with regard to what he calls the "slate formation" of Cornwall:—"This formation is much more complicated than the last (the granite), and affords much greater scope for geological research. It comprehends, as far as I have been able to ascertain, five distinct rocks. These are clay-slate, hornblende rock, greenstone, compact felspar, and slaty felspar. The three first of these are so well known, have such distinctive characters, and are of such general occurrence, that we are not very likely to be mistaken in discriminating and giving them their proper appellation. Of the correctness of application of the two last terms I am less certain. From the peculiarity

* "On the Physical Structure of those Formations which are immediately associated with the Primitive Ridge of Devonshire and Cornwall," by the Rev. Adam Sedgwick, M.A., M.G.S. (Trans. Cambridge Phil. Soc. vol. i. p. 134).

of their characters, and their distinct nature, however, I am sure that, whether rightly named or not, they are as well entitled to appropriate appellations as any rocks can be.

“By felspar rock I mean a rock of small granular structure, consisting, apparently, principally or almost wholly of felspar. By slaty felspar I mean a rock apparently of the same composition, or only with the addition of a very small portion of mica, with a distinct slaty fracture.

“These five rocks, constituting the assemblage to which I have given the name of the *slate formation*, occur in beds of various magnitude, alternating with each other; but, with one very small exception, I have uniformly found the slaty felspar rock in immediate contact with the granite; and I think it not improbable that, in proportion as we recede from this central rock, we shall find the slaty felspar become less frequent, and be finally superseded by some of the varieties of clay-slate”*.

Dr. Forbes subsequently goes on to say that, in tracing the shoreline from Mousehole to Newlyn, nineteen different beds may be distinguished; and he remarks that, in advancing from Newlyn to Penzance, the rocks consist of a series of hornblendic beds of a more or less slaty character, together with slaty rocks intermediate between felsite and hornblende slate. He describes the rocks immediately south of Penzance pier as being precisely similar to the others, excepting that the hornblendic varieties have more decidedly the character of greenstone, and that the slaty rocks approximate more closely to clay-slates. Of this locality he further remarks, that several of the beds are decided and well-characterized clay-slates.

The rocks extending from the pier to Chyandour are stated to be similar to those between Newlyn and Penzance; but their dip, direction, and succession are described as being somewhat less distinct. The same author calls attention to a greater irregularity in the direction and inclination of the strata between Marazion and Cuddan Point.

With the view of ascertaining the correct names of some of the principal Cornish rocks, Mr. John Hawkins forwarded, in 1793, a carefully selected collection of specimens to Prof. Werner, and during the autumn of the same year received the decision of that then eminent petrologist. Mr. Hawkins tells us, “no doubt was expressed of the nature of our metalliferous rock, the *killas*.” It was pronounced to be a genuine *Thonschiefer*, or argillaceous slate, in no respect differing from that which occurs in Saxony. . . . Those taken from the neighbourhood of Penzance were, after a rigid scrutiny, pronounced to be hornblende-rock, intimately mixed with the constituent mass of argillaceous slate, and in part genuine hornblende-slate”†.

Writing in 1827, Messrs. Von Oeynhausen and Von Dechen remark, “the Killas (of Cornwall) is, at its contact with the

* “On the Geology of the Land’s End District,” by John Forbes, M.D. (Trans. Royal Geol. Society of Cornwall, vol. ii. (1822) p. 251).

† ‘On the Nomenclature of the Cornish Rocks,’ by John Hawkins, Esq., F.R.S. (Trans. Royal Geol. Society of Cornwall, vol. ii. (1822) p. 155).

granite, rather hornblende-slate and greenstone than clay-slate; in the Lizard district we have seen the greenstone intimately mixed with granite, both occurring in the same vein. The transition from clay-slate into hornblende-slate and greenstone is commonly so gradual that we have not been able to trace anywhere a line of junction between both rocks"*.

Dr. Boase, in his 'Geology of Cornwall,' observes, that "the compact and schistose greenstones repeatedly pass into each other, so that in traversing them from the granite they appear to alternate; but this does not hold good to any extent in the length of their beds, as may be seen on the shores of Mount's Bay, where the massive rocks are insulated in the body of the slate"†.

The same author, in his 'Primary Geology,' makes the following observations:—"The most abundant species of actynolite rock is hard and compact, known provincially by the names of *blue-stone* or *blue elvan*. This variety is accompanied by, and gradually passes into blue slate, which is fissile in various degrees, and may also be easily separated into small rhomboidal pieces. The massive kind occurs in elevated ridges on the coast, and is very durable, whilst the slate is decayed to a considerable depth, still retaining its form, but progressively diminishing in tenacity from the perfect rock to the surface"‡. He further states that each of the schistose rocks of this district, but particularly the "greenstone," passes into thick lamellar slates, which exhibit various shades of blue and green.

These rocks, as well as all the others forming the subject of this investigation, are laid down on the Map of the Geological Survey as "greenstones;" and this classification appears to have been generally accepted. In 1867, however, Mr. David Forbes, F.R.S., writing in the 'Geological Magazine,' makes the following observations:—"The writer of these remarks, finding, from an examination of the sheets of the Geological Survey, that large masses of greenstone were represented as occurring in Cornwall, near Penzance, and at the Botallack Mines, immediately imagined that he would there find the same relations of this greenstone to the metallic lodes occurring as he had found to be the case in South and North America, Spain, Norway, Sweden, &c., and made a journey expressly for this examination; on arrival he at once found that the rocks had evidently been metamorphosed *in situ*; and they no doubt originally had only been the ordinary sedimentary clay-slates. Had he now been content with the decision of the Geological Survey, that the rocks in question really were greenstones, then he must at once have come to the conclusion that greenstones could be formed by the alteration of clay-slates *in situ*. It did not, however, require a long examination to prove that the rocks were neither petrologically,

* Messrs. Von Oeynhausen and Von Dechen "On the Junction of the Granite and the Killas Rocks in Cornwall" (Phil. Mag. vol. v. p. 246. London, 1829).

† 'Contributions towards a Knowledge of the Geology of Cornwall,' by Henry S. Boase, M.D., p. 235. Penzance, 1832.

‡ 'A Treatise on Primary Geology,' by Henry S. Boase, M.D., p. 44. London, 1834.

mineralogically, or chemically greenstones, or even any allied rock, being nothing more than clay-slates altered *in situ*, and possessing none of the properties of greenstones beyond the greenish tinge which coloured them”*.

Still more recently (1872) the Rev. W. S. Symonds, F.G.S., says that at Penzance the slates are traversed by greenstones and felstones, which occur again at Newlyn, but that what these rocks are it is difficult to determine; he is, however, decided in his statement that there are numerous interbedded traps or elvans everywhere associated with these rocks †.

Having in view the differences of opinion which have at various times been entertained with regard to these rocks, I have endeavoured, by the aid of chemical analysis, and by an examination of thin sections, to obtain such data as may be necessary for their more correct classification, as well as for the approximate determination of the nature of the different changes they may have severally undergone. The various specimens submitted to examination were selected during repeated visits to the locality; and on one of these occasions I had the advantage of being accompanied by Mr. S. Allport, who, I am pleased to learn, purposes laying before this Society the results of a careful microscopical examination of the rocks of the Penzance district.

Their position around the shores of Mount's Bay will be understood by reference to Sheet xxxiii. of the Government Geological Map. In the neighbourhood of Penzance these rocks, at first sight, appear to consist of a series of fissile greenish slates dipping from the granite, and consequently in directions varying from south-east to nearly south. A closer examination, however, reveals the fact, not only that some have a much less slaty structure than others, but also that many of them form compact crystalline beds ‡, in which no distinct trace of lamination can be detected; from these hard rocks, which sometimes, as at Tolcarn, project boldly above the surface, the beds appear to graduate through different varieties of hornblendic slate until they become ordinary killas. In the rocks exposed along the sea-shore these alternations have sometimes the appearance of being very gradual; but where they have been opened upon by quarrying, as on the left of the road at Tolcarn, nearly opposite St. Peter's church, the divisions are more distinctly marked. In this locality an ordinary grey killas overlies a band, some 4 feet in thickness, of a fine-grained slightly lamellar rock, somewhat resembling certain varieties of basalt, which is again succeeded by a tougher and more distinctly crystalline mass. As there is no exposure across this latter band, its width cannot be accurately determined; but it probably does not exceed 20 yards. On the opposite side of the valley it projects above the surface of

* "On the Alleged Hydrothermal Origin of certain Granites and Metamorphic Rocks," by David Forbes, F.R.S. (*Geological Mag.* vol. iv. p. 57).

† 'Records of the Rocks,' by the Rev. W. S. Symonds, F.G.S., Rector of Pendock, p. 297. London, 1872.

Some of these "beds" are probably intrusive.

the ground to a height of several feet, and is traversed in all directions by narrow veins having a similar composition; they are, however, harder, and consequently the weathering of the matrix has caused them to stand out in considerable relief. Below this outcrop, and a few feet north-west of the foundations of the new vicarage, some fresh specimens of a highly crystalline rock were obtained.

This, which is doubtless the "greenstone" of Dr. Forbes, has the usual greenish colour, is crystalline, and appears, in ordinary hand specimens, to consist of an intimate mixture of a dark-coloured mineral with a considerably less amount of crystalline felspar; in other localities crystals of felspar predominate.

Although there is an almost continuous exposure of slates for a considerable distance in a lane immediately east of the Tolcarn outcrop, no distinctly crystalline rocks are visible; and it consequently becomes probable that they do not here extend many yards in that direction, since the road runs nearly at right angles to their usual line of strike.

When thin sections of these rocks are examined under the microscope, they are generally found to have experienced much alteration; but the extent of the change which they have undergone is far more considerable in some cases than in others; and the nature of this alteration varies as well as its degree.

Those which have undergone the least amount of metamorphism are composed of crystalline felspar, augite, or diallage, magnetite, titanite iron*, and occasional specks of pyrites, with a little apatite; they also occasionally contain flakes of brown mica, and, as products of alteration, viridite and hornblende. The more altered rocks, on the other hand, consist of a colourless semitransparent base, through which hornblende and viridite are thickly disseminated. In this are enclosed green pseudomorphs after augite, shadowy outlines of felspar crystals rendered to a considerable extent opaque by flocculent secondary formations, crystals of magnetite, and pseudomorphs after that mineral. Some specimens also enclose crystalline grains or granular patches of quartz. It will thus be observed that the ultimate result of metamorphism has been the removal of almost all the original minerals, and their replacement by others, which nevertheless frequently admit of the forms of the primary constituents being distinguished.

It has been before stated that the nature of the successive changes which have taken place varies in different localities. Thus in the

* A large proportion of the enclosed black opaque mineral appears to have the form of magnetite; but it also occurs imperfectly crystallized, and as irregular disseminated grains, &c. In order, therefore, to ascertain whether titanite is likewise present, a small quantity of black sand was separated by a careful washing of a considerable amount of pulverized rock, and the ferruginous residue subsequently examined for titanite oxide. In this way the presence of that substance was clearly established; but as the quantity is small, and the exact proportion in which it occurs is of little importance to this investigation, its presence has been neglected in the analyses; it is, however, probable that the magnetite in these rocks is generally titaniferous.

rock projecting above the surface on the eastern side of the valley of Tolcarn the majority of the large crystals of felspar are tolerably perfect, and, when seen in polarized light, exhibit very distinctly the coloured striæ usually considered to be characteristic of plagioclase; on the other hand, the augite has been entirely replaced either by hornblende or viridite, while magnetite and apatite remain unchanged. The material constituting the numerous veins by which this rock is traversed is exactly similar to that forming the matrix, excepting that it contains a little more green hornblende.

The augite, in specimens broken from the rock near the north-western foundations of the new parsonage, is, on the contrary, but slightly altered, while the felspar is much decomposed, the crystals of this mineral having frequently become almost merged in a colourless slightly opaque base, in which the form of the original felspar crystals may still be traced. The rock from this locality contains, disseminated through it, a considerable amount of brown hornblende, viridite, magnetite, a little mica, and apatite, with felspar, and pseudomorphs after felspar interpenetrated by green belonites.

The compact greenstone exposed in a quarry on the opposite side of the road has been subjected to a much larger amount of alteration than either of the foregoing; there are, however, to be observed outlines of felspar crystals, some portions of which exhibit striæ when seen in polarized light; and pseudomorphs after augite are tolerably distinct. The apatite is unchanged; but many crystals of magnetite have been, to a great extent, replaced by a grey siliceous mineral*.

The somewhat slaty rock which comes in immediate contact with the above consists of a translucent cloudy base, through which hornblende and magnetite are thickly disseminated, together with a little, apatite. Although its original structure is, to a very great extent, obliterated, faintly delineated outlines both of augite and felspar can be detected.

At Battery Point there is a rock mainly consisting of tolerably

* In the first specimen in which these pseudomorphs were observed the whole of the magnetite had been replaced. I was therefore at a loss to determine the nature of the original crystals, and submitted a section for examination to Mr. Allport, who returned it without having been able to arrive at a decision. A few days after the return of this section, I received a note from Mr. Allport, in which he stated that he had then prepared a specimen containing pseudomorphic bodies, enclosing unaltered magnetite, and that he was satisfied they were pseudomorphs after that mineral, adding, "I have no doubt they will be found to be siderite." Subsequent examination of a large number of such patches in various stages of alteration leaves no doubt of their being pseudomorphs after magnetite; but the substance by which that mineral has been replaced is not generally siderite. On heating a thin section of one of these rocks with hydrochloric acid in a hollow cell before the microscope, no evolution of carbonic anhydride took place; and no action upon the pseudomorphs was apparent after boiling for twenty minutes in dilute hydrochloric acid; the whole of the apatite, however, was removed by this treatment, leaving numerous hexagonal holes through the section.

fresh triclinic feldspar, together with viridite, hornblende, apatite, and magnetite. There are also indications of pseudomorphs after augite; but this mineral has been entirely replaced by various hornblende and chloritic substances. This is probably the "compact feldspar" of Dr. Forbes.

The upper portion of the Chapel Rock, immediately west of the causeway leading to St. Michael's Mount, consists of a mixture of feldspar, hornblende, viridite, magnetite, and apatite. The feldspar, which is chiefly plagioclase, is little altered; but pseudomorphs after augite cannot be very distinctly traced, being represented by patches of viridite and fibrous hornblende; the magnetite is unaltered. This rock contains a few crystalline granules of quartz, and very closely resembles that at Battery Point.

On the sea-shore of the mainland, nearly opposite St. Michael's Mount, the feldspar is less distinctly defined, but augite is more readily detected. This rock contains but little apatite, and much of the magnetite has been replaced by a greenish-grey mineral.

Specimens broken from the nearest point of rock east of the last-mentioned locality resemble those obtained nearer Marazion, but the feldspar has become still more decomposed; pseudomorphic forms after augite may nevertheless be traced; apatite occurs in small quantities; and magnetite is, to a certain extent, replaced.

The rock immediately west of the elvan-course which enters the sea a little to the east of this place consists of crystalline but much altered feldspar, with crystals and patches of augite in a comparatively fresh state; in addition to which it contains green hornblende, perhaps tremolite, a little viridite, and partially replaced crystals of magnetite; no apatite could be detected by the microscope. Sections prepared from a rock on the eastern side of the elvan-dyke do not differ from the foregoing, excepting that the augite is generally in a still less altered condition.

Altogether twenty-three thin sections of crystalline rocks from the shores of Mount's Bay were prepared and examined; but as none of them exhibits any peculiarity not observed in one or other of those already noticed, it would be useless to enter into a lengthened description of them. In order, however, to compare the chemical composition of rocks of this class, differing somewhat in character and in various stages of alteration, analyses were made of four carefully selected specimens, each of which may be regarded as being to some extent typical. Although made in duplicate, the mean results only are, for the sake of convenient comparison, given in the following Table. The mineralogical characteristics of the rock, as deduced from a microscopical examination of thin sections, have also in each case been added; for, although these have already been generally described, it is desirable that the records of the two series of investigations should, as far as practicable, be placed side by side.

Table showing the Composition of Four Varieties of Altered Crystalline Rock from the Penzance District.*

	I.	II.	III.	IV.
Water {				
Silica	46·32	47·22	43·48	47·26
Phosphoric anhydride	·52	·95	distinct trace	·33
Alumina	18·18	19·85	18·60	21·64
Ferric oxide	·82	1·01	3·68	3·97
„ persulphide	·32	·17	traces	traces
Ferrous oxide	10·92	9·87	11·38	8·92
Manganous oxide	trace	trace	trace	trace
Lime	9·32	10·18	12·31	6·01
Magnesia	7·46	6·30	6·01	4·02
Potassa	2·07	1·12	1·12	1·91
Soda	2·95	2·13	1·69	3·77
	99·88	99·81	99·66	100·04
Specific gravity	3·02	2·97	3·01	2·98

I. *Rock immediately North of St. Peter's Vicarage, Tolcarn.*—This is greenish and crystalline, presenting, in hand specimens, the appearance of a mixture of felspar and augite, in which the latter greatly predominates: some of the crystals of this mineral are one fifth of an inch in length; but those of felspar are usually less distinct. Thin sections examined under the microscope are found to contain felspar, augite, viridite, brown and green hornblende, tremolite (?), magnetite, occasional specks of pyrites, apatite, a little granular quartz, and a few flakes of mica. The felspar is much altered, some of the crystals having become merged in a colourless slightly opaque base; a few, when examined in polarized light, still exhibit the characteristic striae of plagioclase, while the remainder are pseudomorphs, either enclosing viridite or traversed by acicular crystals of hornblende. The augite, which occurs in the form of large crystals and in crystalline patches, has undergone comparatively little change, excepting that in some places, and particularly along certain lines of fissure, it has become partly converted into either viridite or hornblende. Magnetite is sometimes partially replaced, while apatite remains unaltered.

II. *Compact Crystalline Rock from Tolcarn Quarry.*—Specimens of this rock do not materially differ in appearance from those of the foregoing, excepting that it is less distinctly crystalline, is some-

* It must be borne in mind that the first three of these analyses are of rocks from the same locality, in different stages of alteration, while the fourth is of a greenstone from a distance of some three miles. In addition to their other constituents the rocks described in this paper not unfrequently afford, as products of alteration, traces both of carbonic and sulphuric acids.

what lighter in colour, and has a browner tint. Examined under the microscope, it is seen to have been subjected to a greater amount of alteration; but it nevertheless retains cloudy outlines of felspar crystals, portions of which afford, in polarized light, the usual striæ of plagioclase. The augite is represented by pseudomorphs after that mineral, coloured by viridite, while magnetite has been partially replaced by a greenish-grey material, and apatite appears to be unchanged.

III. *Fine-grained Crystalline Rock from Tolcarn Quarry.*—This rock is of a dark sage-green colour, is exceedingly fine-grained, and breaks with a somewhat conchoidal fracture. A microscopical examination of thin sections shows it to consist of a granular base, containing quartz, through which hornblende and magnetite are plentifully disseminated.

In spite of the large amount of alteration to which this rock has evidently been subjected, its original constitution may still, to some extent, be traced, augite having become replaced by patches of viridite and hornblende, while felspar is either represented by indistinct pseudomorphic forms, or completely merged in the granular translucent base; magnetite, on the contrary, remains comparatively unchanged, and apatite is apparently absent.

IV. *Chapel Rock, west of causeway leading to St. Michael's Mount.*—This rock, which rests upon slate, is crystalline, of a greenish-grey colour, and is traversed by numerous fissures, some of which have become filled with hornblende; in its general appearance it more nearly resembles a felsite than either of the foregoing. Under the microscope it is seen to be composed of a feldspathic base, porphyritically enclosing crystals of somewhat altered plagioclase, together with a little granular quartz; throughout this are disseminated viridite, apatite, crystals of magnetite, and angular patches of hornblende, the latter representing replaced crystals of augite.

With regard to the petrological character of the rocks above described, I would remark that No. I. is probably a rock resulting from the alteration either of gabbro or dolerite, while No. II. and No. III., which do not differ very materially from it in chemical composition, may be regarded as the results of a still more advanced stage of metamorphism*. In No. IV. the proportion of silica is the same as in Nos. I. and II., but the amount of lime and magnesia is somewhat less, while that of alumina is greater.

Associated with the before-described rocks are others, possessing a distinctly lamellar structure, but which appear to graduate from ordinary killas, on the one hand, to imperfectly cleavable slates, on the other.

A slate belonging to the killas class, which comes in contact with highly crystalline rocks in the Tolcarn Quarry, analyzed in duplicate, afforded the following results (sp. gr. = 2.76):—

* Mr. Allport, when on the ground, suggested that these rocks might be altered gabbros.

	I.	II.
Water { hygrometric	·68	·58
{ combined	3·20	3·14
Silica	63·45	63·37
Phosphoric anhydride	trace	trace
Alumina	18·33	18·31
Ferric oxide	2·68	2·63
„ persulphide	traces	traces
Ferrous oxide	3·66	3·60
Manganous oxide	trace	trace
Lime	·43	·59
Magnesia	3·00	2·92
Potassa	3·73	4·00
Soda	·78	·65
	99·94	99·79

This is a grey killas, of more than usual hardness, and of which some of the transverse headings are stained of a reddish-brown colour by hydrated ferric oxide, while others are coated with chlorite.

Under the microscope it is found to consist of a nearly colourless base, enclosing a little viridite with mica, and numerous distinct fragments of quartz, together with a few aggregations of a granular mineral, having the appearance of minute garnets. These groups vary from $\frac{1}{1000}$ to $\frac{1}{500}$ inch in diameter, and are sometimes darkened and rendered opaque by the liberation of hydrated ferric oxide; when viewed between crossed nicols the base presents the usual coloured mosaic characteristic of such rocks.

Upon a hill a little west of the tin-smelting works in the valley above Tolcarn, a quarry has been opened for the purpose of extracting the hard pyroxenic rock to be used as road material. The killas is here seen between two beds of crystalline rock, and differs from that in the Tolcarn quarry in containing thin foliations of hornblende, with perhaps a little mica, in planes parallel with its cleavage. This rock appears to be intermediate in character between the ordinary clay-slate of the district and the crystalline fissile rocks, which now remain to be described.

These rocks, which are generally fine-grained, vary in colour from bluish green to greenish grey, and differ considerably in the facility with which they may be divided into thin plates. In some cases slaty cleavage is distinctly recognizable, while in others nearly all trace of such a structure has become obliterated, under which circumstances the rock breaks with a subconchoidal fracture; between these extreme limits various degrees of fissility may be observed*. When thin sections are examined under the microscope they are found to consist to a large extent of hornblende, which occurs both as crystalline patches and as felted acicular crystals. Sometimes

* It is often impossible to determine to what extent the fissility of these rocks is due to true slaty cleavage, and how far it may be the result of bedding.

this rock is almost entirely composed of closely felted crystals, among which is disseminated a little flocculent viridite, or more rarely magnetite; not unfrequently the hornblendic mineral is thickly distributed through a colourless slightly opaque base, which forms but a small proportion of the whole. Patches of quartz may also occasionally be observed; and into these minute green crystals project from the surrounding mass like the foliage of a tree into the open spaces between its branches. In addition to green hornblende, and perhaps a little chlorite, these rocks frequently contain brown hornblende, together with colourless crystals of a mineral which is probably tremolite. Magnetite is likewise sometimes present; but instead of being in a crystalline form, as in the case of the rocks before described, it is generally disseminated either as a sooty powder or in rounded aggregations.

Twenty-six different sections of these rocks were cut in various directions, and examined under the microscope with the foregoing general results, while four specimens were subjected to chemical analysis; in each case the mean of two separate estimations is given in the following table; and a description of the appearance of thin sections, seen under the microscope, is appended.

Table showing the Composition of Four Varieties of Crystalline Slaty Rock.

	I.	II.*	III.	IV.
Water { hygrometric	·54	1·37	·53	·68
	·77	1·56	·87	1·06
Silica	37·44	35·58	39·20	36·57
Phosphoric anhydride	·27	distinct trace	·74	·68
Alumina	16·32	21·14	16·22	15·34
Ferric oxide	7·33	14·74	4·82	7·57
„ persulphide.....	·23	traces	...	...
Ferrous oxide.....	14·75	10·32	15·88	14·84
Manganous oxide	trace	trace	...	trace
Lime	12·83	9·20	10·70	12·58
Magnesia	6·06	2·78	6·56	5·98
Potassa	1·50	·95	2·69	1·44
Soda.....	1·85	2·11	1·45	2·99
	99·89	99·75	99·66	99·73
Specific gravity	3·29	3·15	3·26	3·28

I. *Paul Hill, Paul.*—This rock is hard, dark in colour, very fine in grain, and possesses a distinctly slaty structure. Thin sections, examined under the microscope, are found to be composed chiefly of minute thickly matted green crystals, through which are disseminated a little flocculent viridite, and occasionally some dust-like magnetite. It encloses small irregular patches of milky or transparent quartz, traversed by minute hornblendic crystals.

* This analysis was published in the Quart. Journ. Geol. Soc. vol. xxvi. p. 329, but is introduced here for the sake of comparison.

II. *Rosehill, Castle Horneck*.—This rock is brown in colour, and is more fissile than the foregoing, consisting largely of crystalline hornblende, through which hydrated ferric oxide and a chloritic mineral are disseminated; it includes patches of some nearly colourless translucent material, into which minute green crystals project from the circumference*.

III. *Chyandour, Penzance*.—This is a very hard rock, dark in colour, frequently breaking with a subconchoidal fracture, and in which nearly all trace of cleavage or lamination has disappeared; when freshly broken its surface is sometimes spotted with patches of the size of small shot of brown crystalline hornblende. Thin sections are found to be composed of small interlaced acicular crystals, through which a flocculent mineral of a darker green colour is disseminated.

IV. *Rosemorran, Gulval*.—A distinctly lamellar rock of the usual dark green colour, and to a considerable extent fissile. Thin sections are seen to consist of a felted aggregation of a fibrous hornblende mineral, in which are imbedded a few larger crystals of hornblende. Irregular minute patches of granular quartz are scattered throughout the mass; these, which contain liquid-cavities, are sometimes milky, and at others transparent, being traversed in all directions by belonitic crystals, which penetrate from the exterior. A few nebulous stains of viridite and hydrated oxide of iron, together with occasional needles of apatite, are disseminated throughout.

It will be observed that the foregoing specimens of slaty rock, obtained from localities at considerable distances apart, closely resemble one another in general chemical composition, and are almost identical in their petrological characteristics. They contain, on an average, ten per cent. less silica than the more highly crystalline rocks of which analyses are given p. 162; and a small proportion of phosphoric anhydride is present in all of them.

The microscopic closely felted crystals, of which these rocks are often to a considerable extent composed, seldom exhibit distinct outlines, and not unfrequently assume a more or less flocculent appearance.

This mineral, which is dichroic, is believed to be hornblende, although the low percentage of silica found by analysis might appear to indicate the presence of chlorite. When we take into consideration, however, the small proportion of combined water in these rocks, it becomes apparent that if chlorite be present the amount must be very small †.

* All the rocks belonging to this class are to a large extent decomposed by boiling hydrochloric acid; but on placing an unmounted section from this locality on a glass slip under the microscope, and covering it with hot acid, some of the lighter patches were observed to be more readily attacked than the remainder of the mass. In one or two cases a few minute bubbles of carbonic anhydride were evolved, but the quantity was too small for estimation by analysis.

† The proportion of silica in hornblende usually varies between 40 and 50 per cent.; but according to Rammelsberg ('Handbuch der Mineralchemie,' pp. 492, 493) a black crystal of this mineral from Filipstad, Wärmland, con-

In addition to killas and these green slates there is a variety of slaty rock which is somewhat greyer in colour than the fissile hornblendic rocks. This contains a larger amount of magnetite; and the proportion of colourless base is also more considerable. Sections prepared from a rock of this description, which has been quarried near Penlee Point, on the right of the road from Newlyn to Mousehole, were found to consist of a mixture of hornblende, viridite, and magnetite enclosed in a transparent base. The granular colourless base is traversed by parallel undulating irregular bands of feathery green crystals; spongy magnetite is also present, and is either disseminated throughout the mass, or forms a border to bands or patches of hornblende. The base is thickly interlaced with belonites; and its granular character becomes apparent on being examined by the aid of polarized light.

A freshly broken specimen of a greenish-grey rock of this class, from a quarry in the village of Newlyn, was analyzed in duplicate, and afforded the following results (sp. gr. 2·89):—

	I.	II.
Water { hygrometric	·19	·20
{ combined	·55	·63
Silica	50·57	50·51
Phosphoric anhydride	·12	·13
Alumina	19·65	19·69
Ferric oxide	1·46	1·28
,, persulphide	traces	traces
Ferrous oxide	7·24	7·40
Manganous oxide	trace	trace
Lime	7·47	7·38
Magnesia	7·93	8·04
Potassa	1·08	1·00
Soda	3·46	3·41
	99·72	99·67

tained only 37·84 per cent., while the percentage found in a specimen from Fredriksvärn was still less, or 37·34 per cent.

A specimen of black crystalline hornblende from a vein in the cliff near Botallack, analyzed by A. G. Phillips in the author's laboratory, afforded the following results (sp. gr. 3·24):—

Water	·94
Silica	40·12
Alumina	16·75
Ferric oxide	4·32
Ferrous oxide	12·70
Manganous oxide	3·42
Lime	12·37
Magnesia	6·82
Potassa	trace
Soda	2·65
	100·09

Another dark-coloured crystal from a neighbouring locality contained 39·73 per cent. of silica; it is therefore evident that the proportion of this substance in Cornish hornblendes is sometimes unusually low.

This is a fissile and distinctly lamellar rock, which is employed for road-making. Although its prevailing tint is grey, it is spotted with patches of light brown hornblende mixed with a little greenish mica. An examination of thin sections shows it to consist largely of greyish microlites, so thickly matted together in a transparent base as to render the general mass to some extent opaque. In this mixture are patches of brown hornblende, a little mica, tremolite, magnetite, and a few spots of iron pyrites: the magnetite is not generally crystalline; and when seen in polarized light the base exhibits no indication of crystalline structure. This rock contains a few distinct markings having a resemblance to cloudy crystals of plagioclase seen in certain varieties of dolerite.

The foregoing examination of rocks forming the shores of Mount's Bay indicates that they principally belong to three distinct series, differing alike in their chemical composition and mineralogical constitution:—1st, augitic rocks of a class generally believed to be of igneous origin; 2ndly, ordinary clay-slates; 3rdly, hornblendic slaty rocks.

The rocks included in the first of these divisions appear to have been originally composed of felspar, augite, magnetite, and apatite; all have, however, in a greater or less degree, been subjected to influences through the agency of which the crystalline character of the felspar has to some extent been destroyed, while viridite and hornblende have been produced by the alteration of augite. In some instances these secondary changes have reached such an advanced stage that the felspar is either represented by pseudomorphic forms, or has become transformed into an amorphous or granular base; in other cases the augite has been completely removed, giving rise by its decomposition to pseudomorphs of which hornblende or viridite are the chief constituents. In such specimens apatite sometimes appears to be the only original mineral which has not suffered from alteration. That these changes have, to a great extent, been produced by a rearrangement of the ultimate constituents of the rock, rather than by their removal and substitution, is probable from the results of analyses of variously altered specimens.

The rocks of the second class are the ordinary clay-slates or killas of the Cornish mines.

The green lamellar rocks constituting the third class appear to present evidences of sedimentary origin, and may have been produced either by the metamorphism of other rocks subsequent to consolidation; or, when in the state of paste, magma, or mud, they may have become consolidated under such chemical and physical conditions as to lead to the generation and crystallization of the various minerals which they enclose. Reference to the table, p. 165, shows that they not only possess a great resemblance to one another in chemical composition, but also that in this respect they more nearly approach the crystallized igneous rocks than ordinary clay-slates; the proportion of silica present, however, is considerably less than is usually contained in hornblendic slates.

CAPE-CORNWALL DISTRICT.—The so-called greenstones of Cape

Cornwall extend from the northern shore of Porthleden Cove to a quarter of a mile beyond the Levant Mines; their total length is about two miles, and their greatest width not above three hundred yards. In many places, however, they form a mere border along the coast line.

These rocks, which are stratified, and have a general dip from the granite, vary considerably in colour, since they graduate from a bluish-grey through sundry shades of green to dark brown or black. Slaty cleavage is often well defined, but in all cases in which it has become partially obliterated it is rendered apparent by weathering, and there is always a tendency to break into thin plates.

They are generally lighter in colour than the slates bordering Mount's Bay, and hornblende is not unfrequently more or less concentrated in laminæ parallel with the cleavage. In some places, and particularly in the cliff near Botallack, the rocks are traversed by veins of hornblende, axinite, garnet, or magnetite; garnets are also sometimes plentifully imbedded throughout the rock.

In some localities along this part of the coast the slaty beds enclose a considerable amount of quartz in the form of layers following the lamination of the rock; more rarely it forms distinct veins crossing the lines of bedding. Wherever such an admixture of quartz with slaty rocks is observed, the parallelism of the laminæ is interfered with, and the rock becomes more or less bent, corrugated, or twisted; this contortion may perhaps to some extent have been the result of crystallization*.

Thin sections of these rocks are found to be composed of a colourless granular base, throughout which reticulated feathery hornblende crystals are thickly disseminated, together with grains of quartz, magnetite, sometimes minute garnets, and a few flakes of brown mica. This mixture is occasionally traversed by acicular hornblende crystals, which are frequently arranged in stellate groups of about $\frac{6}{100}$ inch in diameter. Sections cut perpendicularly to the foliation show that the magnetite and hornblende are sometimes arranged in corrugated bands, and that the proportion of transparent base is much larger than in the somewhat similar rocks of the vicinity of Penzance.

* I stated in a former paper (Quart. Journ. Geol. Soc. vol. xxxi. p. 341) that it is not improbable that the repeated widenings which have evidently been experienced by fissures enclosing mineral veins, may sometimes have been produced by mechanical forces resulting from crystallization. As somewhat supporting this hypothesis, it may be stated that, in the manufacture of "soda crystals," at the chemical works of Messrs. Gaskell, Deacon & Co. at Widnes, Lancashire, vessels made of thin boiler-plates have been substituted for the ordinary crystallizers of cast iron. The result has been that a film of the solution of carbonate of sodium found its way between the laps where the plates are rivetted, and in crystallizing forced the sheets of metal apart. To such an extent were the vessels damaged by this action, that they very shortly required to have their joints reclosed by careful caulking. Since the publication of the paper above referred to I find that Volger attributes the formation of the fissures enclosing mineral veins to the force of crystallization, and that the notion of vein-fissures being opened as crystallization advances is defended by Grüner. See 'Chemical and Geological Essays,' by T. S. Hunt, F.R.S. &c. p. 202.

In other specimens the crystals are exceedingly minute, and closely matted together, without the stellate or banded arrangement above described. All the sections examined contain magnetite, which is often finely granular, and is seen, with a combination magnifying 250 linear, to be in the form of imperfect crystals, with rounded edges. Less frequently the magnetite is more distinctly crystalline; and when this is the case, it is generally, in part, replaced by some siliceous mineral.

Occasionally the transparent granular base of which these rocks are, to a large extent, composed, instead of containing radial or flocculent crystals, encloses numerous irregular flakes of brown hornblende or mica; magnetite and viridite are also present in this variety.

No altered gabbros or dolerites of the class found in the neighbourhood of Penzance were observed in the Cape-Cornwall district; and the majority of the sections examined, nineteen in number, afforded evidence of the slaty or schistose nature of these rocks*.

GURNARD'S-HEAD DISTRICT.—The greenstones in the vicinity of the Gurnard's Head, as laid down upon the Map of the Geological Survey, extend, with certain interruptions, from that promontory to Porthzennor Cove. An examination of these rocks *in situ* soon renders it apparent that they very closely resemble those found in the neighbourhood of Newlyn and Penzance. The slaty rocks, which here, as elsewhere, dip from the granite, are perhaps more crystalline and somewhat darker in colour than those of the former locality; the gabbros or dolerites, on the other hand, have undergone a still larger amount of metamorphism.

The upper portions of the Gurnard's Head are composed of a hard, dark, bluish-green slate, consisting of a transparent base, through which brown and green microlites, with granular magnetite, are plentifully and regularly disseminated. Beneath this is a dark crystalline rock, which, although apparently stratified, exhibits no evidence of cleavage. Thin sections are seen to consist of the usual transparent base, enclosing hornblende and viridite, with pseudomorphs after magnetite, and small irregular crystalline patches of augite or diallage. It also contains a few small and much-altered crystals of felspar, together with various shadowy patches and outlines suggestive of extensive metamorphism.

A wide band of rock, coloured upon the Geological Map as greenstone, immediately south of the headland, is shown by the microscope to consist of a translucent granular base, containing grains of quartz, throughout which the ordinary minerals are disseminated in the usual way; it also encloses a few minute garnets.

A narrower band, a little south of the above, has sometimes a slaty structure; and sections of it are found to have a similar composition.

The two next headlands north-east of the Gurnard's Head, forming the extreme limits of Porthglaze Cove, are, to a great extent,

* A greenstone from Botallack, analyzed by the author (Quart. Journ. Geol. Soc. vol. xxxi. p. 329), was found to contain 48 per cent. of silica; in all other respects its ultimate composition closely agrees with that of the pyroxenic rocks of Penzance, and the slaty blue elvans occurring between St. Erth and St. Stephen's. These latter rocks do not materially differ in chemical composition from the ash beds of St. Kew.

composed of a crystalline rock of the same class as that near St. Peter's vicarage, Penzance. This, however, has experienced a larger amount of alteration than the majority of those on the shores of Mount's Bay, since none of the sections examined retain any trace of unaltered augite or diallage, the magnetite has been partially replaced, and apatite sometimes appears to be the only unaltered mineral present. Diallage has been found in sinking a shaft at Carnellow Consols, near the point of junction of the crystalline rock with slates. The nature and distribution of the various minerals seen in thin sections of the more highly metamorphosed portions of this rock tend to the supposition that the darker beds forming the base of Gurnard's Head have had a similar origin; but if this be the case, they have been subjected to still more extensive alteration.

At Porthglaze Cove there is a hardened killas, sections of which show it to be composed of a transparent quartzose base, coloured by flocculent green and brown microlites, which are plentifully distributed throughout.

A little north of this point the cliff becomes darker, more highly crystalline, and less distinctly slaty: hand specimens resemble those of the rock forming the eastern base of Gurnard's Head; but when thin sections are examined a marked difference is observed. This rock is chiefly composed of closely matted hornblende, among which are distributed a flocculent mineral of a greyish-green colour, numerous grains of magnetite, a few patches of a granular base, and some grains of quartz.

The northern side of the promontory forming the southern boundary of Pendower Cove is composed of a dark-green crystalline rock approaching to black. In hand specimens it resembles the bottom rock of Gurnard's Head; an examination of thin sections, however, shows that it differs materially from it, being principally composed of matted green hornblende of various shades, a small quantity of transparent base, and occasional grains of quartz, but no magnetite.

An analysis of this rock, made in duplicate, afforded the following results (sp. gr. = 3.35):—

	I.	II.
Water { hygrometric . . . . .	.34	.40
{ combined	1.05	1.07
Silica	37.72	37.63
Phosphoric anhydride . . . . .	.41	.46
Alumina	17.19	17.15
Ferric oxide	7.75	7.53
,, persulphide	traces	traces
Ferrous oxide	15.81	16.03
Manganous oxide . . . . .	.43	.40
Lime	14.00	13.95
Magnesia	3.41	3.52
Potassa	1.02	.94
Soda	1.06	.95
	100.19	100.03

It will be observed that its composition very nearly agrees with that of the crystalline hornblendic slates in the neighbourhood of Penzance.

A similar rock occurs on the headland forming the northern boundary of the Cove, and is associated with a brecciated quartzite, the angular fragments of which have been cemented together by crystalline hornblende.

From the foregoing description of the rocks of this district it will be seen that they are in all respects almost identical with those in the neighbourhood of Penzance. Nineteen sections of rocks from this part of the coast were cut and examined.

ST.-IVES DISTRICT.—The next considerable exposure of rocks belonging to this class is that laid down on the Government Geological Map as extending, with but one inconsiderable break, from a short distance east of Trevail Point to a little beyond Porthminster Point, in St.-Ives Bay; its total length is three miles, and its greatest width about a mile. The only interval in the continuity of these rocks occurs along the valley through which passes the turn-pike-road leading from St. Ives to Halsetown and Towednack; this has been formed by the erosion of clay-slates which here come to the surface. The rocks in this neighbourhood are very similar in character to those forming the shores of Mount's Bay, and consist of hornblendic slates, interbedded with augite rocks and occasional bands of clay-slate.

Although numerous thin sections were prepared from the rocks of this district, they are all so nearly identical in their petrological characteristics with those from the neighbourhood of Penzance, that it has not been thought desirable to subject any of them to analysis, and a detailed description of their appearance under the microscope becomes unnecessary. It may, however, be stated, generally, that a large outcrop of crystalline rock, very similar to that of Tolcarn, occurs in the immediate vicinity of St.-Ives pier. At Clodgy Point the rock contains well-defined and unaltered crystals of plagioclase, slightly altered augite or diallage, with pseudomorphs after one or other of these minerals, and pseudomorphic crystals after magnetite; it also contains viridite, a little granular quartz, and a few crystals of apatite.

Near Carrack Olu there are large banded masses of very hard and tough greenish slates, consisting of reticulated crystals of hornblende, with a little viridite and quartz, disseminated throughout a subordinate amount of apparently felspathic base. Near Porthminster Point, at the eastern extremity of the formation, ordinary clay-slate alternates with more or less crystalline rocks. The slate, which is here much contorted, is hardened by metamorphic action, and is traversed by numerous veins of quartz; quartz also frequently occurs in thin layers following the lines of cleavage; thin sections of these slates present the usual characteristics of ordinary killas. Twelve sections were prepared from these rocks.

DISTRICT BETWEEN ST. ERTH AND CAMBORNE.—On referring to the Geological Map, numerous bands of greenstone will be observed ex-

tending in a north-easterly direction from the former locality to the latter, or for a distance of about six and a half miles: their greatest aggregate thickness approaches half a mile; and all are comprehended within a belt of less than a mile in width. On either side of these rocks, and in their close proximity, at least two large elvan-courses run parallel with them throughout their extent; and small elvans, or branches from the larger ones, sometimes take their course between the different bands.

On the Map of the Geological Survey, Camborne is indicated as being the most eastern limit of these rocks; but it is evident that, although considerably reduced in width, they must be continued at least two miles further east, as they again make their appearance in the workings of South-Roskear, East-Pool, and various other mines. They are generally known as "blue elvans," or "irestones" (ironstones), the latter name being applied to them by miners on account of their extreme hardness.

In some places these rocks stand out boldly above the surface of the soil, as a little north of the viaduct situated two miles west of Camborne; in others they have been laid open either by railway-cuttings, mining-operations, or quarrying. On account of their hardness and exceptional toughness, they are much used throughout the district as a material for metalling roads, and are occasionally sent to considerable distances for that purpose. Their structure is ordinarily more or less slaty; but they sometimes break with a hackly or even subconchoidal fracture. In colour they vary from grey to greyish or bluish green. Rocks of this class often enclose specks of pyrites, and are occasionally mottled with bands or veins of a brown or greenish-brown material, which is sometimes imperfectly crystallized. These veins are probably composed of a mixture of garnet and axinite; but the crystals are so imperfectly developed in the specimens examined as to render their identification somewhat difficult.

At No-Man's-Land, two miles east of the village of St. Erth, a quarry has been opened, for road material, upon a band of exceedingly hard bluish-grey rock, which is frequently spotted with pyrites. It is contorted, and somewhat coarse in texture, exhibiting a disposition to break into plates, in accordance with certain parallel planes. This is mixed with a considerable amount of clay-slate, the cleavage of which approximately coincides with the planes of fracture of the enclosing rock; this slate has evidently been subjected to influences by which its iron has, to a large extent, been converted into hydrated oxide.

Under the microscope thin sections are found to be composed of filamentary reticulated crystals of various shades of green, very thickly pervading a transparent base, which encloses patches of quartz, magnetite, and pyrites. In addition to the greenish crystalline mineral before referred to, there is also present a greyish-green nebulous substance, which usually occurs in patches.

Two miles west of Camborne, after passing through an archway in the embankment supporting the railway viaduct near Carn-Cam-

borne Dressing Floors, a wide band of bluish-grey greenstone, which has a distinctly slaty structure, crops out some thirty or forty feet above the surface.

An analysis, in duplicate, of this rock, afforded the following results (sp. gr.=3.03):—

	I.	II.
Water { hygrometric	·14	·12
{ combined	·60	·65
Silica	48·30	48·41
Phosphoric anhydride	trace	trace
Alumina	17·04	17·02
Ferric oxide	2·73	2·68
,, persulphide	traces	traces
Ferrous oxide	9·50	9·41
Manganous oxide	trace	trace
Lime	13·30	13·15
Magnesia	6·18	6·20
Potassa	·30	·30
Soda	2·01	2·13
	<hr/>	<hr/>
	100·10	100·07

Sections examined under a low power are seen to consist of flaky hornblende and green or brown microlites, thickly disseminated through a transparent base, in which sooty magnetite and cloudy viridite are somewhat abundant; under a moderately high power the latter is observed to closely resemble certain varieties of chlorite. Some of the sections prepared from this rock expose irregular patches of transparent base, into which imperfect hornblendic crystals project from the surrounding mass, as observed in the case of hornblendic slates from the neighbourhood of Penzance. This rock sometimes also encloses small imperfect crystals, which are probably garnets; and a general tendency to a banded arrangement of its constituent minerals is observable.

A little west of the Camborne station the same mass of greenstone has been laid open by the railway-cutting; here the rock is similar to that last described, but a little darker in colour, and perhaps somewhat closer in texture. It is, however, traversed both by bands and veins of a granular brown substance, which has occasionally a pinkish or greenish tint. As in the case of specimens obtained from the same mass of rock two miles further west, the minerals distributed through the base exhibit a tendency to arrange themselves in nearly parallel bands.

A microscopical examination of numerous sections from this locality shows no considerable difference between this rock and that from Carn Camborne: the granular brown substance before referred to as occurring in specimens from this cutting consists principally of small imperfect garnets, with which is probably associated a little axinite. One of the bands of greenstone here laid open, which in hand specimens does not appear to differ materially from the others,

is seen, in thin sections, to consist principally of an aggregation of rounded grains of quartz, having an average diameter of $\frac{1}{100}$ inch. These are closely cemented together by a mineral of a greenish colour; and among them are small fragments of hornblende.

At South Roskear the greenstone is coarser and more slaty in texture than at Camborne; magnetite occurs more plentifully, but has been to some extent replaced by a siliceous material; no garnets were observed in this rock.

The specimens obtained from East Pool are rather fine-grained, contain a less amount of hornblende, and are much mottled by the presence of the brown crystalline mineral before described. Eighteen sections of rocks from this district were cut and examined.

NEWLYN EAST.—At North Huel Rose, in this parish, there is a band of greyish greenstone, which is not laid down upon the Map of the Geological Survey. This rock has a very compact structure, almost resembling that of chert, and although exceedingly hard and tough, exhibits distinct evidence of a disposition to break into plates. An analysis, in duplicate, afforded the following results (sp. gr. 3.02):—

	I.	II.
Water { hygrometric . . . . .	.24	.20
{ combined . . . . .	.64	.52
Silica	46.57	46.70
Phosphoric anhydride . . . . .	.63	.59
Alumina	19.50	19.74
Ferric oxide	1.84	1.81
,, persulphide	traces	traces
Ferrous oxide	12.80	12.81
Manganous oxide	trace	trace
Lime	9.91	9.89
Magnesia	3.93	3.84
Potassa . . . . .	.51	.53
Soda	3.50	3.40
Lithia	trace	trace
	100.07	100.03

Under the microscope it is seen to consist of a transparent base, enclosing matted crystals of hornblende, together with magnetite and viridite. Between crossed prisms the base presents the appearance of a coloured mosaic, indicating its granular constitution. The hornblende is disseminated, principally in the form of undulating filamentary and approximately parallel bands, between which the base is more or less charged with a flocculent green mineral; a nebulous greyish substance is also usually present, and angular patches of magnetite are somewhat numerous. Four sections of this rock were examined.

ST. STEPHENS.—At Terrace, about a mile and a half west of St.-Stephens church, there is a large blue elvan, which has for many years been quarried as a material for repairing the parish roads. This greenstone is not shown on the Geological Map, but is several

fathoms in width, and has a direction north of east and south of west; its dip and apparent cleavage very nearly coincide with those of the enclosing slates. Although large quantities of stone have at various times been removed from this locality, the quarry has not been worked in such a way as to expose a complete transverse section across the band. It is, however, evidently traversed for a considerable distance by a nearly perpendicular fault; and at a point about two hundred fathoms south-west of the quarry it is intersected by the Great Terrace Elvan. This elvan is remarkable from the circumstance that many of its felspar crystals have become replaced by a mixture of schorl and cassiterite, which at different periods has caused it to be worked as a source of tin-ore.

A fresh specimen of this rock afforded by analysis the following results (sp. gr. 3.03):—

	I.	II.
Water { hygrometric . . . . .	.20	.22
{ combined . . . . .	.77	.67
Silica	46.89	46.96
Phosphoric anhydride . . . . .	.31	.32
Alumina	20.46	20.53
Ferric oxide	2.19	2.09
„ persulphide	traces	traces
Ferrous oxide	11.15	11.18
Manganous oxide	trace	trace
Lime	8.37	8.42
Magnesia	5.83	5.91
Potassa	trace	trace
Soda	3.87	3.80
	100.04	100.10

Thin sections, examined microscopically, are not unlike those of the rock from North Huel Rose, excepting that the hornblende is disposed in more regular bands, and the magnetite is also more distinctly banded. The edges of the green hornblendic stripes are fringed by feathery crystals of that mineral; and the patches and crystals of magnetite are often cracked, or have become replaced by a siliceous mineral.

Between the nearly parallel hornblendic bands before referred to, the transparent colourless base is traversed by acicular hornblendic crystals, the longer axes of which lie (mostly in one direction) in planes coinciding with the cleavage. Viridite is always present in small quantity; and one of the sections prepared from this rock encloses small patches of a blue mineral, which is perhaps indicolite. Among the fissile hornblendic rocks, several have been observed to contain occasional small crystals of apparently a schorlaceous mineral. Five sections of the Terrace blue elvan were cut and examined.

It will be observed not only that the blue elvans, or greenstones, occurring between St. Erth on the west and St. Stephens on the east, although varying somewhat in the relative proportions of their several constituents, resemble one another in their general chemical

composition, but also that in this respect they do not materially differ from the highly crystalline augitic rocks of the neighbourhood of Penzance. It is also remarkable that in all these rocks the proportion of silica is very nearly constant. The greenstones, however, which occur between these limits afford distinct indications of slaty cleavage; and thin sections do not exhibit the distinctive angular arrangement of crystals commonly seen in rocks of known igneous origin.

In this latter respect they essentially differ from a greenstone quarried in a field known as the Sanctuaries, a little west of the town of St. Austell, where the central portions of the mass enclose felspathic and other crystals, arranged in such a way as to indicate the probable igneous origin of the rock. Although the central portions of this dyke are crystalline, it gradually becomes slaty on either side; and it is consequently difficult to trace a precise line of demarcation between it and the enclosing killas*.

With regard to the blue elvans found between St. Erth and St. Stephens, it may be remarked that their texture is frequently coarser in the centre than towards the sides of the bands, and that they eventually merge into the enclosing rocks, of which they gradually assume the structure and cleavage. Their ultimate chemical composition agrees closely with that of the crystalline augitic rocks before described; but their structure is invariably slaty, and thin sections do not exhibit any of the characteristics peculiar to igneous rocks. It follows that if these were originally igneous rocks other than ash-beds, they must have been subjected to the action of influences by which the arrangement of their constituent minerals has been completely changed and slaty cleavage produced. They are met with only in the neighbourhood of the granite, or in the vicinity of elvan courses; and when describing those in the district around Camborne, Messrs. Von Oeynhausen and Von Dechen state that they have not the appearance of regular dykes or veins enclosed in clay-slates†. The greenstones occurring in the killas surrounding the granite of Dartmoor are described by the same geologists as being of a highly schistose character, suggestive of the probability of their being highly metamorphosed slates.

Summary.

The foregoing facts may be briefly summarized as follows.

The rocks of the so-called greenstone district of Penzance belong principally to three distinct classes:—

* The writer some years ago examined this greenstone, and described it (*Phil. Mag.* vol. xli. p. 97, 1871) as being probably a diorite which had undergone extensive alteration. Since that time the quarry has been extensively worked; and sections recently prepared have been found to enclose small patches of some augitic mineral. They also contain felspar (of which a portion is triclinic), magnetite, green and brown microlites, a nebulous greenish-grey substance, and apatite. It is therefore more probable that this is a highly altered rock belonging to the class found near St. Michael's Mount and in various other localities in the neighbourhood of Penzance, St. Ives, and the Gurnard's Head.

† *Phil. Mag.* vol. v. p. 247. London, 1829.

- a. Gabbros or dolerites, in which the originally constituent minerals are occasionally, to a great extent, unchanged, but are sometimes almost entirely represented by pseudomorphic forms.
- b. "Killas," or ordinary clay-slates.
- c. Highly basic hornblendic rocks, which exhibit a tendency to break into thin plates; these, under the microscope, present the characteristic appearance of metamorphic slates.

In addition to the foregoing, there are various slaty rocks of a character intermediate between *b* and *c*, as in the village of Newlyn, and on the western side of the valley north of Tolcarn.

It follows that these rocks have been more correctly described by some of the earlier geologists than by the more recent observers, who have regarded them either as being exclusively "greenstones," or as consisting of metamorphosed slates only.

The rocks of the Cape-Cornwall district, coloured as greenstones on the Geological Map, are principally hornblendic slates, which sometimes enclose veins or bands of garnet, magnetite, or axinite. Minute garnets are not unfrequently disseminated throughout these slates.

The rocks in the neighbourhood of the Gurnard's Head are almost identical in character with those on the shores of Mount's Bay; but the slates are generally darker in colour, and are perhaps somewhat more crystalline in structure, while the gabbros or dolerites have sometimes been subjected to a still higher degree of metamorphism.

The crystalline pyroxenic rocks and metamorphic slates of the St.-Ives district exactly resemble those in the neighbourhood of Penzance.

The greenstones exposed between St. Erth and St. Stephens, unlike the hornblendic and augitic rocks of the other districts, do not occur in the immediate vicinity of granite; but elvan courses are invariably found at no considerable distance from them. The structure of these rocks would indicate that they are probably altered ash-beds or hardened hornblendic slates, frequently containing pyrites and minute garnets, with perhaps axinite and some other minerals. Neither augite nor diallage was detected in any of the sections examined.

It is worthy of remark, that the chemical composition of these slaty greenstones, or blue elvans, does not materially differ from that of the gabbros or dolerites in the neighbourhood of Penzance, the percentage of silica in the two series being as (will be observed) nearly constant.

The hornblende slates contain about ten per cent. less silica than the crystalline pyroxenic rocks; and there is an excess of iron oxides present to nearly the same extent; in other respects their composition is very similar.

Apatite is to be detected by the microscope in thin sections of the augitic rocks only; but phosphoric anhydride is to a small extent present in rocks belonging to each of the several classes.

The killas is a highly siliceous rock essentially differing from the foregoing in chemical composition.

DISCUSSION.

Mr. SORBY stated that he had come to nearly the same conclusions with Mr. Phillips with respect to these rocks.

Dr. C. LE NEVE FOSTER agreed with the author in considering some of these so-called greenstones altered rocks, and not intrusive, as had been supposed. He congratulated geologists on having such a combination of chemical and microscopical analysis as that furnished by Mr. Phillips.

Mr. RUTLEY thought that many of the bands might be identical with those occurring in Devonshire, especially near Tavistock. The dipping away from the granite described by the author might be due to the granite having been subsequently intruded. He thought it probable that many of the beds referred to may be ash-beds, and that it was quite possible the schistose character might be superinduced in beds of ashes by the pressure of superincumbent rocks. The mapping of Sir Henry De la Beche is remarkable for the accuracy with which these boundary-lines are drawn; furthermore his determinations of these rocks, as shown in his report, are either absolutely correct or close approximations to the truth, although the small scale of the map does not permit this to be shown.

Mr. KOCH remarked that, in considering the nature and origin of such rocks as these, we ought to notice what rocks overlie them, and to take into account the probable effects of water percolating through such overlying beds and containing much carbonic acid, by deposition of silica and removal of carbonate of lime. The analysis of the killas given by the author was almost that of altered trachyte. He thought that in such investigations the microscope must be our principal guide, but aided by the consideration of the relative positions of the rocks.

Prof. RAMSAY inquired what was the definition of a volcanic rock. He thought that volcanic rocks were either lavas or ashes, and that it was dangerous to affirm that the blue elvans were ashes in so metamorphic a district.

Prof. MASKELYNE, after thanking the author for his paper, inquired as to the meaning in which he used the terms "gabbro" and "igneous rock." He also remarked that it was strange to find apatite the only mineral that was unaltered.

Mr. DREW inquired as to the possible future colouring of the Survey Map of this district. It appeared from the author's paper that the parts coloured as "greenstone" in the present maps included various rocks which ought to be subdivided.

The AUTHOR, in his reply, stated that igneous rocks have a certain amount of cleavage, which is often rendered very distinct by weathering. The crystals of hornblende are very distinct in the rocks described. Gabbro is a felspathic rock with diallage, smaragdite, or hypersthene instead of augite: but with regard to some of them it may be doubtful whether they are gabbros or dolerites.

20. HÆMATITE *in the* SILURIANS. By J. D. KENDALL, Esq., F.G.S.
(Read March 8, 1876.)

IN a paper read last session before the Society, I pointed out some of the most important features of the Hæmatite deposits that occur in the Carboniferous Limestone of Cumberland and Lancashire. Amongst other things I showed that the direction of the deposits was invariably parallel to that of the meridional divisional planes by which the rocks are intersected; and as an explanation of that fact I suggested that the hæmatite had probably been deposited in caverns which had been hollowed out by chemical action along the meridional planes, or that the hæmatite had replaced the Limestone along those lines.

The paper also briefly referred to the deposits of hæmatite in the Silurians of the same districts, and went to show that these deposits (which are in the form of veins), like those in the Carboniferous Limestone, were in direction parallel to the divisional planes. There was, however, this difference between these Silurian deposits and those in the Carboniferous Limestone, that whereas all the deposits in the latter were parallel to one another, and had a direction nearly north and south (that is the same as the meridional divisional planes), those in the Silurian had two directions, some being parallel to one set of divisional planes and some to the other.

Since the delivery of that paper I have had an opportunity of examining a Silurian deposit which appears to me to be altogether unlike (as regards the relation between the direction of the deposit and the divisional planes) either those deposits to which I before alluded in the same series of rocks, or those in the Carboniferous Limestone. I therefore deem it may be interesting to the Society if I give an account of my observations on that deposit.

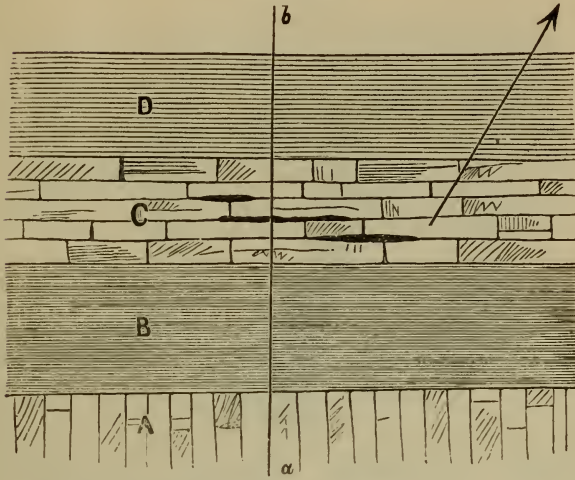
The deposit to which I refer is in the parish of Millom and county of Cumberland, and is now being worked by the Water-Blean Mining Co., their works being known as the Water-Blean Mines.

The geological structure of the district in which the deposit occurs is somewhat as shown in the following plan and section (figs. 1 and 2).

The Silurians are all conformable, and strike about 65° N.E. and S.W., with a dip of about 80° to the N.W. Their order is thus inverted, the Limestone appearing to dip in below the Ash-beds, and the Flags below the Limestone, whereas in reality the Ash-beds underlie the Limestone, which in its turn forms the base of the Flags.

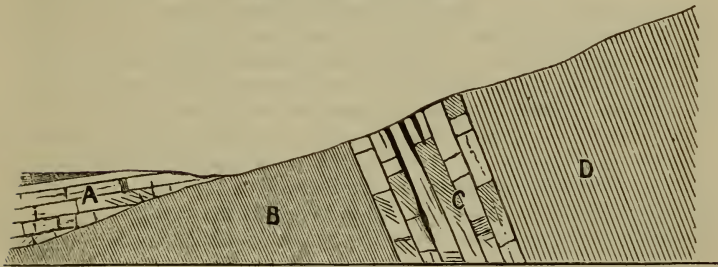
The Limestone is part of that narrow band which stretches through the country in a nearly straight line from Millom to Shap, a distance of about thirty miles. It is in this rock that the hæmatite occurs to which I wish to call attention. The form of the deposit (or,

Fig. 1. Plan of arrangement of Hæmatite deposits, Millom, Cumberland.



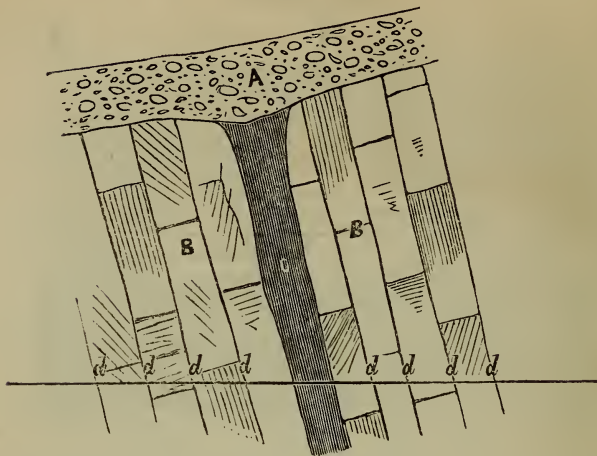
- A. Carboniferous Limestone.
 - B. Coniston Flags
 - C. Coniston Limestone
 - D. Ash-beds (Green Slates and Porphyries)
- } Silurian.
- Hæmatite Veins.
- a, b. Line of Section, fig. 2.

Fig. 2. Vertical Section across Hæmatite deposits, Millom, Cumberland, in line a, b, fig. 1.



For explanation see fig. 1.

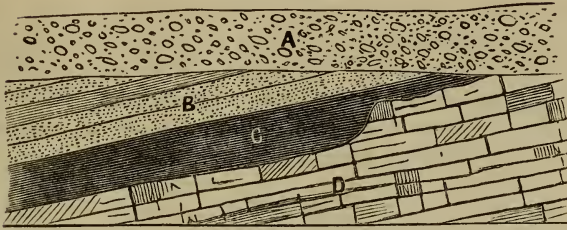
rather, deposits; for there are several of them) is that of short veins, which vary in width from a few inches to 9 feet. The ore is very hard, and has a high red stain, and where it joins the Limestone appears in most cases to be grown to that rock, as the ore in the Carboniferous Limestone is with it. The direction of the veins is about 65° N.E. and S.W., and they dip at an angle of about 80° to the N.W. The following vertical cross section (fig. 3) will partly show their mode of occurrence.

Fig. 3. *Vertical Section of Hæmatite vein.*A. Glacial drift. B. Limestone. C. Hæmatite. *d, d, d.* Bed-joints.

The direction and dip of the veins, it will be observed, are exactly the same as the direction and dip of the bed-joints of the Limestone, the strike of both being about 65° N.E. and S.W., and their dip about 80° to the N.W. This is the point which I wish chiefly to place before the Society. In the paper before referred to, as already stated, I pointed out that the hæmatite deposits in the Carboniferous Limestone of Whitehaven and Furness invariably coincide in direction with the meridional divisional planes intersecting that rock, and that the deposits in the Silurian slates at Knockmurton, near Whitehaven, have two directions, which coincide with either one or the other of the divisional planes of those rocks. The Water-Blean deposit, however, appears to me to be different from either of these, *the deposition of the ore having taken place along the bed-joints of the rock.* In some of the Whitehaven deposits, as at Parkside and Bigrigg Moor, a phenomenon somewhat similar to this is to be seen, as shown in fig. 4, which is a vertical section of the Parkside deposit; but there the strata lie at such a low angle that the ore-deposit is more like a bed than a vein. Their likeness to the Water-Blean deposits, however, is only partial; for, notwithstanding their bed-like appearance, and the fact of their being parallel to the bed-joints of the rocks, the deposits nevertheless have their *longest axis parallel to the meridional divisional planes; and the strike of the rocks does not in any way determine the direction of the deposits,* as it does at Water Blean.

The direction of the Water-Blean deposit is *exactly the same as the strike of the rocks in which it occurs, and altogether different from the directions of either of the divisional planes.*

Fig. 4. *Vertical section of Hæmatite vein in Carboniferous Limestone at Parkside.*



A. Drift.

B. Millstone Grit.

C. Hæmatite.

D. Carboniferous Limestone.

A question which here naturally suggests itself is, Why was not the ore deposited along the meridional divisional planes of the Limestone at Water Bleau, in the same way that it is in the Carboniferous Limestone of Furness and Whitehaven? To answer that question it appears to me to be necessary to state that the bed-joints in the Limestone at Water Bleau are much more persistent than the divisional planes are, the latter being very irregular in direction, and not by any means so strong and open as the bed-joints. We should therefore naturally expect the carbonated water to act most powerfully on the bed-joints, as it, in my opinion, for the same reason, has done on the meridional, in preference to the transverse divisional planes in the Carboniferous Limestone of the district of Whitehaven and Furness.

DISCUSSION.

Mr. FORBES considered that this paper was equivalent to a withdrawal on the part of the author of the opinions expressed in his former paper. Mr. Forbes maintained that the direction of the vein-like deposits is due to their being formed in preexisting fissures, into which the hæmatite has been injected. When hæmatite is found in caverns it has been washed in by water.

Prof. HUGHES thought that the only rule as to the mode of occurrence of these deposits was dependent on the direction of the joints and bedding, pointing out that in the Mountain Limestone it was determined chiefly by the joints, while in the highly inclined Coniston Limestone the ore was found along the Limestone bands, which were separated by impervious shales.

Mr. WARINGTON W. SMYTH remarked that this is a problem in the investigation of which great caution is necessary. In some localities undoubtedly the veins of hæmatite have a general direction; and in many cases there is a considerable coincidence of the veins of hæmatite with joints.

21. OBSERVATIONS *on the UNEQUAL DISTRIBUTION of DRIFT on OPPOSITE SIDES of the PENNINE CHAIN, in the country about the SOURCE of the RIVER CALDER, with Suggestions as to the CAUSES which led to that RESULT, together with some Notices on the HIGH-LEVEL DRIFT in the UPPER PART of the VALLEY of the RIVER IRWELL.* By JOHN AITKEN, Esq., F.G.S. (Read June 23, 1875.)

[Abridged.]

FOR many years past the attention of geologists has been more or less directed to the fact that a marked difference exists in the distribution of drift on opposite sides of the Pennine chain, a difference amounting in some instances to an entire absence of that material on the easterly slopes for many miles from the watershed of the country, and over a considerable portion of its length, notwithstanding that these deposits overspread the great plains of Lancashire and Cheshire in great force, and are found mounting up upon the flanks of those hills on their western sides to very considerable elevations, approaching closely in some cases to the culminating ridge, and in others, where the chain is crossed by intersecting valleys, to some hundreds of feet in excess of the summit-level of these gorges. It would further appear from facts hereafter to be adduced, that although some of these cross valleys attain to only very moderate altitudes, no communication existed during the glacial period of such a character as to permit of the passage of a body of land ice from one side of the chain to the other. Whilst, however, these phenomena have not wholly escaped the notice of those observers who have, more particularly of late years, directed their attention to the surface accumulations of the northern counties of England, allusion having been made to the subject by Messrs. Binney, Tidde-man, Green, Foster, Dakyns, Goodchild, and others, yet no serious attempt has, I believe, so far been made to grapple fully with the subject by any of those who have hitherto given attention to it.

The subject has long perplexed me, amongst other observers; and it is only after a lengthened consideration that I have ventured to suggest a theory which, whilst offering an explanation of the phenomena, does no violence to any of the well-established principles of physical or geological science. My object, then, in presenting the present communication is to show that the whole of these phenomena are explicable on the supposition that, during the flow of the great ice-sheet over this region, these intersecting channels were sealed and blocked up so effectually as to completely cut off all communication between the eastern and western sides of the chain, and that the only agency fully meeting the requirements of this supposition is that of ice or snow so consolidated and fixed in the sinuous channels as to remain stationary and inert while the great mass of glacial ice, in two sheets separated by the more elevated portions

of the great anticlinal range, traversed its eastern and western sides on its march from north to south.

That vast masses of drift deposits overspread the wide plains of Western Lancashire and adjoining counties, extending from the Irish Sea in one unbroken sheet to the slopes of the Pennine Hills, and thence mounting up to higher levels, and penetrating almost every upland valley and mountain-gorge to considerable elevations, is too well known and too generally acknowledged to require any amplification from me on the present occasion.

A great number of facts, and the statements of various authorities as to the altitude of high-level drift on the western slopes of the Pennine chain, indicate a general elevation of from 1100 to 1200 feet, whilst scattered boulders and pebbles of travelled rocks may be detected at various places in the locality some 200 feet in excess of that; and I contend that these more elevated stray boulders and pebbles owed their origin to icebergs during the interglacial period, and not to the period of land ice.

I wish particularly to direct attention to the circumstance of drift having been found at an elevation of 930 feet above sea-level, on the shoulders of the hills on both sides of the southerly termination of the Walsden defile at the summit near Littleborough, whilst all traces of them vanish in a line almost coincident with the watershed of the valley, which has an elevation of 627 feet, beyond which no accumulations of this character are met with in travelling east for a distance of about 15 miles. The first indication of their presence as a regular bed of drift occurs in the valley of the Calder at North Dean, near Halifax, where, in sinking for the foundations of a railway viaduct, the following section was observed by Mr. James Spencer, of Halifax, to whom I am indebted for the accompanying particulars:—

	ft.
Soil	1
Fine alluvial sand	8
Gravel derived from local rocks.....	2
Gravel containing granite, trap, slate, and Silurian rocks	3
	—
Total	14

It is, however, stated that an occasional pebble foreign to the district has been noticed in the bed of the river Calder, a little further to the west than the spot just named*.

Close to the railway bridge at Elland, in the bank on the south side of the river Calder, under about 5 feet of sandy loam, a bed of gravel exists, about 4 feet of which is exposed, and which I am informed by Mr. Davis, F.G.S., of Greetland, has been proved by a well-sinking to be from 15 to 20 feet in thickness, in which red

* Dr. Alexander, in describing the geology of the parish of Halifax, in the 'Tracts' of the Geological and Polytechnic Society of the West Riding of Yorkshire, 3rd June, 1841. p. 201, mentions that "in prosecuting the works on the line of railway some blocks of granite had been found near Hebden Bridge;" and Mr. Binney also informs me that he has seen foreign pebbles at Hebden Bridge.

granite, silurian porphyritic greenstone, and other foreign pebbles occur; and at and below this point examples of these rocks may be detected in the bed of the river wherever gravel is exposed. This is situated at an elevation of about 200 feet above the sea level.

At the Elland railway-station, the following section has been exposed by some recent operations of the Company:—

	ft.	in.
Soil	1	4
Fine subangular gravelly surface wash	2	6
Loamy sand	6 inches to	1 0
Fine sandy gravel	2	6
Gravel coarser than that above; stones all waterworn and much abraded, of local origin, resting upon a bed of Carboniferous shale	5	0
Total	12	4

At the cemetery, a few hundred yards to the north-west of the last-named place, and at an elevation of about 300 feet, a bed of gravel, sand, and loam, varying in thickness from 5 to 10 feet, analogous in character to the section last described, reposes upon the Carboniferous shale. And in the Shibden valley, deposits precisely similar to these are found at about a corresponding elevation.

In the three last-named instances the stones composing the gravel consist of well-rounded waterworn rocks, derived exclusively from the basin of the Calder and its tributaries, not a foreign pebble being found incorporated with them. This gravel may therefore be regarded as having a purely local origin, and probably dates from the time when the river ran at this level, and is consequently in no way connected with the glacial drift which occurs in the valley below.

Precisely analogous conditions to those already described as occurring in the Walsden defile exist in the Cliviger valley, the drift running up on the sides of the hills near the entrance of the gorge to a height of 1075 feet, its southerly termination taking place both on the sides of the hills and in the valley in a line almost corresponding with the summit-level of the latter at Calder Head, which has an elevation of 768 feet.

It appears from a paper* read some time ago by Mr. R. H. Tideman, of the Geological Survey, that a very similar state of things occurs with regard to the distribution of drift in the great watershed of the north, opening between the basins of the Ribble and the Aire, which has a summit-level of 700 feet. No ice-scratches are shown on the excellent map which accompanies that paper as existing east of the watershed of the Pennine range in that part of the country; and those which do occur near to that line run, with one exception, in a direction closely approaching to north and south.

* "On the Evidence for the Ice-sheet in North Lancashire and adjacent parts of Yorkshire and Westmoreland," *Quart. Journ. Geol. Soc.* for Nov. 1872, p. 478, a contribution the value of which it is difficult to overestimate.

In the southerly portion of the chain the behaviour of the drift in the neighbourhood of Castleton (a town situated just beyond the central axis, on the easterly slope of the range) entirely corresponds with the instances already adduced; and this is confirmed by the following quotation from a paper by Prof. W. B. Dawkins* :—“From what I can see, there is nothing whatever in this deposit to separate it from the superficial deposits in the valley near Castleton, which you will find pretty well everywhere. When I examined these the other day in the company of Mr. Prestwich and Mr. Tiddeman, we came to the conclusion that they are not glacial, but the result of subaerial wear and tear of the rocks in the neighbourhood.” These examples will, I trust, suffice to show that over this large area, extending from Skipton in the north, by Todmorden, to Castleton in the south, a general absence of drift deposits and of all other indications of glacial action characterizes the eastern slope of the great axial chain in this division of the country, thus establishing the first part of the proposition with which I set out.

We may now inquire if there is any legitimate reason for supposing that drift was at one time deposited over the now barren area, and that its absence at the present time is to be accounted for by subsequent denudation, as suggested by Mr. Tiddeman in the paper previously referred to. It appears to me, from a full consideration of all the facts, exceedingly problematical that this can have been the case; for it is difficult, if not impossible, to conceive of any known force which could act in so capricious and anomalous a manner as to have swept and cleared off the surface of the driftless area to the east so completely that not a trace of its former existence should remain, even in the deep sheltered valleys which intersect the district in all directions and thus present conditions of the most favourable character for its preservation, and yet at the same time leave intact the vast bodies of drift which so completely envelop the country to the west.

The drift found in the lower reaches of the eastern valleys was probably derived from the section of the great ice sheet which traversed that side of the country; and its presence there is no indication of its having been carried through the cross valleys from the west.

Having so far endeavoured to prove, and, I hope, successfully, that a marked difference exists in the distribution of drift on the two sides of the Pennine chain, it now remains to show that this phenomenon has in all probability been induced by the valleys in question having been blocked up during the glacial period by accumulations of ice or snow held firmly in their places by the physical and other characters of the gorges themselves, acting in combination with the force exerted by glaciers pressing against the ends of these blocked-up channels, thus effectually holding stationary the imbedded masses in the places of their deposition.

* Trans. Manchester Geological Society, vol. xiii. p. 124.

For a full and clear comprehension of this subject, it will be necessary to glance at the physical and geographical features of the district and to trace their relation and bearing to the surrounding country. In treating of this branch of the subject, our attention will be principally directed to that part lying between Burnley and Littleborough on one side, and Todmorden on the other—a district embracing the deep valleys of Cliviger and Walsden, in which are contained the two lowest watersheds in the whole of this central range of hills.

If, then, we take Todmorden as the central point of the district, from which to commence our observations, we shall find that that town is situated almost on a line with the highest summits of the Pennine Hills, in a deep gorge at the junction of the two streams which flow through the two defiles already mentioned, and on the main axis of that series of dislocations known as the great Pennine fault, which run in a line roughly coincident with the Walsden and Cliviger valleys, and the effect of which has been, not only to fracture and break up the rocks to a marvellous extent, but also to cause a reversal in the dip of the strata, those on the east dipping at an angle of about 5° to the S.E., and those to the west declining at an angle of from 20° to 45° to the W.S.W.

Starting from this centre, three valleys radiate in different directions, in lines almost equidistant from each other:—one stretching off through Walsden to Littleborough for a space of about 5 miles in a direction a little W. of S.; another taking a N.W. course through the sinuous gorge of Cliviger to Burnley, a distance of about 8 miles; whilst the third, the valley of the Calder, takes an E.N.E. direction.

The appearance thus presented, when traced on a geological map, reminds one forcibly of the device which characterizes the Manx copper coinage. By an examination of these arms, we shall find that they are three deep, narrow, rocky, tortuous channels, hemmed in on every side by massive walls of rock, cut into at intervals along their course by the entrance of tributary streams.

The watersheds of the Walsden and Cliviger valleys are at a comparatively low level, that of the first having an altitude of 627 feet above sea-level, and being eaten into to a depth of 330 feet below the shoulder, or first platform bounding the valley*; whilst that of the second is crossed at an elevation of 768 feet, and is excavated to a depth below the immediate country of 475 feet, a depression which would be greatly increased if the summit-level of the surrounding hills were taken as the datum-line for measurement.

The valley of the Calder, which forms the line of drainage through which the waters of the aforesaid tributary valleys, from their junction at Todmorden, pass off to the German Ocean, is cut in to a depth considerably in excess of those already described.

If, then, we view these valleys in relation to the initial period of their formation, structure, and physical characters, the total absence of drift or other indication of ice-action within their boundaries, or the marked contrast presented in the configuration of these and other

* Prof. Hull, *Geol. Mag.* vol. iii. p. 475.

valleys in the neighbourhood, and the general surface-contour of the surrounding district as compared with the country on the western slope of the chain immediately beyond the watershed, where ice is known to have been, and where the hills and dales lose their stern angular character, and become characterized by a soft, rounded, and flowing appearance, indicating unmistakably the operation of divergent forces, and the existence of wholly different conditions, we shall have no difficulty in concluding that glacial or land ice has had no share in their formation or subsequent modification, but that they owe their origin in the first instance to the fracturing of the rocks, and subsequently to the operation of subaerial forces.

Having now pointed out the physical features of the district, I shall proceed to offer some reasons for concluding that during the glacial period these lines of communication were blocked up by snow or ice so as to cut off all connexion between the two sides of this chain of hills. On the approach of the long winter which preceded the period when ice overspread the county of Lancaster and the whole of the northern part of our island, the severity of the climate would gradually increase; and during this time large accumulations of snow would take place, and ice be formed in deep and sheltered situations like those presented by the Walsden, Cliviger, and Todmorden valleys. The snow, thus accumulated to a depth of from 800 to 1000 feet, would, by being partially melted and recongealed, become in time a consolidated compact mass, little if at all inferior to that of ice itself in density and consistency.

Accepting, then, this proposition, we shall have no difficulty in concluding that these bodies, held firmly in their places in the tortuous serrated valleys which are so constructed, and holding such relations to each other that any attempt to move on the part of the accumulations in one of the arms would be resisted and counterbalanced by the opposing force of the other two branches, each of which would have a tendency to move in an opposite direction, would thus be able to offer an effectual resistance to the force of the great northern glacier, on its approach so far south, to dislodge them from their strongly intrenched positions,—the resistance to all motion on their part being still further increased by the presence of the glaciers acting upon the terminal portions of the two arms at the mouths of the valleys by which those bodies, if in motion, would have to emerge, with a force equal to that exerted at the northerly end of the Cliviger gorge, where the glacier would seek to effect an entrance therein, thus completely neutralizing each other, and preventing any motion on their part taking place. The progress of the glacier in its journey south being thus arrested by an impassable barrier, at or near Holmes Chapel, in the Cliviger gorge, where the valley suddenly contracts and becomes hemmed in on both hands by massive beds of grit rocks, in some places almost vertical, it is evident that the ice forcing its way so far would be compelled either to move on over the imbedded and stationary mass, or be deflected from its course, and compelled to take a more westerly direction, part of it finding its way over the pass separating the Easden

Clough from the Whitewell valley at an elevation of 1170 feet, and passing on east of Deerplay Hill and the high land adjoining into the valley of the Irwell, thence skirting the hilly district east of Bacup and crossing Brandwood Moor, the dividing line between the basin of the Roach and Irwell, and so continuing its course on to Manchester and the great Cheshire plain; whilst another stream of ice would doubtless cross from Burnley into the Whitewell valley by the Wholaw-Nook pass, becoming there confluent with the arm already described, the main body moving off in the direction of Burnley and Accrington, on the westerly side of Hambleton Hill, thence pursuing its course south and uniting with the other streams, finally debouching onto the plains of South Lancashire.

In support of the theory that a large body of moving ice meeting with resistance sufficiently powerful can be either entirely arrested, or its various portions be endowed with varying and diverse motions, we have the authority of the Duke of Argyll, Prof. Ramsay, and Mr. Goodchild, some of whose statements fully justify the conclusion that such was the behaviour of the ice in this instance.

In all probability ice did not overflow the higher hills in this part of the axial range, as is manifested by the absence of all trace of its action upon the surface-contour of the country, and by the fact that there are no remains of morainic or other matter to indicate that it had ever been in those situations.

It may be assumed that the great ice-sheet in this part of Lancashire did not rise to so great an elevation by some hundreds of feet as it is proved to have done further to the north by the observations of Mr. Tiddeman, Mr. J. Clifton Ward, and Mr. Goodchild; and I contend that satisfactory reasons may be given for this variation by taking into consideration the gradual slope of the ground, the waste by melting to which the ice would be subjected in travelling south, and its tendency to spread out and become diffused on reaching the flatter and more level plains of Lancashire and Cheshire.

Statements contained in the memoir by A. H. Green, C. Le Neve Foster, and J. R. Dakyns on the Geology of the Carboniferous Limestone, Yoredale Rocks, and Millstone Grit of North Derbyshire and the adjoining parts of Yorkshire, confirm many of these conclusions arrived at by me on independent grounds.

I have thus endeavoured to lay before the reader such facts as have come within my reach tending to illustrate the question forming the subject of this essay, with what success he will be able to judge. If, however, the facts and arguments should fail to carry conviction, I trust that the effort I have made to solve this somewhat difficult and perplexing question may not prove altogether fruitless; for should no other result follow than that of attracting the attention of other observers to the subject, so that eventually a satisfactory solution may be arrived at, my object will, at all events to some extent, have been attained.

22. NOTES on the PHYSICAL GEOLOGY of EAST ANGLIA during the GLACIAL PERIOD. By W. H. PENNING, Esq., F.G.S. (Read December 15, 1875.)

[PLATE XV.].

INTRODUCTION.

IN submitting to the consideration of the Society the following observations, I would remark that they are intended to form, not a full description, but a sketch of the physical geology of East Anglia during the glacial period. The evidence upon which they are founded is derived from deposits that either have been, or will be, mapped by the officers of the Geological Survey. Full descriptions will appear in their published maps and memoirs; therefore the subject will here be treated generally, and all details omitted.

The object I have more especially in view, is to offer an explanation of the origin of a somewhat puzzling series of gravels and sands, classed by Mr. S. V. Wood, Jun., as "Middle Glacial," to give a reason for their occurrence in certain areas and non-occurrence in others, and to account, on mechanical grounds alone, for the almost total absence therefrom of any (except derived) fossil remains. I wish also to remark briefly on the probable means of formation of the so-called "Denudation gravels."

The subject is divided, for reasons that will appear, into two parts; the first relates to the district south and east, and the second to that north and west, of the great Chalk escarpment.

By the term "East Anglia" is meant a tract of country, north of the Thames, which may be considered to be bounded on the west by a line passing from London through Hertford, Royston, and St. Ives to the estuary of the "Wash," and which includes all Norfolk, Suffolk, and Essex, with part of Cambridgeshire, Hertfordshire, and Middlesex. The general contours of the southern part of the district at every hundred feet above the sea are shown by the dotted lines on the map (fig. 1, Pl. XV.), the smaller and later-formed features being omitted as immaterial to the argument.

The lowest tract in the district may conveniently be termed the "Cambridge Valley:" a large portion of it is fen-land bounded on the south and east by Gault, which is, with trifling exceptions, the lowest geological formation that comes to the surface in the area in question. On the right side of the Cambridge valley runs the chalk escarpment, divided as usual into two main lines, one of the Lower and one of the Upper Chalk. The latter forms some of the highest ground in the district*, and may be traced as an uneven ridge, with rounded hills and hollows, from Buntingford, by Saffron Walden, Haverhill, Thetford and Swaffham, to the sea. The ground slopes gradually away from this ridge towards the London Basin, where the Tertiaries set in, one of the series (the London Clay)

* At Tharfield (S. of Royston) 550 feet, and in West Norfolk 450 to 650 feet above the sea.

forming an escarpment roughly parallel to that of the Chalk. The northern and eastern portions of the district are in part occupied by deposits of later Tertiary age—the Crag, the Chillesford beds, and the Forest-beds.

The general altitude of the line of escarpment of the Upper Chalk may be taken as from 300 to 500 feet, that of the London Clay from 200 to 300 feet above the sea.

PART 1.—*The Drift-deposits to the South and East of the Chalk escarpment.*

Pliocene.—Along the coast of Norfolk, Suffolk, and part of Essex, as well as for some distance inland, occur the “Crag” deposits. Of these sands, the older or “Coralline Crag” contains the remains of a *deep-sea* fauna; in the “Red Crag,” immediately succeeding, *littoral* forms prevail; while the newer or “Norwich Crag” also contains littoral forms with *land and freshwater* shells in addition. A gradual rising of the coast during the Crag period is thus indicated; and this continued until the land stood slightly higher than at present, admitting the growth of the Cromer “Forest-bed.”

These Crag-beds perhaps scarcely belong to the drift-deposits that present the evidence on which the following arguments are founded, although I believe that there is a gradual passage up from them to those of recent date. This gradual passage will probably be found to exist stratigraphically, as well as in regard to their enclosed fossil remains and to the climate* that prevailed during the different periods of their deposition.

Lower Glacial.—After the formation of the Cromer Forest-bed the land again sank beneath the water, gradually and to a depth of certainly not less than 400 or 500 feet †: during the progress of the submergence the advancing shore-line gave rise to the “pebbly sands” which, according to Messrs. Wood and Harmer, “form the base of the whole glacial series, indicate shore-conditions and the first setting-in of the great glacial subsidence” ‡. Arctic conditions of climate began to prevail; and here and there patches of clay were dropped by icebergs, heralds of those to follow in such vast numbers during the Upper Glacial epoch. The contorted drift, which occupies a large area in the north-east portion of the district, was deposited during the early part of this submergence of the land; its mode of formation I consider to have been much the same as that of the Upper Boulder-clay presently to be considered. The contortions sometimes exhibited by this deposit are probably due to agencies acting on the clay at a subsequent period.

Middle Glacial.—The Lower Glacial beds are overlain and considerably overlapped by a series of gravels and sands called the “Middle Glacial.” These beds occupy, or have occupied, almost all the area covered by the Lower Glacial, and extend far beyond it in a southerly direction. It will be seen on reference to the map (fig. 1,

* Lyell, ‘Student’s Elements,’ p. 177.

† Lyell, ‘Student’s Elements,’ p. 167.

‡ ‘Outline of the Geology of the Upper Tertiaries of East Anglia,’ p. 16.

Pl. XV.), that many of the valleys running S. and E. from the chalk escarpment to the sea are, almost to their source, cut through the Upper Boulder-clay, and expose these gravels beneath it. They are thus proved to be very persistent over a definite area, within which it is a rare occurrence for the clay to be seen resting on the older geological formations. It is probable that the gravels extend beneath the clay over nearly all the intervening area, in greater force along the lines of the larger valleys (which I believe to have been carved into nearly their present form in *preglacial* times), and in a more attenuated, or even patchy condition under the higher grounds.

But the gravels can in no instance of which I am aware be traced up to the *escarpment* of the Chalk, or, in other words, beyond a certain definite level. It is not that they disappear beneath a great thickness of Boulder-clay to reappear at its opposite boundary; on the contrary, it is evident that they gradually thin out; and a few miles before the escarpment is reached we find the Boulder-clay overlapping them and resting directly on the Chalk (fig. 2, Pl. XV.). This is well seen in many sections, also along the N.W. face of the scarp, where the junction of the Chalk and the clay forms for many miles a well-marked line, the absence of any intervening sand or gravel being constant and remarkable. The fact of the gravels not running up to the escarpment was noticed, but no inference drawn therefrom, in 1835, by Mr. Caleb Burrell Rose, who writes* :—
 “The general surface of the chalk must have suffered prodigious abrasions from the violence of the elements, as evidenced by the immense quantity of gravel formed and collected in various situations, as well as by the different altitudes at which the chalk is found, it appearing immediately beneath the vegetable soil, even on the highest ground; and at a level of *not less than 50 feet lower* it may be found covered by more than 150 feet of sand and clay containing boulders.”

In the thinning-out of the Middle Glacial beds against the Chalk, and their not rising beyond a certain height, we have a clue to the conditions under which they were formed. The great chalk escarpment, as a long and narrow ridge, standing at this time well above the sea, was an important feature in the physical geography of the period; and the Middle Glacial sands and gravels, as such, are entirely owing to its existence. For it formed a barrier opposing itself to the strong current which must at that time have been sweeping round from the North Sea to the Atlantic Ocean. By this current were brought down the materials of which the gravels are composed, and which consist of pebbles derived from the rocks of the northern and eastern coast along which it travelled, mixed with a large percentage of flints from the chalk barrier itself.

In the gravels are intercalated occasional masses of Boulder-clay which were brought down by icebergs, and which, heavily descending from them, have distorted the gravels wherein they now lie without any approach to order or arrangement. Further evidence

* “Geology of West Norfolk,” *Phil. Mag.* vols. vii. and viii.

of icebergs during this period is found in the associated series, or parts of series, of fossil remains taken from the gravels—as, for instance, at Bishop Stortford, where a good number of vertebræ and other bones of *Pliosaurus*, parts of the same animal, were discovered. These of course were derived from some of the Secondary rocks to the northward, and must have been transported in a large mass of the matrix in which they had been previously fossilized.

The submergence, which began at the commencement of the Lower Glacial series went on until the waters of the North Sea were again united to those of the Atlantic*, when a strong current was set up in that direction. It steadily continued during the accumulation of the Middle Glacial beds, bringing them up to the level at which they are now found. But while yet the higher ranges of the Chalk were above the water, the lower parts of the escarpment had gone down sufficiently to admit of the passage over them of the sea; and this of course began to give rise to a set of very different physical conditions. In place of the strong southerly current confined to the eastern side of the chalk ridge, the waters having admission to a much larger area, their power (within that area) of transporting gravels was materially lessened, and, as submergence went on, absolutely lost. For this reason the gravels are found running not quite although nearly up to the lower levels of the chalk escarpment.

[The ground to the N. and W. of the escarpment (fig. 2, Pl. XV.) being at even a lower level than where the gravels occur, was of course also under water; it was, however, land-locked on every side but one, and formed a bay in which no current of any extent was possible; consequently we find in it but few (if any) deposits that undoubtedly belong to the Middle Glacial series. The waters from the bay flowed outward through the “Wash” to join the southerly current, and contributed their share of pebbles to the gravel that it deposited.]

It is almost impossible to locally classify in detail these drifts; but, speaking generally, the coarser gravels are found, as might naturally be expected, in positions nearest to the chalk ridge, as in the neighbourhood of Clare, the finer gravels in the intermediate country between it and the most distant deposits at Hertford, where they take the form of brick-earth. Throughout are interspersed masses of current-bedded sand and occasional patches of iceborne clay.

The general absence from these beds of fossil remains may be accounted for by the conditions of deposit; they were formed in a strong current, which would be (except, perhaps, at the *commencement and end* of the period) unfavourable to the existence of animal life, while the remains of any plants or animals that may have come within its sweep would speedily be reduced by attrition, except of course those which were previously fossilized, and all of

* “England was again joined to the continent during the time that the vegetation of the ‘Forest-bed’ flourished” (Ramsay, ‘Physical Geology,’ p. 178).

which are much rolled and waterworn. In the exceptional cases where shells do occur, they are found to be of such species as would perhaps indicate a climate warmer than that which prevailed before and after the Middle Glacial period. This fact is probably due not so much to a real difference of climate as to the temperature of the current, which would be governed by its direction and the conditions affecting it before reaching these islands.

If these views be correct, there is between the Lower and Middle Glacial no definite line of demarcation.

Upper Glacial.—The Great Chalky Boulder-clay in East Anglia extends in mass, or in patches that once formed part of the main mass, over the northern half of the London Basin, the Pliocene area, and the dip slope of the Chalk, rises over the escarpment of the same formation, and plunges down into the Cambridge valley. It now caps the highest hills; and it occupies the deepest valleys, except where it has been removed by recent denudation.

The submergence which began with the Lower Glacial and continued during the Middle Glacial periods still proceeded; consequently the strong northern current was, as we have seen, gradually replaced by a more open sea. During the succeeding era the bottom of this sea became covered with a thick deposit of ice-transported clay. This clay, made up of chalk and the *débris* of other rocks also found to the northward of the area, having been brought down and dropped in masses, presents within itself no traces of stratification. Still it is seen in most instances resting evenly on the Middle Glacial beds; it is, indeed, as a bed, stratified with them, although its own structure is not the result of stratification. There are no signs of grinding or thrusting of their surface, such as must have been apparent had the clay been formed beneath a covering of ice sliding over the land. This latter mode of formation is accepted by many as a true explanation of the phenomena presented by the Boulder-clay; but for this reason especially I differ from that conclusion. Moreover, if the clay be a *direct* result of ice moving over the land, an emergence after the deposition of the Middle Glacial gravels must have intervened; but of this there seems to be no evidence beyond the disputed point of the method of the clay's formation.

In this district we have no indications of the greatest depth of the glacial submergence; it was probably many hundreds of feet. That it continued for a lengthened period is certain, judging from the great thickness in many places of the Boulder-clay. Whatever oscillations of level may have occurred elsewhere during the Glacial period, there appear to be in East Anglia no marks of any but one, and that a gradual and long-continued movement of depression succeeded by another, equally gradual, of relevation.

Postglacial.—When at length the land again assumed an upward movement, and as it rose from beneath the sea, every part in turn, as a receding shore-line, would be subject to the action of the waves, and the surface of the Boulder-clay thereby eroded and to some extent reassorted. A clayey gravel would naturally result;

and the whole of the uneven surface of the clay would be more or less covered by such material, although on the flats, in the hollows, and in the channels the larger portions of it would be accumulated.

As it invariably happens that subaerial erosion acts most powerfully along an anticlinal line, the gravels in the hollows and channels would be the longest-preserved from destruction. And we find here and there on the surface of the Boulder-clay patches of this clayey gravel or loam generally capping the higher grounds, frequently many of them in a curved or straight line, showing the direction of the old channel in which they were originally formed. These so-called "Denudation gravels" are never of any great extent or thickness, nearly all having been removed by erosion. Where they exist it may be inferred that there the Boulder-clay still retains its original thickness; and a line drawn from point to point where they occur would give a rough measure of the *minimum* amount of Postglacial denudation.

PART 2.—*The Drift-deposits in the Cambridge Valley.*

The title of "Cambridge Valley" I consider to be most applicable to that main branch of the valley which is occupied by the river Cam, or Rhee, a stream that rises on the Chalk a few miles from the town of Royston (fig. 1, Pl. XV.) This stream runs in a N.E. direction along a line roughly parallel to the Chalk escarpment, until, south of Cambridge, it is joined by the Cam, or Granta. Thence the united streams, under the name of the river Cam, run nearly due north, still parallel to the escarpment. By Ely their waters flow into the Ouse, a river which continues the course hitherto taken by the Cam, and falls into the "Wash" at King's Lynn. The valley occupied by the Cam and its extension the Ouse thus lies parallel to and near the base of the Chalk; it has been in fact cut back, and is still being cut back into the escarpment. In this operation the river is aided by several streams having their source well up in the Chalk district and running across the strike into the Cambridge valley. These are:—the Cam, or Granta, which rises near Saffron Walden, and has a branch from Bartlow; the Lark, from Bury St. Edmunds and Mildenhall; the Little Ouse, from Brandon; the Wissey, from Watton; and the Nar, from the west of Swaffham.

The valley has been, along the greater part of its course, cut down to the horizon of the Gault (fig. 2, Pl. XV.)—its upper portion being enclosed on either side by gentle slopes of Chalk-marl, succeeded by hills of the Lower Chalk. North of Cambridge it opens out into a broad expanse of fen-land, overlooked from the east side only by the high chalk range. Rarely do any beds lower than the Neocomian crop out; but by these and the Gault the Fen is skirted all the way to the sea.

The Chalk escarpment receded to its present position or thereabouts in the Pliocene period: during the progress of its submergence for, and reelevation after, the Eocene deposits it had been subjected to some disturbance, many small faults, flexures, and contortions

being the result. To a considerable flexure of this period is owing the present position of an upper extremity of the valley.

That the Cambridge valley, as such, is mainly preglacial is evident from the consideration of several reasons, amongst others the position which the Boulder-clay now occupies therein*. It rests on the escarpment at an elevation of more than 500 feet; it is found here and there on the flank at lower and lower levels; and it occurs in the bottom of the valley at but a small height above the sea. It is true that in those instances where Boulder-clay is found on the flank it is in small outlying patches only (fig. 2, Pl. XV.); but this is inevitable from the progress of recent erosion; and they are quite sufficient to prove the former extension of the mass. These patches now cap small elevations resulting from denudation; and a line drawn from the escarpment to the low ground would intersect them all.

Although the escarpment had been cut back to nearly its present position during the Pliocene period, and the land was somewhat submerged during the deposition on the east coast of the Pliocene beds, we find in this valley no signs of their present or former existence. For the valley was not excavated to its present depth, by perhaps 50 or 100 feet; consequently any deposits that may have been left in it during the Pliocene era have long been swept away. For the same reason, perhaps, we have no beds of Lower Glacial age, which are, so far as I have seen, confined to areas of comparatively slight elevation. It is not difficult to suppose that these *Lower* Glacial deposits would be excluded from this valley by its then height relatively to that at which they are now found, or that any which may possibly have once occupied the area have been subsequently removed.

But it is far more difficult to account for the apparently total absence of the Middle Glacial deposits, which, just over the Chalk escarpment, run up to a height of 300 feet or more above the sea, and to at least 200 feet above what must have been the bottom of this valley at the time of their deposition. The subsequent physical conditions were not favourable to, nor was the time sufficient for, the removal from the valley of beds of any extent (assuming them to have been therein deposited) before the deposition of the Great Chalky Upper Boulder-clay. We should find them still, however great the subsequent denudation, between the older rocks and the Boulder-clay in some at least of the many instances in which it occurs. It cannot be assumed, as in the case of the Pliocene and the Lower Glacial, that the Middle Glacial beds at one time occupied the valley, and were afterwards, and before the Upper Boulder-clay period, removed; yet in no instance do we find the Boulder-clay resting on any other than preglacial formations. As suggested in the first part of this paper†, the currents from the north that formed the Middle Glacial gravels and sands were *confined to the seaward side* of the Chalk range, which was not wholly submerged, and were entirely excluded from the Cambridge valley; for, as we

* Ramsay, 'Physical Geology,' p. 211.

† *Ante*, p. 193.

have seen, if they had had access to the valley, and had not been excluded therefrom as suggested, some undoubted traces of the series of gravels and sands would remain and testify to the fact. There are certain gravels which, I admit, bear a striking resemblance to those of undoubted Middle Glacial origin; but my reasons will presently be given for believing them to be of much more recent date. In some cases the Boulder-clay has a gravelly base; but it is that and nothing more, representing the gradual change of physical conditions which occurred when the Chalk-ridge was nearly submerged. At this time, although the southerly set of the water still continued*, its currents possessed much less power of transporting and rearranging gravels, and their deposition ceased. But the change was gradual; and we may readily conceive that during the transition-period the surface of the Chalk, being slowly encroached upon, would be partly covered over with a wash from the rock itself, and perhaps also from the gravels. This wash is not a clean gravel; and it gradually passes up into the Boulder-clay, which then began to be deposited.

We have seen that the Cambridge Valley was excavated in pre-glacial times, and that in all probability no Lower or Middle glacial beds were formed within its area. But when the Chalk was wholly submerged †, the sweeping currents, hitherto confined to the east side of the range, were replaced by an open sea extending over every part of East Anglia that does not now attain to an elevation of 500 feet. In this sea the icebergs laden with rocky *débris* from the north were slowly melted; and their freights, descending *in mass*, formed on the bottom the unstratified Boulder-clay. There had been icebergs borne along in the Middle-glacial currents also; but they were swept off more quickly to the southward, and probably a great majority of them may have melted over an area still beneath the waters of the Atlantic.

The Upper Boulder-clay is found all along the top of the Chalk range; it caps the minor elevations on the flank, and it occupies some of the lower ground in the valley. At one time it doubtless spread as a sheet over the whole area, from the highest point of the 'scarp down to, if not below, the present sea-level. It has since been so much denuded that its main mass on the hills is disconnected from the remainder, which now exists merely as outliers on the smaller hills and ridges.

Noting that the Boulder-clay is found on the back and top of the escarpment, as well as on the low ground beyond the foot of it, we might assume that there is no "horizontality" in its mode of occurrence, and that its present boundary-lines would ignore all the contours, and features even, of the country. To some extent, and in small areas, this may be so; but looking at the Boulder-clay as a whole, there is a striking regularity in its occurrence. When viewed on a true scale, in the exceptional case of the Chalk escarpment it is seen to plunge down about 500 feet; but this being in a distance of not less than 10 miles, represents a fall of 1 in 100 only, or an

* *Ante*, p. 194.

† *Ante*, p. 195.

angle of about half a degree. It touches, as any other formation would be expected to do, the outliers and hills within the larger valley which are sufficiently high to reach its horizon; and its boundary-line conforms generally to the present features of the district.

As the surface of the Chalk, when gradually encroached on by the glacial sea, became partly covered by a gravelly wash, so also did the Boulder-clay on its emergence*. Of this gravel or loam but little remains, and that invariably on the higher grounds, in patches which once formed portions of extensive plateaux. I think it can scarcely be assumed that so large a mass of material as the Boulder-clay which once filled the valley could have been removed by denudation, marine or subaerial, or by both combined, without its component particles having been more or less reassorted and re-deposited on the denuded surface. This may have been the origin of certain deposits of doubtful age which occur, here in the form of loam, there as an impure gravel.

Besides the high-level deposits, there are in the valley broad sheets of much newer valley-gravel, enclosing the remains of recent shells and of extinct mammalia. They occur in three or more terraces at different levels, marking as many points in the progress of the valley's formation, the higher and older terraces having been already reduced to mere patches, indicating a former extension, and testifying to the rapidity of denudation. These gravels have been made up mainly from the waste of the Chalk and superincumbent Boulder-clay, and may be seen in many sections in the neighbourhood of Cambridge. Much has been already written about them; they have now been mapped by the Geological-Survey Officers, and will be fully described by them also in their publications. The same remark applies to the Fen-lands, which are of more recent date than the Drifts proper that form the subject of this communication.

But there are within the area certain other gravels upon which a few remarks are necessary, owing to their resemblance to those of Middle-glacial age. These deposits occur at an elevation of 20 to 60 feet, or thereabouts, above the level of the river, and consist of gravels and sands with intercalated masses of loam and clay, the latter having somewhat the appearance of Boulder-clay, or, rather, of a wash from Boulder-clay in its immediate vicinity. The lines of stratification are irregular, sometimes horizontal, more frequently inclined, and, in the two most noteworthy sections, several miles apart, dip north at an angle of 15° . In one of these sections are *two* gravels, or, rather, a gravel and a loam, the latter being banked up against a scooped-out edge of the former, thus presenting the appearance of a fault.

There is a Middle-glacial appearance about the gravels; but still I think that all the phenomena might occur as well either in an esker or in deposits left by a river of tolerable magnitude. Inclined bedding is not unusual in river-gravels; and the included

* *Ante*, p. 198 and Part 1, p. 196.

masses of wash from Boulder-clay are easily accounted for, if we assume that the gravels were formed during the removal by denudation of the Boulder-clay which once filled the valley. The uniformity of level at which they occur would also seem to indicate a fluvial rather than a glacial origin. But the strongest argument in support of this view is the fact that the gravels in places contain recent land and freshwater shells (*Helix*, *Pupa*, *Succinea*); this would be conclusive evidence if the shells could be more generally found. But it is just possible, although far from probable, that in the few instances only in which (so far as I know) they have been discovered, a newer gravel may have been deposited in channels cut by streams through that which is of older date. In my opinion the parts of the gravel where the shells do occur so exactly resemble the other portions where they do not, that such a proposition cannot be entertained. Therefore without hesitation I refer these deposits to the existence of an ancient river running, as does the present one, along the foot of the escarpment, although, of course, not on the ground occupied by the Cam of our own time. The Chalk 'scarp was then somewhat different from what it is now; it had been cut down to such a level only that its foot was higher by as much as these gravels are now above the river. The line of this old river is now indicated by an elongated series of patches of the gravel in question which formerly occupied its channel. The remaining portions of these gravels now form long, low, and rounded ridges, occupying, probably, slight depressions in the Chalk, which depressions (formerly a part of the old river-course) are now somewhat elevated above the surrounding area, the gravels having partly preserved, as usual, the lines of hollow from denudation. This series commences near Royston, in a hollow formed by the flexure in the Chalk previously mentioned*, runs in an easterly direction about parallel to the present course of the river, crosses the minor valley of the Cam or Granta, is joined by another line of similar patches from the east, and then sweeps round to the north of Cambridge, being lost in the fens beyond (fig. 1, Pl. XV.).

I am well aware that this solution may not explain the origin of all the patches of gravel that are found in the valley and cannot with certainty be referred either to the Glacial, Postglacial, or Recent period. But I do not think that any of them have been actually traced under the Boulder-clay, as they would have been if of Lower- or Middle-glacial origin. It is possible that during the period in which the drifts were being formed by the Middle-glacial currents traversing the east coast, a stray iceberg may have occasionally found its way into the land-locked inlet of the Wash and its extension the Ouse and Cam valleys, at that time so much broader through greater submergence. But this would be, I apprehend, a very exceptional occurrence; and any deposits dropped from such bergs are not to be classed with the current-formed gravels that occur in such force on the other side of the escarpment.

Taking all the facts into consideration, I feel justified in drawing

* *Ante*, p. 197.

the conclusion that, strictly speaking, there are no Lower or Middle Glacial deposits within the area of the Cambridge valley*.

SUPPLEMENTARY NOTES.

Since the above notes and the conclusions therefrom were brought before the Society, the completion of the mapping of some of the gravels, mentioned as of doubtful age, seems to have thrown light upon the date and mode of their formation. It has afforded, also, additional evidence in support of the theory advanced respecting those gravels which were thereby asserted to be relics of an ancient river Cam.

There is a hill called "The Rivey," situated about ten miles S.E. of Cambridge; its height above the Cam is about 325 feet; it is, as it were, an outlier from the escarpment, and it is similarly covered by Boulder-clay. This Boulder-clay rests directly on the Chalk, and is capped by a few feet of gravel; it is supposed that this is a patch of "Denudation gravel," and that the Boulder-clay beneath it retains its full thickness; or it may be a higher example of those to be described. In a direction running away from the escarpment are patches of gravel at a level several feet lower; then, further on, other patches at a still lower level, and others, still further away, with less elevation, the Boulder-clay being continuous beneath them all. At Hildersham, in the valley, $1\frac{1}{2}$ mile from the Rivey and 200 feet below the summit of the hill, the gravel and Boulder-clay occur in the same relative positions; and a little further on, the gravel overlaps the clay and rests on the Chalk.

This interesting and well-marked geological feature has been preserved, it may be, by its position in the bend to the north of the escarpment; and it affords a key to many other patches of gravel in similar positions, and heretofore considered as of doubtful age (p. 200). All the patches (many of which are small), and the indications of several other patches removed by recent denudation, seem to form parts of lines that once were continuous, and which are more or less at right angles to the long series ascribed to an old course of the Cam. They continue in a gradually descending order from almost the top of the 'scarp down to the level of that series—that is, from 325 feet down to 20 feet above the present river.

The explanation proposed is, that the slope of the Preglacial 'scarp was entirely covered by Boulder-clay, that the valley was, in fact, almost filled by that deposit, the patches of Boulder-clay which here and there remain marking out the line of that Preglacial escarpment (see *ante*, p. 198). This Boulder-clay has been removed

* Since the above paper was read the author's attention has been called to the fact that in the 'Geological Magazine' for February 1870, Mr. S. V. Wood, Jun., published a statement to the effect that the Middle Glacial beds in East Anglia do not occur at a greater elevation than 250 feet; also, that in a section illustrating a paper by him read before the Society, June 19, 1867, the overlap of those beds by the Boulder-clay, and the occurrence of the latter in the Cambridge valley without any Middle Glacial are represented. Although Mr. Wood did not draw the same inferences from these facts, he is entitled to priority in their observation.—W. H. P.

entirely by postglacial erosion ; and the Chalk has been cut back beyond the old line, except where such patches still remain. In the early Postglacial times, when the valley began to be reexcavated, a main stream must have run approximately in the same direction as the present river, but then, of course, at a height considerably above it—as much higher really as the thickness of the Boulder-clay that has since been removed. The escarpment covered by Boulder-clay was cut back then in the same way as it is being cut back now, by minor streams running across the strike (p. 196) into the main river parallel thereto. This operation began immediately upon the relevation of the land after the great submergence, and has continued up to the present time.

There must have been very considerable accumulation of detritus from the removal of such a mass of Boulder-clay ; and that removal would be the more rapid in proportion to the greater steepness of the area subject to denudation. These accumulations would, in turn, be removed ; but it is suggested that in the mass of Boulder-clay and overlying patches of gravel leading down from the Rivey to the valley below we have evidence of the later stages of that clay's denudation, and small remnants of the resulting accumulation.

The gravels are made up of exactly such material as would be derived from the waste of Boulder-clay—rolled lumps of hard and soft chalk, flint pebbles, with some fragments of quartz, limestone, and other derived rocks, enclosing broken pieces of derived fossils. They constitute also a gradually descending series, without any very great break in their continuity, either in regard to level or position. All the patches appear to occupy hollows in the surface of the clay, by which circumstance they have, indeed, been preserved—that is, down to the level of the Preglacial valley-system ; below it the gravels rest on the excavated chalk. In many instances they occur in hollows along the top of a ridge—the old stream-channels in which they were left now forming synclinals, and thus preserving the gravels and the clay or chalk immediately beneath, while that on either side has been worn away.

The marine Middle-glacial currents could not have formed these gravels, even if they had access to the valley, as some of the ridges run up into coombe-like valleys where such currents would have been impossible. The streams that deposited them were doubtless rapid, and occupied gorges in the clay ; this would account for the false-bedding sometimes exhibited.

The series described as indicating the ancient course of the Cam represents the latest stage of all, previous to the present system of drainage ; in this series and in patches at or slightly above the same level occur the recent land and freshwater shells. At one place in this series shells of *Cardium edule* have been found ; and their occurrence would seem to bear out the suggestion made, that during the Glacial period the Cam valley formed a land-locked bay, on the sandy shores of which this mollusk flourished (p. 194). It occurs, but not plentifully, at the base of the deposit, and probably indicates the position of the old shore-line.

If the explanation offered be the true one, we have here a series of *river-gravel terraces* occurring at all heights, from nearly the bottom of the present valley up almost to the top of the Chalk escarpment.

Approximate Elevations (above the Cam) of two lines of Gravel Patches.

	feet.		feet.
The Rivey	325	Balsham	370
Intermediate patches.....	{ 270	Small patch W. of Balsham	250
	{ 200	Gravel-pits	205
Hildersham	125	(Possible continuation of the above.)	
(Indications of other patches between the above.)		Gravel-pits N.W. of Dun-	} 175
		gate.....	
		Wrattling valley	110
Ancient course of the Cam, 20 to 60 feet.			

EXPLANATION OF PLATE XV.

- Fig. 1. Map of a part of East Anglia, showing the Drift-deposits. Scale 8 miles to 1 inch.
2. Section from London-Clay escarpment to the Cambridge valley along the line indicated on the map. Horizontal scale 4 miles to 1 inch; vertical scale 800 feet to 1 inch.

DISCUSSION.

Prof. DUNCAN said that his impressions, formed twenty years ago, agreed with those of the author. It was a very simple case of geology complicated by geologists. He inquired whether the author thought that such valleys as extend up to the Chalk from the German Ocean were excavated before the Glacial period, or whether they were then filled up and afterwards excavated. He also asked whether the author was quite satisfied that all the gravels are water-worn by tidal action. It seemed to him exceedingly interesting to find that Mr. Penning pushed the ice-cap a little further back.

Prof. Morris remarked that the valley of the Cam presents two or three different conditions; near Cambridge the river flows over the Gault, cutting through the old gravel between Barnwell and Chesterton. The valley was probably excavated in the Boulder-clay, which occurs at higher levels, and once no doubt covered the whole district.

Mr. JUKES-BROWNE thought that the Boulder-clay did fill the valleys, and that the boulders referred to by the author had been derived from the Boulder-clay. One point of special interest in the paper seemed to him to be that the author regarded the whole Glacial series as continuous, in opposition to those who would place the excavation of all the valleys in the Glacial period, while the author considers them preglacial. At Cromer the so-called Middle Glacial is nothing but blown sand.

Mr. GEORGE MAW inquired as to the order of sequence of certain beds known as Lower, Middle, and Upper Glacial, what evidence

there is with regard to those extensive coast-beds which occur all along the coast from Yarmouth to Cromer, and especially what evidence we have as to the so-called Upper Boulder-clay on the coast being really newer than the great mass of the drift of high Suffolk.

Prof. RAMSAY thought that the question raised by Mr. Maw had been thoroughly discussed at the last meeting of the Society. He had had much pleasure in listening to Mr. Penning's paper, because that gentleman seemed to have aimed at getting rid of the infinite refinements in the classification of these beds as Upper, Lower, and Middle Glacial deposits, these things being generally treated in such a manner as to produce, at least in the popular mind, a notion that these deposits are of as great importance as Upper and Lower Silurian, for example, with beds thousands of feet thick. He thought that the effects of Glacial action had been immensely exaggerated, and believed that all the great features of the country existed before the Glacial period.

The PRESIDENT (Mr. Evans) considered Mr. Penning's paper of great importance from two points of view—first, with respect to the sequence of the Glacial beds, and, secondly, with regard to the Cambridge valley. He thought that the author's views as to the southern part of the Cambridge valley would be borne out when he came to examine the portion north of the Lark, and further north in the neighbourhood of Brandon, where he would be able to trace the connexion between the Glacial and Postglacial gravels. With regard to the ice-cap, there were certain points that deserve great attention, especially the question whence are derived the materials of the Boulder-clay. These seem to be in great measure derived from the Upper Cretaceous and Tertiary beds in the neighbourhood. And in some cases unworn flints show glacial scratches; hence he suggested that inquiry should be made whether they were due to local glaciers.

The AUTHOR, in reply, stated that the Cambridge valley was excavated in Preglacial times. There is no evidence of extended denudation in Glacial times, but only of local unconformity.

FIG 1, MAP
of a part of
EAST ANGLIA.
Shewing the Drift Deposits.

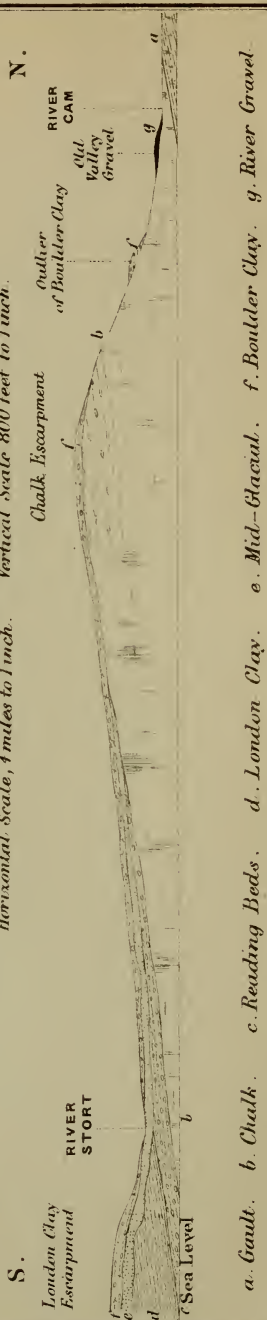


- Alluvium
- Post Glacial Gravel
- Boulder Clay
- Middle Glacial Gravel &c.
- Older Rocks (Chalk &c.)

Scale, 8 miles to 1 inch.

Contour Lines,
 100, 200, 300, and 400 feet above the sea.

FIG 2. Section from London Clay Escarpment to the Cambridge Valley.
Horizontal Scale, 4 miles to 1 inch. Vertical Scale 800 feet to 1 inch.



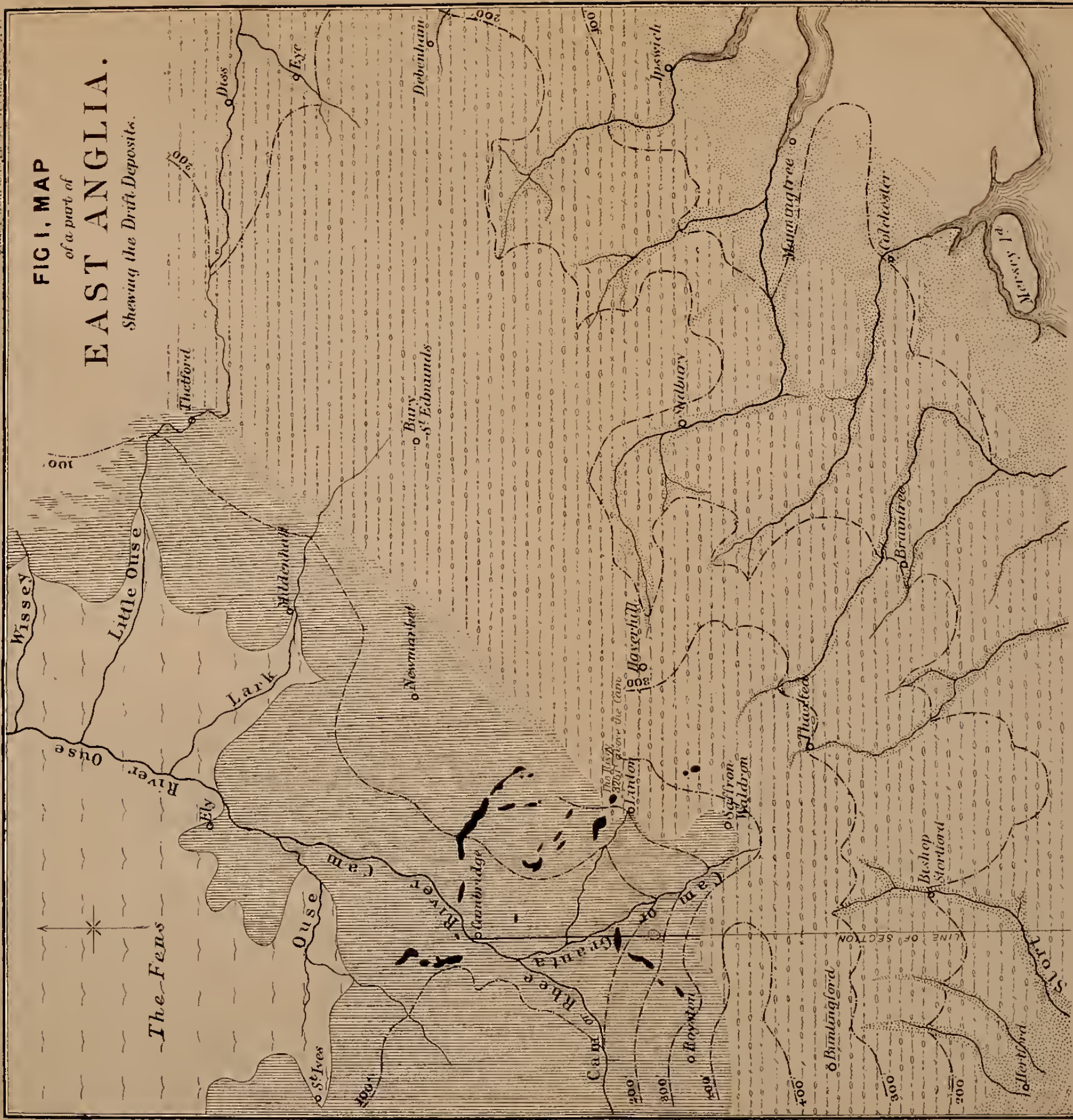
S.

N.

- a. Gault.
- b. Chalk.
- c. Reading Beds.
- d. London Clay.
- e. Mid-Glacial.
- f. Boulder Clay.
- g. River Gravel.

FIG 1. MAP of a part of EAST ANGLIA.

Shewing the Drift Deposits.



- Alluvium
- Post-glacial Gravel
- Boulder Clay
- Middle glacial Gravel &c.
- Older Rocks (Chalk &c.)

Scale, 8 miles to 1 inch.
 Contour Lines,
 100, 200, 300, and 400 feet above the sea.

FIG 2. Section, from London Clay Escarpment to the Cambridge Valley.
 Horizontal Scale, 4 miles to 1 inch. Vertical Scale 800 feet to 1 inch.



- a. Gault.
- b. Chalk.
- c. Reading Beds.
- d. London Clay.
- e. Mid-glacial.
- f. Boulder Clay.
- g. River Gravel

23. *On some UNICELLULAR ALGÆ parasitic within SILURIAN and TERTIARY CORALS, with a Notice of their Presence in CALCEOLA SANDALINA and other Fossils.* By Professor P. MARTIN DUNCAN, F.R.S., V.P.Geol. Soc., &c. (Read January 19, 1876.)

[PLATE XV.]

JOHN QUEKETT described, in his lectures at the Royal College of Surgeons in 1851–1852, certain tubes or canals as being very frequently met with in the skeletons of corals; and in his Lectures on Histology, published in 1854, and which contained the subject matter of his previous discourses, he wrote as follows: “Confervoid growths also are very frequently met with in the skeletons of corals, as all these bodies possess animal matter which, decomposing after death, becomes a nidus for the development of confervæ; and hardly a section can be examined without exhibiting such an appearance as shown in fig. 78”*. This figure shows long, short, and almost straight canals cutting across the normal coral structure at different angles.

In 1859 Kölliker gave the results of his examination of some corals to the Royal Society, in a communication “On the frequent occurrence of vegetable parasites in the hard structures of animals”†. He said:—“All the genera of corals which I investigated contained parasitical fungi, viz. *Astræa diffusa*, *Porites clavaria*, *Tubipora musica*, *Corallium rubrum*, *Oculina diffusa*, *Oculina*, sp., *Alloporina mirabilis*, *Madrepora cornuta*, *Lophohelia prolifera* and *Nullipora alcicornis*. The fungi were most frequent in the genera *Tubipora*, *Astræa*, *Porites* and *Oculina*, the last three of which contained also many sporangia, which in the red coral were very scarce or wanting.”

Before Quekett lectured, and contemporaneously with his and Kölliker’s researches, Dr. Carpenter‡ and C. Wedl§ investigated the corresponding tubes or canals in shells; and the last-named naturalist communicated a most admirable paper on the subject just before Kölliker came forward. Wedl described and delineated the tubes in perfect and in decalcified specimens of shells, and obtained a view of the parasite itself when removed from its nidus in *Melania Hollandri* under the effects of a dilute acid. He agreed with Quekett in ascribing the parasite to the Confervæ, and

* John Quekett, Lectures on Histology, vol. ii. p. 153. Parasitic borings corresponding to those noticed by Quekett were described by C. B. Rose, F.G.S., in fossil-fish scales from the Chalk and Kimmeridge Clay, in the Transactions of the Microscopical Society, 1855, p. 7. He figured them; and his faithful delineations show ramifying tubes and occasional globular enlargements. He attributed them to the operation of infusorial parasites.

† A. W. Kölliker, of Würzburg, Proc. Royal Soc. June 9, 1859, vol. x.

‡ Carpenter, Cyclop. Anat. Physiol. art. “Shell.”

§ Wedl, Sitzungsber. d. kais. Akad. d. Wiss. in Wien, B. xxxiii. no. 28. Dec. 1858.

believed it to be the *Saprolegnia ferax* of Kützing. He did not examine the corals; but after satisfying himself about the occurrence of the parasite in recent species, he examined some fossil shells, and detected it (amongst others) in *Leptaena lævis* from the Devonian.

Thus these investigations showed that there were parasitic vegetable growths in modern corals and in many shells even as old as the Devonian, and that they either were confervæ or fungi.

During the course of some investigations into the minute structures of Tertiary corals, I was greatly puzzled by the omnipresence of a system of branching canals ending in *culs-de-sac* and having dark borders and a refractive central area. In one instance (in a *Thamnastræa* * from Tasmania) the tubes frequently merged into an irregular dark mass, and resembled the tubuli of bone (Haversian canals) passing into lacunæ; and as they surrounded in a circular series a radiating mass of closely approximated normal spicula, the resemblance to a low class of osseous tissue was extraordinary. These canals had their length, direction, and frequency evidently in relation with the situation and regularity of disposition of the denser and normal coral structures: where the spicula were closely united laterally, their extremities radiating from a common centre, the tubes did not pass into, but surrounded the mass; and when these nodules of normal tissues were in long series the tubes ran down by their sides. Hence sections cut across the calices and septa did not exhibit many tubes, but numerous dot-like markings, which were their cut ends; on the other hand, sections longitudinal to the septa and costæ presented long lines of tubes with ramifications and swellings. The resemblance in shape and size of these tubes to Quekett and Wedl's figures led to the belief that even this hard coral had not been without its parasite, and incited me to follow up the subject in living, recently dead, and other fossil species.

The results of my work on the recent forms, as they enter especially into questions foreign to those considered by this Society, are about to be presented to the Royal Society; but I thought that a notice of the occurrence of these interesting parasites in such old forms as *Goniophyllum* and *Calceola* would be of interest.

I chose this species of coral and *Calceola* because their hard parts admit of thin and wide sections, and also because I was working upon them in conjunction with Mr. H. Woodward, F.R.S., in investigating the question of the *Rugosa operculata* of Lindström. But I have examined others also, with different degrees of success. In the specimens which Mr. H. Woodward had had cut, the fossilization had been very perfect, and much of the calcite had been replaced by crystalline carbonate of lime. The calicular fossa and the cavities,

* On decalcifying a part of a thin transverse section of this *Thamnastræa*, and after careful washing, a $\frac{1}{16}$ -in. immersion-lens was used. It showed a basement tissue almost homogeneous, on which were numerous straight and a few ramifying tubes, resembling in shape the refractive tubes of the perfect specimen. The tubes were such, and not excavations in the homogeneous tissue; and they had each a proper and hyaline-looking wall; the contents were more refractive than it and than the surrounding structures. Hence the cellulose wall was preserved during the process of fossilization.

generally speaking, were filled either with sand and minute fossils of the same period as the mass, or with crystalline carbonate of lime. The specimens were very perfect and had not been rolled.

In investigating these parasitic growths and perforations in recent and fossil specimens, it is necessary to use thin sections for transmitted light; but a thick section often exhibits the refractive tubes when reflected light is employed. The sections of the fossils should be carefully made, and scratches on their surfaces noted; and in order to prevent erroneous interpretations, it is as well not to record any tubes as parasitical in their formation unless they contain matters resembling more or less those of the recent forms, and unless they can be traced in and amongst the normal tissue, and not only on the surface.

The best plan is to examine, first of all, that part of the section of the coral or shell which was formerly exposed to the sea; there it is exceptional not to find one or more straight dark lines passing from close to the external margin or old surface inwards at different angles (fig. 6). (A magnifying power of 350 linear is necessary, and careful and good illumination and definition.) When they are satisfactorily seen it is necessary to examine them throughout their length, and to establish, if possible, their relation with others and with the outside, and to notice their contents.

These perforations or tubes, and the concavities and little loculi with which they are often connected at the surface, cannot be mistaken for *Cliona*-borings; for these last are larger, contain spicules, and do not present the long and often tubular branchings of the vegetable parasites, which, moreover, never contain spicula. But the loculi, when some of the Algæ get into the corals, do often resemble the results of the early efforts of *Cliona* to perforate; and it is quite possible that the Algæ may have subsequently occupied the space where a *Cliona* had been at work ineffectually.

Their length, minute size, and general characters separate them from some very ill-defined organic perforations seen in Belemnites and modern shells, and which Fischer* and Quenstedt have termed *Dendrinæ*. It is hardly necessary to suggest that the edges of the planes of crystallization in no way resemble the tubes.

Appearance of the tubes and other parasitic productions in Goniophyllum pyramidale (Plate XVI).—The microscopical elements to be observed, are:—

1. Tubes which have no proper wall, and which are excavations out of the coral-structures. They are found (*a*) just beneath the surface, running parallel to it; but these are rare (fig. 2); (*β*) running more or less inwards at different angles to the surface, many being found near to the edge of the coral-wall, and a few far away towards the interior (figs. 6 & 9). These last-mentioned tubes do not vary much in size, and average in diameter about 0.008 in. Their calibre does not alter in different parts of their course, which is rarely curved, usually straight, and occasionally branching, the branches being often as large as the parent tube.

* Fischer, 'Comptes Rendus.' Dec. 6, 1875.

Both the kinds (α and β) are usually filled, except in the axis, by a dark granular matter; and the tubes therefore present the appearance of dark edges with a longitudinal central clear line. The length, in some instances, extended over more than one field of the microscope. Each ends in a *cul-de-sac*, which in this instance is not swollen out; and often where there are no cell-contents for a little space the absence of special walls can be readily determined. Usually no origin or ending of the tubes can be seen; but in a few instances their commencement in dark spots at the margin of the coral-wall can be readily seen (fig. 6). These spots are either not much larger than the tube, or are very much bigger, and are filled with a mass of globules with whose exterior the tubes seem to be continuous. Occasionally small dark pigment-masses with a definite globular shape are in contact with one end of the tubes (fig. 14). The large masses are probably the remains of resting spores or oospores; and the others are conidia (fig. 3). With regard to the numbers of the tubes β there appears to be no regularity; in some places they are very widely apart, and in others crowded; but they never appear to inosculate with others, but simply branch.

In one or two tubes in the specimens examined there are dark spots; and in one the calibre is swollen out at one spot.

γ . There are here and there very minute tubes which ramify frequently and in a short space, so as to be very dendritic in appearance; they are densely black and opaque, and their diameter is about one half that of the other tubes.

2. More or less globular conidium-like masses are either separate or crowded, and in this last instance often are in linear series. (α) They constitute moniliform bodies (fig. 3), sometimes with tubular projections. (β) They are in evident linear series, but are disconnected; nevertheless traces of excavations, which probably are relics of old tubes which once contained them, are occasionally visible.

3. Tubes having a calibre twice as large as the others, or even more, and whose contents are discontinuous, dark and often in the form of the conidium-globule (fig. 8).

There is a piece of a Brachiopod shell in the matrix within the calicular fossa of the coral; and it shows tubes β to perfection; and they look like so many straight and curved wires (fig. 4).

The tubes mentioned under section γ , and the more or less irregular black spots with which they are continuous, readily receive explanation after the study of the Algæ parasitic in the *Thamnastræa* from Tasmania (fig. 1), and of *Calceola sandalina* (fig. 11).

In the *Thamnastræa* the enormous multitude of tubes simulate radiating spicula in appearance, and here and there one or two can readily be traced running into a black mass. This irregular shape produced by the growth of the Alga depends on the special molecular structure of the coral. If the tubes were obliterated by fossilization, and the black spaces, not unlike the lacunæ of bone, remained, the appearance would greatly resemble that of some parts of *Gonio-phyllum*.

Examination of Calceola sandalina.—In the *Calceola* examined the tubes of all kinds were seen and conidia of globular shape included in the larger ones. The largest tubes (fig. 12) are four or five times as broad as the medium-sized straight tubes (fig. 11); and their exit in a loculus opening outwards at the surface can be seen. The loculus (figs. 12 & 13) sometimes contains a crowd of spores; and little wavy canals pass out from all sides. The contents of the tubes have undergone alteration in some, and a reddish tint has replaced the ordinary greenish-black colour.

The sections of such fossils necessarily contain tubes at different angles; and some which lie parallel to the line of incision are injured; hence the continuity of the conidium-bearing tubes is interfered with, and these are often left without a trace of the former tube. The same occurs with regard to the small branching tubes, which become broken up and isolated by the section. This is seen in a Lower Silurian Foraminifer (fig. 5).

REMARKS.

A comparison of the parasitic excavations of recent corals with those of the Secondary and Palæozoic ages presents most remarkable resemblances. Tube may be compared with tube in all its parts; but fossilization has produced appearances in the spores and conidia which suggest distinction between the recent and the fossil kinds of Algæ. Nevertheless the general character of the reproductive resting spores and the conidia arising from the vegetative part of the organism remain much the same. The large tubes in the palæozoic coral and Brachiopod, or whatever else *Calceola* may be, would at first sight indicate a different species of parasite from those which formed the smaller penetrations; but both large and medium-sized tubes often exist in the same recent corallum, and these last now and then give off others so small and so finely linear that their diameter cannot be measured. Whilst recognizing two or three forms of parasitic Algæ within these sclerenchymatous structures of recent and ancient date, it does not follow that they are to be made into different species. They may all be parts of the same mycelium-like growth of the parasite, and may depend upon the nature of the nidus in which growth has taken place.

Tubes of analogous sizes and shapes are found together in recent corals, and they are often continuous.

Wedl suggested that the Conferva which grew into the shells was *Saprolegnia ferax*. Kützing and Kölliker, from the want of cell-like partitions in the tubes, objected to the confervoid nature of the parasite, and urged that it is one of the Fungi—one of a group which grows at the expense of animal tissues, and secretes carbonic anhydride.

The distinction between *Saprolegnia* and the Fungi, however, is but doubtful. Its spores vegetate; and the tube growing from them, in some species, speedily perforates Confervæ and dives into their cells, growing and developing at their cost. It is really in-

separable from the group of the *Achlyæ*, or, rather, from a group which embraces *Achlya*, *Empusina*, *Sporendonema* and possibly *Botrytis**, all being members of the Protista group, whose natural distinctions, evident enough sometimes, are not so in some parts of their life-cycle. That one becomes the other, on a change of the surrounding medium occurring, is one of the most interesting and suggestive of facts. Evidently the parasite got into the old corals, as it does into those now living, from the outside, and by contact, growth, pressure, protoplasmic movement and the dissolving effect of the evolved gas, slowly and surely penetrated. The course, size, shape, and length of the tube being determined by the presence of the organic matter within the sclerenchyma and the arrangement of the coral-spicula, it is best to term the entophyte an Alga, and to classify it amongst the unicellular types in the neighbourhood of *Achlya*, calling it *Palæachlya perforans*. It is of course important to decide when the perforations were made. Were they forming contemporaneously with the growth of the coral and shell, or were they of subsequent date? In the first case the Silurian and Devonian age of the Achlyan becomes apparent; but if the second supposition be at all consistent with facts, the whole interest of the subject vanishes.

In favour of the theory of the simultaneous life of the host and the parasite, the theory of the growth of the Algæ in recent times must be advanced and the presence of sea-water and of animal tissue of a low vitality assumed. In addition there is the fact that a portion of a Brachiopod included in a sandy matrix within the coral, and not continuous with coral-structures, contains the tubes. Moreover the crystalline mass of the interstices of the coral, although it holds mechanically abundance of spores, does not present tubes or any evidence of growth. It is therefore in accordance with our knowledge to assert that the parasites lived at the same time as the organisms which they penetrated, and that this minute Alga presents one of the most singular proofs of the persistence of form and life-cycle from the palæozoic age to the present. In conclusion, I have to thank Mr. W. S. Dallas, Prof. Morris, and Mr. H. Woodward for references, suggestions, and sections.

The characteristic tubes of this Alga have been found by me in species of *Cyathophyllum* from the Upper Silurian, and in a Foraminifer from the Lower Silurian of Canada.

EXPLANATION OF PLATE XV.

- Fig. 1. Tubes in *Thamnastræa* from the Miocene of Tasmania, $\times 350$.
2. Tubes in *Goniophyllum pyramidale* from the Upper Silurian, close to the wall, $\times 350$.
3. Spores in *Goniophyllum pyramidale*, $\times 450$.
4. Tubes in the shell of a Brachiopod imbedded in *Goniophyllum pyramidale*, $\times 350$.

* See Micrographic Dictionary, 1875, 3rd edit. for these genera.



D. Blair F.L.S. del et lith.

Murtern Bros. imp.

PALÆACHLYA PERFORANS.

- Fig. 5. Tube with conidia, from an American Lower-Silurian Foraminifer, $\times 400$.
6. Tube near the edge of *Goniophyllum pyramidale*, showing the entrance of the tube from the outside, $\times 350$.
 7. Tubes in *Goniophyllum pyramidale*, alternately dark and light.
 8. Tubes with conidia in *Goniophyllum pyramidale*, $\times 400$.
 9. Tube of moniliform appearance from *Goniophyllum*, $\times 350$.
 10. Tubes cut across, showing their lumen, from *Goniophyllum*, $\times 350$.
 11. Tubes in *Calceola sandalina*, from the Devonian, $\times 350$.
 12. Large tube, opening at the surface of *Calceola sandalina*, reaching in but a short distance, and containing oospores, some of which have germinated and formed canals, which radiate from the end of the tube, $\times 400$.
 13. A similar tube from *Calceola sandalina*, containing oospores, $\times 400$.
 14. Tube with spherical spore-sac, from *Goniophyllum pyramidale*, $\times 350$.

DISCUSSION.

Prof. MORRIS expressed his agreement with the author's concluding remarks, and thought that the discovery of these low parasitic organisms so far back in geological time was especially interesting, as showing the identity of conditions in all periods. He remarked that another tubular structure different from those described by Dr. Duncan had been observed by M'Coy in *Pterinea demissa*, from the Wenlock Limestone, and referred to *Cliona*. This latter structure had also been observed in some Jurassic and Cretaceous Mollusca.

Mr. ETHERIDGE agreed with Prof. Duncan in regarding these parasites as Algæ, and remarked especially the similarity of the phenomena to those presented by many freshwater Algæ, referring especially to *Vaucheria*. The continuity of conditions of life thus manifested was, he thought, very remarkable. He stated that numerous sections of Scandinavian palæozoic Corals given to him by Sir Roderick Murchison were full of tubular forms like those described in the paper.

Prof. RAMSAY asked Prof. Duncan to state how much of the contents of his paper was to be regarded as new.

The AUTHOR, in reply, suggested that a similar question might just as well be put to the author of every paper. His new points were the establishment of the extension of these parasitic organisms to a much earlier period than any in which they had previously been recognized, especially their occurrence in the very ancient Corals to which he had referred, and certain particulars as to their characters and mode of occurrence. The parasitic Algæ could not be confounded with such sponges as that found by M'Coy or with *Cliona*, as their tubules were very much smaller than those formed by the sponge; in fact the tubules of the parasitic plants had about the same diameter as the spicules of *Cliona*.

24. *On the Occurrence of the RHÆTIC BEDS in LEICESTERSHIRE.*

By WM. J. HARRISON, Esq., F.G.S., Curator of the Town Museum, Leicester. (Read March 8, 1876.)

Good inland sections, exhibiting the junction of the Triassic and Liassic beds, are rather scarce in this country. I wish, therefore, to describe an exposure of the Rhætic beds near this town, which is of interest as proving the continuity of that formation and the remarkable persistence of lithological conditions in its strata; whilst the occurrence of some new species of fossils shows that our knowledge of the life of that period is, as yet, very incomplete.

These Rhætic beds are to be seen in three brick-pits situated at the northern extremity of the Spinney Hills, a low range forming the eastern boundary of the town of Leicester and the Soar valley (fig. 2).

The Rhætics form a capping to the hills at this northern end; but southwards, as the ridge rises, they are overlain by a thick covering of drift to the depth of at least 20 or 30 feet.

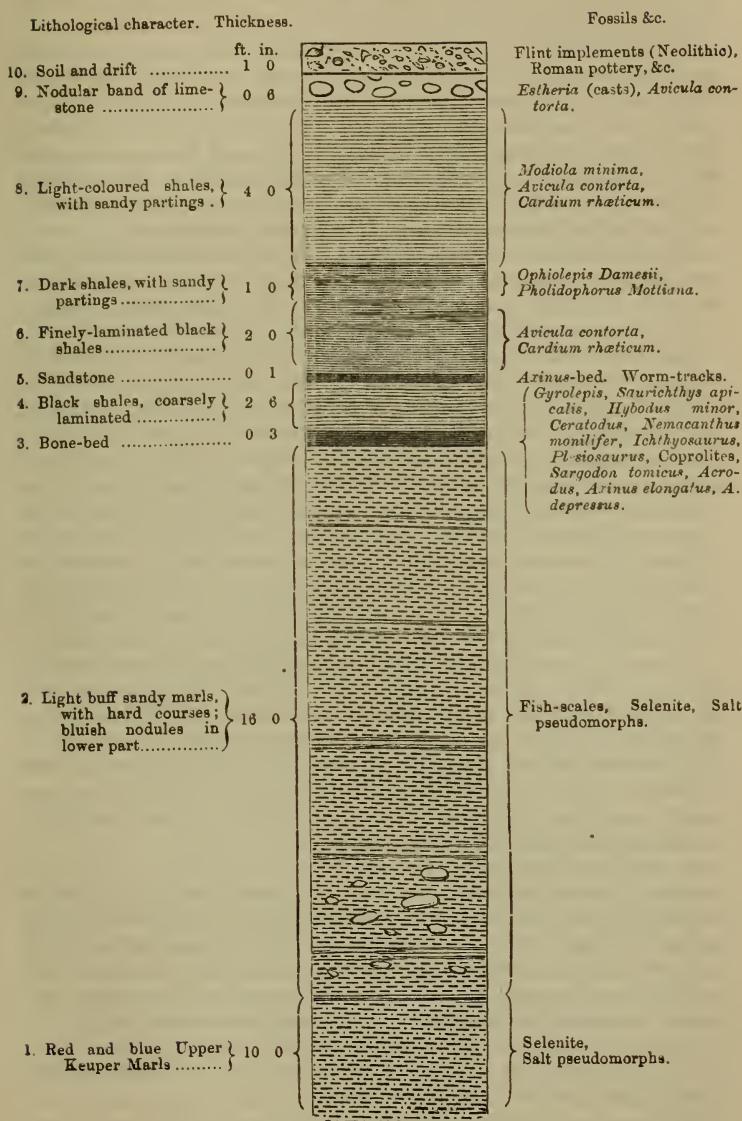
Eastwards the upper members have been denuded by a little stream, the Willow Brook, although the lowest bed (the Grey Marl) is nearly, but not quite, continuous right across to Crown Hill, where Lower Lias beds (yellow fucoidal limestones) first put in an appearance (see fig. 2).

The floor of the brick-pits just mentioned is about 10 feet deep in red Upper Keuper Marls. Descending sections in neighbouring pits and in the railway-cutting near the station show an alternation of Red, Grey, and Blue Marls to a depth of from 80 to 100 feet. It is noticeable that the relative thickness of the red bands becomes less as we approach the top. Selenitic crystals and salt pseudomorphs occur in these beds; but they have as yet exhibited no traces of life. A thick nodular band of gypsum occurs about 60 feet down.

Close to the eastern foot of the Spinney Hills a boring for coal has reached the depth of 741 feet (fig. 2). This commences just below the Rhætic Grey Marl, and passes through 690 feet of Keuper Red Marls containing much fibrous gypsum, and in the lower part thick red clays, and then enters a bed of sandstone, through which it is now passing. It would thus seem probable that these Triassic beds thicken in this direction; and as we are receding from Charnwood Forest (a Triassic island), this would be a likely consequence. Of the 51 feet of Lower Keuper Sandstone, the first 20 feet is described by Mr. J. A. Bosworth, F.G.S., the engineer, as a perfect quicksand, no solid cores being obtained. At Hinckley, twelve miles to the S.W., the Red Marls are of the same thickness, as proved by a borehole for water, of which a good supply was obtained, but too much impregnated with mineral matters for use; the same thickness of marl was also proved at Rugby, where the water was equally bad.

In the brick-pits the Rhætics are seen to rise nearly vertically for about 30 feet above the Red Marl, to which their stratification is

Fig. 1.—Vertical Section of Rhætic Beds, Spinney Hills, near Leicester.



parallel. The upper surface of the Red Marl, however, is somewhat uneven, being hollowed out here and there in long curves. There is a slight dip to the south-east. The bed which I consider to be the lowest member of the Rhætics is No. 2 in the accompanying section (fig. 1). It is a light buff-coloured hard sandy marl, some 16 feet in thickness, often of a greenish tint, with blue nodules here and there in the lower part. It is very much fissured, and has a conchoidal fracture. It is traversed by three or four courses of harder, whiter stone, which weather out from the rest, and are more laminated. Crystals of selenite are plentiful in this bed; and I have also specimens from it of pseudomorphic salt-crystals, and a slab showing ripple-marks. Small fish-scales are numerous, and dark brown markings as of vegetable matter. I have obtained a single insect-wing from this bed. Pittings, as of rain-drops, occur in all parts, and the upper surface is very uneven. This lowest Rhætic bed extends for some distance to the north and east of the Spinney Hills.

On the uneven upper surface just mentioned rests the bone-bed, a stratum not more than 2 or 3 inches in thickness. This bed is not easy to note on the "face" of the working, which is usually in a very "mashy" soft condition; and I had much difficulty in finding it. On digging back some distance it becomes comparatively hard; but its contents are then so brittle as to be very difficult of extraction. For the detection of the numerous small teeth, scales, &c. which it contains I have found the best plan to be to take home baskets full, which can then be sorted and examined at leisure with a lens. From this bone-bed I have obtained large vertebræ of *Ichthyosaurus*, numerous fragments of rib-bones, one probably of *Plesiosaurus*, about 18 inches long, together with numerous undetermined bones, some of which have a Labyrinthodont character.

Spines of *Nemacanthus monilifer* and *Hybodus minor*, teeth, scales, &c. of *Hybodus*, *Acrodus*, *Saurichthys apicalis*, *Sargodon tomicus*, *Gyrolepis*, *Ceratodus*, large Saurian teeth, worn and rolled bones, phosphatic nodules, coprolites containing fish-scales, &c. are all of more or less frequent occurrence in this bed. I have found in some coprolites small quartz pebbles, and fragments of sandstone precisely resembling the Upper Keuper Sandstone of the Dane Hills, on the opposite side of the Soar valley.

Pebbles of all sizes are numerous in this bone-bed. They are mostly quartzose or slaty, and rounded; many are 3 or 4 inches in length; and I should refer them all to our Charnwood-Forest rocks. All the bones are highly mineralized, being heavy, and of a brownish colour. Small concavo-convex bodies are common, much like *Discina* in appearance; these are probably the ends of bi-concave vertebræ, of which the central part has decayed away.

Two small bivalve shells (*Axinus elongatus* and *A. depressus*) occur loose in the bone-bed; they also occur in the "flinty bed" at Beer Crowcombe*.

Next above the bone-bed come about 2 feet 6 inches of coarse black shales (No. 4 in section), very pyritous, the fossils being

* Quart. Journ. Geol. Soc. vol. xvii. p. 503.

decomposed; and these are overlain by a thin irregular band of hard reddish sandstone from $\frac{1}{2}$ an inch to 1 inch thick, whose surface is covered with casts of *Axinus* (formerly called *Pullastra*).

Then come about 2 feet of finely laminated black shales (No. 6). It was this bed which, in February 1874, yielded me the first fossil evidence (*Cardium rhæticum* and *Avicula contorta*) by which I was enabled to prove these beds to be of Rhætic age.

From the next stratum (No. 7) in March 1874, I got a Starfish, the first found in British Rhætics. Curiously enough, the same species occurred, about that time, to Professor F. Römer in the Rhætic beds of Hildesheim*, whilst it has since been found by Mr. G. Embrey at Westbury-on-Severn. It has been determined by Dr. Wright to be his *Ophiolepis Damesii*. I have recently found a thin band in the shales almost made up of the remains of these beautiful Starfishes, their joints occurring by thousands. There are apparently at least two distinct species.

This bed (No. 7) consists of rather dark shales with sandy partings. Here I also found a new species of *Pholidophorus*, which I propose, provisionally, to name *P. Mottiana*, after my friend Mr. F. T. Mott, President of the Leicester Literary and Philosophical Society. *Avicula contorta* and *Cardium rhæticum* also occur. There are, too, some curious oval markings, with fine striæ radiating from the centre; but these may be inorganic. Worm-tracks are numerous. A white amorphous mineral, Kaolinite, with a little bitumen, fills many fissures in these beds of shale; and the cavities left by radiating selenite crystals cover the surfaces in great abundance. Flakes of mica spangle many of the sandy partings which occur in the upper part.

The uppermost shales seen in the section (No. 8) are very light in colour, and about 4 feet thick. All the shells already mentioned occur in them, together with *Modiola minima*.

Indications of a bed of hard rubbly limestone are to be seen capping the brick-pit sections. Drainage-operations higher up the crest of the Spinney Hills, in connexion with new streets to be built there, have, however, lately offered a good opportunity of examining beds somewhat higher in the series than those already noticed.

The bed of limestone (No. 9) is nodular, the nodules occurring at intervals of a foot or more. They are intensely hard, but soon break up into cubical masses on exposure to the air, being traversed in all directions by cracks filled with calcite. I have recognized this limestone as entering into the composition of Roman pavements found in Leicester; it would, in fact, present ready-made tesserae to the hand of the artisan. It has a conchoidal fracture, and is of a bluish tint, but grey on the outside. Fossils are very rare in it; but I have found casts of *Estheria minuta* and *Avicula contorta* on the outer surfaces.

A second nodular bed of limestone exists, I believe, about 2 feet above the one just mentioned, and then beds of light-coloured clay and sand; but here the drift obscures the section, and, as it thickens

* Zeitschr. d. deutsch. geol. Ges. 1874.

rapidly along the crest of the hill, prevents further investigation. The existence, however, of beds higher in the series is shown by the occurrence of blocks of limestone in the drift, with *Monotis decussata* and *Anoplophora musculoides*.

I have found further traces of the Rhætics at a point about a mile north of the Spinney Hills, near the site of the Borough Asylum; and I believe Mr. R. Etheridge, F.R.S., has noted their occurrence at a spot about 9 miles further north between Barrow and Sibley. I noted them here during the widening of the Midland main line in 1873, and the section is mentioned by Mr. H. B. Woodward (Geol. Mag. 1874, p. 480).

Still further to the north-east the same beds have been cut through near Stanton by the railway now in course of construction from Nottingham to Melton; but here, again, the higher Rhætic beds seem to have been much denuded. The nearest southern exposure seems to be at Copt Heath, near Knowle, in Warwickshire, as noted by the Rev. P. B. Brodie (Quart. Journ. Geol. Soc. vol. xxx. p. 746).

In the deep boring for water at Rugby the Rhætics were reached at a depth of about 450 feet. The black shales were there 8 feet thick, and the hard sandy marls beneath about 10 feet.

Although good sections of the Rhætic beds are rare in Leicestershire, yet the line of outcrop of the strata can be clearly traced from Leicester northwards, forming the eastern boundary of the Soar valley, and varying from a quarter to about half a mile in width. Southwards the great thickness of drift makes an exact tracing difficult.

At Crown Hill (fig. 2) I have lately detected, in the preliminary works for the Great Northern line from Melton to Leicester, certain beds of limestone, called in Warwickshire the "Firestones" and "Guineas," which mark the passage of the Rhætics into the Lower Lias, together with a thick bed which is probably true White Lias. The cutting here will, I believe, exhibit a very interesting series of beds, and enable us to trace the succession for a long way up.

Wherever the true junction of the Lias and Trias is exposed in this country, the Rhætic beds appear to be invariably present. In 1874 I examined a fine section exposed in widening the Midland main line between Leicester and Wigston, which seemed to contradict this; Lower Lias Shales and Limestones, with *Ammonites planorbis*, appeared to be resting on Upper Keuper Marls. A close examination of the latter, however, showed them to be recomposed stuff; the Rhætics had been eroded, probably by glacial action, and their place filled with transported material.

I am much indebted to the Rev. P. B. Brodie, Messrs. W. H. Hudleston, W. Davies, L. C. Miall, C. Moore, and others, for their kind assistance in the determination of specimens.

The students in my science classes, especially Messrs. J. E. Elgood, J. R. Plant, L. H. Llewellyn, and W. J. Harrison, jun., have rendered valuable aid in searching the beds.

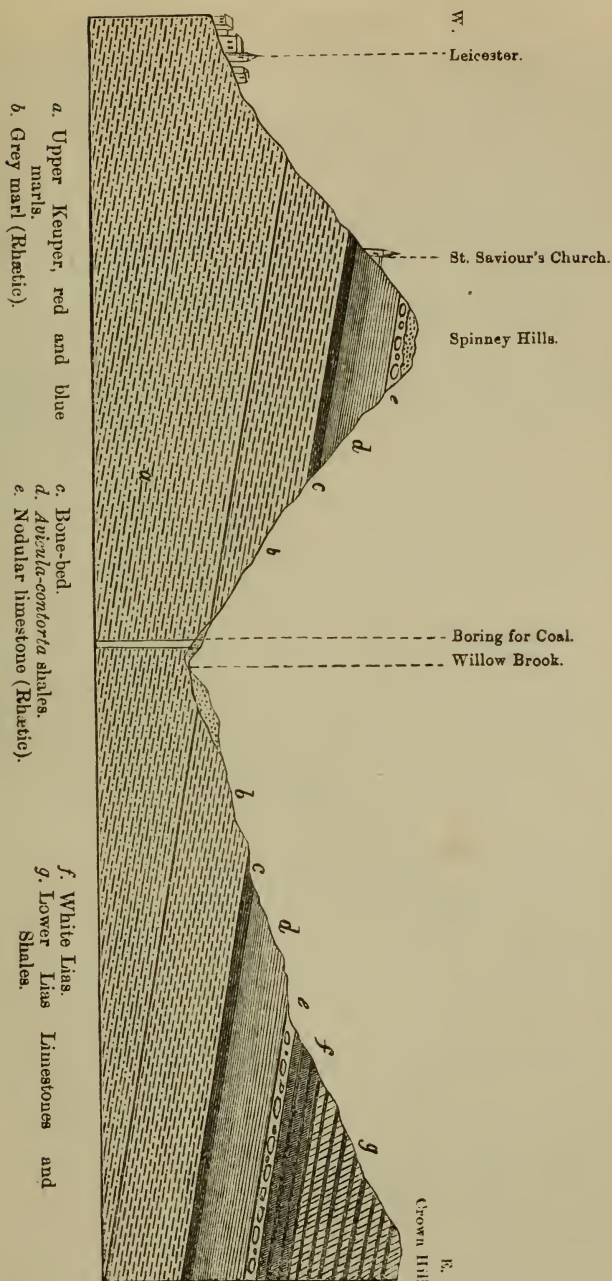


Fig. 2.—Diagram Section across the Valley of the Willow Brook, at Leicester.

DISCUSSION.

Prof. T. RUPERT JONES referred to Mr. Harrison's exactness and praiseworthy energy in working out the geology of Leicestershire, and also alluded to the enlightened and liberal support of science on the part of the Corporation of Leicester. He remarked that some of the bones found in the Bone-bed of the Spinney Hills were of large size and apparently perfect.

Mr. JUDD pointed out the great interest and value of this new exposure of Rhætic strata which had been so admirably described in Mr. Harrison's paper. Hitherto we had no knowledge of any sections of the beds of this age between those of the Warwickshire outliers described by the Rev. P. B. Brodie and that seen at Newark.

Prof. SEELEY wished to correct an error into which he had fallen in describing a species of *Tanystrophæus* from Leicester. He had ascribed it to the Rhætic beds; but it was really from the Keuper.

25. *On the PHYSICAL HISTORY of the DEE, WALES.* By Professor A. C. RAMSAY, LL.D., F.R.S., V.P.G.S. (Read April 26, 1876.)

[PLATE XIV.]

THE surface of Bala Lake is 600 feet above the level of the sea, and is bounded on the north-west and south-east by hills that near the lake have elevations of about 1200 and 1300 feet, and therefore rise to heights of 600 and 700 feet above its level, while at greater distances, but still not far off, they rise to heights of 1800 and 1900 feet. On the south-west there is a long gentle slope, which attains a height of about 800 feet above the sea at the watershed close by the road to Dolgelli, or 200 feet above the lake, beyond which the river Wnion drains the country in a south-westerly direction into the estuary of the Mawddach.

The lake is about 130 feet in depth; and at its north-eastern end the waters of the Dee, escaping from this basin, first traverse an alluvial tract nearly three miles in length, the detritus of which has been carried from the adjoining hills by rivers, the largest of which enters the Dee near Pont Treweryn, about half a mile below Bala. Other good-sized streams form tributaries of the Dee below this point, and have helped to distribute the materials of the alluvial plain, beyond which, for a space of about a mile, the hills close in upon the banks of the river between Glan-dwynant and Pont Llanderfel. Between this point and the neighbourhood of Corwen, the river, for more than six miles, again wanders through broad alluvial flats, after which it flows in many curvatures, sometimes making great loops, between the steep slopes of the vale of Llangollen, which form the high and often flat-topped hills of Wenlock shale and slate, that sometimes, not far from the river, slope up to 800 and 1200 feet above its banks.

Leaving this part of the valley, the Dee, with an exceedingly tortuous course, cuts through the marked escarpment of the Carboniferous rocks of the Denbighshire coal-fields east of Llangollen, and, passing through a less elevated tract of Permian strata, emerges on the low undulating country of New Red sandstone south of Chester, and finally, by a winding channel, enters the large tidal estuary known as that of the Dee.

Emerging from the Permian region at Erbistock, the country through which the Dee flows to Chester may still be called a valley, in so far that, miles to the west, there rises the long slope of Permian and Carboniferous strata, while the eastern boundary is formed of the escarpments of Keuper Sandstone of the Peckforton Hills and Delamere Forest. Eliminating the minor modern effect on the scenery produced by a shroud of glacial drift, with other geologists I do not doubt that before the Glacial epoch the contours of this wide valley were much the same as now, or, in other words, that, like the valley of the Mersey and others in the west of England,

it is preglacial. The broad features of the history of this part of the valley are sufficiently obvious; but from Erbistock to the source of the river in Bala Lake, the case is different; and the physical history of that long and often steep-sided river-valley has, as far as I know, not been analyzed.

At Holt, seven miles south of Chester, the river is about 100 feet above the level of the sea; near Erbistock, eight miles further south, where the valley enters the Permian strata, about 225 feet; in the vale of Llangollen, four miles west of the town, about 475 feet; near Corwen, about 500 feet; while the level of the lake where the Dee rises is only 600 feet above the level of the sea. The fall, therefore, from Erbistock to Chester, where the river is tidal, is about 225 feet in a north and south distance of 15 miles as the crow flies, and from Bala Lake to Erbistock about 375 feet on a direct line nearly east and west; so that the average slope is nearly the same the whole way, or about 15 feet per mile, taking no account of the numerous minor curvatures of the river.

I have said in previous memoirs that the main great contours of Wales were approximately the same as now, before the beginning of the Glacial epoch, and that all the glacial striations of the mountain regions of North Wales correspond to the trend of the greater valleys. The chief effect of the glaciers was therefore to grind and smooth the rocks into *moutonnée* forms in the bottoms of the valleys and on the sides of the mountains, and in doing this more or less to deepen and widen these valleys, and here and there to scoop out those rock-bound lake-basins so common in all old intensely glaciated regions, of which Bala Lake is one. The proof of its being a true rock-basin is simple.

At present the outflow of the lake is through an alluvial flat, the western end of which helps to dam up the water. But this alluvium, as already shown, is the gift of the tributary rivers that here enter the Dee. In older times the lake was more than double its present length; for while a mile and a half of delta at its south-western end, where the river Wnion enters, marks its ancient extent in that direction, the sheet of water also once extended $2\frac{3}{4}$ miles east of Bala over the area now occupied by alluvium, giving the ancient lake a curved form, before torrents and rivers from the north and south filled that space with detritus borne down valleys that penetrate far in among the hills. The effect of this is, that the lake now is little more than $3\frac{1}{2}$ miles long, while formerly it was 8 miles in length.

Bala Lake being 600 feet above the sea, and about 130 feet deep, its bottom is 470 feet above the sea-level: and probably its rock-bottom may be deeper still; for two large and three small streams enter the lake on either side as it now stands, in addition to the main rivers of Afon Llyn, and Dwfrdwy, which have deposited the delta at its south-western end; and doubtless the bottom of the lake, by means of these rivers, may be covered with detrital matter.

But even assuming that the present depth of the lake represents its rocky bottom, the fall of the river is only a few feet in the whole

of the alluvial tract at its eastern end. Beyond this the Dee runs through a narrow valley, with solid rocks down, or almost down, to its banks, where in older times the original outflow of the Lake was; and it may be considered certain that the old point of outflow is a true rock barrier. If, however, there should still be any doubt about this gorge having formed the original rocky dam of Bala Lake, there remains other evidence on the question of its being a true rock-basin; for, about two miles further on towards Llandrillo, the rocky bottom of the river is from 500 to 510 feet above the sea, while the bottom of the lake is only 470 feet above that level; and even beyond this, at the ferry halfway between Corwen and Llangollen, 14 miles in a straight line E.N.E. of the lake, the rocky bottom of the river is about 475 feet above the sea, or 5 feet above the bottom of Bala Lake. As there is not, and never could have been, any other possible outlet for the water of the lake than the channel of the Dee, it is quite certain that it lies in a rock-bound basin; and indeed it seems to me more than likely that the large alluvial flat more than six miles in length between Llandrillo and Corwen may conceal one or more lake-basins, now filled with detritus brought down to the hollow by the numerous streams, large and small, that, over this space, now form tributaries of the Dee*. Similar alluvial flats, once lake-basins, are common in many old glacier-valleys in Switzerland, Cumberland, Scotland, and elsewhere.

The glaciers that did this work of erosion came chiefly from both sides of Aran Mowddwy, down Cwm Croes and the valley of Dwfrdwy; and these converging near where Llanuwchllyn now stands, and aided by other tributary ice streams, scooped out the basin of Bala Lake, and went far beyond its ancient boundary, *in a valley older than the beginning of the Glacial epoch*, like all the other great valleys of Wales.

Such being certainly the case with this upper part of the valley of the Dee, it is natural, and indeed inevitable, to suppose that the further continuation of the valley towards and beyond Llangollen is also of preglacial origin; and this, in my opinion, seems to be strengthened by the erratic blocks and glacial striations mentioned by Mr. Mackintosh in a memoir on boulders and erratics in Denbighshire, even though the author seems doubtfully to attribute some of these striations to the action of floating ice†. If, for the sake of argument, we assume that this part of the valley (unlike the upper part) is not preglacial, then the mass of country through which it runs must have formed a dam to the drainage of the waters of the upper Dee, which would have had the effect, even if these waters were only raised 200 feet, of filling with a lake ramifying in all directions among the hills, vast tracts of Merionethshire. Of this supposititious lake there is no sign whatever.

* All the heights mentioned above were determined by angular measurements with the theodolite by the late Professor Jukes, Mr. Aveline, and others. They are therefore not to be depended on within a few feet; but any possible errors of this kind are too small to affect the general argument.

† Quart. Journ. Geol. Soc. vol. xxx. p. 711 (1874).

Beyond Erbistock, where the Dee leaves the hills, and all down the estuary, the valley is undoubtedly preglacial, in so far that the country is largely shrouded by glacial drifts.

The question thus arises, by what means was the valley of the Dee excavated, and if it be possible to discover during what geological epoch that excavation began.

The valley, in some aspects, may be compared to that of the Moselle, the physical character of which I have elsewhere indicated*; for, especially east of Corwen, between banks of Wenlock shale or slate, that form a high and much-eroded tableland, the Dee winds in many a curve, two of which, about two miles above Llangollen, form great loops, closely resembling the well-known loops of the Moselle above Alf. In both rivers a steep rocky high bank is apt to be opposed to the concave curve of the stream, while, on the opposite, or convex side, the ground generally rises from the river with a long and gentle slope. This form of ground is characteristic of many rivers that flow through deep valleys, the elevated ground of which on either side is more or less flat-topped, and invariably indicates a long-continued course of fluvial erosion, begun at first by a wandering river on a high and slightly undulating tableland or plain.

The Silurian rocks of the region now called North Wales underwent great disturbance and erosion, both atmospheric and marine, both before and during the deposition of the Carboniferous Limestone—one result of this being that as the country was in great part slowly submerged the limestone series was laid in a very unconformable manner on the denuded edges of both the Lower and Upper Silurian strata.

The high escarpment of Carboniferous Limestone in Denbighshire facing west clearly shows that this limestone once extended a great deal further in that direction across much of the Lower Silurian rocks of the Berwyn Hills and the Wenlock slates and shales that form the high land on either side of the valley of the Dee. This fact, if it needed confirmation, is further proved by the well-known outlier of Carboniferous Limestone that lies, far in among the hills in the valley of the Dee, two miles west of Corwen, ten miles distant from the nearest point of the escarpment, and six miles from the limestone at the southern end of the Vale of Clwyd. This little patch, which occupies an area of something less than three quarters of a square mile, lies quite unconformably on the Wenlock shale on its south-western side, while on the south-east and north-east it is, as it were, dovetailed into the Silurian strata by two faults; and as its thickness, according to the late Professor Jukes, may be about 2000 feet, it is clear that the Carboniferous Limestone, *in force*, once spread well across this and the neighbouring region.

Furthermore, everywhere to the east in Denbighshire and Flintshire, the limestone is overlain by the Millstone Grit and Coal-

* Physical Geology and Geography of Great Britain, chap. 15.

measures; and I have no doubt that these upper Carboniferous strata at one time also spread far to the westward above the limestone across those parts of the Silurian strata now under review; but how far, it may perhaps be impossible to determine. I feel certain, however, that what is now the high mountain region of Snowdonia, at that time very different from its present form, was never, except on its low western outskirts, covered by Carboniferous strata.

The statement that so much of Wales was once buried beneath Carboniferous rocks is, at first sight, somewhat startling, involving, as it does, such large revolutions in the physical geography of the district in early times.

First. An immense amount of denudation undergone by the Silurian rock before the deposition of the Upper Old Red Sandstone (which sparingly exists in North Wales) and the Carboniferous Limestone*.

Secondly. It appears to me that this waste was accompanied by a gradual depression of the old land, so that, over part of Wales, what, many years ago, I termed "a plain of marine denudation" was produced, similar to that well-known high plain of Carboniferous Limestone and Old Red Sandstone of the Mendip Hills, on which the Liassic and Oolitic strata lie unconformably. In like manner the Carboniferous Limestone overlain by Millstone Grit and Coal-measures, covered in flat-lying strata the much older Silurian plain of marine denudation.

Thirdly. By succeeding changes of physical geography after the deposition of the Millstone Grit, the region was converted into part of one of those vast deltas, or at all events broad swamps, undergoing slow intermittent depressions, during which the Coal-measures, with all their successive terrestrial growths, were formed.

Fourthly. The region was again disturbed and elevated before and during the deposition of the Permian strata, which, taken on a large scale, often lie unconformably on the Coal-measures, and were, in my opinion, true continental deposits. Then by slow degrees, under subaerial agencies, a vast amount of the Carboniferous rocks were removed from above the Silurian formations, and the plain of marine denudation was again to a great extent exposed, not less high, but probably even more elevated than it is now, lying as it then did in the midst of a broad continental area.

This plain (or, rather, its relics) is of much wider extent than that part of it with which I am now concerned, lying on either side of the valley of the Dee; for beyond that area it extends far and wide into the northern part of Denbighshire, and also into Montgomeryshire and South Wales. Standing on the summit of Cader Idris or of Aran Mowddwy, 2960 feet high, and looking east and south, the eye, as far as it can reach, ranges across a vast extent of old table-

* This amount could be approximately estimated by any one who would take the pains to restore the pre-Carboniferous anticlinal curves of the Silurian strata; but the doing of this in detail is not essential to my present argument. For the method see memoir "On the denudation of South Wales," etc., *Memoirs of the Geological Survey*, vol. i. 1846.

land, the plane surface of which near the Arans is about 1900 feet above the level of the sea, or more than 1000 feet below the summits of the neighbouring mountains. All intersected by unnumbered valleys, to the ordinary observer it is merely a hilly country, while an eye versed in physical geology at once recognizes that all the diversities of feature are due to fluvial erosions that have scooped out the valleys.

This brings me to the main object of this memoir, the origin and geological date of the valley of the Dee.

The country having been upheaved after the deposition of the Carboniferous strata, and a large part of these strata having been removed by denudation, the valley of the Dee did not then exist, or existed only in a very rudimentary stage on the surface of a wide slightly undulating tableland having a gentle slope towards the east. It was then that first the Permian rocks were deposited, and afterwards the New Red Sandstone and Marl; and it may be recollected that, at all events in my opinion, both sets of these formations were deposited in inland salt lakes or seas. During these epochs, therefore, I hold that the old tableland lay high above the level of the sea, probably even higher than it does now, and that it formed part of a wide continental area.

After the Trias came the Jurassic formations, deposited around groups of islands in shallow seas, the effect of partial submergence of an older land, and themselves, in the middle and north of England, partly of fluvial origin, the result of minor oscillations of level. Then followed the long fluvial conditions under which the Purbeck and Wealden beds were deposited, during which epoch the greater part of what is now Britain must have remained as part of a much larger land. After this came the Cretaceous formations, the lower half of which in the British area were certainly deposited near shore; while in later times, during the deposition of the Chalk, there is no proof that the higher parts of Wales were submerged, but rather the opposite. Later still come the Eocene deposits, some of them of freshwater origin, and which in a large sense may be regarded as estuarine, even including the London Clay, which seems to have been formed at the mouth of a great river such as the Amazons or the Ganges. Our Miocene rocks are unmistakably of terrestrial and freshwater origin; and the different members of the Crag were mere eastern shallow-sea or shore deposits.

It thus appears that, since the beginning of the Permian epoch, the higher ground of Wales has formed land well raised above the level of the sea; and even if there be some doubt about this with respect to the time of the deposition of part of the Chalk (to which doubt I do not attach much importance), that must have been but a short episode when compared with the whole of the terrestrial period.

During that long lapse of geological ages, there was therefore ample time for the action of all the ordinary processes of subaerial denudation, the most powerful of which is the action of rain, rivers, and glaciers.

In the most elevated parts of North Wales, the height of the highest mountains as they now stand between Cader Idris, Aran Mowddwy, and Snowdonia varies from about 2900 to 3571 feet. During the time of submergence, when the ground further east was buried under Carboniferous strata, the western mountain region stood well above the level of the sea, and higher relatively to the plain of denudation than it does now; for long before the Carboniferous epoch, and ever since that time, it has suffered from unceasing subaerial degradation, and long-lost hills and valleys must have prevailed in that old land, the shape of which it is now vain to speculate about.

Outside of this region, after the partial removal of the Carboniferous rocks, there lay, as already said, a wide tableland, extending far to the south, and also to the east and north-east. In the latter district this tableland sloped gently north-easterly and easterly; judging by those elevated parts of it that still remain more or less entire, in a distance of about 30 miles between Aran Mowddwy and the highest part of the Carboniferous escarpment, not far north of the Dee, the slope probably fell in height 700 or 800 feet, at an angle of about 14° , equal to 23 feet in a mile.

When by the drainage of this old land, the Dee began to flow in its earliest channel, induced by minor undulations of the ground, it is clear that its present source, Bala Lake, had no existence; for whereas the river at that time must have flowed on a surface of land not less high than that on either side of the present valley near Corwen and Llangollen (now, in places, from 1600 to 1800 feet high), the surface of Bala Lake is only 600 feet above the level of the sea, while the neighbouring watershed between the lake and Dolgelli is only 200 feet higher. As the river could not flow up hill, it is clear that in that early stage of its history the valley of the Dee about Bala must have been at least from 1300 to 1400 feet higher than it is now, and consisted of a mass of Silurian rocks, great part of which has since been removed by denudation.

As that country, according to the view already stated, has in the main been land ever since the Permian epoch, it seems to me that this waste of rocks was essentially produced by watery erosion, aided in a much less degree at a late epoch by glacier ice; and thus it happened that the Dee, a river of very ancient date, wandering hither and thither, by degrees deepened its channel in the same manner that the Rhine and the tortuous Moselle have cut out theirs, as described in my memoir "On the Physical History of the Valley of the Rhine"*.

For this reason it also happens that the Dee now cuts right across the Carboniferous escarpment west of Erbistock and the lower area of the Permian strata; for when the Dee began to run, the Carboniferous escarpment had no existence, and the strata of these formations stretched further to the west, ending along some line now unknown in a sort of feather edge, and forming part of the

* Quart. Journ. Geol. Soc. vol. xxx. (1874), p. 81.

great inclined plane over which the Dee ran at a level hundreds of feet above the bottom of its present valley. By and by, as the river-channel deepened, the escarpment began to be formed, its face sloping in a direction at right angles to the general dip of the strata (after the habit of all such escarpments), by a process of recession that has often been explained. The whole was strictly analogous to the manner in which the rivers of the Weald acted at a later date, as described in 'The Physical Geology and Geography of Great Britain'—and also for the same reason that the Thames now cuts across the escarpment of the Chalk, as described in my memoir "On the River-courses of England and Wales"*.

Escaped into the low country of the New Red series, the history of the Dee becomes simple, and requires no special illustration.

But this process of ordinary fluvial erosion is not the only agent that has been at work in Wales; for in late geological times the Glacial epoch supervened, and the moving ice of thick glaciers exercised a strong abrading power. Then it was that in the mountain-region of the west so many lake-basins were scooped out, and among others the rock-bound basin of Bala Lake; and though the face of the country is always being slowly changed, the time that has elapsed since the close of the Glacial epoch is comparatively so short that the large essential rocky features of the region traversed by the river have since that time undergone no important alteration.

I shall conclude with a few words about the length of geological time occupied in the excavation of the valley.

It may be remembered that in the paper on the excavation of the valley and gorge of the Rhine, I explained that the work of scooping it down to the present levels of the river has been accomplished since the close of the Miocene epoch, and that the direction of the flow of its water then and now is connected with changes of physical geography brought about by a great post-Miocene disturbance of the Alps.

The height of the old high-level terrace or old bed of the Rhine is about 400 feet above the present river; and the same is the case with its tributary, the Moselle. The height of the relics of the old plain of marine denudation above the Dee where it passes through the Wenlock strata is, to take a low estimate, not less than from 1100 to 1200 feet; and the time occupied in cutting that depth extends from the Permian epoch down to the present day. The depth excavated in that period of time is not less than three times as great as that performed by the Rhine and Moselle; and I think no geologist will doubt that the time that elapsed between the Permian and Miocene epochs was much more than three times the length of that which has elapsed since the close of Miocene times down to the present day. The Dee is but a petty stream when compared with even the smaller of the two German rivers; and it is obvious that the greater the body of water in a river, taken

* Quart. Journ. Geol. Soc. vol. xxviii. (1872), p. 148.

in connexion with the angle of its fall, the more powerful is its erosive force; and this may account for the proportionately much greater amount of time taken by our little river in the work of excavating its valley as compared with the work done by the Rhine.

This great lapse of time also accounts for what I may call the ruinous state of the old tableland that lies on either side of the valley through which the Dee flows; for in the long geological ages that the region has remained as land there has been ample time, as the river gradually excavated its valley to lower levels, for the drainage from the north and south to cut out tributary valleys, which by watery erosion got deeper and deeper in proportion to the gradual excavation of the main artery of the valley of the Dee; and thus it happens that what was once a long slightly undulating inclined plane has by degrees been converted into a very hilly country, simply by the power of rain and running water, and, in a minor degree, for a time by glacier ice.

According to these views the sum of the whole matter is:—

1. That after the last important disturbance of the pre-Permian rocks, North Wales was carved by slow degrees and by subaerial agencies into its present mountainous form, chiefly between Permian times and the present day.

2. That by far the greater part of that valley-excavating work was performed between Permian and pre-Glacial times.

3. That the work of the glaciers of the latter period somewhat deepened, widened, smoothed, and striated the outlines of the mountains and valleys, and excavated many rock-bound lake-basins, but on a grand scale did not effect any great changes on the preexisting larger contours of the country.

4. That a minor submergence of part of Britain during part of the Glacial epoch produced no important effects on the large outlines of the rocky scenery.

5. That the effects of subaerial waste subsequent to the Glacial epoch have been comparatively small, simply for lack of time.

I may also remark that the method of analysis employed in this paper is, I am convinced, applicable, with variations, to the reading of the history of all the more important rivers of Wales, to Cumberland, and to much of Scotland.

Facts of a broad kind, setting forth the general principles of watery erosion, have been well known ever since the days of Hutton—though for long, with a large class of geologists, his views fell into undeserved neglect. The subject, indeed, with some definiteness, is far older than Hutton; for it was insisted upon by Ray, who, while the fourth edition of his ‘*Physico-Theological Discourses*’* was passing through the press, was surprised and delighted to find that his opinion had been anticipated by Josephus Blancanus, in his book ‘*De Mundi Fabricâ*,’ in which he stated, among other physical matters bearing on modern geology, that “our Appenine was at first

* Edit. 4, p. 359.

one continued, even, eminent ridge of land, not divided into particular mountains and hills by intervening valleys, as now it is, but that *after the rivers began to flow down from the top of it*, by little and little fretting and corroding the ground, they made valleys, and daily more and more; and by this means the whole Appenine came to be divided into many hills and mountains."

It is not, however, to insist on these simple principles, enlarged by modern research, *versus* unnumbered unproved open faults, fractures, and tumultuous splittings of mountains, that this paper has been prepared; but having already written on the physical history of rivers both foreign and British, the details of which, comparatively simple, only grew on my mind by slow degrees, I have at length fallen on the Dee as an example of one of many rivers, the history of which is much more complicated than, for example, that of the Po, the Rhine, the Severn, or the Thames; and I hope I have succeeded in unravelling that history. If so, the Dee, as a living river, has a history compared with which those of the Thames, the Rhine, the Ganges, and many other great rivers of the modern world are matters of yesterday.

DISCUSSION.

Mr. THORPE stated that Arenig Lake, and not the Bala Lake, was the source of the Dee, and wished to know what origin Prof. Ramsay attributed to the former.

Mr. HICKS considered that the author's explanation of the origin of the lake and the gorge through which the Dee afterwards flows was not a correct one, and that these hills were only elevated at the close of the Palæozoic period, and not, as maintained by the author, in Silurian times. In a previous paper Prof. Ramsay claimed that the Menai Straits had been excavated by a huge glacier moving from N.E. to S.W.; whilst in the present communication he attributed Bala Lake to a glacier moving in exactly the opposite direction. Now, as the valley of the Dee and the basin of Bala Lake are roughly parallel to the Menai Straits, they should have been formed by the same glacier. Neither, however, is due to glacial action; but both are produced by two parallel faults that were formed at the close of the Palæozoic period.

Prof. SEELEY inquired what grounds there were for attributing such an ancient date to the Dee. There was no proof that the Lias had not formerly extended over this district. With regard to this old tableland, which the author considered to have been formed in pre-Carboniferous times, and subsequently covered by Carboniferous strata, he thought it was impossible that these Carboniferous strata could have been denuded and the old tableland left intact. The water running off the land as it rose would form the first valley; and both would suffer together.

Prof. RAMSAY, in reply, stated that he considered Bala Lake to be the commonly acknowledged source of the Dee. The Arenig lakes were also due to glacial action. He had treated the disturbances of

[To face page 228.]

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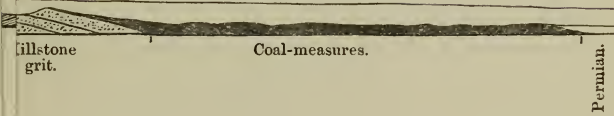
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General slope of old inclined tableland.

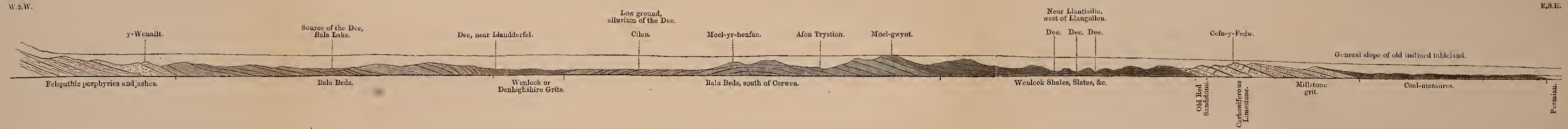


Millstone
grit.

Coal-measures.

Permian.

Section, to scale, along the Course of the Valley of the Dee, on line C-D of Map, Plate XIV.



the Lower and Upper Silurian rocks as occurring at one time for the sake of convenience, there being no unconformity locally visible in this area. There was no fault down the Menai Straits, though faults occurred to the right and left of it. The point which Prof. Seeley had raised was an important one, and one which it was difficult to give a direct reply to. The Carboniferous strata, by covering the tableland, would in a great measure tend to preserve it. They probably thinned out towards Snowdon.

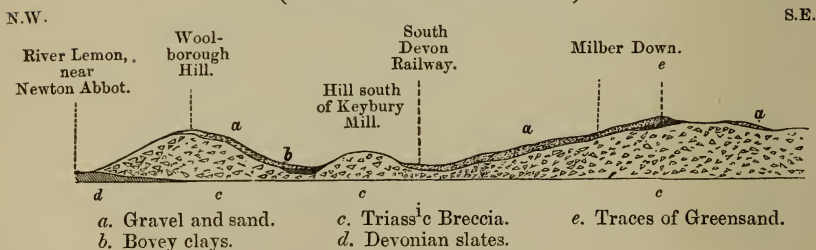
26. NOTES on the GRAVELS, SANDS, and other SUPERFICIAL DEPOSITS in the NEIGHBOURHOOD of NEWTON ABBOT, DEVONSHIRE*. By HORACE B. WOODWARD, Esq., F.G.S., of the Geological Survey of England and Wales. (Read April 5, 1876.)

THE visitor to Newton Abbot cannot fail to be struck with the number of sand- and gravel-pits, some of great size, which are scattered about the neighbourhood, not only in the valleys, but high up the slopes of the hills, and in several instances on their summits.

On giving some attention to the character and distribution of these deposits of sand and gravel, it will be found:—*first*, that two main divisions may be made in them, namely those of an evidently alluvial character, and those which occupy positions quite unconnected with the present systems of drainage; and, *secondly*, that these latter deposits are nevertheless confined to the Bovey Basin and bordering hills, not descending into any of the other lateral or outlying valleys.

A reference to the geological maps of the country will not serve to throw much light on the correlation or identification of the beds when they are examined in detail. But since the days when De la Beche and Godwin-Austen recorded their observations, many new sections have been opened up. The rapid growth of Torquay and Newton Abbot has been attended by a call for sand, which is largely used in the preparation of “cobb,” a kind of plaster, unfortunately necessary to envelop and keep the damp out of houses for the most part built of marble.

Diagram Section from near Newton Abbot to Milber Down.
(Distance about three miles.)



The examination of these sections, together with those dug for the foundations of new villas on Woolborough Hill, has led me to differ from the opinions and conclusions which have been hitherto accepted.

Since Mr. Godwin-Austen's paper was published †, no particular

* This paper is communicated by permission of the Director-General of the Geological Survey of the United Kingdom.

† Trans. Geol. Soc. 2nd series, vol. viii. p. 433.

account of these deposits has been given; but in 1867, in an address delivered to the Devonshire Association at Barnstaple, Mr. Pengelly observed that it may be doubted whether all the localities so represented in the maps of the Geological Survey are really true Greensand localities.

While engaged in carrying on the Geological Survey in the neighbourhood of Newton Abbot (1874-75) for the new edition of Sheet 22, I was for some time sorely perplexed with the various sands and gravels met with. To give one instance:—certain sandy beds opened up in front of my own house were at the first glance thought to be Triassic; a short examination led me to class them doubtfully as Greensand; further observation caused me to regard them as possibly Bovey beds; and before I left the country I was persuaded that they were Drifts, using this last term in its conveniently indefinite sense.

The fact is, the sections vary very much in detail. There is sand, gravel, clay, and fine sandy clay, sometimes dovetailing one into the other, but sometimes forming individually the entire mass of the open sections; so that the geologist familiar with the Greensand of Haldon and the Blackdown Hills may recognize some beds similar in character to that deposit; and if he be acquainted with the sandy strata of the Bovey formation, he may, in isolated sections, be puzzled to discriminate between the two.

The examination and comparison of the numerous fine sections, and, above all, the tracing of the beds on the ground, prove the connexion of deposits that might otherwise be considered distinct, and have led me to class all the sands and gravels in the neighbourhood of Newton Abbot, with one or, at most, two exceptions, as certainly of an age posterior to the Bovey beds.

Beds regarded as Upper Greensand have been mapped on Woolborough Hill and Milber Down, at White Hill, Staple Hill, and near Kingsteignton. At each of these localities there are beds of sand that, on lithological grounds, might be identified with the lower beds of the Greensand series; but, except at the very summit of Milber Down, and perhaps also near Coombe Farm, north of Sandy Gate, there is evidence for connecting them with the coarse gravels containing fragments of Greensand chert and Chalk flint, thus indicating their post-Cretaceous age; while, again, the fact that in places the gravels and sands overlies the clays of the Bovey formation at once indicates their age to be still more recent.

The sands are generally composed of quartz, sometimes rounded, sometimes angular; and they graduate into gravel or shingle, composed of pebbles of quartz, grit, &c.; and these pass into or become interstratified with very coarse gravel-beds, composed of large blocks and pebbles of grit and chert, flint and quartz. All the fragments are apparently of local derivation.

Some sections show only sand, as at Whitehill and in the Torquay road at Newton Abbot; others display only gravel, coarse, rolled and angular, as shown in several pits on the summit of Milber Down. Again, some of the largest pits exhibit all the different kinds of de-

posit in ever varying order, and very irregularly accumulated; such are the pits on Woolborough Hill, near the base of the Milber Down, and Kingsteignton. Here white clay, coarse gravel, fine and coarse sand occur anywhere and at all horizons in the series.

The coarse quartzose sands, largely dug on Woolborough Hill, may be traced over the Bovey clays at the Newton station; and at Courtenay Park I have been informed by Mr. C. D. Blake that the clays were similarly reached beneath them.

A very variable set of beds occupies the hill-sides between Woolborough and Longford. One pit, dug in very fine and coarse sand, situated on the ridge just north of Longford, might be thought to be opened in Greensand; but an adjoining pit, at a little lower level, shows about 25 feet of sand, gravel, and whitish clay, with a wedge of the very fine sand in the middle of it, which wedge is evidently the continuation and termination of the sand worked in the other pit. The gravel is composed mainly of quartz, grit, flint, and chert.

These old deposits of gravel and sand extend along the borders of the valley from Staple Hill to Kingskerswell, and from Milber Down to Sandy Gate and Ugbrooke Park. They occupy the old Bovey Basin, which did not, when the beds were deposited, extend very far eastwards of Kingsteignton, there being then no opening at the present mouth of the Teign.

They extend in places from the tops of the hills bordering the basin to the bottom of it, attaining between Haccombe and Coffinswell a height of 540 feet.

The beds moreover exhibit, in places, at Whitehill, Woolborough, and near Kingskerswell, a very remarkable dip into the valley,—a feature observable in both sands and gravels, and one which tends to connect the several deposits.

The position occupied by these deposits is thus very dissimilar to that occupied by the Greensand of Haldon and the Blackdown Hills.

At Staple Hill the beds consist for the most part of sands banked up against the Devonian and Carbonaceous slates, at such a high angle (noticed by Mr. Godwin-Austen) that I was at one time disposed to consider a fault, which affects the older rocks in the neighbourhood, to have been instrumental in producing the very remarkable inclination of the sands*. But this inclination seems evidently one produced during the deposition of the beds, because it is marked at several other points corresponding with the course of the valley, as before mentioned, and it does not always affect the whole of the beds seen in one section, being very irregular, although inclining into the valley †.

* De la Beche, referring to the deposits of Greensand in the neighbourhood of Newton, and which had been brought to light by Mr. Godwin-Austen, concludes that probably a combination of faults and of a depression, produced either previously or subsequently to the deposit of the Greensand, may best explain the phenomena observed (Geol. Report, p. 236).

† Mr. J. H. Key, in describing the Bovey Clays and Lignites, has pointed out how the dip of these beds increases from the sides towards the centre of the basin (Quart. Journ. Geol. Soc. vol. xviii. p. 14).

At Staple Hill, moreover, there are coarse gravelly seams containing a few flints, as well as many other fragments of local rocks interstratified in the sands, in one of the large sand-pits now worked at that locality.

On the western margin of Milber Down, and just inside the lodge-gates on the carriage-road leading to Haccombe, is a small pit exposing fine and rather loamy sands with a few irregular chert blocks, which may very likely represent an outlier of Upper Greensand. In any case it would only extend along the top of the ridge, and be almost entirely concealed by the coarse gravelly deposits which descend towards the bottom of the valley, and there become intermingled with finer sediments. Another small outlier may be present beneath the gravels worked east of Combe Farm on the old and new high roads between Newton and Exeter. At the base of the gravels there is exposed sand much like the Greensand; but I could not determine whether it was in any way intercalated (as exactly similar beds are in other places) with the coarse gravel containing flint and chert.

These two patches, however, occur in positions which might connect them with the Greensand of Haldon.

At Haccombe, indeed, Mr. Godwin-Austen recorded beds of true Greensand, with included layers of chert and whetstone, and covered with characteristic fossils; but I cannot agree with him in considering that the Greensand ranges over the summits of the hills above Coffinwell, that it passes into the valley a little below Kingskerswell, and then rises into the opposite hills. Near Combe Farm Mr. Godwin-Austen obtained *Exogyra* and *Pecten quinquecostatus*.

He has, however, recorded some fossils from localities where I have been unable to identify any Greensand *in situ*. Thus at Staple Hill he has found *Trigonia* and *Inoceramus concentricus*, at Lyndridge Hill *Orbiculae* and *Orbitolites*.

Although I searched diligently, and had the assistance of one of the fossil-collectors of the Geological Survey, we obtained not the fragment of a fossil in any of the sandy beds. This of course is in itself negative evidence, and of no great value; for in many sections of undoubted Upper Greensand one may search long and find no reward in the shape of a fossil.

Looking to the facts that at Staple Hill one of the large pits contains one or two bands of gravel yielding flints sparingly, that the beds have that remarkable inclination repeated at Whitehill and between Newton and Kingskerswell, where the same sands become interbedded with coarse gravel containing flint and chert, and overlie the Bovey beds, I feel no hesitation in considering the few fossils that have been found at these localities to have been redeposited along with much material derived from the denudation of the Greensand.

Although these older deposits are roughly confined to the main valley of the Teign and its tributaries west of Kingsteignton, yet, as I have noticed, they extend to a height of 540 feet between Haccombe and Coffinwell, and they do not descend into valleys beyond

the Bovey basin. This tends to show that most of the minor features of the country have been produced subsequently to the deposition of the gravel.

Further, these deposits can be traced from Sandy Gate upwards to Gappath and the borders of Ugbrooke Park; and were the slope continued without break, we might reach the Greensand of Haldon, which is capped by analogous deposits of drift sand and gravel. There seems to be some connexion between these plateau-gravels which cap all the Greensand heights of Devonshire, and those which were accumulated with this high marginal dip in the Bovey basin.

The question of their formation seems to me to be a large one, and to require for its solution a more extended study of the superficial deposits of Devonshire than I have been enabled to make. Mr. Belt, however, has taken up the subject boldly; and my colleague, Mr. Ussher, is gathering facts which will, I hope, soon lead to very interesting results.

It is not always easy and is sometimes impossible to tell where these older deposits of gravel end in the valley, and where the modern alluvial gravels come on. This, however, is only natural, because the alluvial deposits are evidently very largely made up of the older materials.

The Bovey Clays are worked beneath the "Head" of gravel, sometimes called "Pengelly's Head," which in most instances is a comparatively modern fluvatile and estuarine deposit. It often occupies a position above the alluvium proper, but is sometimes not to be distinguished from it.

Mr. J. H. Key, who has given an excellent description of this deposit, has found in it the rib and jaw of a deer, and shells of the oyster and cockle*. In the collection of Messrs. Watts, Blake, Bearne and Co., of Newton Abbot, are bones of the Ox, Deer, and Man, obtained from the same deposit, and what is most remarkable, a wooden doll, or idol, about a foot in length, which was obtained at a depth of 20 feet in the coarse gravel, on the left bank of the river Teign, in a pit called the Zitherixton pit, near the toll-gate between Newton Abbot and Kingsteignton. A bronze spear-head was also found in the same pit at a depth of 15 feet.

There is no doubt that this deposit was on the whole the latest formed in the valley, partly by river and partly by estuarine action.

The material was evidently for the most part obtained "ready-made," as it were, from the older gravels; and therefore the deductions are indicative of the rapid accumulation of the gravels rather than of the antiquity of the remains found in them.

Mr. John Evans considers that the spear-head "belonged to the latter part of the British Bronze Period—say some few centuries B.C., or even only one or two. The wooden figure," he adds, "is much like some of those from the peat of the Somme valley, described by Boucher de Perthes. It is hard to say what is their age or object." Mr. Carruthers, who examined the wooden figure, con-

* See Quart. Journ. Geol. Soc. vol. xviii. (1862), p. 9.

sidered that it was formed of bog-oak, and was probably shaped from a piece of fossil and not recent wood*.

I mention these facts as affording interesting evidence of the accumulation of alluvial deposits, and as furnishing one indication out of many that might be given that our modern river-gravels are to a great extent made up of older gravels.

The deposits now being formed in the bed and along the margin of the estuary of the Teign between Newton Abbot and Teignmouth are many of them identical in character with the Triassic breccia. Low cliffs of Devonian slate, with here and there igneous rocks, border the water in places. These slaty rocks by constant saturation become soft, and break up into small angular fragments, forming a beach, which sometimes lies at an angle of 8° or 9° . This beach contains a few pebbles of quartz, grit, &c., which are derived from bordering patches of gravel. The slates break up along lines of jointage and cleavage: and large masses frequently slip into the water and gradually fall to pieces. Large blocks of hard rock fall by atmospheric wear and tear, and become imbedded in time amidst the slaty fragments without being worn or rolled about, a fact which might account for some, at least, of the large blocks of igneous rock met with in the Triassic breccia.

[For the Discussion on this paper see p. 238.]

* The wooden image has been figured by Mr. Pengelly in the Trans. Devon Assoc. for 1875, vol. vii. p. 200. See also Trans. Anthropol. Inst. vol. v. p. 299.

27. *On certain ALLUVIAL DEPOSITS associated with the PLYMOUTH LIMESTONE.* By R. N. WORTH, Esq., F.G.S. (Read April 5, 1876.)

IN the ingenious paper on the Drift of Devon and Cornwall, read by Mr. Belt before this Society in November last, that gentleman speaks of the lowland gravels of Devon and Cornwall as showing "signs of sudden and tumultuous deposition." Whether he is right or wrong in this assumption can best be settled by a reference to detail in various localities; and it is with the view of aiding in this work that I would direct attention to certain alluvial deposits associated with the Plymouth limestone, which seem, so far as that locality is concerned, to negative Mr. Belt's hypothesis.

The limestone of Plymouth, and that of Yealmpton (which commences about two miles distant from the eastward termination of the first), abound in fissures and caverns. Some of the latter have become celebrated by their ossiferous contents. Some of the former contain the alluvial deposits to which I refer, and which, denuded off elsewhere, are therein preserved.

The best examples of these deposits have occurred in connexion with Plymouth Hoe, where the so-called drift-gravel fills sundry fissures, and has been found to entomb remains corresponding very closely to the fauna of the Oreston caverns, which are less than a mile distant, on the other side of the Cattewater.

The chief deposit occurs about midway on the Hoe, and fills a huge "pocket" in the limestone. Beneath the turf there is a bed of clayey soil containing pebbles, which range from a very small size up to boulders a dozen pounds or more in weight. They are chiefly quartzose; some composed of quartz and schorl, others granitoid, and a few of slate. But for the absence of granite, this part of the deposit in no respect differs from the ordinary alluvium of our Dartmoor rivers.

Beneath this pebble-bed are patches of white and red clay, containing few pebbles; and beneath this, again, a large quantity of siliceous sand, the depth of which has not yet been ascertained, as the excavations have not reached the bottom of the fissure. The sand is chiefly of a cream-colour.

Similar deposits to this series are by no means of unfrequent occurrence in association with the limestone, though sometimes the sand, sometimes the clay, and sometimes the pebbles appear to predominate. They are found not only on the Hoe, but at Cattedown (where, in Deadman's Bay, is a "pocket" at least 40 feet in depth, containing white clay similar to that described), at Billacombe (near the termination eastward of the Plymouth limestone), and at Yealm Bridge (where a fissure contains pebbles identical in character with those in the bed of the Yealm, 50 feet below).

We have here, I think, clearly the remains of considerable deposits which once occupied large areas in the valleys of the south of Devon, and which, in part at least, are fairly entitled to be considered the lowland gravels of which Mr. Belt speaks. If they are not, then in this immediate district these gravels are not represented. As to their date, there is substantial evidence that the same stream, or streams, to which they are due, also carried into the Oreston caverns the extinct mammals whose remains have been found there, and that the cavern- and fissure- or "pocket"-deposits are contemporaneous.

Mr. Belt, following authorities of such eminence as Professor Sedgwick and Sir H. De la Beche, and concurring with Mr. Joseph Carne, holds that the lowland gravels were spread out by a great débâcle. If this view be correct, the evidence should be continuous throughout the district presumed to be exposed to its action. But, in the deposits here briefly described, there is not only no evidence whatever of a cataclysmal character, but every indication of orderly deposition:—inland, nearer to the source of the débris, the bulk of the pebbles and gravels proper; further from their origin the sands and clays, in fair orderly succession.

The idea that the stanniferous gravels of Cornwall and Devon were formed by some great catastrophe is at least three centuries old; for Carew, in his 'Survey,' says that the miners attributed them to the deluge. Nearly fifty years since, Mr. Carne contended that these gravels were deposited by a deluge of water from the north, because the productive stream-works are situated in valleys opening to the south. This fact of position, however, is easily explained by reference to the peculiarity of the watershed of Cornwall. There are only two rivers in the north of that county; and one of these does not pass through a stanniferous district. On the south coast rivers abound. From its superior weight, the tin ore would naturally form the lower layer of the deposits with which it was associated—and this whether the whole of the materials were in motion at once or not, since the effect of the continuous action of a stream on gravel in its channel is to carry forward the lighter and leave the heavier behind. Moreover the natural separation of the tin-gravel would be materially aided by the occurrence of times of flood.

Sir Henry De la Beche clearly shows that all that is required to account for the production of the stanniferous deposits is the existence of a mass of decomposed granite containing tin-ore, and its subjection to the action of water—though it is not necessary, as I hold, to assume with him that this water should be "driven violently against or over it." In such a body of decomposed granite I conceive, not merely the stanniferous gravels of the Dartmoor rivers, but the deposits of clay and sand here noticed, have their origin—the clay representing the felspar, and the sand the quartz. This accounts also for the absence of granitic pebbles in a deposit derived from the Dartmoor Granite.

DISCUSSION.

Mr. USSHER stated that he had been inclined to consider that the sands flanking the Bovey valley were of peculiarly local occurrence; but the observations of Mr. Woodward as to their similarity to certain arenaceous deposits on Great Haldon and the Blackdown Hills, recalled to his mind an instance where, in a pit on the former, sand of granitic origin, much resembling portions of the sands in the neighbourhood of Newton, is shown, underlying an accumulation of broken unworn chalk flints in a clayey matrix, ascribed by Sir H. de la Beche and French geologists to the Plastic-Clay formation. Owing to the removal of Post-tertiary deposits, he was unfortunately unable to trace any connexion between them.

The sands of which Mr. Woodward's paper treats skirt the Bovey valley at heights of from less than 100 to more than 500 feet above the sea-level, dipping down the slopes of the hills at angles roughly coincident with them, as gravel seams in the deposits show. Hence it seems evident that they cannot have been originally deposited upon their present uneven surface, but owe their position to those forces of elevation and depression the prevalence of which in Devon during the Post-tertiary period is elsewhere distinctly evidenced. With regard to one statement, he desired further information from Mr. Woodward—namely, as to the direct superposition of these sands upon the clays of the Bovey valley; for he agreed with Mr. Woodward that the superficial deposits of the valley, including the gravels of the Zitherixon pit (in which the wooden doll or idol was found), were of much later date, and due to the redistributing action of the stream now occupying the valley at a period when its volume was much greater than at present.

With Mr. Worth he entirely agreed in considering that Mr. Belt's explanation of the gravels of Devon and Cornwall was unsatisfactory; for not only were there no signs in their mode of occurrence of a general dispersion involving more or less of cataclysmal action, but indications of a clear order of sequence, manifested, for instance, by the gravels on the sides of such valleys as those of the Exe, Otter, Taw, and Torridge, indicating successive deposition by the former representatives of the present streams in their erosion of the valleys, the most recent deposits occurring as alluvia and gravels occupying flat tracts of land through which the rivers now flow.

He considered that if, in addition to the evidence furnished by these gravels, the raised beaches on the Devon and Cornish coasts, the stony loam or head of angular débris overlying them, the cavern deposits of Devon and other phenomena were taken into account, an order of sequence proving physical changes might be established, by which some conclusion respecting the vicissitudes experienced by the counties of Somerset, Devon, and Cornwall during the Pleistocene epoch might be arrived at.

Mr. THORPE was glad that steps had been taken for properly working out this interesting district, as there were few reliable

papers on the subject, Mr. Holles' elaborate paper being in many points untrustworthy.

The PRESIDENT (Prof. Duncan) read a letter from Mr. H. B. Woodward, in which the latter stated that his reason for bringing this paper forward was that many sections were now to be seen in the course of excavations for building around Newton-Abbot, which would soon be obliterated. The President also said that he had been over the ground mentioned by Mr. Worth in his paper, and entirely agreed with the views expressed by that gentleman.

28. *The BONE-CAVES of CRESWELL CRAGS.*—2nd Paper. By the
 Rev. J. MAGENS MELLO, M.A., F.G.S. (Read April 5, 1876.)

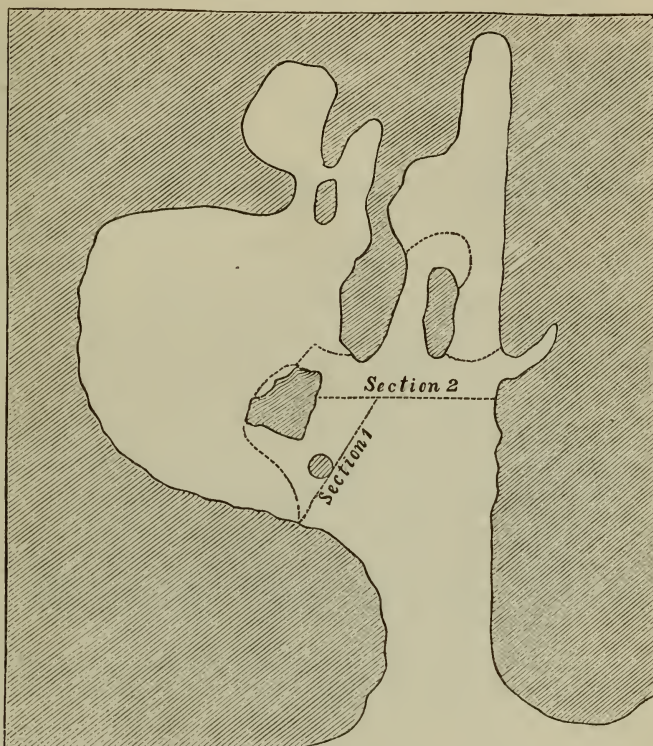
I HAD the honour last June of reporting to the Society my discovery of some interesting bone-caves and fissures in Creswell Crags, in the Lower Magnesian Limestone of N.E. Derbyshire, which contained a large number of species of Pleistocene mammalia, together with some traces of the presence of man*. I was able on that occasion to exhibit portions of some 15 or 16 species belonging to no fewer than 12 genera obtained from one cave alone, locally known as the Pin-hole, so called from a curious custom which prevails amongst some of its visitors of dropping a pin into a small water-filled hollow, removing at the same time a pin deposited by some previous visitor. Amongst the animals which had left their remains in this cave the most important were the Irish Elk, the Glutton, and the Arctic Fox; together with these were a large number of Hyæna remains, and also bones and teeth of the Mammoth, the Woolly Rhinoceros, the Brown Bear, the Reindeer, the Urus, and of some other animals. During the past summer I have been able to carry on the work of exploration, assisted by Mr. Thomas Heath, F.R.H.S., Curator of the Derby Museum, who has been able to devote a good deal of time to it, and whose skilful help has been of great value in carrying on the researches; and I must also acknowledge the energetic assistance given us by Mr. F. Tebbet, superintendent at the Creswell quarries, who from the beginning has taken much interest in these discoveries.

We commenced the renewed search by continuing the excavation of the floor of the Pin-hole, trusting that amongst other remains we might obtain some more evidence of the presence of the Arctic Fox; in this, however, we were not successful. All the front of the cavern was thoroughly searched, the chief bones found being two perfect pelves of *Rhinoceros tichorhinus*, and also two atlases of the same animal, together with a few Reindeer- and other bones of no particular interest. As we worked our way further into the fissure the number of bones found was very small indeed; the bed of red sand, which at the entrance of the cave had proved so rich in its contents, became filled with limestone fragments, and was nearly destitute of bones; and we determined, under these circumstances, to desert that cave for the time and begin the exploration of a neighbouring one a little lower down the ravine, and in the same side of it. This, which is called the Robin-Hood Cave, is of moderate size, containing several chambers communicating with each other, the separation merely consisting of narrow walls of the limestone rock (fig. 1).

We began work here by making a section of the floor at the entrance, cutting down to a depth of about 8 feet, where blocks of limestone were met with, which probably form part of the original

* Quart. Journ. Geol. Soc. vol. xxxi. p. 679.

Fig. 1.—*Rough Ground-plan of the Robin-Hood Cave, Creswell Crags.*
(Scale 20 feet to 1 inch.)

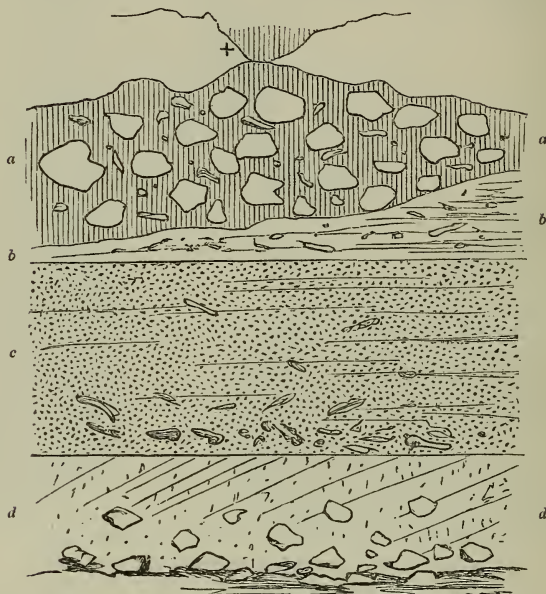


The curved broken lines indicate the portion worked out.

floor of the cave. We gradually worked forward into the cave, carefully examining each stratum as it was removed. As in the Pin-hole, so here there was a certain amount of dark surface-soil of inconsiderable thickness, seldom, if ever, exceeding 5 or 6 inches, and near the entrance not above 2 inches; in this in different parts of the cavern we found some broken fragments of Roman and Mediæval pottery, a human incisor, and some bones of recent animals (sheep etc.). On the left-hand side of the cave, and extending a considerable way across its mouth, there was a very hard limestone breccia, varying in thickness from a few inches up to about 3 feet; beneath the breccia was a deposit of light-coloured cave-earth, more or less sandy and very calcareous; where the breccia attained its greatest thickness the cave-earth was almost wanting, being only a few inches thick at the side of the cave; but further in, under the thinner portions of the breccia, the cave-earth was fully 3 feet thick; the succeeding layer was of dark-red sand, very similar in

character to the bone-bearing bed of the Pin-hole, but differing from it in containing, near its base, patches of highly laminated red clay. Small nodular masses of black oxide of manganese occurred here and there in the sand, and also some quartzite and other pebbles. This middle red sand bed was about 3 feet thick, and rested upon a bed of lighter-coloured sand, containing many rough blocks of limestone already mentioned as apparently forming part of the original floor of the cavern. Fig. 2 gives a section across the

Fig. 2.—Section in the Robin-Hood Cave, in line 1, Fig. 1.



+ Stalactite uniting breccia with roof.

a. Stalagmitic breccia, with bones and implements, 18 in. to 3 ft.

b. Cave-earth, with bones and implements, of variable thickness.

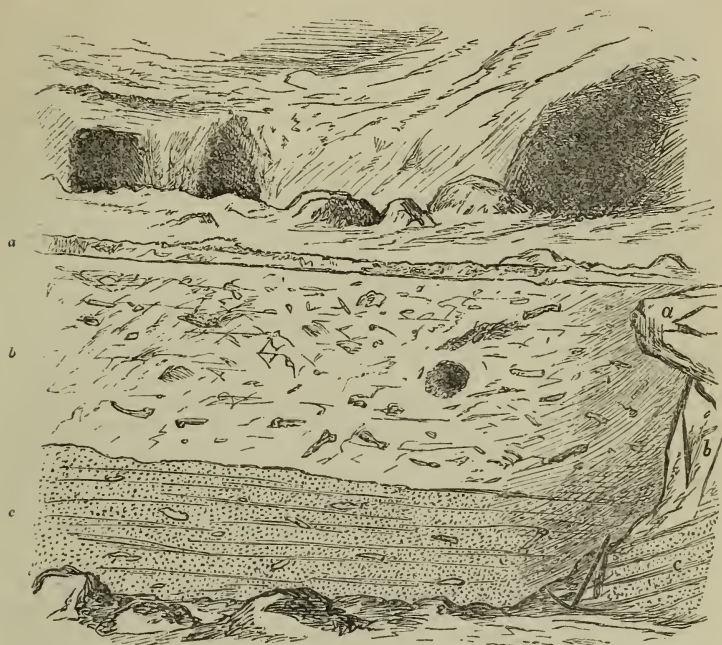
c. Middle red sand with laminated red clay at base, containing bones, 3 ft.

d. Lighter-coloured sand with limestone fragments, 2 ft. ?

side of the cavern where the thickness of the breccia was greatest. Fig. 3 is another section, taken across the cavern, facing the openings of the chambers, which are shown above the cutting.

The Breccia.—The Breccia (a) was firmly cemented together by stalagmite, many thick masses of which were interspersed with it; and the whole deposit was so hard that it had frequently to be blasted in order to remove it and examine its contents. It was found to contain a large number of bones, mostly of small animals, including the Water-vole; but together with these were some of the Reindeer, and also teeth of the Hyæna, *Rhinoceros tichorhinus*, and Horse.

Fig. 3.—Section in the Robin-Hood Cave, in line 2, Fig. 1.



- a. Surface-soil and thin breccia, 2-3 in.
- b. Cave-earth, with flint and quartzite implements, teeth, bones, angular limestone fragments, and charcoal, 3 ft.
- c. Red Sand with laminated clay, few bones, 3 ft.
- 1. Fox-hole?

Besides the bones, the breccia contained numerous flint flakes and chips, as well as one or two flint cores. Although the majority of the flints were chips, or flakes of the simplest character, some few of them were of superior workmanship, being well-shaped spear-heads, or large arrow-heads chipped on both surfaces; there were also one or two sharply pointed flints of the awl type. A few quartzite implements, similar to those to be described in the succeeding bed, were found in the breccia.

The Cave-earth (b).—The cave-earth contained some flint implements; but besides these were a large number of split or chipped quartzite pebbles, evidently fashioned by man, most of them having a very definite bulb of percussion, and a general uniformity of design prevailing amongst them. Amongst these quartzite implements are some fashioned on both faces, and which present in their oval form a decidedly palæolithic aspect; a similarly shaped implement of clay-ironstone was found with these. Some of the pebble implements were designed for hammers, one large one having a few

chips struck off one end, and the opposite face being much bruised. Besides these implements there were a considerable number of unfashioned pebbles of quartzite, together with one or two of black chert and of quartz, both in the cave-earth and in the red sand. The cave-earth, as well as the breccia, contained a good many small fragments of charcoal. We found numerous animal remains in this bed. Horse-teeth were specially numerous, and also those of the *Rhinoceros tichorhinus*, and of the Hyæna; a good many very perfect fragments of both the upper and lower jawbones of the latter animal were found, one of the upper jaws still retaining, in addition to the canine and large molars, the small fifth molar that is so generally lost. A left ramus of a lower jaw has also some of the incisors *in situ*. The numerous Rhinoceros-teeth are both upper and lower molars and premolars, together with some milk-teeth, most of them being very perfect. In this bed were found bones of the Reindeer, as well as teeth, and also some fine teeth of the Cave-Lion and of Bears. At the base of the cave-earth, at one place on the left-hand side of the cavern there was a thin bed of small pebbles, apparently deposited by water; this and the laminated red clay were the only traces of any thing like regular bedding in the floor of the cave, apart from the chief divisions already mentioned. At one point the cave-earth had been considerably disturbed by a fox-hole; this was the only instance in which such disturbance was seen (see 1, fig. 2).

The Red Sand (c).—The Red Sand underlying the cave-earth contained comparatively few bones, except in one place near the entrance of the cavern, where a considerable number of large bones were found at its base, almost resting on the underlying light sand. The bones consisted of portions of antlers and other remains of the Reindeer, some very perfect metacarpals and metatarsals, and vertebræ of the Bison, and some bones of the Hyæna etc. At another place was found an extremely perfect small molar of *Elephas primigenius* with a portion of the jawbone still attached to it. A further and detailed account of the implements and bones of this cavern has been kindly prepared for me by my friend Prof. Boyd Dawkins, and will be found in the following paper. One thing to which I should call attention is the somewhat strange fact that although a very large majority of the bones discovered have been gnawed by hyænas, to whose agency we must attribute the presence of most of the animal remains found in these caves, yet up to the present time we have been able to find no trace of the coprolites of these animals, which are usually so numerous in hyæna-dens; I hardly know how to account for their absence. I hope that we shall be able to continue the work of exploration during the ensuing summer; and the results of such further explorations I trust I shall have the honour of bringing before the Society at a later period.

[For the DISCUSSION on this paper see p. 256.]

29. *On the MAMMALIA and Traces of MAN found in the ROBIN-HOOD CAVE.* By W. BOYD DAWKINS, Esq., M.A., F.R.S., F.G.S., F.S.A., Professor of Geology and Palæontology in the Owens College. (Read April 5, 1876.)

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THE discovery of the fossil remains in the Robin-Hood Cave, brought before the Geological Society by the Rev. J. Magens Mello in the preceding paper, is of no common interest. It proves not only that the caves of Derbyshire were the lairs of Hyænas in ancient times, but that they were inhabited by the same kind of Palæolithic men as those of the caves of the south of England, of France, Belgium, and Switzerland. The remains have been handed over to me for description by Mr. Mello and his coadjutor Mr. Heath, and are the subject of the following remarks.

1. *Cave occupied by Hyænas during deposition of Lower and Middle strata.*

A comparison of the bones and teeth from the lower red sand and clay, and from the cave-earth, with those from Wookey Hole, Kent's Hole, Kirkdale, and other hyæna-dens, renders it impossible to doubt that the great majority of the animals in the cave were killed and eaten by the Hyænas. With few exceptions the solid bones are alone perfect, the long bones containing marrow and the vertebræ being represented merely by gnawed fragments. All the lower jaws have lost their angles and coronoid process; and the number of teeth stands in a greater ratio to the quantity of bones, than would have been the case had not their possessors fallen a prey to a bone-destroying animal. The only long bones and vertebræ which were found without marks of the teeth of Hyæna were met with in the lowest ossiferous stratum, and belong to the Bison and Reindeer. Their presence may be explained by the supposition that they were introduced by the stream flowing past the entrance.

2. *Occupation of cave by Hyænas interrupted by Floods.*

The red sand and clay of the lower ossiferous stratum are the results of an occasional flooding; and the smoothed and rounded surfaces of many of the bones and teeth are due to the friction of the sand set in motion by the currents of water in the cave.

It seems, therefore, tolerably clear that the occupation of the cave by the Hyæna, during the time of the deposition of the lower ossiferous stratum, was occasionally interrupted by floods.

3. *Occupation of cave by Hyænas during deposition of cave-earth interrupted by Man.*

The middle deposit of red loam, of the kind so abundant in caves in the south of England, has probably been introduced during heavy rains, and is to some extent the result of the decomposition of the limestone. During its accumulation Hyænas inhabited the cave; but their occupation was disturbed by the visits of Palæolithic hunters, who left behind them the implements to be presently described.

4. *Occupation by Man during the period of the Breccia.*

The remains from the breccia above the cave-earth seem to me to indicate that the cave at that time was inhabited by Man, and that it was not so frequently visited by the Hyænas as before. The pieces of breccia, which I have carefully broken up in search after bone needles, contain for the most part the split and broken bones and a few vertebræ of the Hare. Had the Hyænas then frequented the cave, the vertebræ would have been eaten, and some of the bones would have been gnawed.

5. *Dog not present.*

The presence of the vertebræ also implies that the Dog was not used by the hunters who then lived in the cave. It will be remembered that a similar conclusion was drawn by MM. Lartet and Christy from the vertebræ of Reindeer in the caves of Périgord with regard to the Palæolithic hunters in the south of France. It seems, to me, indeed, after a careful examination of all the evidence, that the Dog was not the servant of Man in the Palæolithic age in Europe, and that the reputed occurrence of its remains in deposits of Pleistocene age is the result of mistaken identity, or of mistaken *gisement*.

6. *Fauna of the Breccia different from that of underlying strata.*

The group of remains from the breccia differs, as may be seen from the following Table, considerably from those of the underlying strata. The carnivores of the latter, with the exception of the Hyænas and Wolf, are conspicuous by their absence; while all the herbivores are represented, with the exception of the Bison. The Hare, on the other hand, so rare in the latter, is abundant in the breccia. This difference in the mammal faunas is accompanied, as will be seen, by corresponding differences in the implements. The

The faunas of the three lowest stages in the cave present no important differences worthy of note, with the exception of that between the breccia and the cave-earth already pointed out—a difference, be it remarked, that may be the result of one animal falling more easily into the hands of man than another, and not of a change in the fauna of the district.

9. Notes on Species.

Order CARNIVORA.

Lion.—The Lion is represented by three canines, two worn down to the stump and one belonging to a young adult, and by m. l. These teeth belong to four individuals, and are rather smaller than the average of those from the British caves described in the Monograph on *Felis spelæa* by Mr. Ayshford Sanford and myself (Pal. Soc. 1866 *et seq.*)

Spotted Hyæna.—The cave variety of the Spotted Hyæna is proved to have inhabited the cave through many generations by the numerous jaws and teeth of all ages, ranging from whelphood to the extreme of old age. All the jaws are gnawed to the patterns figured in Buckland's 'Reliquiæ Diluvianæ,' pls. 3, 4, 5, and in 'Cave-hunting,' fig. 92.

Fox (*Canis vulpes*).—A femur, two lower jaws, and a few separate teeth fall within the limits of size offered by the corresponding parts of the common Fox; and I therefore regarded them as belonging to that rather than to the arctic species, which has been determined by Prof. Busk, F.R.S., from a neighbouring cave (Quart. Journ. Geol. Soc. 1875, p. 686).

Wolf.—The jaws, teeth, and phalanges of Wolf cannot be distinguished from those of the *Canis lupus* of Europe and Asia. They belonged to adult animals.

Bear.—The teeth of Bear (consisting of canines, premolars, and molars) indicate the existence of two closely allied forms. One of the canines is identical with that of *U. arctos*, while the rest, and the molars and premolars, are undistinguishable from those of the *U. ferox* or Grisly Bear as defined by Prof. Busk. None of them belong to cubs.

With regard to the further question as to whether the two Bears are closely related species, or well-marked varieties of one species, speech may be silvern, but silence is golden. The examination of a vast number of the remains of fossil Bears in this country and on the continent has forced on my mind the extreme difficulty of defining the one from the other from the study of the hard parts. Both forms, however, are quite distinct from the largest of the cave-haunting Bears (*Ursus spelæus*).

Order ARTIODACTYLA.

Suborder RUMINANTIA.

Irish Elk and Reindeer.—The alveolar portion of the lower jaw, a fragment of a metacarpal, and two molars belong to the Irish Elk, while numerous antlers, some shed, and others torn from the head, teeth, and gnawed bones may be referred to the Reindeer. It is worthy of remark that all these remains are those of adults.

Bison.—Of the Bison it need only be remarked that the remains fall within the limits of measurement of those from Windy Knoll (Q. J. G. S. vol. xxxi. 1875, p. 247). Some of the long bones belong to young animals.

Suborder NON-RUMINANTIA.

Wild Boar.—A small fragment of jaw containing the first three premolars proves that the Wild Boar also lived in the district during the time of the accumulation of the breccia.

Order PERISSODACTYLA.

The Horse and Woolly Rhinoceros.—The teeth and the bones of Horses prove that the adults were here with their foals: and this may also be observed of the Woolly Rhinoceroses, the milk-teeth of which amounted to 19, or very nearly one third of the total number of teeth of that animal in the cave. All the long bones are gnawed to the usual patterns (see 'Cave-hunting,' p. 314 *et seq.*). The humeri have been docked of their proximal, the ulnæ of their distal ends, while the radii, femora, and tibiæ are represented merely by the stout middle portion of the shaft; and in all, the nutriment stored in the cancellous portion of the interior of the bones has been scooped out by the jaws and tongues of the Hyænas.

Order PROBOSCIDEA.

Mammoth.—Five out of the six molars of Mammoth belong to the milk-series, and three of them are *dm* 2. The true molar is a stump worn down to the fangs. There are also fragments of tusks and of bones.

Order RODENTIA.

The Hare.—The split and broken bones of the Hare were very abundant in the breccia; and that animal had formed the principal food of the inhabitants during the time of its accumulation. All the long bones had been split for the sake of their contents. There are also numerous jaws and teeth of *Arvicola*.

10. *Traces of Man in the Cave.*

The traces of Man found in the cave in association with the extinct mammalia, consist of fragments of charcoal, and implements of antler and mammoth-tooth, of quartzite, ironstone, greenstone, and of flint.

11. *Implements of Antler and Mammoth-tooth.*

An awl, pin, or possibly a lance-head, has been fashioned out of

a tyne, which has been ground down to a sharp point (fig. 1), similar to many of those found in the caves of the Dordogne, and figured in the 'Reliquiæ Aquitanicæ.' It may have formed part of a pin such as that figured by Mr. John Evans from Kent's Hole (Ancient Stone Implements, fig. 406). Another pointed tyne may also have been used for the same purpose as fig. 1; but the marks of Man's handiwork are not so decided. A fragment of the base of a Reindeer-antler from the cave-earth may perhaps have been cut and perforated by the hand of Man. Another is a triangular sharp-pointed arrow-head or piercer (?), formed of one of the plates of an Elephant's molar, probably of a milk-molar. Its surface is highly polished, and it has been formed by the loss of the enamel and the grinding of the surface of the dentine until it assumed its present form*. A loose plate of the milk-molar of a Mammoth was also found in the cave.



Point made
of antler.
Full size.
Cave-earth.

12. Implements of Quartzite and Ironstone.

The implements of quartzite and ironstone, eighty-six in number (irrespective of splinters), belong to well-known types in other regions, which are generally fashioned out of flint. They have all been made

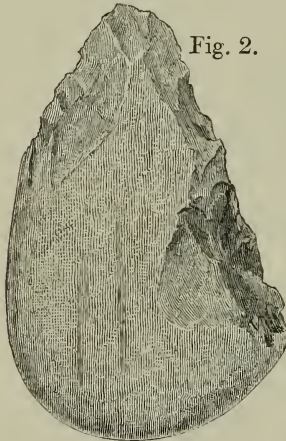
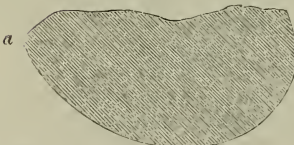


Fig. 2.



Quartzite hache, $\times \frac{1}{2}$. Cave-earth. a. Section.

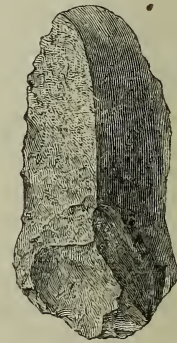


Fig. 3.



Quartzite flake, $\times \frac{1}{2}$. Cave-earth.
a. Section.

* This singular specimen is considered by Mr. Evans to be non-artificial. After a further examination of it in the British Museum, Mr. Davies and myself cannot look upon it otherwise than as expressed in the text.

out of pebbles, in which advantage has been taken of the smooth surface to form one side of the implement.

A triangular implement (fig. 2), tapering from the unworked base to an obtuse point, and carefully worked at the sides and point, was obviously intended to be used in the hand like those of the Pleistocene river-gravels. The side which is not figured is flat, and has been produced by one blow which has split the pebble; it measures 4.4 inches.

A second rudely chipped stone has also probably been intended for use in the hand; its point, however, has been broken away, so that its exact original form cannot be ascertained.

A third, with curved hatchet-edge, is notched by use; and its rounded shape bears a resemblance to some of the "choppers" of Le Moustier, La Madelaine, and of the British river-gravels figured by Mr. Evans (fig. 443). It consists of a pebble broken so that the blunt end may be easily grasped in the fingers.

Figure 3 represents a rude flake which has the bulb of percussion and the surface of the chipping-block as well marked as in most flint implements of the same kind. One of its surfaces is composed of the water-worn surface of the pebble; and both its edges have been chipped by wear.

Another form may be described as a flake of the rude kind found in the valley-gravels and in the cave of Moustier. Its edges are considerably worn by use. It is the only quartzite implement found in the breccia, the two others being splinters.

The implements, fig. 4, of quartzite, and, fig. 5, of ironstone,

Fig. 4.



Oval quartzite implement, $\times \frac{1}{2}$.
Cave-earth. *a*. Section.

Fig. 5.



Oval implement of ironstone, $\times \frac{1}{2}$.
Cave-earth. *a*. Section.

have been chipped all round, and are of the oval shape common at St. Acheul and at Moustier. The first corresponds in form with that which I have figured from Wookey Hole in the Journal of the Society, and the second with one which I have in my possession

from the same cavern, although the former is thicker than the latter. They measure respectively 3×2.2 and 2.4×1.6 inches.

Five quartzite hammer-stones bruised and broken by use were also found, and many quartzite pebbles.

It may be remarked that palæolithic implements of quartzite have been met with in India in the Lateritic strata and in a river-deposit in the valley of the Narbadá ('Cave Hunting,' p. 426). In the Museum at Toulouse they are also to be seen from the valley-gravels of that neighbourhood.

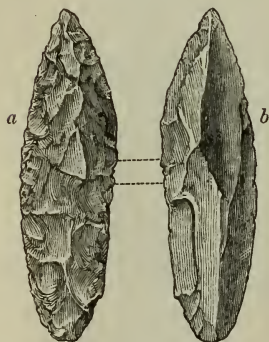
Among the specimens sent to me by the Rev. J. M. Mello is a ground and polished fragment of Silurian or Cambrian flagstone (measuring $4 \times 3 \times 0.5$ inches). It has formed part of a slab which has been broken up.

13. *The Flint Implements.*

The flints which bear the trace of man's handiwork in the cave amount to upwards of 267. Among them the most striking are the flakes which have been wrought into finely pointed lanceolate forms. One of these, fig. 6 (measuring 3.35×0.95 inches), is carefully worked on the flat side (*a*), while the opposite surfaces are worked at the extremities. It is carefully chipped at both ends.

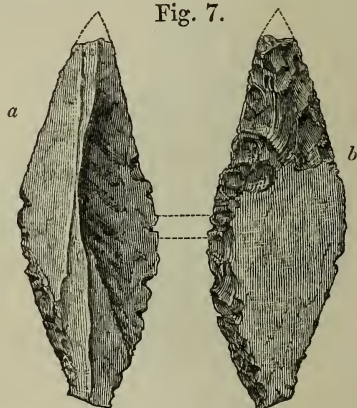
A second and smaller specimen presents the same general form. This type is identical with that figured by Mr. Evans from Kent's Hole, fig. 300, except that in the specimens from Robin-Hood Cave the greater part of the working is to be seen on the flat side.

Fig. 6.



Lanceolate flint flake, $\times \frac{1}{2}$. Breccia.

Fig. 7.



Lance-head of flint, $\times \frac{1}{2}$. Breccia.

The double-pointed lanceolate flake (fig. 7), which tapers from the wide central portion to the ends, from which apparently the points have been broken, is also carefully worked on the upper half of the flat surface; and the chipping has been continued to the end of the left lower side of the implement (*a*). On the other side (*b*) the opposite edge is worked on the opposite surface, with the practical result of producing a twist in the edges analogous to that

which has been observed in neolithic arrow-heads, intended to make the arrow revolve in its flight. It measures 3·8 by 1·42 inches. A fragment of a second specimen was also found corresponding with the upper part of fig. 7, and as nearly as possible of the same size and form as a specimen in the Oxford Museum from Wookey Hole. In all these implements the salient midrib of the flake has been left intact.

If this latter form (fig. 7) be compared with those figured in the 'Reliquiæ Aquitanicæ' from Périgord, it will be seen that it bears a strong family resemblance to some of those from Laugerie Haute (A, pl. iv. figs. 7, 8, 9). They are also of the same type as those from the Pleistocene portion of the deposits at Solutré figured by MM. Ducrost and Lortet (Archives du Muséum d'Histoire Naturelle de Lyon, ii. pl. v.), and considered by M. de Mortillet to be characteristic of a stage in the Palæolithic culture.

Two other fragments of trimmed flakes were found, both with the salient ribs worked carefully off and the flat inferior surface intact.

In fig. 8 an implement is represented formed of a flake with the cutting-edge carefully and minutely chipped. The inferior surface is, for the most part, flat and unworked, while the superior is occupied by the natural surface of the flint-pebble. It is probably a scraper, analogous to that from Kent's Hole, fig. 392 of 'Ancient Stone Implements.'

Eleven flakes, with one of their extremities trimmed to a rounded edge, were met with. They are of the usual type so common in the caves of Périgord. One fragment is of the same form as the upper half of fig. 396 of 'Ancient Stone Implements,' and is composed of a flake struck from the outer side of a flint-pebble.

Fig. 8.



Flint scraper, $\times \frac{1}{2}$.
Cave-earth. a. Section.

Fig. 9.



Flint implement.
Full size. Breccia.

Fig. 10.



Flint implement.
Full size. Breccia.

Figs. 9 and 10 represent two very singularly worn flakes like those which have been figured by Mr. Evans (figs. 398, 399, 400) from Kent's Hole. The first consists of a flake with "an oblique straight scraping edge, forming an obtuse angle with one side of the flake, and an

14. *Distribution of Implements in the Cave.*

The distribution of implements in the cave represents, as may be seen from the preceding Table, three distinct stages. During the time of the deposit of the lower stratum Man is not represented among the fauna of the district. While the cave-earth was being accumulated, his presence is marked principally by the quartzite implements formed out of an intractable material, and far ruder than those which are generally formed out of the more easily fashioned flint.

Of ninety-four worked quartzite pebbles, only three were found in the breccia, while eight only of the 267 worked flints were met with in the cave-earth (including fig. 8). The hunter, therefore, of the cave-earth period used quartzite for most of his implements, while that of the age of the breccia used flint, the overlapping of the two materials in this cave being comparatively slight.

15. *The Ruder Implements the Older.*

The workmanship of the later of these two periods of human occupation is of a higher order than the former. If, for example, we compare figs. 6, 9, 10, 11 with figs. 2, 3, 4, 5, it is impossible to resist the conclusion that the hunter of the breccia-age was better equipped than his predecessor of the era of the cave-earth.

If these groups of implements be compared with those found in other palæolithic deposits, it will be seen that the older quartzite division corresponds in its general form with that series which is assigned by M. de Mortillet ('*Matériaux*,' Mars 1869, "*Essai d'une Classification*") to "the age of Moustier and St. Acheul," and which is represented in this country by the rude implements of the lower breccia in Kent's Hole. The newer or flint division, on the other hand, contains among its forms more highly finished implements, such as figs. 6 and 7, which correspond with those which are considered by M. de Mortillet to belong to "the age of Solutré," and which are found in this country in the cave-earth of Kent's Hole and Wookey Hole. In this cave, therefore, we have a direct relation, in point of time, established between the rude types of implements below and the more finished ones above, which is a fact of no small importance in the classification of Palæolithic implements. In all future cave-explorations it will be necessary to keep a keen look-out for broken pebbles and roughly-edged stones, with scarcely any marks of design, which may have served the ends of savages of a far lower culture than those whose history has been revealed to us in the caves of Périgord and of Belgium.

16. *North-western Range of Palæolithic Hunters.*

This discovery of implements in Derbyshire extends considerably the known range of the Palæolithic hunter to the north and to the west. Hitherto the Vale of Clwyd has been the district furthest to the north in this country in which his implements have been discovered. The fragment of human fibula in the Victoria cave has

proved his presence in the Pleistocene age in Yorkshire; the caves of the south of England prove that he wandered over the plains now submerged beneath the waters of the Channel; those of Somerset, Pembroke, and Herefordshire, that he inhabited the valleys of the British Channel, the Severn, and the Wye. He is proved by M. Dupont to have hunted the reindeer and mammoth in Belgium, on the eastern side of the great valley which, during the latest stage of the Pleistocene, extended across where now exists the German ocean, and joined the eastern counties to Belgium. That savage tribes living on the chase should be found on one side only of a great valley, while the animals which they hunted were equally abundant on both, was in the highest degree improbable. We now have proof that their hunting-grounds extended as far to the west as the hills of Derbyshire—hills which in those times abounded with Bisons, Reindeer, Horses and Woolly Rhinoceroses, and in which (as I have shown in my "Essay on the Animals found at Windy Knoll") there was a continual swinging to and fro of migratory animals as in North America. And further, we now have proof of the presence of the Palæolithic hunters close to the glaciated region to the north-west, which was probably covered with glaciers in the late Pleistocene age. We have, however, no evidence as to the relation of the contents of the Creswell Caves to the Boulder Clays.

DISCUSSION.

Mr. EVANS considered the cave to be of a most interesting character. Implements of worked flints were here found in one bed lying on another in which implements of quartzite occurred, the latter being the ruder. That the implements from the lower bed were less finished than those of the upper was doubtless to a great extent due to the nature of the material of which they were formed. Some of them resemble in character forms from the upper valley-gravels of the Somme. Almost identical specimens had been obtained, from what were apparently valley-gravels, near Toulouse. On the other hand, the implements in the upper layer resembled those of Solutré, Aurignac, and Kent's Cavern, and possibly represented a period earlier than that of La Madelaine. Amongst the specimens were some of great interest. One flake was worked off at the end in a diagonal direction, like specimens from Kent's Cavern. There was also a borer like those from La Madelaine. Some of the scrapers, however, might be taken to represent any period in the French caves subsequent to that of Le Moustier, while one "side-scraper," or "chopper," was much like those from Le Moustier. The paper was one of the greatest interest; and he hoped that it would be supplemented by further reports as the work progressed.

Prof. PRESTWICH remarked that the superposition of the bed containing the more perfectly formed implements over that in which those less highly finished were found, was better marked in this cave than in any other in this country. The absence of the coprolites of the Hyæna in this as in the Brixham Cave was probably due to their

being acted on by water, during floods, and washed away. It was not to be assumed, from the absence of any traces of man in the lowermost deposit, that he did not exist in that spot at this period, as he would hardly be likely to occupy dens along with the *Hyæna*. Some of the flint implements found in the valley-gravels were of extreme rudeness as compared with those of the high-level gravels, though the latter were the older. Fineness of finish does not necessarily prove more modern date, as is exemplified by the Shrub-Hill implements; but much would depend on the material, and he had not yet seen Mr. Mello's specimens.

Mr. ETHERIDGE inquired whether the absence of coprolites from these dens might not be accounted for by the cleanly habits of the animals. The Carnivora, as a rule, were exceedingly cleanly in this respect.

Prof. HUGHES suggested that the difference of material might be explained on the supposition that the people who left the quartzite implements had lived in that or some other district where quartzite was the only or most common material; while the flint was brought by a tribe who came from a district where flint was abundant. The rougher material did not of itself prove greater antiquity. Quartz and quartzite had been used at all periods from that of the laterite of India to that of the neolithic graves of Britain, and even later elsewhere. So also he had found grey felstone implements in Wales of neolithic as well as of palæolithic type; while polished weapons of the same material were occasionally found in the fenlands near Cambridge.

Mr. HOWARTH stated that the African *Hyæna* does not resort to caves, and he could not understand why the extinct *Hyæna* should have done so. The remains of *Hyænas* had been found in caves on the banks of the Lena and Obi in Siberia; and this led him to think that possibly the *Hyæna* of that period, owing to the intensity of cold, was in the habit of hibernating, as the bears of cold climates do at the present day. The African *Hyænas* only prey on sickly members of the antelope tribe; and it therefore seemed to him doubtful that those found in caves would have preyed on such large animals as the *Rhinoceros*.

The PRESIDENT inquired at what distance from the cave flint was obtainable, and also where quartzite pebbles could be found.

Dr. MERYON considered that the development of man was more clearly proved by the progressive improvements in the manufacture of his implements than by the physical formation of his skull.

Mr. BINNEY stated that quartzite pebbles could be obtained within seven or eight miles of the spot, whilst flints were abundant at not more than about forty miles distant.

Mr. MELLO, in reply, said that quartzite pebbles occurred abundantly in some sands near the caverns. They were probably derived originally from the Bunter. The flints might have been obtained at no great distance, possibly from the valley of the Trent; for some specimens were weathered, and evidently derived from gravel; others, however, were probably obtained directly from

the Chalk. He could not account, however, for the implement fashioned out of ironstone, which is not found in the vicinity of these caves. He had been under the impression that coprolites were of frequent occurrence in the Hyæna-dens. The filling-in of the cavern had doubtless been accelerated by the water overflowing into it from the stream now flowing at the base of the Crag, but which at that period ran at a higher level. There were slight traces of a rearrangement of the bones such as would be effected by water.

Prof. BOYD DAWKINS, in reply, stated that he had no intention of generalizing from this single example; but it was worthy of note that here, as in M. Mortillet's classification, the ruder implements were older than the more highly wrought flint flakes. The Hyæna, like other animals, takes refuge in whatever place will best suit him, and round the mouth of his den bones and coprolites accumulate. The absence of coprolites in this cave was probably due to moisture dripping from the roof, which would dissolve and wash them away; the caves in which coprolites are found were probably dry. The evidence of the cave-Hyænas having preyed on large game, such as the Rhinoceros, rests on the fact that the bones of those animals found in the caves show marks indicating that they have been gnawed. A sick or wounded animal, even though of large size, would easily fall a prey to their numbers. The occurrence of the remains of Hyænas as far north in Siberia as the banks of the Lena and Obi was an important fact and new to him. It indicated a difference of climatal conditions in that country of a marked character.

30. *On the Genus MERYCOCHÆRUS (Family OREODONTIDÆ), with Descriptions of two New Species.* By G. T. BETTANY, Esq., B.A., B.Sc., Shuttleworth Scholar, Caius College, Cambridge. (Read February 2, 1876.)

(Communicated by Prof. Hughes, F.G.S.)

[PLATES XVII. & XVIII.]

A VALUABLE series of mammalian remains, chiefly consisting of skulls and portions of skulls, collected by Lord Walsingham in the valley of John Day's river, a tributary of the Columbia, in Upper Oregon, in the winter of 1871-72, was presented by him to the Woodwardian Museum, Cambridge. Most of the specimens were obtained from near the head of a small stream called Bridge Creek; but a few were from the Great Cañon, higher up on John Day's River, nearly opposite Old Camp Watson. Lord Walsingham secured indeed a rich prize in the portions of three days which he devoted to a search for these remains.

The specimens were, fortunately, for the most part brought to England in masses of the original rock, and had therefore the great advantage of Mr. H. Keeping's care and skill in developing them from the matrix. His labours have given us a valuable and, I believe, unique series of specimens, which serve to extend very largely our acquaintance with the two principal genera of the family Oreodontidæ.

A summary of these fossils may here be given:—

1. A large nearly complete skull, with lower jaw attached, the zygomatic arches being, however, almost destroyed (*Merycochærus Leidyi*, n. sp.).
2. The greater part of a large skull preserving very completely one zygomatic arch with posterior crest (*Merycochærus temporalis*, n. sp.).
3. Another skull of *Merycochærus temporalis*, showing the part anterior to the bifurcation of the sagittal crest.
4. Another skull of *Merycochærus*, probably *M. Leidyi*, wanting the greater part of the face.
5. A nearly complete skull of *Oreodon major*.
6. The greater portions of two skulls of *Oreodon Culbertsoni* (the first-described species of the family).
7. Half of the frontal region of a *Merycochærus* larger than any of the others.
8. Casts of the brain of a large and of a small species, with determinable parts of bone attached.
9. Many portions of skulls, chiefly parts of upper and lower jaws with teeth, including a number which show the canine and incisor teeth.
10. Portions of limb-bones and a number of vertebæ.

Professor Hughes having kindly permitted me to examine these remains, I now present an account of *Merycochærus*, so far as I am at present able to give one, together with a description of two new species, which are remarkable additions to the Tertiary vertebrate fauna—hoping at some future time to furnish a more complete account of the family and its relations to extinct and existing Ungulates.

The progress of our knowledge of the Oreodontidæ has been comparatively slow, extending now over nearly 30 years. Fossils belonging to this family were first obtained from the Mauvaises Terres, Nebraska; and a jaw of a large species, supposed to be a *Palæotherium*, was described in 1846 and 1847 by Dr. Prout, in the 'American Journal of Science and Art.' Gradually other specimens came to light, and were described by Prof. Leidy, who gives the following account of their mode of occurrence. "The deposits of the Mauvaises Terres are remarkable for the great quantity of fossil remains of mammals and turtles they have yielded without further exploration than picking them up from the surface of the country. Detached from the neighbouring soft and readily disintegrating rocks, the fossils lie strewn about, and have often attracted the attention of the least curious of those who have traversed the district. Many of the loose fossils have gradually been collected by travellers and others. Of those collected, by far the greater part have been submitted to my investigation; and these have amounted to the enormous quantity of between three and four tons in weight." Prof. Leidy collected and completed his earlier descriptions in 1852, when he published, in the Smithsonian Contributions, "The Ancient Fauna of Nebraska," consisting of 126 pages, with 24 splendid plates. In succeeding years the Mauvaises Terres were further explored by Drs. David Dale Owen, John Evans, and F. V. Hayden, who brought to Philadelphia large collections of fossils. Altogether Prof. Leidy supposed, some years ago, that he had seen entire skulls or portions of skulls of about 500 individual Oreodonts, a very large proportion of them belonging to one species, *Oreodon Culbertsoni*. In 1869 the results of his twenty years' labour were published, forming the seventh volume of the second series of the 'Journal of the Academy of Natural Sciences of Philadelphia,' and entitled "The Extinct Mammalian Fauna of Dakota and Nebraska." This work contains 472 pages and 29 plates, and gives a synopsis of the entire mammalian remains of North America, with the most complete references and the author's valuable critical opinions. A considerable portion of this work is devoted to the Oreodontidæ. Still more recently, Prof. Leidy's 'Contributions to the Extinct Vertebrate Fauna of the Western Territories,' published in 1873, records further progress in reference to the Oreodontidæ, especially *Merycochærus*, which, however, is still described only from incomplete upper and lower jaws. In a letter to myself, dated Oct. 26, 1875, Prof. Leidy says, "In answer to your question about *Merycochærus*, I have seen no other remains than those described in my two works" (those already referred to).

The following is given as a brief definition of the family Oreodontidæ:—

Hornless Ungulates, in which the posterior region of the skull presents a strong sagittal crest flanked by large temporal fossæ. Orbits closed. Zygomatic arches strong. No unossified spaces on the side of the face. Teeth 44, a complete series. Canines large, the lower being transformed premolars. Molars of typical ruminant form.

The following more extended definition is copied, for convenience of reference, from the "Extinct Mammalian Fauna," p. 71.

"OREODONTIDÆ. The skull has somewhat the form of that of the peccaries; the cranial portion especially resembles that of the camel. It is hornless. The temporal fossæ are large, and separated by a median sagittal crest as in the camel. The zygomatic arches are strong. The orbits are closed behind by an arch. Large and comparatively deep fossæ impress the lachrymal bones in advance of the orbits. No unossified spaces occupy any part of the face. The auditory capsules are variable in degree of development. The paramastoids are long and strong. The lower jaw is broad and deep posteriorly, and impressed with a comparatively deep fossa below the lunar notch. The teeth in both jaws form nearly unbroken arches. The formula of dentition is $i. \frac{3-3}{4-4}$, $c. \frac{1-1}{1-1}$, $pm. \frac{4-4}{3-3}$, $m. \frac{3-3}{3-3}$ = 44; well-developed incisors in both jaws, the fourth of the lower jaw being a transformed canine, as in ordinary ruminants. Canines well developed and strong in both jaws, suilline in their resemblance, those of the lower jaw being transformed premolars. The anterior three premolars having the crown in the form of a demicone, with more or less rudimental elements at the base internally. The fourth upper premolars and the true molars of both jaws constructed after the ordinary ruminant type, and most nearly resembling in form those of the Deer family."

This description may be supplemented and modified by observation of our specimens as follows:—In the first place, the general resemblance to the skull of the Peccary is very much less strong in the larger species than in the smaller. The temporal fossæ are in some very large, and the median sagittal crest may be very strong and prominent. The only breaks in the series of teeth are those caused by the protrusion of the large canine teeth in each jaw into corresponding intervals in the series of teeth in the other jaw. It is better to amend the dental formula according to the definition which defines the canine of the lower jaw as the tooth which bites *in front* of the first tooth in the superior maxillary bone; the first premolar in the lower jaw of Oreodontidæ will then be called a caniniform premolar. Thus we get the normal dental formula, so frequently met with in early Mammalia,

$$i. \frac{3-3}{3-3}, c. \frac{1-1}{1-1}, pm. \frac{4-4}{4-4}, m. \frac{3-3}{3-3} = 44.$$

The suilline resemblance attributed to the canines should be omitted,

as it gives rise to an erroneous conception of the nature and appearance of these teeth.

The following are the distinctive characters assigned by Prof. Leidy to the genera of *Oreodontidæ* established by himself ("Contributions," pp. 201, 202).

"*Oreodon*: Molar teeth with short crowns, as in the deer, and, as in this, at maturity inserted by fangs. Anterior premolars straight, with the diameters nearly equal, and with their points median or nearly so. Face gradually convergent, conical. Infraorbital arch narrow or of moderate depth, gradually declining upon the side of the face. Infraorbital foramen small and situated above the third premolar. Nasal orifice nearly as wide as high, and situated immediately above the incisive alveolar border, as usual in most animals. Premaxillaries and maxillaries remaining distinct from one another. Incisive foramina of moderate size.

"*Merycochærus*: Crowns of the molars proportionately longer than in *Oreodon*, and protruding gradually as they were worn away, the anterior having their sculptured triturating surface obliterated before the posterior are fully protruded. Anterior premolars with the length and breadth exceeding the width, and the upper ones inclining posteriorly, and with their points in advance of the middle. Facial cone abruptly narrowed in advance of the orbits. Infraorbital arches deep and rapidly declining on the face. Orbits smaller and more externally situated than in *Oreodon*. Infraorbital foramen above the interval of the first and second molars. Nasal orifice situated far above the alveolar border, as in the tapir, and commencing below as an angular notch of the premaxillaries, which are firmly coossified together and with the maxillaries. Incisive foramen large.

"*Merychyus*: Teeth as in *Merycochærus*. Facial cone intermediate in character to the latter and *Oreodon*. Infraorbital foramen situated above the last premolar, or in a position intermediate to that of *Oreodon* and *Merycochærus*."

The following corrections must be made in the generic characters of *Merycochærus*, in consequence of the greater perfection of our specimens:—

1. The facial narrowing in front of the orbits is very little greater or more sudden in *Merycochærus* than in *Oreodon*, although it is considerable.

2. The orbits are not relatively smaller than in *Oreodon*.

3. The position of the infraorbital foramen relatively to the teeth seems to be variable. In our specimens it is above the 3rd premolar, or the interval between the 3rd and 4th.

4. The nasal orifice extends far above the alveolar border, and appears to be uninterruptedly open from the apex of the notch between the premaxillaries, only half an inch above their continuous alveolar border, to the horizontal projecting spine of the connate nasals.

Since the position of the infraorbital foramen varies in different species, the genus *Merychyus* may very well be dropped, as it is founded upon this single character. The teeth and portions of jaws

assigned to *Merychys elegans* and *medius* (Extinct Mammalian Fauna, pp. 118-121) appear to belong to *Oreodon*, while the teeth figured under the name of *Merychys major* are referable on equally good grounds to *Merycochærus*.

In the third of his great works above referred to ('Contributions,' p. 201), Prof. Leidy says "*Merychys* would appear to be the same as *Merycochærus*, and the fossils which had been referred to it belong to the same geological horizon."

The following are to be added to the characters of *Merycochærus*:—

1. The side of the face is very nearly oblong (that of *Oreodon* being a triangle truncated in front); and the whole upper surface of the skull slants downward much less from behind forward than that of *Oreodon*.

2. The temporal fossa is much wider and deeper than in *Oreodon*.

3. The outward curvature of the temporal ridges from the sagittal crest is much more gentle and prolonged than in *Oreodon*.

4. The whole squamous portion of the temporal bone is very large. The length, breadth, height, and outward curvature of the zygoma are much greater than in *Oreodon*. The form of the zygomatic crest differs very considerably, being greatly extended transversely, and looking principally forwards and backwards, while its aspect in *Oreodon* is principally inwards and outwards.

5. The postglenoid processes are large and transversely extended.

6. The suborbital arch is unusually deep and strong.

7. The occipital foramen approaches nearly to a circular shape (it is transversely oval in *Oreodon*).

8. The posterior part of the basiscranial axis is set at a much greater angle with the longitudinal axis of the palate than in *Oreodon*; and its shape is that of a continuous curve of comparatively small radius. In *M. temporalis* the posterior extremity of the basioccipital axis descends even below the plane of the palatal surface.

9. The palate extends considerably behind the last molar tooth, viz. to one third of the distance between the latter and the auditory bullæ. In *Oreodon* the palate only extends to about the level of the last molar tooth.

I now proceed to a detailed description of this remarkable skull.

The skull in *Merycochærus* is elongated, high, and massive. Its median longitudinal section would be an oblong with the length between three and four times as great as the height. Viewed from above, a high and strong sagittal crest is seen proceeding forwards from a small transverse occipital crest. The sagittal crest is flanked on each side by the convex wall of the cranial cavity, by a wide temporal fossa, and a strongly arched zygoma, reaching out much beyond the glenoid cavity. The sagittal crest bifurcates into two gently and very symmetrically curved temporal ridges, which extend to the posterior border of the orbit and then become lost on the malar bone. The frontal surface of the skull is of considerable size, and very nearly lozenge-shaped, the posterior angle being situated between the two temporal ridges, the lateral angles corresponding

with the posterior border of the orbit, and the anterior angle being undefined, as the surface is continued by the nasal bones. The frontal surface is generally somewhat convex; but it is slightly concave behind, in the angle between the two temporal ridges, and also in front of the supraorbital foramina, which are about three quarters of an inch distant from one another, on a level rather behind the middle of the orbit, and about half an inch in front of the median point to which the nasal bones converge. From each foramen a groove, more or less marked in different species, runs forward and is gradually lost on the nasal bones.

The upper surface of the face is elongated and comparatively narrow. It is constituted entirely by the nasal bones, which do not extend downwards on the side of the face. Each nasal bone is slightly convex transversely; and the two together form a very regular convexity, which is greater or less in different species. Posteriorly the outer margins of the two nasals converge gently to a point in the middle line. Anteriorly they together form a projecting triangle, which is thickened below at the apex; this latter overhangs the nasal aperture, but does not extend quite so far forward as to overhang the extremity of the præmaxillæ.

The upper part of the nasal aperture is almost square; but inferiorly it is produced to an angle of 30° , ending in a rounded form as a notch between the diverging præmaxillary bones, which are ankylosed at the alveolar border and for about half an inch above it. The inner margin of each præmaxilla bounds the nasal aperture entirely in rather more than its lower half; the maxillary bone bounds it at its widest upper part, while the nasals complete the boundary above.

The lateral aspect of the face is nearly oblong, and almost vertical; and its height is, within a little, equal to its length. The posterior part of the face is not more than three quarters of an inch higher than the anterior. The facial surface presents, in front of the orbits, the following inequalities. First, the lachrymal fossæ, just in front of the middle of the inner boundary of the orbit. This fossa may vary from comparative shallowness to considerable depth, and from a rounded to a nearly conical shape. Secondly, the gently convex continuation of the lower part of the zygoma on to the face, graduating above into the lachrymal fossa, in front into the vertical and flat anterior part of the face, and below into the depression above the premolar teeth. Thirdly, the latter depression, more marked anteriorly than posteriorly, and containing just below the anterior termination of the zygomatic ridge the infraorbital foramen, a vertically-placed oval opening directed forwards; its position varies, as also does the depth of the fossa. Fourthly, a rounded convexity corresponding to the fang of the upper canine tooth, forming the extreme external part of the front of the face. Between this prominence and the upper vertical part of the side face, an oblique groove, which probably served to convey a nerve to the upper lip, passes downwards to the front of the præmaxilla.

Unfortunately I have to describe the zygoma and its posterior

crest from a single specimen of *M. temporalis*, where it is almost perfectly preserved on the right side. I have thought it best to describe the temporal fossa and its boundaries fully here, instead of leaving it for the subsequent description of the species.

The long axis of the temporal fossa is directed forwards and outwards at an angle of about 40° with the middle line. Its extreme length could not have been less than eight inches in *M. temporalis*; but this cannot be exactly determined, because the upper and posterior boundary is almost entirely broken off. But it may be stated, to give some idea of its size, that, notwithstanding the high development of the face and nasal cavities, the temporal fossa is larger than the face. It is bounded behind by the transverse occipital crest, thus extending almost to the extreme posterior limit of the skull. This boundary was continued by the anterior of the forks into which that crest divides, running outwards and somewhat forwards. The height of this crest cannot be determined; but it appears probable that it was not less than an inch high. The external angle of the temporal fossa, situated midway on its lateral aspect, is occupied by the great posterior transversely-placed zygomatic crest. The crest slopes away in front so as to leave no external boundary to the fossa. Internally the fossa was bounded by the high sagittal crest, which appears to have continued at the same level as the frontal surface, or very little lower than it. The bifurcation of the sagittal crest forms the antero-internal wall of the fossa, which was in front limited by the posterior orbital arch.

The whole internal surface of the temporal fossa is very smooth, and gently and beautifully curved. The lateral wall of the cranium, which may be said to constitute the internal floor of the fossa, is convex, and is formed almost equally by the squamous and the parietal bones. Their suture is along the line of the most marked prominence of the convexity, and lies midway between the middle line and the outer boundary of the fossa. This prominence, together with a slighter ridge above it and parallel with it, constitutes a rather broad shallow groove. I would suggest that this ridge marks the limit separating the upper and anterior from the lower and posterior portion of the origin of the temporal muscle. Near the posterior termination of this ridge, which is on the parietal, and between it and the squamous suture, is a large foramen which Dr. Leidy identifies as venous. There is in our specimens a smaller foramen just behind and below this.

The internal lateral boundary and floor of the fossa in its middle portion presents, from above downwards:—first, a considerable concavity formed by the nearly vertical rise of the sagittal ridge; secondly, the convexity on the side wall of the cranium; and, lastly, another deep but gently curved concavity directed downwards, forwards, and outwards along the inside of the posterior and external ridge, which extends forwards from the occipital crest.

The extreme depth of the fossa depends on the height of the sagittal ridge; but it was at any rate equal to two thirds of the total length of the fossa.

Unfortunately the surface of the postero-inferior part of the orbit and the suborbital arch are broken away on the right side in our specimens, so that it is impossible to determine how the very deep suborbital arch graduated into the much less deep middle portion of the zygoma. Certainly the zygoma projected forward and was intercalated between the prongs of a fork formed by the processes of the malar. The two prongs of the fork seem gradually to have diminished to nothing, while the zygoma descended to the same level as the lower margin of the malar. The broken-off anterior extremity of the zygoma, as we possess it, is about half the height of the suborbital arch. Its external surface is smooth and gently rounded. Its upper surface is as broad as its external is high; in front it is obliquely directed inwards; but posteriorly its direction changes until it is quite parallel with the middle line of the skull. At the same time the internal height of the zygoma becomes very much less than the external, and ultimately thins away to a sharp edge.

The upper surface of the zygoma in passing backwards now becomes very much wider. Its inner edge curves round until it passes transversely inwards to join with the lateral wall of the cranium at about its anterior third; while its external border rises in a concave curve, passing inwards at the same time, till it has reached a height of $2\frac{3}{8}$ inches above its origin, and of $3\frac{1}{4}$ inches above the lowest part of the zygoma.

This crest and arch differ from those of *Oreodon* in their much greater proportional size and in their form. In *Oreodon* the zygoma continues the direction of the infraorbital arch, or even curves inwards to the cranial wall. In *Merycochærus* it diverges considerably further from the middle line than the infraorbital arch. In *Oreodon* the crest on the hinder part of the zygoma is very little higher than the rest of the arch; it is almost constituted by the arch thinning in a vertical direction behind; and its concave surface, of no great extent, looks mainly inwards, only slightly forwards. In *Merycochærus* the crest is much higher than the rest of the zygoma, and, far from being constituted by the compression of the latter, it is set at right angles with its anterior part; and its large concave surface looks directly forwards. Its concave area is about six square inches; in a good-sized *Oreodon* it is only about one square inch.

The posterior aspect of the skull presents, in the middle line below, the nearly vertical and circular occipital foramen, flanked by the antero-posteriorly compressed occipital condyles. The upper and posterior of the two surfaces produced by the compression of the condyle, is separated from the lower and anterior by a blunt ridge. The former is convex and oval, with an acute termination below. The condyles are considerably separated from one another; and there appears to have been an emargination of the basioccipital in the middle line.

The lateral margins of the foramen are continued above into blunt ridges, which soon join and then bifurcate to form strong

sharp projecting ridges which extend upwards to the transverse occipital crest, enclosing between them a fossa of moderate size and varying depth. Outside these ridges, on each side, is a much larger and deeper fossa, bounded above by the lateral occipital crest proceeding obliquely downwards and forwards to the zygoma, below by the occipital condyle of either side, and externally by the large blunt convex postauditory process. Below this is the large paroccipital process, which is triangular at the base, and extends downwards and somewhat inwards for an indeterminate distance closely behind and externally to the auditory bulla. The smallest length that can be allowed for the paroccipital process, consistently with the size of its basal part and its length in *Oreodon*, is an inch and a half. The external auditory meatus looks upwards and outwards in the angle between the posterior zygomatic root and the postauditory process.

The hinder parts of the zygomatic arch, the postglenoid processes, the auditory bullæ, and paroccipital processes are important features in the widely extended posterior part of the under surface of the skull. The under surface of the basioccipital is convex, with a strong median longitudinal ridge expanding into a blunt eminence of considerable size, which is gradually lost anteriorly on the basisphenoid. The latter bone, as well as the presphenoid, is smooth, nearly flat, and narrow. The base of the cranium forms a very regular curve, extending very much upwards and forwards.

The auditory bullæ, in the two specimens in which they have been perfectly preserved, arise just in front of the foramina lacera posteriora internally, and of the paroccipital processes externally. Their hinder limit extends slightly behind a line joining the posterior surfaces of the postglenoid processes. The bullæ are large and somewhat nipple-shaped and compressed, their long axis making an angle of about 10° with the median line of the skull. The external surface is more irregular than the internal, which may be perfectly smooth. The large foramina lacera media are situated at the inner anterior side of the base of the bullæ, and are elongated parallel with the bullæ, so as to terminate acutely behind. Each foramen is divided by a process projecting from the anterior boundary into a smaller anterior and a larger posterior region.

The glenoid articular surface, with its postglenoid process, is situated externally to the auditory bulla, separated from it and the paroccipital process by a deep sigmoid fossa. The fore part of the articular surface is nearly horizontally situated. It is slightly convex antero-posteriorly, shelving away in front and laterally, where it is continuous with the under surface of the zygoma. A posterior vertically descending portion is contributed to the glenoid surface by the anterior flat smooth surface of the very large postglenoid process. This latter is transversely extended, somewhat compressed antero-posteriorly, and strongly convex behind. It projects less deeply than the auditory bulla by a quarter or three eighths of an inch.

The under surface of the zygoma extends far outward beyond the

glenoid surface. Its breadth is about equal to the distance between the middle line and the outer edge of the glenoid surface. Between the postglenoid tubercle and the outer margin of the zygoma the latter forms a wide concavity; for the lower edge of the zygoma at its most prominent part descends to as low a level as the apex of the auditory bulla. The surface is smooth. The lower fork of the malar extends backwards, beneath and internally to the zygoma, lying on it, but not ankylosed with it, as far as the region of the great transverse crest. It ends in a thin flat rounded lamina. The posterior surface of the crest is smooth and slightly concave below.

The palate is broad and arched, and only widens slightly between the molar teeth. There is an anterior major concavity between the premolars and the first two molars of each side, and a posterior smaller concavity behind the level of the last molars. The palate is continued behind the alveolar processes for about one third of the distance between them and the auditory bullæ; its width diminishes to about half that of the anterior portion; and there is a deep notch on each side between this posterior portion of the palate and the alveolar processes. The palatal surface ends by a posterior edge which possesses a median prominence and two lateral shallow concavities, which pass on each side into the vertical pterygoid plates. The latter extend, at about the same level as the palate, nearly back to the auditory bullæ, and consequently enclose a large and deep median fossa behind the palate. I am not able to describe the pterygoid fossæ; they were certainly comparatively small.

The teeth do not need much remark, since Leidy has described the teeth of *Oreodon* so elaborately in the 'Extinct Mammalian Fauna of Dakota and Nebraska,' and those of *Merycochærus* do not differ from them in many points except those mentioned in the generic definition given above. One of the most conspicuous characters appears to be the more rapid increase of the molars in size from before backwards, and the increased strength of the external columns of the upper molars.

The lower jaw exhibits a considerably greater size and prominence of the lower posterior rounded angle than in *Oreodon*. The condyles are very narrow, and are transversely elongated. The ascending rami are vertical, and consequently parallel to one another. Their external surfaces are concave posteriorly and convex anteriorly, the convexity being lost on the horizontal rami. The ascending rami are most remarkable for their breadth, though their height is considerable. The horizontal rami are not very deep; they are vertical, but have a strong convexity externally, proceeding from behind and above obliquely downwards and forwards to the lower extremity of the ramus. The mental foramen is large, oval, and directed obliquely forwards; it is placed just below the third premolar (the caniniform tooth being reckoned as the first). The anterior symphyseal surface of the jaw is broad, in correspondence with the breadth of the row of incisor teeth with the caniniform premolar. It is twice as broad above as below, and is regularly convex from side to side. From its lower extremity it ascends at

an angle of 40° with the horizontal. The two halves of the mandible do not appear to have become ankylosed at any period. They are separated at the symphysis by an eighth to a quarter of an inch in our specimens; and the opposed surfaces are very simply denticulated. The posterior and inferior margins of the mandible are rounded and thickened, but are less thick at the angle. The lower margins of the horizontal rami very gradually approach each other, and meet anteriorly by forming a small semicircular curve at the symphysis. Nothing can be said about the coronoid process or the inner surfaces of the rami, because the space between them in our *M. Leidyi* is filled up by peculiarly hard matrix.

Since the species of *Merycochærus* founded by Prof. Leidy are chiefly based on their teeth with portions of jaws, and I am not able to determine their identity or non-identity with those in the Woodwardian Museum, I think it better to describe the two principal forms which I have determined as new species, especially as they are distinguished on grounds independent of the teeth.

MERYCOCHÆRUS TEMPORALIS, n. sp. Pl. XVII.

This species is founded mainly upon two specimens, numbered 2 and 3 in the list given above. The first of these is of unique interest. Anteriorly it is vertically truncated in the region of the third premaxilla. The frontal surface and the lateral walls of the skull are entire. On the right side the margins of the orbit are much injured, and the infraorbital arch is almost entirely lost; but the great zygomatic crest behind this is complete. Unfortunately the ridge leading from the posterior part of the zygoma to the transverse occipital crest is broken off, as is almost all the sagittal crest. On the left side the orbit with its infraorbital arch is almost perfect, but the zygomatic crest is deficient. Posteriorly the lateral occipital fossæ are plain, but they lack the bounding projecting ridges; the condyles are broken off. On the under surface of the skull the surfaces of the basioccipital and basisphenoid are almost perfect; the auditory bulla, the glenoid surfaces, and the postglenoid processes are in excellent preservation; and the palate, so far as the anterior truncation, is complete. The teeth, however, are broken off, not simply worn down.

The other specimen is more complete anteriorly, and includes considerable portions of the canines and the nasals up to their anterior terminations. The sides of the face are more or less damaged; but the orbits can be pretty well defined, and the suborbital arches are entire, with a little piece of the zygoma on the right side. The greater part of the frontal surface is present; but nearly the whole skull behind the posterior boundary of the orbits is broken off. Below, the palate is in a very imperfect condition; the outlines of a number of teeth are seen broken off down to the level of the palate.

The chief characteristics of *M. temporalis* are the following:—

1. The lachrymal pits are wide and shallow.
2. The infraorbital arch is directed somewhat obliquely outwards

and downwards; its surface is remarkably even, unmarked by furrows or prominences.

3. A plane lying on the orbit is directed more obliquely downward and forward than the infraorbital arch. Thus the eye would look considerably forwards and upwards as well as outwards. The orbit is larger and more oval than in *M. Leidyi*.

4. The very great outward extension of the zygomatic arch.

5. The great size of the posterior zygomatic crest and of the temporal fossa, whose long axis makes between 10° and 15° greater angle with the middle line than in the following species.

6. The greater breadth and size of the postglenoid process.

MERYCOCHÆRUS LEIDYI, n. sp. Pl. XVIII.

I desire to connect this species with the name of Prof. Leidy, whose magnificent works have done so much for our knowledge of the palæontology of North America.

It is founded on a large skull, which is nearly complete, lacking unfortunately the posterior part of the zygoma with its crest on both sides, and also the orbit and the suborbital arch on the left side. The face, however, is almost perfect, the fore part of the nasals only being injured. The mandible is firmly united by the matrix to the skull almost *in situ*, but a little laterally displaced behind. The front teeth are a good deal broken; the lateral view of the teeth of the upper jaw is very good, especially on the left side; the lower premolars are also partially visible. The occipital crest is injured behind. The comparatively small portion of the base of the skull that exists behind the glenoid articulation is well exposed; but the auditory bullæ and paroccipital processes are almost entirely destroyed. The occipital condyles are very perfectly preserved.

The characteristics of *M. Leidyi* are as follows, in contrast to those of *M. temporalis* given above:—

1. The lachrymal pits are conical at the bottom and of considerable depth; there is a moderate-sized lachrymal tubercle on the margin of the orbit.

2. The infraorbital arch, of somewhat greater depth than that of *M. temporalis*, is almost vertically situated. Instead of being flat, it presents from above downwards:—first, the raised rim of the orbit; secondly, a broad groove passing round from the fore part of the lachrymal depression and backwards on the lower fork of the malar, being overhung by the strong prominence of the anterior part of the zygomatic process itself where it fits into the malar; and, thirdly, the convexity of the malar process of the maxillary bone, which gradually dies away forwards on the side of the face, and becomes quickly lost behind.

3. The orbit is considerably more vertically placed than in *M. temporalis*, and looks much more directly outward; it is nearly circular.

4. It is impossible to determine how far the zygomatic arches extended outwards; but from the direction of the parts existing,

especially of the inferior fork of the malar, it would appear that they could not have extended outwards so far as in *M. temporalis*.

5. The smaller size of the temporal fossæ, and the more acute angle (by about 10°) which its long axis makes with the middle line of the skull. The cranium itself is considerably smaller in proportion to the size of the skull than in *M. temporalis*.

6. The postglenoid processes are much less broad and proportionally deeper.

The relative position of the auditory bullæ, postglenoid processes, and occipital condyles differs in the two species. A line drawn through the postglenoid and paroccipital processes to the middle posterior point of the basioccipital in *M. temporalis* makes an angle of about 60° with the median line; the same angle is only about 45° in *M. Leidyi*. The absolute distance is greater in the latter; and the postglenoid processes, instead of being opposite the middle of the auditory bulla, are situated opposite its anterior extremity.

The following are the dimensions of *M. temporalis* :—

	inches.
Probable extreme length of skull	14
Length of the larger portion in the Woodwardian Museum	$9\frac{3}{4}$
Length of the small portion	$7\frac{3}{4}$
Half width across frontal surface	$2\frac{3}{4}$
Distance from median line to external limit of zygo- matic arch	5
Greatest width of brain-case	$3\frac{3}{4}$
Width of palate within teeth	3
Breadth between outer surfaces of postglenoid pro- cesses	$5\frac{1}{2}$
Depth of auditory bulla behind	$1\frac{1}{8}$
Depth of auditory bulla in front	$1\frac{1}{2}$
Height of zygomatic crest	$3\frac{1}{4}$
Depth of skull in middle	4
Probable depth at posterior extremity	5
Longest diameter of orbit	2
Depth of infraorbital arch	$1\frac{7}{8}$
Width of face just in front of orbit	$2\frac{3}{4}$
Height of face in front	$3\frac{1}{4}$
Length of last molar tooth	$1\frac{3}{8}$

Dimensions of *M. Leidyi* :—

Total length of skull (possibly the actual length was $\frac{1}{2}$ inch greater when uninjured)	$12\frac{1}{2}$
Half width across frontal surface	$2\frac{1}{8}$
Greatest width from middle line to exterior of zygo- ma, so far as existing	$3\frac{1}{4}$
Greatest width of brain-case	$2\frac{7}{8}$
Width between external surfaces of postglenoid pro- cesses	$4\frac{1}{2}$

	inches.
Long diameter of orbit	1 $\frac{7}{8}$
Depth of infraorbital arch	1 $\frac{9}{16}$
Width of face 2 $\frac{1}{2}$ inches in front of orbit	2 $\frac{7}{12}$
Height of face anteriorly	3 $\frac{5}{8}$
Length of last molar tooth	1 $\frac{1}{2}$
Extreme length of lower jaw	10

Appendix on the Geological Position of the Oreodontidæ.

It has been thought desirable to add to the foregoing paper a view of the species of Oreodontidæ already established, the localities from which they have been obtained, and the age of the deposits, so far as they have been determined. There can be little doubt that the number of species is less than is here indicated; but it would be futile at present to attempt such a revision as is required. For similar reasons the name *Merychyus* is retained for the species characterized by Prof. Leidy.

- Oreodon affinis?, *Leidy*. Bed A, Mauvaises Terres, White R., Dakota. Miocene.
 — hybridus?, *Leidy*. " " " "
 — bullatus?, *Leidy*. " " " "
 — Culbertsoni, *Leidy*. Beds B, C, and D, Mauvaises Terres, White R., Dakota. Miocene.
 — Culbertsoni, *Cope*. North Colorado, equivalent to White-river beds. Miocene.
 — Culbertsoni, *nobis*. Bridge Creek, John Day's R., Oregon. Miocene.
 — gracilis, *Leidy*. Beds B, C, and D, White R., Dakota. Miocene.
 — gracilis, *Cope*. North Colorado. Miocene.
 — major, *Leidy*. Bed D, White R., Dakota. Miocene.
 — major, *nobis*. John Day's R., Oregon. Miocene.
 — superbus, *Leidy*. " " " "
 — occidentalis?, *Marsh*. " " " "
 Merycochærus proprius, *Leidy*. Bed D, Niobrara R., Nebraska. Miocene.
 — temporalis, *nobis*. John Day's R., Oregon. Miocene.
 — Leidyi, *nobis*. " " " "
 — rusticus, *Leidy*. Sweetwater R., Wyoming. Pliocene.
 Merychyus elegans, *Cope*. North Colorado. Miocene.
 — elegans, *Leidy*. Niobrara R., Nebraska. Pliocene.
 — medius, *Leidy*. " " " "
 — major, *Cope*. North Colorado. Miocene. "
 — major, *Leidy*. Niobrara R., Nebraska. Pliocene.

The John-Day's-River deposits are indicated as Miocene in accordance with Prof. Leidy's conclusion that the zoological character and state of preservation of the fossils renders it probable that the formation to which they belong is of contemporaneous age with those of the White River, Nebraska. With regard to the first-named species in the list, Prof. Leidy says that certain facts "indicate *Oreodon affinis*, *hybridus*, and *bullatus* to be species which preceded the others in time, and were perhaps their ancestors, from one or another of which they may have been derived." A further statement of interest, borne out by the above Table, is that "*Merycochærus proprius* appears not to have inhabited the same locality with the Oreodons, at least contemporaneously."

Fig. 1.

$\times \frac{1}{2}$

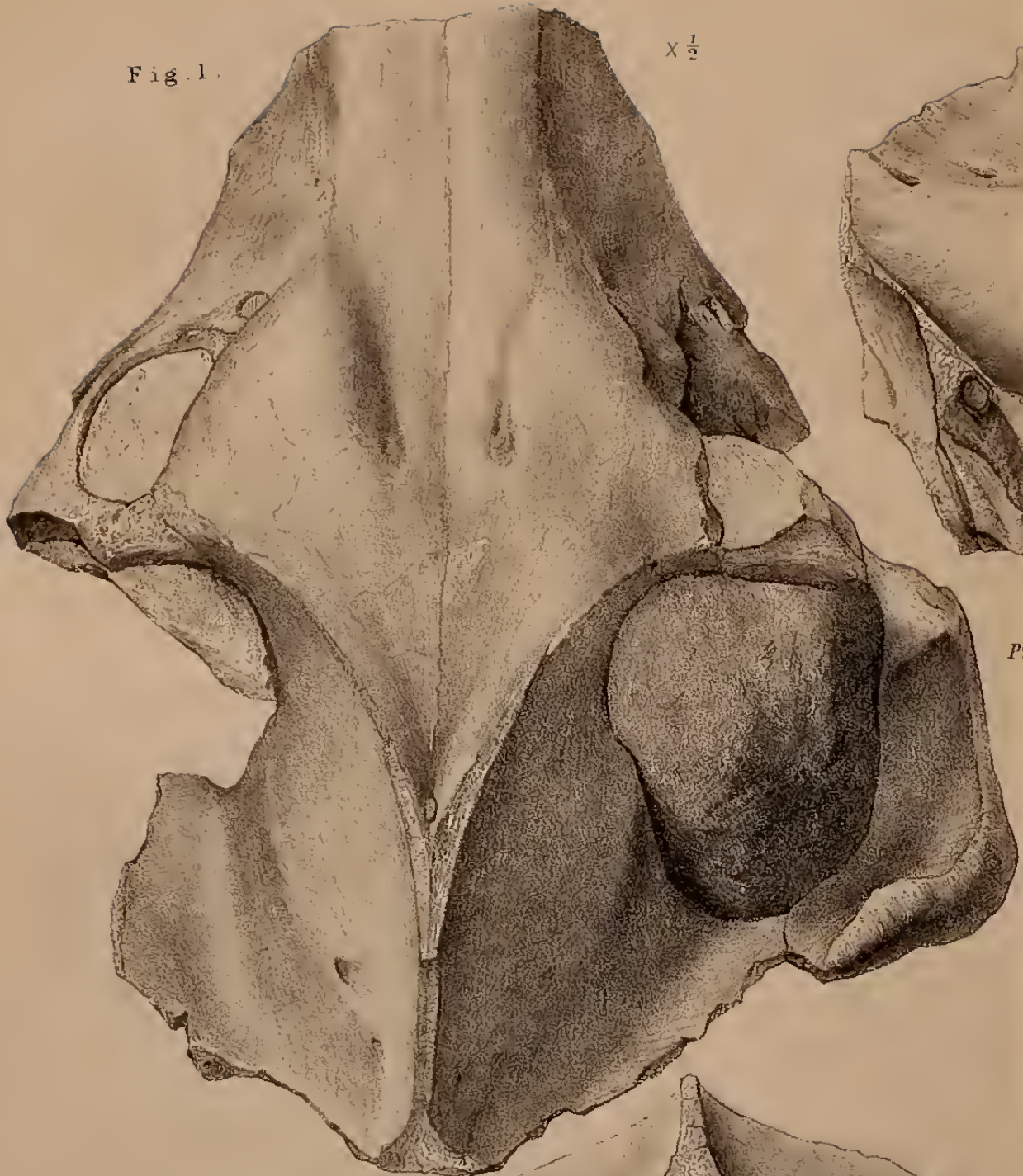


Fig. 3.



$\times \frac{1}{2}$

pgl au. b

$\times \frac{1}{2}$

Fig. 2.



po

au. b

pgl

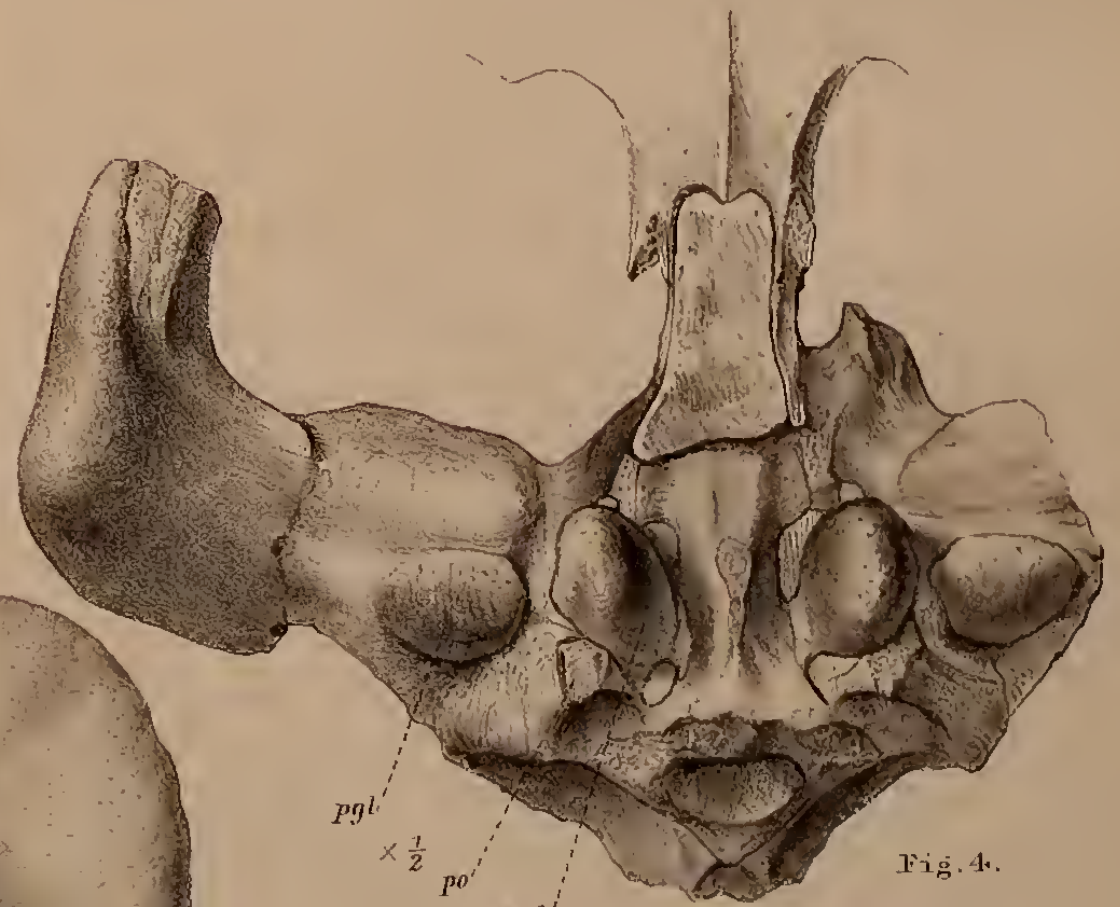
pgl

$\times \frac{1}{2}$

po

au. b

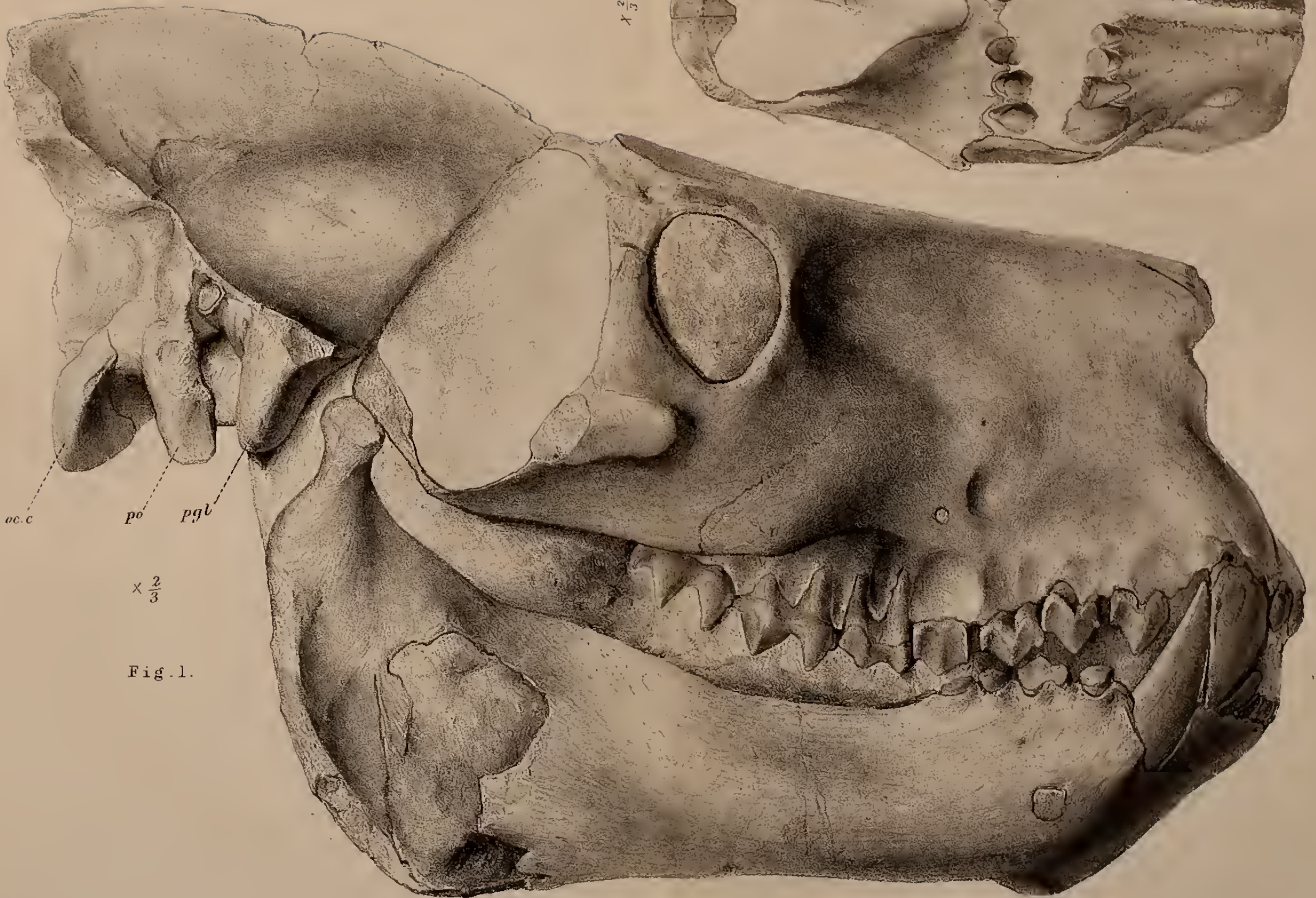
Fig. 4.



MERYCOCHÆRUS TEMPORALIS.

Fig. 2.

$\times \frac{2}{3}$



oc. c

po

pgl

$\times \frac{2}{3}$

Fig. 1.

EXPLANATION OF THE PLATES.

PLATE XVII.

Merycochærus temporalis, half natural size. All the views are from the same specimen.

- Fig. 1. Upper view of skull.
 2. Skull seen from behind.
 3. View of right side; orbital region partly restored from the left side.
 4. Posterior basicranial region.

(*au.b*, auditory bulla; *po*, paroccipital process; *p.gl*, postglenoid process.)

PLATE XVIII.

Merycochærus Leidyi, two thirds natural size.

- Fig. 1. Right side of skull, somewhat completed from the left side.
 2. Front view of face of same specimen.

(*oc.c*, occipital condyle; *po*, paroccipital process; *p.gl*, postglenoid process.)

DISCUSSION.

Prof. DUNCAN remarked that these late American forms seem to be very variable. Notwithstanding its name, the affinities of this genus to the Pigs was but small. The teeth appeared to be very variable; and this tendency to variation would seem to indicate a near passing-away of this type.

31. *On the TRIASSIC STRATA which are EXPOSED in the CLIFF-SECTIONS near SIDMOUTH, and a NOTE on the OCCURRENCE of an OSSIFEROUS ZONE containing BONES of a LABYRINTHODON.* By H. J. JOHNSTON-LAVIS, Esq., F.G.S. (Read March 22, 1876.)

IN describing the locality and geological position of the vertebrate fossils which were obtained from the Triassic rocks near Sidmouth, perhaps it would be as well to commence with a description of the coast-sections for a short distance east and west of that town.

Starting from the east, we find that the Marl* (which is the uppermost subdivision of the Trias of South Devon) makes its appearance at Branscomb Mouth, exposed beneath the Greensand and Chalk in the cliff-sections, and in the ramifying valley cut through by the small stream which runs out to sea at this point. It now forms the lower portion of the cliff under Littlecomb Hill and Branscomb Hill, being overlain by the Greensand and Chalk until it is exposed inland at Weston Mouth by the action of the little stream called Weston Water, which runs out here.

It again forms the base of the cliff under Dunscomb Hill, being still overlain by the Greensand and a small patch of Chalk; again it is exposed and partly excavated by the little brook at Salcomb Mouth; thence it forms the base of the cliff under Salcomb Hill, being now capped by the Greensand alone; it is then largely exposed on the surface in the valley of the river Sid.

A few yards east of where the Sid runs into the sea, the Upper Sandstone (of Mr. Ussher) crops out, forming a cliff overhanging the Sid, and constituting the bed of the stream for half a mile from its mouth, and also the whole valley except where covered by gravel, which Mr. Ussher tells me is in some places 15 feet thick, containing a bed of peat about a foot in thickness. The gravel is chiefly composed of chert, and contains teeth of Elephant, numerous specimens of which have been found by Mr. P. O. Hutchinson and others.

To the west of Sidmouth, at the end of the Parade, we meet with a low projecting cliff, called Chit Rock. Mr. Ussher, who has surveyed this district, tells me he has met with no evidence of a fault having existed in the valley; and therefore we may conclude that it is the continuation of the small exposure of sandstone which is seen to exist east of the river, as in section, fig. 1 (p. 276). At the western end of the Chit Rock we find a fault which has given the Chit Rock an upthrow of at least 40 feet; but it is very possible it may be as much as 80 feet, since it has no marl capping it, and in its lithological character resembles the middle of the Upper Sandstone. We see, on the western side of the fault, the Marl brought down within a short distance of the beach, there being a small mass of Sandstone exposed beneath it. All the Triassic beds from Branscomb up to the present place dip gently to the east; but now we find them dipping to the west; this only takes place for the distance of about half a mile;

* See Ussher, 'Geological Magazine,' Decade II. vol. ii. No. 4, April 1875.

for the Sandstone which had disappeared, soon makes its appearance again, having formed a synclinal curve. During the whole of this distance it has been covered by the marl, which, as it advances westward becomes thicker, being less denuded; it has cappings of Greensand and chalk-gravel at Peake Hill and High Peake. The Sandstone continues to rise gradually to the westward; but the Marl and overlying Greensand have been cut down by atmospheric denudation, forming Windy Gap, which separates High Peake and Peake Hill—High Peake being the higher of the two, but resembling Peake in every other respect. The Sandstone gradually rises until, at a short distance to the west of High Peake, the Marl has been entirely denuded (save in a few places where through faulting it has been brought to a lower level) and it appears on the surface.

The upper marls are variegated, and especially in the higher part, east of Sidmouth, contain very thin layers of a greenish-grey sand mixed with a large quantity of mica, intercalated with layers of marl, varying in thickness up to two inches, but of the same light colour; they show ripple-marks, and occasionally contain pseudomorphs of rock-salt.

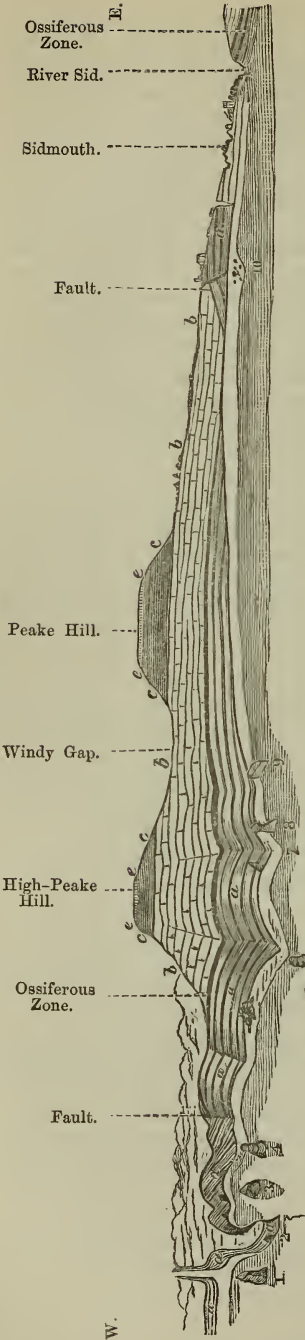
The marls between Weston and Branscomb Mouths contain a large quantity of gypsum, which at one time was worked at Branscomb Mouth. A few small veins are to be seen between Salcomb and Weston Mouths. The marls also contain bands of potato-stones enclosing a cavity lined with calcite. Mr. H. B. Woodward objects to my giving them the name of potato-stones, as they do not contain quartz crystals.

The Sandstone, especially at its upper part, where it resembles very much in lithological characters the upper beds of marl, contains a large number of pseudomorphs of rock salt, ripple-marks, and sun-cracks; but in no case have I met with rain-marks, which we might expect; neither have I met with any foot-prints. Some of the upper sandstones effervesce with hydrochloric acid. Between High Peake and Otterton Point the sandstones contain spherical masses sometimes almost like a cannon-ball, composed of iron pyrites; these are washed out of their matrix and lodge at the bottom of the little rocky pools.

The sandstones also contain curious irregular branching-shaped masses of a harder texture, which withstand the weathering and give the cliff a rugged aspect. It is worthy of notice that, at the points where the Marl reaches down to the beach, there are no reefs on the foreshore opposite, but a beautiful fine-grained red sand, except where large blocks of chert have fallen from the Greensand capping the cliffs; but wherever the Sandstone appears above the beach one sees large reefs running out to sea for nearly half a mile at low tide; it does not seem to be the sandstone itself which withstands the weathering, but these curious hard masses contained in it, since they occur in all the projecting points of the cliff formed by the sandstone strata.

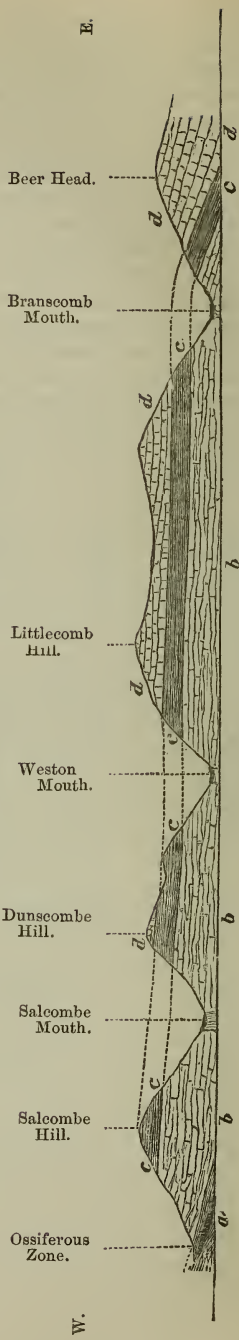
Last autumn, while on a visit to Sidmouth for the second time, I had the good fortune to find the bones of a Labyrinthodont.

Fig. 1.—Bird's-eye View of the Cliff-section from Ladrham Bay to Sidmouth.



- 1. Ladrham Bay.
 - 2. Arch.
 - 3. Horn Rock.
 - 4. Rock detached since 1860.
 - 5. Little Picket Rock.
 - 6. Picket Rock.
 - 7. Green Point.
 - 8. Man-of-God Rock.
 - 9. Tortoiseshell Rock.
 - 10. Chit Rocks.
- a.* Sandstone. *b.* Marl. *c.* Greensand. *d.* Chalk. *e.* Chalk-gravel.

Fig. 2.—Section from Sidmouth to Beer Head.



For explanation of letters see fig. 1.

These were brought to light at different periods during my month's stay. It may be mentioned that those described by Prof. Seeley are merely the bones which I considered capable of identification; for I met with a great number of small fragments dispersed throughout a particular series of beds situated about 10 feet from the top of the Sandstone. These bones were mostly found in fallen blocks which were derived from these beds in a little cove known as Picket-Rock Cove. It may be well termed an ossiferous zone, as it does not consist of one single bed, but of from one to four; not that I mean to imply that bones are only found in this zone, since Mr. Whitaker's *Hyperodapedon* was found at the very bottom of the Sandstone. This zone is characterized by lithological differences, inasmuch as the matrix is composed of much coarser sandstone, containing here and there masses of marl varying in size from that of a pea to that of a hen's egg. It is nearly hard enough in some places for building-purposes. In these beds ripple-marks are very plentiful. The fragments of bone which are found in this zone seem to be very slightly waterworn.

I cannot conclude without expressing my thanks to Messrs. H. B. Woodward, W. A. E. Ussher, and W. Whitaker for the kind assistance they have afforded me, and to Mr. P. O. Hutchinson, of Sidmouth, for the artistic diagrams with which he has furnished me.

P.S.—Since writing the above I have received from the Rev. S. H. Cook some fragments of bone obtained by him about twenty years ago from the same zone west of Sidmouth, as well as one which he recently obtained from the small outcrop of sandstone with the ossiferous zone on the western side of the Chit-rock fault.

Below the ordinary red sand on the beach one finds a stratum of black sand which has been derived from the sandstone, but is of greater specific gravity than the red sand, which accounts for its position on the beach. Mr. R. W. Cheadle has kindly made a qualitative analysis for me, with the following rough results—Silica, magnetic iron oxide, manganese, titanium, and alumina.

[For the Discussion on this paper see p. 283.]

32. *On the POSTERIOR PORTION of a LOWER JAW of Labyrinthodon (L. Lavisii), from the TRIAS of SIDMOUTH.* By HARRY GOVIER SEELEY, Esq., F.L.S., F.Z.S., F.G.S., Professor of Physical Geography in Bedford College, London. (Read March 22, 1876.)

[PLATE XIX.]

NOTWITHSTANDING all that has been done of late years by Prof. Huxley and those who have continued his labours, for the elucidation of the Labyrinthodontia, less is probably known of the structure and affinities of that group than of any other long-established Order of vertebrates. It may perhaps be an open question whether Labyrinthodonts can rightly be referred to an existing class of animals; for the nature of the affinities of these fossils with Amphibia, Palæosauria, and Reptilia is a subject rather for inquiry than for dogmatism; and unfortunately the new materials now to be described are too few to do more than slightly modify accepted surmises.

No apology seems to be necessary for the restoration of Prof. Owen's name *Labyrinthodon*, because neither Prof. Huxley nor Mr. Miall have attempted to justify either its suppression or reconstruction, while I am inclined to urge that demonstration is wanting that any foreign Labyrinthodont genus, such as *Mastodonsaurus*, has ever occurred in the British Isles. The single dermal plate figured by Mr. Miall, so similar to one hereinafter described from Sidmouth, seems to me no evidence; for Labyrinthodonts like Crocodilia and Teleosauria may well have resembled each other in the dermal armour of allied genera; and in describing an English fossil closely allied to one of those originally described by Prof. Owen from Warwickshire, it seems better to refer it to the genus *Labyrinthodon* as constituted by Prof. Owen, there being no evidence adduced or available for the subdivision of that genus in the manner proposed by Mr. Miall.

To H. J. J. Lavis, Esq., F.G.S., we are indebted not only for the discovery of the present specimen, unexampled among Labyrinthodont remains for its beautiful preservation, but also for untiring labour and skill in extricating the fossil from the matrix, and reuniting its multitudinous fragments into the handsome and instructive remains of a right lower jaw exhibited.

The fossil is 13 inches long, and absolutely free from matrix, so that every aspect and its component structures can be studied. It demonstrates that the lower jaw does not consist of articular, angular, and dentary elements only, as generally described, from which it is evident that the jaw is not constructed according to the Batrachian type. In addition to those three bones, there are certainly separate splenial and surangular elements, and not improbably a separate coronoid bone also. These five or six bones in each ramus are arranged so as to enclose a deep narrow cavity at least 9 inches long, in the hinder part of the jaw, extending forward from beneath

the articulation (Pl. XIX. fig. 2). This cavity has two perforations. There is one long narrow superior perforation, which looks upward and extends for more than 4 inches in front of the articulation; it is margined externally by the surangular bone, internally, presumably, by the splenial. The internal lateral perforation is much smaller; its place is from 7 to 8 inches in front of the hindmost extremity of the jaw, and half an inch from its inferior border. Its lower border is made by the splenial bone (fig. 2 *a*), and its upper border probably by the surangular (fig. 2 *d*), unless a small coronoid were present. The specimen does not show whether the perforations communicated or were separate. The internal cavity, like the jaw itself, is somewhat compressed from side to side behind on its inferior border, and widens a little anteriorly; it widens more from below upward. It is straight and in the same plane.

All the bones unite by sagittate sutures, and scarcely show any indications of squamous overlap. They are all more or less seen on the external aspect of the jaw (fig. 1), except the splenial bone; while every bone is seen on the internal aspect (fig. 2), where all the bones are free from sculpture. The internal aspect is largely occupied by the *splenial element* (fig. 2 *a*), which is fractured at its anterior extremity, and along all its upper border behind the lateral perforation. As preserved, it is $11\frac{1}{2}$ inches long, and was probably some inches longer. It terminates behind by a suture inclined slightly backward, but nearly vertical where it joins the articular bone (fig. 2 *e*); and it rests upon the angular bone (fig. 2 *c*) below, which extends along this aspect of the jaw for $7\frac{1}{4}$ inches. This suture with the angular bone has the outline of a low hill, of which the summit is at $3\frac{3}{4}$ inches from the hinder extremity, and the height about $1\frac{1}{8}$ inch. Hence the splenial bone descends in position as it passes forward, and then for $1\frac{1}{2}$ inch it crosses obliquely on the underside of the jaw, and so appears on its exterior aspect for $4\frac{1}{2}$ inches, extending forward as a very narrow strip, not a quarter of an inch deep (fig. 1 *a*), which has the angular bone above it for $2\frac{1}{2}$ inches behind, and the dentary bone above it in front. It is strongly marked on the flattened underside of the jaw with a radiate ornament reaching through half a circle. The ornament extends from a centre on the inner margin of the bone, half an inch below an oblong vascular perforation on the inner aspect; around the centre are close-set pits; but further away these are elongated into grooves. Every pit and groove has a perforation or channel for one large blood-vessel.

Of the *dentary bone* only a small posterior part is preserved (fig. 1 *b*). It extends backward on the upper surface of the jaw to within 2 inches of the articulation, and 4 inches of the extremity of the heel, terminating in a point. It rapidly widens and deepens. The surangular bone, over which it extends by squamous overlap, is internal to it on the superior aspect. Externally it descends down the side of the jaw by a long oblique suture, resting at first on the surangular bone for $1\frac{1}{2}$ inch, then on the angular bone for $5\frac{3}{4}$ inches, and finally upon the splenial bone. The dentary differs from the other external bones in being smooth and free from ornament, except faint longitudinal

striations. It is separated from the angular by a deep depression, looking as though due to its extension behind the angular, but probably resulting from the elevation of the ornament on the angular bone. The dentary bone makes an angular bend, so as to form a superior surface for the teeth, which appear to look upward and outward. Where the bone ends behind, the jaw extends for $2\frac{1}{4}$ inches below it, and $\frac{1}{4}$ inch above it, being $2\frac{1}{2}$ inches deep.

The *angular bone* (fig. 1 *c*) is the most striking part of the specimen. It forms the lower portion of the jaw on both aspects, and is an elongated bone tapering towards both ends on both sides. Externally it is $10\frac{1}{2}$ inches long, is received between the splenial and dentary bones in front, and posteriorly becomes depressed and reduced in depth from $1\frac{3}{4}$ inch at 5 inches from the end of the bone, to less than half an inch under the articulation. Its basal border is straight to within the posterior two inches, when it curves gently upwards, terminating half an inch short of the surangular bone, which extends along its superior $5\frac{1}{4}$ inches behind the point where the dentary bone terminates. This bone is marked by a semicircle of radiated sculpture, the centre of which is rather behind the middle of the bone on its basal border. As on the splenial bone, the ornament consists of an irregular honeycomb of pits near the centre, these becoming elongated laterally into grooves which run towards the extremities of the bone, harmonizing with the sculpture on the splenial and surangular elements. The grooves as they proceed become subdivided by ridges, of which five may be counted above the suture with the splenial bone at 8 inches from the end of the bone. The pits and grooves are full of perforations for blood-vessels, which take the same directions as the grooves. A broader groove, also vascular, shaped like the tail of a cursive *y* reversed, ascends to join the \vee -shaped groove on the surangular bone, which extends below the articulation of the jaw. These grooves only differ from the others in being broader. Altogether there are about 60 pits or grooves on the angular bone, mostly averaging $\frac{3}{16}$ inch in diameter, though some are punctures $\frac{1}{16}$ inch in size; while the broad posterior groove is half an inch in diameter, and the long anterior groove is 6 inches in length.

On the interior aspect of the jaw the angular bone occupies a smaller area (fig. 2, *c*). It reaches as far back, but not so far forward, as in front, being only about $7\frac{1}{4}$ inches long. Its greatest depth is $1\frac{1}{8}$ inch at 3 inches from its posterior end. The hinder part of the bone is concave from above downward, and has two conspicuous descending foramina under the part where it is deepest.

The *surangular* element (figs. 1, 2, 3, *d*) has hitherto been named the articular; but it extends in front of the articular bone so as to hide the whole of it except the surface seen in the articulation. The branch of the surangular which extends between the angular and dentary bones is about $5\frac{3}{4}$ inches long; but the part which, extending interior to the alveolar margin of the dentary bone, is imperfect anteriorly, is $8\frac{1}{4}$ inches long from the heel of the bone. Superiorly the bone bends over towards the inner side, so as to form a sort of back-

ward prolongation of the alveolar table, nearly an inch wide. From this a sharp slightly elevated coronoid ridge [imperfectly preserved] arises, which extends forward in the median line, originating at the outer and anterior border of the articulation. Another ridge at right angles to this, and somewhat thicker, is directed outward, so that a concavity extends along the bone between them. This ridge extends backward for 3 inches, inclined very slightly downward, and then curves in a semicircle upward, to terminate just behind the articulation. Below this ridge, under the articulation, is a shallow groove less than $\frac{1}{4}$ inch wide, and below this an elevated ∇ -shaped rudely sculptured mass of ornament, $1\frac{1}{4}$ inch long and $\frac{5}{8}$ inch deep. Below this is the broad \vee -shaped groove, with a few tear-like ornaments. The hinder arm of the \vee extends upward behind the articulation; the front arm extends upward and forward; both arms are connected by the narrow curved groove below the articulation.

Behind the \vee -shaped groove is a triangular piece of vascular honeycomb-like ornament, $1\frac{3}{4}$ inch deep and $1\frac{1}{4}$ inch long at its base, where it is underlapped by the angular bone. It extends the jaw externally behind the articulation. Nothing is behind the straight inclined posterior line of this sculpture except the heel of the bone—a subquadrate process half an inch deep, developed backward and inward, so as with the angular bone below to nearly enclose the hindmost termination of the articular bone, which is greatly attenuated. The surangular bone is reflected behind the articular element, so that superiorly it almost meets the splenial element. Posteriorly, below the articulation, the bone is deeply impressed on the irregular smooth hinder surface.

The *articular bone* (figs. 1, 2, 3, e) forms a narrow strip on the inner side of the jaw, oblique and curved backward, extending from the articulation to below the heel of the surangular bone. The articular surface is subrhomboid, extending further backward and outward on the external margin, and further forward on the inner margin, which slightly overhangs the bones beneath. It measures $\frac{3}{4}$ inch from front to back, and $1\frac{1}{8}$ from within outward. Its greatest oblique measurement is less than 2 inches. The hinder margin (formed by the surangular bone) rises above the anterior margin. From back to front the area is semicylindrically concave, and marked with two broad slightly elevated ridges with a longitudinal groove between them, while a second incomplete sulcus forms the internal margin to the articulation.

Though the bones now described have a reptilian aspect, and somewhat of a reptilian arrangement, they do not go far towards suggesting the affinities of *Labyrinthodon*. There seems no reason to doubt that the central hollow space in the jaw received the primitive cartilage round which the bones were ossified; and the persistence of this character is rather a link with the lower than with the higher Vertebrata. The jaw differs from the Batrachian mandible in possessing well-developed angular and surangular elements, by which this cartilage and its articular ossification are enclosed. But some reptiles, such as Crocodiles and the marine

Chelonia, present many analogies in the perforations, in the structure of the jaw, and in the sculpture of the bones. But in the absence of more important parts of the skeleton, no conclusions can be drawn from these resemblances.

The species indicated by this specimen is almost identical in size with the fragment attributed by Mr. Miall to *Labyrinthodon pachygnathus*, and, so far as I can judge from figures, resembles that fossil closely both in form and ornamentation. But the depth and outline of the postarticular part of the jaw, and the differences of sculpture in the lateral subarticular ornament, supply characters for distinction which, if the Warwickshire specimens are accurately figured, must separate the Dorsetshire fossil as a distinct species: this I propose to name *Labyrinthodon Lavisi*, in honour of its discoverer.

Associated Fragments.—Within a yard or two of the spot where the jaw was found, Mr. Lavis picked up several other *Labyrinthodon* fragments, which he supposes, with good reason, to have been portions of the same skeleton. These comprise two small pieces of bones from the upper part of the skull, which are too imperfect to be determined with certainty at present, though one forms a portion probably of the orbit of the eye, and the other shows a portion of a narrow channel of the kind which has been called mucous groove: its radiated sculpture is finer than on the other specimens; and it may belong to a young animal or a small species. Another compressed curved bone about $2\frac{1}{2}$ inches long, $\frac{5}{8}$ inch deep at one end, narrowing along the curve, and less than $\frac{1}{4}$ inch thick, I am disposed to regard (if *Labyrinthodon* at all) as possibly a vomer. The concave border of the specimen appears to have been palatal. Along it, and on part of the adjacent side of the bone, extend three or four ill-preserved rows of small conical teeth, which vary in size. These present a suggestive resemblance to the rows of teeth on the specimen figured by Prof. Huxley, and named *Hyperodapedon*, especially as some of them are similarly worn down; and it is possible that this fragment may pertain to that genus.

Two other specimens are portions of thoracic plates. A narrow fragment, $2\frac{1}{2}$ inches long, probably belongs to the median thoracic plate; while the principal fragment, 3 inches long and $1\frac{3}{4}$ inch wide, may be the right thoracic plate. It is thin, and marked by the usual radiated sculpture, but has the broad external border compressed and smooth.

Other smaller but imperfect plates were found, which are marked with shallow pits which do not become elongated into grooves.

Another portion of bone may be a segment from the upper part of a strong rib.

A chevron bone (fig. 4) shows the articular surfaces on one side, which prove it to have been articulated between two vertebræ, as in most of the Reptilia and Palæosauria.

Portions of dense cylindrical or more compressed bones, having the appearance of weathered teeth, were found; but the transverse sections which Mr. Cuttell has endeavoured to prepare are too thick and opaque to demonstrate their real nature.

EXPLANATION OF PLATE XIX.

Fig. 1. External view of posterior part of right ramus of lower jaw.

2. Internal aspect of the same specimen.

3. Articular region, seen from above.

4. Chevron bone.

a, splenic bone; *b*, dentary bone; *c*, angular bone; *d*, surangular bone; *e*, articular bone.

DISCUSSION.

Mr. USSHER remarked that the Trias of South Devon was too variable in character to furnish reliable evidence as to the persistence of individual beds as lithological or palæontological zones. The conglomerate bed of Otterton Point, which crops out below High-Peake Hill, is cut out at Ladram Bay by a fault, but reappears towards Otterton Point for a distance of a mile and a half. It varies very much in character, and exhibits false bedding in parts. Organic remains have been found in the Trias at Ruishton, in a marly gritty conglomerate, which contains *Labyrinthodon*, *Estheria*, &c.—also near Stoke St. Mary's, where *Estheria minuta* occurs,—in the Vale of Taunton, in sandstone not contemporaneous with that on the coast, and at North Curry, where *Estheria* and plant-remains are found in arenaceous beds under marl.

Mr. WHITAKER stated that while Mr. Lavis's *Labyrinthodon* was obtained from near the top of the sandstone, his *Hyperodapedon* came from near its base.

Prof. RAMSAY remarked that all these bones were from the Keuper, and not from the Bunter.

The PRESIDENT (Prof. Duncan) said that Professor Seeley had very properly treated this bone from his own point of view; but he would not doubt admit that there were others from which it might be looked at. It seemed to him that if this were the lower jaw of *Labyrinthodon*, it was very distinct from any other specimen. He noticed that from Mr. Miall's description it would seem that he had got upon the trace of the surangular bone in *Diadetoagnathus*, as in one of his specimens he describes a ridge which may be the indication of a bone wanting in the Warwickshire specimen but present in this one. He thought that some fish exhibited a somewhat similar construction, but that the lower jaw alone could never be sufficient for the purpose of classification; and here the other and more essential parts of the skull were wanting. The *Labyrinthodonts* seemed to him to be unquestionably an order of Amphibia.

Mr. LAVIS, in reply, said that his estimate of the upthrow was made from the lithological characters of the beds. The zone indicated by him was not conspicuous by its lithological characters. It contained small grains of quartzite and pockets of marl.

Prof. SEELEY, after thanking the President for his remarks, stated
Q. J. G. S. No. 127.

that the fossil described by him presented analogies to the Teleosauria and marine Chelonia, a fact which supports the evidence derived from the skeleton of the Labyrinthodontia. The skulls in those animals present characters found nowhere except among the true Reptilia. With regard to the identification of the specimen, he said that if those from Warwickshire described by Mr. Miall were Labyrinthodonts, then this was one also.

Fig. 4.

Fig. 3.

Fig. 2.

Fig. 1.

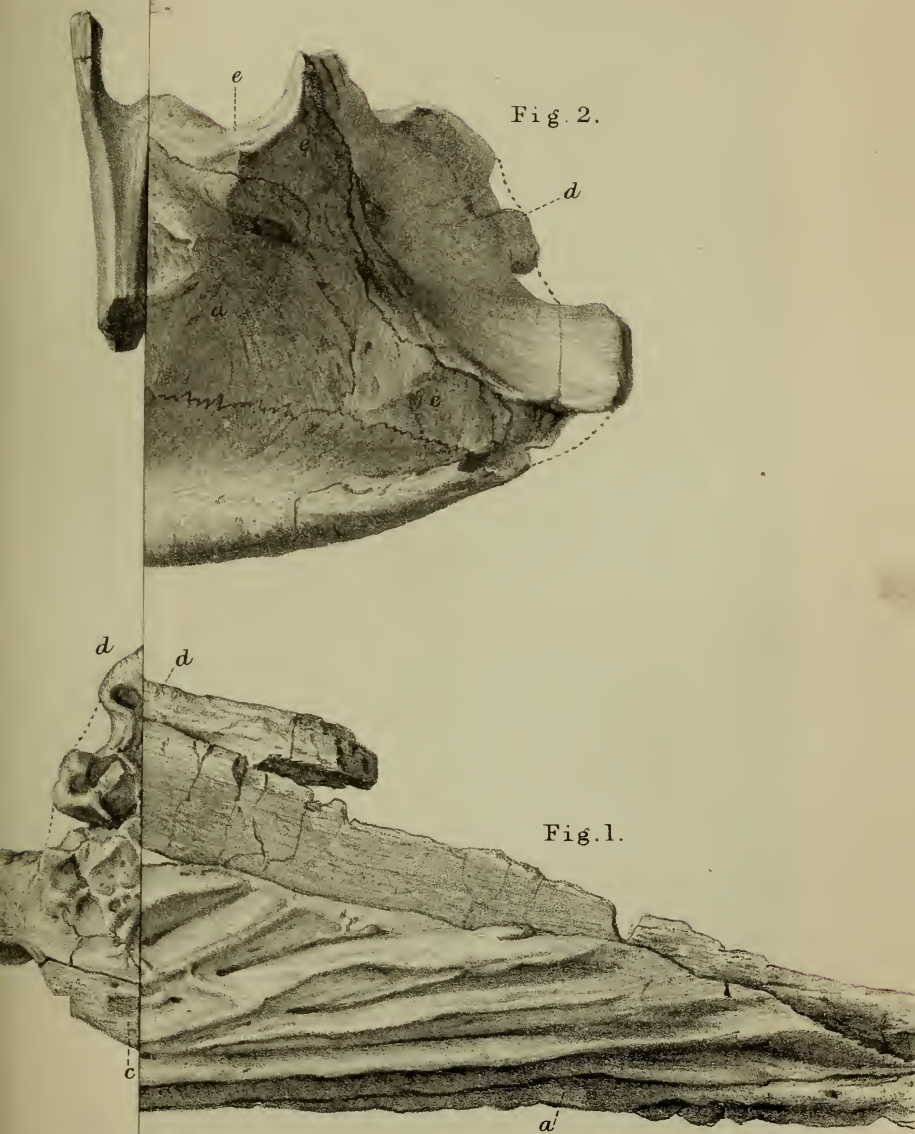


Fig. 4.



Fig. 3.

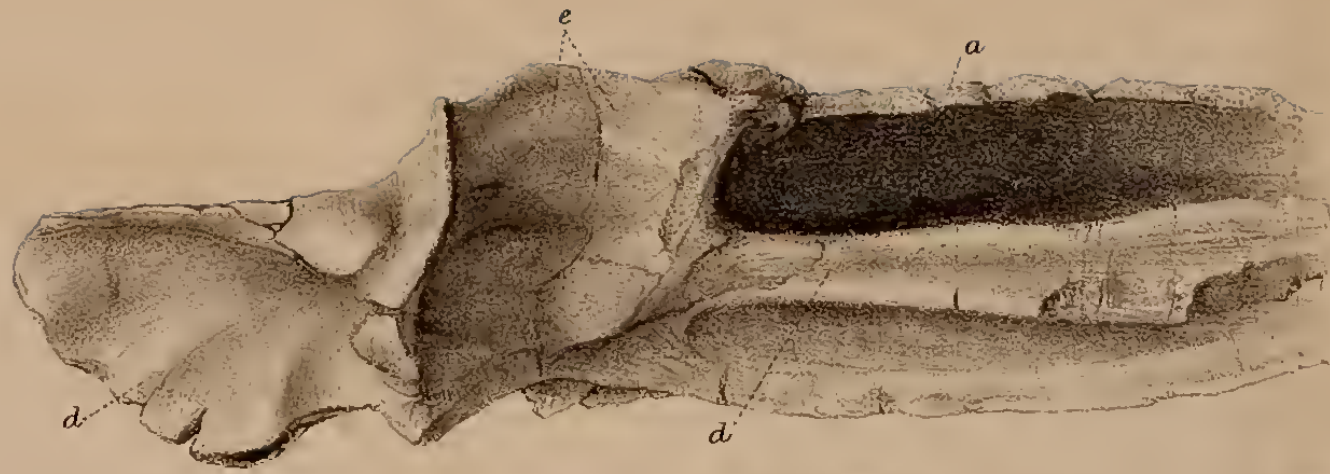


Fig. 2.



Fig. 1.



33. NOTE on the PHOSPHATES of the LAURENTIAN and CAMBRIAN ROCKS of CANADA. By J. W. DAWSON, LL.D., F.R.S., F.G.S. (Read March 22, 1876.)

THE extent and distribution of the deposits of apatite contained in the Laurentian of Canada and in the succeeding Palæozoic formations, have not escaped the notice of our Geological Survey, and have been referred to in some detail in Reports of Mr. Vennor, Mr. Richardson, and others, as well as in the General Report prepared by Sir W. E. Logan in 1863. Some attention has also been given, more especially by Dr. Sterry Hunt, to the question of the probable origin of these deposits*. My own attention has been directed to the subject by its close connexion with the discussions concerning *Eozoon*; and I have therefore embraced such opportunities as offered to visit the localities in which phosphates occur, and to examine their relations and structure. I would now present some facts and conclusions respecting these minerals, more especially in their relation to the life of the Laurentian period, but which may also be of interest to British geologists in connexion with the facts recently published in the 'Journal' of this Society in relation to the similar deposits found in the Cambrian and Silurian of Wales †.

In the Lower Silurian and Cambrian rocks of Canada phosphatic deposits occur in many localities, though apparently not of sufficient extent to compete successfully for commercial purposes with the rich Laurentian beds and veins of crystalline apatite.

In the Chazy formation, at Alumette Island, and also at Grenville, Hawkesbury, and Lochiel, dark-coloured phosphatic nodules abound. They hold fragments of *Linguleæ*, which also occur in the containing beds. They also contain grains of sand, and, when heated, emit an ammoniacal odour. They are regarded by Sir W. Logan and Dr. Hunt as coprolitic, and are said to consist of "a paste of comminuted fragments of *Linguleæ*, evidently the food of the animals from which the coprolites were derived" ‡. It has also been suggested that these animals may have been some of the larger species of Trilobites. In the same formation, at some of the above places, phosphatic matter is seen to fill the moulds of shells of *Pleurotomaria* and *Holopea*.

In the Graptolite shales of the Quebec group, at Point Levis, similar nodules occur; and they are found at Rivière Ouelle, Kamouraska, and elsewhere on the Lower St. Lawrence, in limestones and limestone conglomerates of the Lower Potsdam group, which is probably only a little above the horizon of the Menevian or Acadian series. In these beds there are also small phosphatic tubes with thick walls, which have been compared to the supposed worm-tubes of the genus *Serpulites* §.

* Geology of Canada, 1863; Chemical and Geological Essays, 1875.

† Davies & Hicks in Quart. Journ. Geol. Soc. August 1875.

‡ Geology of Canada, p. 125.

§ Geology of Canada, p. 259; Richardson's Report, 1869.

The Acadian or Menevian group, as developed near St. John, New Brunswick, contains layers of calcareous sandstone blackened with phosphatic matter, which can be seen, under the lens, to consist entirely of shells of *Lingule*, often entire, and lying close together in the plane of the deposit, of which in some thin layers they appear to constitute the principal part*. Mr. Matthew informs me that these layers belong to the upper part of the formation, and that the layers crowded with *Lingule* are thin, none of them exceeding two inches in thickness; but he thinks that the dark colour of some of the associated sandstones and shales is due to comminuted *Lingule*.

At Kamouraska, where I have studied these deposits, the ordinary phosphatic nodules are of a black colour, appearing brown with blue spots when examined in thin slices with transmitted light. They are of rounded forms, having a glazed but somewhat pitted surface—and are very hard and compact, breaking with glistening surfaces. They occur in thin bands of compact or brecciated limestone, which are very sparingly fossiliferous, holding only a few shells of *Hyolithes* and certain *Scolithus*-like cylindrical markings. In some of these beds siliceous pebbles occur with the nodules, rendering it possible that the latter may have been derived from the disintegration of older beds; but their forms show that they are not themselves pebbles. Phosphatic nodules also occur sparingly in the thick beds of limestone conglomerate which are characteristic of this formation; they are found both in the included fragments of limestone and in the paste. The conglomerates contain large slabs and boulders of limestone rich in *Trilobites* and *Hyolithes*; but in these I have not observed phosphatic nodules.

In some of the limestones the phosphatic bodies present a very different appearance, first noticed by Richardson at Rivière Ouelle, and of which I have found numerous examples at Kamouraska. A specimen now before me is a portion of a band of grey limestone, about four inches in thickness, and imbedded in dark red or purple shale. It is filled with irregular, black, thick-walled, cylindrical tubes, and fragments of such tubes, along with phosphatic nodules—the whole crushed together confusedly, and constituting half of the mass of the rock. The tubes are of various diameters, from a quarter of an inch downward; and the colour and texture of their walls are similar to those of the ordinary phosphatic nodules.

Under the microscope the nodules and the walls of the tubes show no organic structure or lamination, but appear to consist of a finely granular paste holding a few grains of sand, a few small fragments of shells without apparent structure, and some small spicular bodies or minute setæ. The general colour by transmitted light is brown; but irregular spots show a bright blue colour, due probably to the presence of phosphate of iron (vivianite). The enclosing limestone and the filling of the tubes present a coarser texture, and appear made up of fragments of limestone and broken shells, with some dark-coloured fibres, probably portions of Zoophytes. Scattered

* Bailey and Matthew, "Geology of New Brunswick," Geol. Survey Reports.

through the matrix there are also small fragments, invisible to the naked eye, of brown and blue phosphatic matter.

One of the nodules from Alumette gave to Dr. Hunt 36.38 of calcic phosphate; one from Hawkesbury 44.70; another from Rivière Ouelle 40.34; and a tube from the same place 67.53*. A specimen from Kamouraska, analyzed by Dr. Harrington, gave 55.65 per cent. One of the richest pieces of the linguliferous sandstone from St. John yielded to the same chemist 30.82 of calcic phosphate and 32.44 of insoluble siliceous sand, the remainder being chiefly carbonate of lime.

Various opinions may be entertained as to the origin of these phosphatic bodies; but the weight of evidence inclines to the view originally put forward by Dr. Hunt †, that the nodules are coprolitic; and I would extend this conclusion with some little modification to the tubes as well. The forms, both of the tubes and nodules, and the nature of the matrix, seem to exclude the idea that they are simply concretionary, though they may in some cases have been modified by concretionary action. There are in the same beds little piles of worm-castings of much smaller diameter than the tubes, and less phosphatic; and there are also *Scolithus*-like burrows penetrating some of the limestones, and lined with thin coatings of phosphatic matter similar to that of the tubes. Further, the association of similar nodules in the Chazy limestone with comminuted *Lingula*, as already stated, is a strongly confirmatory fact.

The tubes are of unusual form when regarded as coprolitic; but they may have been moulded on the sides of the burrows of marine worms; or these creatures may have constructed their tubes of this material, either consisting of their own excreta or of that of other animals lying on the sea-bottom. In any case, the food of the animals producing such excreta must have been very rich in solid phosphates, and these animals must have abounded on the sea-bottoms on which the remains have accumulated. It is also evident that such phosphatic dejections might either retain their original forms, or be aggregated into nodular masses, or shaped into tubes or burrows of Annelids, or, if accumulated in mass, might form more or less continuous beds.

The food of the animals producing such coprolites can scarcely have been vegetable; for though marine plants collect and contain phosphates, the quantity in these is very minute, and usually not more than that required by the animals feeding on them.

We must therefore look to the animal kingdom for such highly phosphatic food. Here we find that a large proportion of the animals inhabiting the primordial seas employed calcic phosphate in the construction of their hard parts. Dr. Hunt has shown that the shells of *Lingula* and some of its allies are composed of calcic phosphate; and he has found the same to be the case with certain Pteropods, as *Conularia*, and with the supposed worm-tubes called *Serpulites*, which, however, are very different in structure from the tubes above referred to.

* Geology of Canada, p. 461.

† Ibid.

It has long been known that the crusts of modern Crustaceans contain a notable percentage of calcic phosphate; and Hicks and Hudleston have shown that this is the case also with the Cambrian Trilobites. Dr. Harrington has kindly verified this for me by analyzing a specimen of highly trilobitic limestone from the Lower Potsdam formation at St. Simon, in which the crusts of these animals are so well preserved that they show their minutely tubulated structure in great perfection under the microscope. He finds the percentage of calcic phosphate due to these crusts to be 1.49 per cent. of the whole mass. It is to be observed, however, that the crusts of Trilobites must have consisted very largely of chitinous matter, which, in some cases, still exists in them in a carbonized state. A crust of the modern *Limulus*, or King Crab, which I had supposed might resemble in this respect that of the Trilobites, was analyzed also by Dr. Harrington. It belonged to a half-grown individual, measuring 5.25 inches across, and was found to contain only 1.845 per cent. of ashes, and of this only 1.51 per cent. of calcic phosphate. The crusts of some Trilobites may have contained as large a proportion of organic matter; but they would seem to have been richer in phosphates. Next to *Lingule* and Trilobites, the most abundant fossils in the formations containing the phosphatic nodules are the shells of the genus *Hyolithes*, of which several species have been described by Mr. Billings*. Dr. Harrington has ascertained that these shells also contain calcic phosphate in considerable proportion. The proportion of this substance in a shell not quite freed from matrix was 2.09 per cent. These shells have usually been regarded as Pteropods; but I find that the Canadian primordial species show a structure very different from that of this group. They are much thicker than the shells of proper Pteropods; and the outer layer of shell is perforated with round pores, which in one species are arranged in vertical rows. The inner layer, which is usually very thin, is imperforate. In one species (I believe, the *H. americanus* of Billings) the perforations resemble in size and appearance those in the shells of *Terebratulæ*. In another species (*H. micans* probably) they are very fine and close together, as in some shells of tubicolous worms. I am therefore disposed to regard the claim of these shells to the rank of Pteropods as very doubtful. They may be tubicolous worms, or even some peculiar and abnormal type of Brachiopod. In connexion with this last view, it may be remarked that the operculum of some of the species much resembles a valve of a Brachiopod, and that the conical tube is in some of them not a much greater exaggeration of the ventral valve of one of these shells than the peculiar *Calceola* of the Upper Silurian and Devonian, which has been regarded by some palæontologists as a true Brachiopod. I have not, however, had any opportunity of comparing the intimate structure of *Calceola* with that of these shells. Shells of *Hyolithes* occur in the Lower Potsdam in the same beds with the phosphatic nodules; and in one of these Mr. Weston has found a series of conical shells

* Canadian Naturalist, Dec. 1871.

of *Hyalolithes* pressed one within another, as if they had passed in an entire state through the intestine of the animal which produced the coprolite.

Inasmuch, then, as some of the most common invertebrates of the Cambrian seas secreted phosphatic shells, it is not more incredible that carnivorous animals feeding on them should produce phosphatic coprolites than that this should occur in the case of more modern animals feeding on fishes and other vertebrates.

We may now turn to the question as to the source of the abundant apatite of the Laurentian rocks. Were this diffused uniformly through the beds of this great system, or collected merely in fissure or segregation veins, it might be regarded as having no connexion with other than merely mineral causes of deposit. It appears, however, from the careful stratigraphical explorations of the Canadian Survey, in the districts of Burgess and Elmsley, which are especially rich in apatite, that the mineral occurs largely in beds interstratified with the other members of the series, though deposits of the nature of veins likewise occur. It also appears that the principal beds are confined to certain horizons in the upper part of the Lower Laurentian, above the limestones containing *Eozoon*, though some less important deposits occur in lower positions*.

The principal apatite-bearing band of the Laurentian consists of beds of gneiss, limestone, and pyroxene-rock, and has a thickness of from 2600 to 3600 feet. It has been traced over a great extent of country west of the Ottawa river, and has also been recognized on the east side of that river as well. The mineral often forms compact beds with little foreign intermixture; and these sometimes attain a thickness of several feet, though it has been observed that their thickness is variable in tracing them along their outcrops. Several beds often lie near to each other in the same member of the series. Thin layers of apatite also occur in the lines of bedding of the pyroxene-rock. In other cases disseminated crystals are found throughout thick beds of limestone, sometimes, according to Dr. Hunt, amounting to two or three per cent. of the whole mass. Disseminated crystals also occur in some of the beds of magnetite, a mode of occurrence which, according to Dr. Hunt, has also been observed in Sweden and in New York in the Laurentian magnetites of those regions.

The veins of apatite fill narrow and usually irregular fissures; and the mineral is associated in these veins with calcite and with large crystals of mica. In one instance, at Ticonderoga, in New York, the apatite, instead of its usual crystalline condition, assumes the form of radiating and botryoidal masses, constituting the Eupyrchroite of Emmons. Since these veins are found principally in the same members of the series in which the beds occur, it is a fair inference that the former are a secondary formation, dependent on the original deposition of apatite in the latter, which must belong to the time when the gneisses and limestones were laid down as sediments and organic accumulations.

* Vennor's Reports, 1872-73 & 1873-74.

In all the localities in which I have been able to examine the Laurentian apatite, it presents a perfectly crystalline texture, while the containing strata are highly metamorphosed; and this appears to be its general condition wherever it has been examined. Numerous slices of the more compact apatite of the beds have been prepared by Mr. Weston, of the Geological Survey; but, as might be expected, they show no trace of organic structure. All direct evidence for the organic origin of this substance is therefore still wanting. There are, however, certain considerations, based on its mode of occurrence, which may be considered to afford some indirect testimony.

If, with Hunt, we regard the iron ores of the Laurentian as organic in origin, the apatite which occurs in them may reasonably be supposed to be of the same character with the phosphatic matter which contaminates the fossiliferous iron ores of the Silurian and Devonian, and which is manifestly derived from the included organic remains.

If we consider the evidence of *Eozoon* sufficient to establish the organic origin, in part at least, of the Laurentian limestones, we may suppose the disseminated crystals of apatite to represent coprolitic masses or the débris of phosphatic shells and crusts, the structure of which may have been obliterated by concretionary action and metamorphism.

Such Silurian beds of compact and concretionary apatite (without structure, yet manifestly of organic origin) as that described by Mr. Davies in the 'Journal' of this Society, may be taken as fair representatives of the bedded apatite of the Laurentian. Further, the presence of graphite in association with the apatite in both cases may not be an accidental circumstance, but may depend in both on the association of carbonaceous organisms, whether vegetable or animal.

Again, the linguliferous sandstone of the Acadian group is a material which, by metamorphism, might readily afford a pyroxenite with layers of apatite like those which occur in the Laurentian.

The probability of the animal origin of the Laurentian apatite is perhaps further strengthened by the prevalence of animals with phosphatic crusts and skeletons in the Primordial age, giving a presumption that in the still earlier Laurentian a similar preference for phosphatic matter may have existed, and, perhaps, may have extended to still lower forms of life, just as the appropriation in more modern times of phosphate of lime by the higher animals for their bones seems to have been accompanied by a diminution of its use in animals of lower grade.

The Laurentian apatite pretty constantly contains a small percentage of calcium fluoride; and this salt also occurs in bones, more especially in certain fossil bones. This may in both cases be a chemical accident; but it supplies an additional coincidence.

In the lowest portions of the Lower Laurentian no organic remains have yet been detected; and these beds are also poor in phosphates. The horizon of special prevalence of *Eozoon* is the Grenville band of

limestone, which, according to Sir William Logan's sections, is about 11,500 feet above the fundamental gneiss. It appears, from recent observations of Mr. Vennor and Mr. W. T. Morris, that the bed holding the Burgess *Eozoon* is on the same horizon with the limestone of Grenville. The phosphates are most abundant in the beds overlying this band. This gives a further presumption that the collection and separation of the apatite is due to some organic agency, and may indicate that animals having phosphatic skeletons first became abundant after the sea-bottom had been largely occupied by *Eozoon*.

I would not attach too great value to the above considerations; but, taken together, and in connexion with the occurrence of apatite in the Cambrian and Silurian, they seem to afford at least a probability that the separation of the Laurentian phosphate from the sea-water, and its accumulation in particular beds, may have been due to the agency of marine life. Positive proof of this can be obtained only by the recognition of organic form and structure; and for this we can scarcely hope, unless we should be so fortunate as to find some portion of the Lower Laurentian series in a less altered condition than that in which it occurs in the apatite districts of Canada. Should such structures be found, however, it is not improbable that they may belong to forms of life almost as much lower than the *Lingula* and Trilobites of the Cambrian as these are inferior to the fishes and reptiles of the Mesozoic.

DISCUSSION.

Mr. HICKS said that the author had traced the existence of these phosphatic nodules considerably lower in America than had been done in England. He was inclined to accept the view of their organic origin, seeing that in England certainly the abundance of phosphates depends on that of organic life. The phosphate was due chiefly to the shell and to the decomposition of the substance of the body of the animals.

Mr. KEEPING remarked that the presence of graphite in these rocks had been ascribed to plants; if so, the deposit was formed not far from shore, and consequently we should not get that freedom from sediment which is necessary for the production of an extensive deposit of animal origin. It seemed to him that attributing to these deposits an animal origin was like going round to the back door when the front door was open; for there was plenty of apatite in the igneous rocks. He believed that even in later ages, when life was more abundant, no workable deposits of coprolite nodules had been formed where now found, but they had been sifted out by the action of water from older deposits; for example, those of Cambridge from the Gault, and those of the Red Crag from the London Clay.

34. *On the ANCIENT VOLCANO of the DISTRICT of SCHEMNITZ, HUNGARY.* By JOHN W. JUDD, Esq., F.G.S. (Read April 26, 1876.)

[PLATE XX.]

INTRODUCTORY.

WHEN, two years ago, the conclusions at which I had arrived concerning the relations of the so-called *plutonic* rocks to those of undoubted *volcanic* origin in the Scottish Highlands were laid before this Society, it was suggested by the late Sir Charles Lyell that probably no series of igneous rocks would be found to offer better illustrations of the phenomena which I then described, or would furnish more valuable opportunities for testing the truth of the general conclusions to which I had been led, than the old volcanic masses encircled by the mountain-ranges of the Carpathians. From Mr. Poulett Scrope, ever ready with generous aid to those who devoted themselves to the studies which he had himself so successfully prosecuted in earlier days, a suggestion from his lifelong friend was always sure to meet with a ready response; and thus I found myself afforded an opportunity of continuing the examination of these interesting questions, by a careful study of the volcanic rocks of Hungary and Transylvania. From both the friends I was privileged to receive much valuable advice in preparing for the work I proposed to undertake; and when the one was taken from our midst, the other seemed to redouble his efforts to counsel and aid me in its execution. In laying before this Society the first portion of the results of an investigation, in the conception and conduct of which these fathers of our science so warmly interested themselves, it is impossible to avoid giving expression to those feelings of sadness which the reflection that neither of them has survived to witness the completion of my task so powerfully awakens within me.

There is probably no country in the world where the geologist finds more valuable aid in carrying on his researches than the Austrian Empire. The Imperial Geological Institute of Vienna has, under the successive direction of Haidinger and Von Hauer, issued geologically coloured copies of the whole of the 165 sheets of the military map of the empire; and these have been accompanied by most valuable memoirs on the different districts, published in the well-known 'Jahrbuch' of the institute. Franz von Hauer has, further, completed a reduction of these large-scale maps to a general map consisting of twelve sheets, with a memoir descriptive of each, and has, finally, in his most valuable and useful work 'Die Geologie und ihre Anwendung auf die Kenntniss der Bodenbeschaffenheit der österr.-ungar. Monarchie,' which is accompanied by a single-sheet map of the whole country, summarized in a most able manner the entire mass of information hitherto obtained concerning the geology of the empire. Of the great importance of

the palæontological, petrographical, and chemical researches which have been carried on in the Vienna Institute, in illustration of the work done in the field, it is quite unnecessary to speak in this place; they are far too well known to all geologists to need recapitulation.

Nor do the results already enumerated by any means exhaust the mass of materials which the geologist finds ready to aid him in his researches within the Austrian dominions. The Geological Institutes of Vienna and Buda-Pest still continue to carry their valuable explorations of the geology of the country into still greater detail; and numerous private associations of scientific workers in every state of the Empire, or connected with its several universities, constantly make the most valuable new contributions to our science.

I have to thankfully acknowledge the very great liberality and courtesy with which the various sources of information were thrown open to aid me in the task I had undertaken. In Vienna the director of the Reichsanstalt and his colleagues afforded me every facility in my inquiries, while, in the University, Prof. Suess and Dr. Neumayr, and, in the Hof-Mineralien-Cabinet, Prof. Tschermak and Dr. Brezina rendered me equally kind assistance. In Buda-Pest, Prof. Szabó, at the University, and Dr. von Hantken, as director of the Hungarian Survey, spared no pains in affording me all needful help; while in Schemnitz I had the most ready aid of the veteran geologist, Von Pettko, of Directors Poeschl, and Pech, and of Prof. Winkler of the Berg-Akademie.

In spite, however, of all the important assistance afforded by the labours of preceding investigators, the student of the Hungarian volcanic rocks finds himself placed in one respect at a great disadvantage, in comparison with the opportunities which he enjoys in examining the similar rocks in Scotland. The absence of the magnificent sea-cliffs with their extensive and wonderfully clear sections (which, as I have shown, afford us such invaluable aid in determining the true relations of the various rock-masses in the latter country) constitutes a great drawback to the successful investigation of the structure of the Hungarian volcanos; and a further difficulty is created by the circumstance that very large portions of the country are covered by almost impenetrable forests. The analogies which are presented by a district of which the internal structure is so admirably exposed by denuding agencies as is that of the Western Isles of Scotland, may therefore be not unreasonably supposed capable of throwing new light upon the more intricate and difficult, because less clearly exhibited, relations of the volcanic, plutonic, metamorphic and sedimentary rock-masses of Hungary and Transylvania.

There is no portion of the Transleithan provinces of the Austrian Empire in which the characters and relative positions of the different volcanic rocks can be so conveniently studied as in the district which surrounds the famous old mining-towns of Schemnitz, Kremnitz, and Königsberg. And perhaps few areas could be named which, within so small a space, present rock-masses in more puzzling

and apparently inexplicable relations, or concerning the true interpretation of the structure of which greater diversities of opinion have existed among geologists. If, therefore, I venture on this occasion to offer a new explanation of the phenomena of a district which has already been so patiently and accurately studied and so often described by able geologists, it is not in any spirit of presumption, but rather from the conviction that what is necessary to the more perfect elucidation of the singularly involved questions concerning the age and relations of the different geological formations of the district is the means of comparison with another area in which the rock-masses are more perfectly exhibited. And such a key to the right understanding of the often perplexing and sometimes seemingly contradictory phenomena presented by the Hungarian rocks, I hope to show in the present memoir, is afforded by those districts of Scotland which furnish us with such singularly favourable opportunities for geological research. And if, as I hope to make manifest in the sequel, harmony and simplicity are by this explanation introduced where all before was complication and confusion, the circumstance may be fairly claimed as an additional confirmation of the truth of the solution offered.

In treating this question it will be most convenient to present, in the first place, a general sketch of the universally accepted facts concerning the geological structure of the district in question, and, in the second, to discuss the various interpretations which have been offered with a view to explaining the *origin* of that structure.

PART I.—*Sketch of the Geological Structure of the Schemnitz District.*

The volcanic rocks of the Schemnitz district cover an area about 50 miles in diameter. It will not be necessary for our present purpose to notice in detail the various sedimentary formations of more ancient date, through which these Tertiary volcanic masses have been erupted, and upon which they are seen at many points to be superimposed; suffice it to remark that the rocks subjacent to those igneous formations with which we are more particularly engaged in the present memoir include many old granitic and metamorphic masses, together with representatives of nearly the whole series of fossiliferous strata, from the Trias to the Eocene Nummulitic inclusive—and that the whole succession of Secondary and older Tertiary rocks in this district appears to have been continuously deposited, and without any of those great breaks which are indicated either by a sudden change in fauna or by wide-spread physical unconformity between them.

The outer portion of the great tract of volcanic rocks which we are here considering, constitutes a broad girdle consisting of lavas with their associated agglomerates and tuffs; these, reduced by denudation to a number of more or less isolated mountain-masses, from 3000 to 4000 feet above the sea, and almost everywhere covered by dense forests, overlook the central depressed area in which lie the

well-known mining-towns of Schemnitz, Kremnitz, and Königsberg, with numerous populous villages, and the health-resorts of Eisenbach and Glashütte, which enjoy a considerable local celebrity. Traversing this area in a diagonal direction from north-east to south-west is the deep valley of the Gran, one of the most considerable feeders of the Danube.

The lavas which everywhere compose the outer mountain girdle of the Schemnitz district are all of the type intermediate between the acid quartz-trachytes and the basic basalts. In all of them the predominating felspar is *plagioclase*; and they therefore belong to the class of igneous rocks now very generally called "andesites," and not to the true or sanidine-trachytes, in which latter the most abundant felspar is always orthoclase. With regard to the exact species of felspar which constitutes the principal portion of the widely spread Hungarian lavas, the researches made by Karl von Hauer, in the laboratory of the Reichsanstalt of Vienna, and those by Prof. Szabó, of the University of Buda-Pest, lead to closely concordant results—the former being made by the ordinary analytical methods, and the latter by the application of Bunsen's-flame reactions, in a manner devised by the Hungarian Professor himself for distinguishing the chemical composition of minute quantities of minerals contained in rocks*. From the researches of both these investigators it appears that the principal ingredient of the Schemnitz lavas is a lime-soda felspar, sometimes approaching to the labradorite and at others to the andesine type. These so-called andesite rocks have been further classed by Tschermak and Doelter, according to the additional constituents which distinguish them, into augite-andesites, hornblende-andesites, and mica-andesites. The resemblance of these modern andesite lavas to the old "porphyrites" of Devonian and Carboniferous age, in Scotland, is very striking; in the volcano of Santorin, rocks of precisely similar chemical and mineralogical character are being erupted at the present day.

The most interesting fact with regard to the constitution of these Hungarian lavas, which in the central parts of their masses are often found to assume a very coarsely crystalline and almost granitic character, while their outer portions present a strikingly scoriaceous or slaggy appearance, remains to be noticed. It is that though the predominant felspar in them is always of the basic type, yet they not unfrequently contain *free quartz*, sometimes in very large proportion. This free quartz is in some cases found to constitute large irregular crystalline grains in the mass, just like those of the ordinary orthoclase quartz-trachytes; but at other times its presence can only be detected by the microscope in thin sections. These quartziferous andesites were by Stache, who first clearly pointed out their true character, styled "Dacites," from the circumstance of their prevalence in Transylvania (the ancient "Dacia"). They find their exact analogues, among the more ancient volcanic rocks, in the

* Ueber eine neue Methode die Felspathe auch in Gesteinen zu bestimmen, von Dr. Josef Szabó. (Hungarian edition, 1873; German edition in 1876.)

“quartz-porphyrates.” The “dacites,” or quartz-andesites, are not of frequent occurrence in the Schemnitz district, but are seen at a few points, as the Hodritsch Thal near Schemnitz, the Kopanitzer Thal near Dilln, and the Berg Szitnya near Sz. Antal; but in some other parts of Hungary and throughout Transylvania they have a very wide distribution.

The agglomerates, tuffs, and ash-beds which are associated and alternate with the sheets of lava are almost wholly made up of fragments of volcanic rock, sometimes mingled with portions of the subjacent sedimentary deposits. In some places the agglomerates consist of irregular masses of all dimensions, including blocks of prodigious size and weight, confusedly heaped together; at others they pass into the most perfectly stratified tuffs and ashes. Such stratification in the ejected volcanic lapilli and sand must not, however, in the absence of marine or freshwater organic remains, be accepted as any proof of their having been accumulated beneath water; for, as we know from the example of many recent volcanos, ejected materials in falling through the air, or while being swept down the mountain-slopes in those torrents of mud so characteristic of great volcanic outbursts, may assume the most perfectly stratified and even *finely laminated* condition. The masses of volcanic agglomerate, as well as the rocks on which they rest, are frequently seen to be traversed by numerous dykes of lava.

The more finely divided tuffs and ashes are not unfrequently found to contain numerous remains of plants. These have been most carefully studied, and their relations to the existing flora and to those of earlier geological periods very clearly determined by Unger, Von Ettingshausen, Kováts, Andrac, Heer, and Stur. From the examination of these plant-remains we are enabled to infer the conditions of climate, soil, and elevation which distinguished the old land on which these volcanic eruptions took place. Besides the plants, some remains of terrestrial mollusca, reptiles, and mammals have also been found imbedded in these volcanic tuffs.

That these agglomerates, tuffs, and ashes were formed by the ordinary explosive volcanic action, there is, I think, not the smallest room to doubt; and that the volcano which they helped to build up was a subaerial one, there is also abundant proof. That, as is so common among volcanic cones, numerous ponds, marshes, and even lakes of considerable size, were successively formed and filled up by the ejected materials and sediments derived from them, is also, I believe, rendered sufficiently clear from the lacustrine deposits with remains of freshwater mollusca and fishes which are so frequently found alternating with the agglomerates and lavas. But it is also evident that the ancient volcanos of Hungary, like so many existing ones, rose directly from the margin of the ocean, or rather of a more or less isolated inland sea, with semi-marine or brackish-water conditions. That into some of the depressions among the great volcanic masses of Schemnitz the sea must, from time to time, have had access, is proved by the marine or brackish-water shells found in the basins of Handlova and Rybnik,

both of which, however, are on the outer margin of the volcanic area in question.

It would lead me too far from the main objects of the present memoir were I to attempt any thing like an analysis of the splendid flora associated with these tuffs, numbering as it at present does many hundreds of species. Suffice it at present to notice that in the opinion of Th. Fuchs, the greatest living authority on the subject of the Tertiaries of Eastern Europe, they indicate the existence at the period of these volcanic outbursts of a warm temperate climate—and that the nearest living analogues of the plants of the period are now found in Asia Minor, the Caucasus, the Himalaya, Central and Northern Asia, and Japan.

The exact period of the grand outbursts of andesitic lavas and agglomerates in Hungary, which gave rise to the formation of a series of volcanos exceeding Etna in dimensions, the relics of one of which we are now studying in detail, is fixed, by means of the palæontological evidence we have above alluded to, as that of the "Sarmatische Stufe," a geological horizon which may be paralleled with that of the beds which in Western Europe are classified as the Miocene proper of Beyrich, or the Upper Miocene of Lyell.

The structure, then, of the girdle of volcanic rocks which surrounds the Schemnitz mining-district is, as will have appeared from the foregoing description, sufficiently simple and intelligible. We see in it the ruins, greatly wasted by denuding causes, of an enormous volcanic cone, built up both by eruptions from its centre and also by innumerable outbursts upon its flanks.

But when we proceed to examine the central area which the great girdle of lavas and tuffs encircles, we discover a series of rocks presenting the most complicated and puzzling relations with one another.

We may notice, in the first place (see Plate XX.), the masses of stratified rocks, including dolomitic limestones, with sandstones and shales, containing fossils which clearly show that they are of the age of the Werfener Schichten (Lower Trias), and upon which is seen resting at one point, namely near Eisenbach, a small patch of Eocene limestone crowded with *Nummulites*. Very intimately associated with these sedimentary rocks, of which the exact geological age is thus rendered perfectly clear by their contained fossils, we find a series of unfossiliferous and highly metamorphic rocks, consisting of crystalline limestone, quartzite and quartz-schiefer, various schistose rocks, gneiss, and aplite or granulite. In equally close connexion with these metamorphic rocks we find a number of clearly intrusive igneous masses, consisting of greenstone or diorite, and of rocks which have been almost universally classed, by the geologists who have studied the district, as "syenite and granite."

By all the earlier writers on the geology of the Schemnitz area, this central mass of metamorphic and igneous rocks was regarded as being of *Primary* age; but it has been gradually made clear by later observations that, so far as the so-called "greenstones" are concerned, they are undoubtedly connected with the Tertiary ande-

sites of the surrounding volcanic girdle, and indeed pass into the latter by the most insensible gradations; hence by the more modern writers on the district they have been called "greenstone-trachytes," while Richthofen suggested for them the name of "propylites," a term which has not, however, met with any thing like general acceptance among petrologists.

The "greenstone-trachytes" of Hungary are rocks usually consisting of a more or less felspathic base, in which large crystals of plagioclase felspar with others of hornblende and mica are imbedded, so as to give them a more or less strikingly porphyritic character. In places, however, the rock becomes granular, and sometimes almost compact, in which cases it is dark-coloured and is known locally as "aphanitic greenstone." Occasionally this rock is found to contain spherical concretionary masses, and is then known as "Kugelgrünstein;" sometimes it contains irregular cavities, which are lined with various crystallized minerals. Occasionally the greenstone-trachytes contain grains of free quartz, and so pass into "dacites" or quartziferous-andesites of porphyroid or granitoid structure. Such rocks present the closest analogies with the quartz-diorites of the older geological periods.

The greenstone-trachytes are clearly *intrusive* rocks, and are found traversing the Triassic strata in dykes, and also enclosing in their midst enormous masses of these latter deposits, which have been subjected to intense metamorphism. Many portions of these greenstone-trachytes have undergone great alteration, evidently through having been traversed by acid vapours; and they now contain, disseminated through their mass, large quantities of pyrites and other metallic minerals, including gold and silver. The rock occasionally assumes a brecciated appearance and would appear at times to constitute a true "friction-breccia;" some of the masses which have been most profoundly altered by the percolation through them of acid gases have assumed a white and earthy appearance, and have been called, though erroneously, "greenstone-tuffs." The greenstone-trachytes are traversed by veins of quartz, often of large size, which constitute the principal receptacles of those valuable metallic ores for which the district is so famous. These metallic lodes traverse the so-called "syenite and granite," the "greenstone-trachyte," and the various stratified rocks through which these igneous masses have been extruded. The most productive deposits of ore, however, appear to be found near the junctions of the intrusive masses with the metamorphosed sedimentary rocks.

The beautiful so-called *syenitic* rock of the Schemnitz area forms four distinct bosses, which are surrounded by highly metamorphosed rocks, and are at the same time very intimately associated with the greenstone-trachytes. The rock in question is a perfectly crystalline aggregate, either coarse or fine-grained, and occasionally porphyritic in structure. So strikingly granitic is its aspect, that all geologists who have studied the district have named the rock either syenite or granite, according to the absence or presence

in it of free quartz. Microscopic study of this rock, however, shows that its predominating constituent is always a *plagioclase* felspar, to which hornblende and mica, and a variable quantity of orthoclase is added. This rock ought therefore, it is clear, to be classed with the diorites rather than with the syenites; but its felspar is probably not oligoclase but labradorite. When, as is frequently the case, a considerable quantity of free quartz is present in it, the rock, though called a "granite," should be rather referred to the quartziferous diorites. The rock with which these granitic masses of Hungary appear to have the closest points of resemblance is the so-called granite of the Adamello group in the Alps, which Vom Rath has distinguished under the name of *Tonalite*. Of the exact relations of these bosses of granitic rock in the Schemnitz district to the stratified, metamorphic, and volcanic rocks which surround them we shall have to treat more fully in the sequel.

Besides those volcanic rocks of the Schemnitz area already described, and which belong, as we have seen, to the class intermediate in composition between the acid and basic types, there are evidences of a number of eruptions of rocks of totally different composition, almost all of which are of later date than the widely spread andesitic lavas of Hungary. They belong either to the extremely acid class (of liparites, perlites, obsidians, &c.) or to the extremely basic type (basalts and agate-andesites).

Of certainly later date than the great masses of amphibole-andesites, with their associated "greenstone-trachytes" and dacites (propylites), are those interesting rhyolitic rocks which rise in the very centre of the district we are describing. They are especially well exposed at Königsberg, near Vichnye (Eisenbach), in the Hliniker Thal, and in the country north of the Gran, extending from Heiligen Kreuz, nearly as far as Kremnitz (see the map and section, Plate XX.). These rocks present, in their chemical composition, in their mineralogical constitution, and in their general features, the most marked contrasts with the andesitic rocks which cover so large a portion of the surrounding country. The Hungarian rhyolites contain from 70 to 81 per cent. of silica; the proportion of iron and of the alkaline earths is very small in them, while that of the alkalis is very high, the quantity of the potash usually exceeding that of the soda. These rhyolites always contain free quartz, sometimes in considerable quantity; the predominating felspar in them is always orthoclase; and their other principal ingredients are hornblende and biotite, which occur sometimes separately, and at others in association with one another.

The features of greatest interest presented by these rhyolitic rocks, however, are those connected with their structure. They exhibit, as is so constantly the case with rocks of the most acid class, a great tendency to assume the vitreous character; and hence arise all those interesting modifications of rock-structure which were first clearly described by Beudant in 1822, and which have made the locality of Hlinik so famous among petrologists.

In the Schemnitz district, however, the rhyolitic rocks are seldom

found assuming the perfectly glassy character and becoming true obsidians, like those of Lipari, Iceland, Mexico, Ascension, &c.; their lustre scarcely ever passes beyond the semivitreous or resinous; and hence they may be rather classed with the pitchstones, or, being frequently porphyritic in structure, with the "pitchstone-porphyrries." Throughout Hungary, indeed, true obsidians are very rare; and although most interesting varieties of this rock of black, red, and green colours are found in the Tokay-Hegyalja, some of which have been well described by Vogelsang, yet, so far as my own observations go, these never form large rock-masses as in Lipari, but occur only as "Saalbands" on the sides of intrusive dykes of rhyolitic or quartz-trachyte rock.

Of the different varieties of the curious *perlitic* variety of structure, however, the Hungarian rhyolites, and especially those of the vicinity of Schemnitz, afford the most interesting and instructive examples. Indeed almost all the vitreous rocks of Hungary exhibit, under the microscope, the presence of those peculiar and little-understood spiral and concentric structures so characteristic of perlite; and in addition to these we frequently find various modifications of true spherulitic concretions which are always quite independent of, and evidently owe their formation to quite different causes from the former.

Although the stony and slightly vitreous varieties of the Schemnitz rhyolites frequently assume a scoriaceous character, and thus give rise to the formation of those beautiful "millstone-porphyrries" which are so extensively worked at Do Sminje, near Hlinik, and at Himmelreich, near Königsberg, yet *pumice* is rare. The so-called pumice of the Hliniker Thal presents, indeed, a slight approximation to the typical characters of this rock, and, under the microscope, is seen to be full of gas-pores; yet the sponge-like character which in true pumice is so manifest to the naked eye, is almost always wanting in the Hungarian rock, and I have never found specimens of the latter that would float in water. This may in part be accounted for, no doubt, by the circumstance that the rhyolitic rocks have undergone a very considerable amount of denudation, by which the lighter and more fragile materials would be easily swept away; but I believe there is also evidence that a considerable amount of subsidence took place before the extrusion of these rhyolitic lavas, and that they were erupted under a pressure of water sufficient to prevent the full distention of the liquefied mass by the escaping gases and vapours.

Through the so-called hornstone modification, the semivitreous and perlite rocks of Hungary graduate into the stony varieties. These exhibit great diversities of character, being sometimes exceedingly compact and fine-grained, and at others highly porphyritic, in the latter case frequently exhibiting approximations towards the granitic structure. The beautiful red rhyolite of the "Stein-Meer," near Eisenbach, containing large but imperfect double pyramids and rounded grains of quartz, is almost identical in appearance and characters with many quartz-porphyrries of the older geological periods.

The rhyolites of the Schemnitz district frequently assume those remarkably banded and ribboned structures which are so admirably exhibited by the rocks of similar composition in the Ponza Islands, Lipari, Ascension, &c.; but, as I propose to discuss the nature and origin of this remarkable structure in all these instances in a special communication to this Society, I will not dwell longer on the subject on the present occasion.

With regard to the relations of the rhyolitic to the andesitic rocks, there is fortunately no room for the smallest doubt, inasmuch as the beautiful natural sections of the Hliniker Thal, and the fine artificial exposures of the rocks along the line of railway which has recently been carried across the Carpathians by the pass of Berg, furnish the geologist with abundant evidence upon the subject. In studying these very instructive sections, I am much indebted to the kind aid of Dr. Gustav Zechenter, of Kremnitz, who has constructed a detailed geological map of the country through which the railway passes. These clear sections seen in the railway-cuttings show that the rhyolites constitute great vertical intrusive masses, forced through the midst of the older andesite lavas, and that the tuffs and agglomerates belonging to the former class of rocks always overlie those of the latter.

The tuffs and agglomerates, which are not unfrequently associated with the rocks of the rhyolitic class, are in many localities found to yield numerous plant-remains. The rhyolitic tuffs of Heiligen Kreuz and of Jastraba, south of Kremnitz, are especially famous for the fine floras they have afforded. These, and some animal remains found with them, enable us to fix the period of the rhyolitic outbursts as coinciding with the latter part of the Miocene epoch; and they also serve to show that the climatal conditions of the period were considerably more temperate than during the great andesitic eruptions, the flora being more nearly related to that existing in the same area at the present day.

We have spoken of the rhyolitic as younger than the andesitic eruptions of the Schemnitz area. There is proof, indeed, that the great volcano built up by the earliest and grandest ejections, which supplied such prodigious volumes of lavas and agglomerates, had undergone great denudation, and was, in fact, reduced almost to a state of ruin before the occurrence of the second series of eruptions in their midst. The former, indeed, sustain to the latter precisely the same relations which in Auvergne are seen to subsist between the skeleton volcanos of Mont Dore, the Cantal, and the Mezen, and the more recent volcanic outbursts (forming the "puy") which have taken place in the midst of their ruins.

Of still more recent date than the rhyolites of the Schemnitz district are the sporadic outbursts of basaltic rocks, of which, for the most part, there remain only the central lava masses, which filled the throats of these small volcanos ("puy"). Such centres of volcanic action, now marked only by intrusive plugs of basalt, are seen at many points within and around the grand old volcano of the Schemnitz district. At one locality, however, namely Ostra Hora,

near Heiligen Kreuz, the remains of a central cone and of a lava-stream proceeding from it, the latter broken up by denudation into miniature plateaux like those of the Auvergne, can be very distinctly traced, as was long ago shown by Von Pettko*.

The basalts of the Schemnitz district exhibit some very interesting diversities in character. In some instances, like that of the well-known Calvarien Berg of Schemnitz, they contain very large quantities of olivine, while in others, as, for example, the intrusive mass of Gieshübl, that mineral is almost wholly wanting. The latter variety constitutes a link between the true basalts and a rock which is very extensively developed in Hungary, consisting of a triclinic felspar, augite, and magnetite, with occasional crystals of hornblende. These are the rocks now usually called augite-andesites; but, according to Prof. Szabó, the feldspathic ingredient in them may be any variety of the lime-soda felspars, from andesine to anorthite. In the volcanic district of the Matra, which lies to the south-east of that of the Schemnitz area, the augite-anorthite rocks are very extensively developed; and hence Prof. Szabó has proposed for this particular variety of the augite-andesite group the name of "matraite."

With regard to the exact age of the basaltic rocks of the neighbourhood of Schemnitz we have not such clear and unmistakable evidence as in the cases of the andesitic and rhyolitic varieties. But it is manifest that while these basaltic rocks are certainly younger than the rhyolites, they must nevertheless be of considerable antiquity, seeing how greatly they have suffered from denudation. As we have in other parts of Hungary, as well as Transylvania and Styria, good palæontological evidence that numerous outbursts of rock of precisely similar character to the basalts of Schemnitz took place during the formation of the Congerian and Inzendorf beds, we can scarcely be wrong in assigning the latter volcanic rocks to the same age—that is, to the older portion of the Pliocene period.

We have spoken of the outburst of the andesitic, rhyolitic, and basaltic lavas of the Schemnitz area as taking place *successively*; it must not, however, be assumed that the production of the different varieties of volcanic materials at this igneous centre can be correlated with sharply defined and distinctly separated geological periods. On the contrary, it is clear that although *the great mass* of the andesitic lavas was erupted before, and most of the basalts subsequently to the rhyolites, yet the three periods of eruption of different classes of rock to some extent overlapped one another. Indeed at Zapolenka, near Hodritsch, we find evidence, as Von Pettko has so well shown †, that a cone and lava-stream of comparatively modern date exist; for its features can be distinctly traced. The lava-stream, it is clear, must have dammed up the river-course, and

* "Geognostische Skizze der Gegend von Kremnitz, von Johann von Pettko," Haidinger's 'Naturwissenschaftliche Abhandlungen,' Bd. i. (Wien, 1847) p. 302.

† "Ueber den erloschenen Vulcan Zapolenka in der Nähe von Schemnitz, von Herrn Johann von Pettko," Haidinger, Bericht vi. (1850) p. 168.

thus given rise to the formation of a rather extensive lake, which has been partially filled up with sediments and then drained by the cutting-through by the stream of the barrier of lava which retained it. This comparatively modern stream of lava, however, is of andesitic composition; and the cone is formed by scoriæ of the same rock.

The following table exhibits the average composition of the most characteristic varieties of volcanic rock which have been erupted in Hungary. These averages have been calculated from a considerable number of published analyses.

	I. Rhyolites or Quartz- Trachytes.	II. Dacites or Quartz- Andesites.	III. Horn- blende and Mica-Ande- sites.	IV. Augite- Andesites.
Specific gravity ..	2.375	2.629	2.643	2.715
Silica	73.49	65.03	58.49	56.21
Alumina	13.63	14.80	20.45	17.26
Oxides of Iron and Manganese }	2.27	6.20	7.65	11.56
Lime.....	1.24	3.61	5.58	6.79
Magnesia	0.32	1.01	1.72	1.49
Alkalies	7.23	5.58	6.19	4.43

The quantities of soda and potash are not given separately in these averages; for in the analyses of Von Sommaruga, on which they are based, the separation of the alkalies was effected by a method which, as has been since shown by Tschermak and Doelter, does not yield reliable results.

The volcanic formations of Hungary offer some peculiarities of great interest, especially in the remarkable abundance of rocks mainly composed of plagioclase felspar, with or without free quartz. To the British geologist they are of especial interest, on account of their numerous and striking points of analogy with the newer Palæozoic volcanic rocks of Scotland. Indeed we may safely assert that the Palæozoic hornblende-, mica-, and augite-porphyrates of our own island present the exact counterparts of the Tertiary hornblende-, mica-, and augite-andesites of Hungary; and, excepting in the condition of their preservation, I know of no grounds whatever for placing them in different categories, and assigning to them distinct names. Rocks of precisely similar composition to those of Hungary are abundantly developed in various parts of the Turkish Empire; and in the island of Santorin, as we have already remarked, they are being erupted at the present day.

No contrast, however, can possibly be greater than that afforded by the volcanic rocks of Hungary on the one hand, and those *contemporaneously formed* in Bohemia and Central Germany on the other. While, in the former, plagioclase felspars almost always predominate, even when the rocks are highly quartziferous, in the latter orthoclase is everywhere the most abundant constituent, occurring in rocks even of the most basic type. On the north-west side of the

Carpathian chain, leucite, sodalite, nepheline, nosean, and h a yne are most abundant rock-forming constituents; while on the south-east of that mountain-range these minerals appear to be wholly unknown. A glance at the ultimate analyses of series of the Tertiary volcanic rocks of Hungary and Bohemia respectively will show that while potash is an abundant constituent in the latter, it is present only in very small proportion in the former.

In no way, perhaps, will it be possible to make this contrast in composition between the volcanic ejections of the two areas more striking than by placing side by side the analyses of rocks from either of them which contain nearly the same percentage of silica. I. is the average of two analyses of Bohemian phonolites by Rammelsberg; II. the average of three analyses of Hungarian augite-andesites by Doelter.

	I.	II.
Silica	57.05	58.75
Alumina	21.57	17.02
Oxides of Iron and Manganese	2.91	8.05
Lime and Magnesia	2.16	9.43
Potash	5.89	1.26
Soda	8.69	3.50

We shall not here stay to discuss the interesting problem which is suggested by these curious differences. Suffice it for the present to notice the fact that while on the one side of the Carpathian chain nepheline-, leucite-, and h a yne-basalts with various phonolites were building up the vast volcanos of Bohemia and Central Germany, on the other side of that mountain-range andesitic lavas with some rhyolites and felspar-basalts were being erupted on an equally gigantic scale. In the two districts the volcanic activity began, attained its climax of intensity, and fell into decline in corresponding geological periods; yet the products of the volcanic action in the two districts are as different from one another as it is possible to conceive.

Since the extinction of the volcano of Schemnitz the igneous forces have given rise to a number of minor symptoms. Hot springs (probably forming geysers like those of Iceland and the Rocky Mountains) have deposited enormous quantities of siliceous sinter (freshwater quartz), which is found to yield at many points the beautifully preserved remains of a flora not very different from that existing at the present day. The localities of Ilia, Hlinik, and Lutilla are particularly famous for presenting us with the relics of this flora. Other springs, like those so abundant in Auvergne and Central Italy, were highly carbonated, and have deposited enormous quantities of calcareous tufa.

Several hot and mineral springs still rise in the midst of the old volcanic district of Schemnitz. Two of these, namely those of Vichnye (Eisenbach), which has a temperature of 101  Fahr., and Skleno (Glash tte), with a temperature of 120  Fahr., have given origin to locally famous bathing-places. At both points a consi-

derable quantity of tufa is deposited by the hot springs. We shall show in the sequel how large a part must probably be assigned to the action of mineral springs and fumaroles in filling those fissures in the old volcanic rocks of the Schemnitz district which now constitute its far-famed mineral veins. Some of these are, as Von Pettko has shown, of later date than the eruption of the basalts.

That since the country has assumed its present form it has been visited with severe earthquake-shocks, we have sufficient proof. Near Eisenbach there occurs, on the slope of a mountain composed of quartz-trachyte, a most remarkable accumulation of gigantic blocks, which is known as the "Stein-Meer." Although no record or tradition of the formation of this singular mass of débris appears to be in existence, I think that no geologist will be inclined to doubt that its origin must be assigned to the secondary effects of some great earthquake-shock, which has affected the district and hurled down from the mountain-side the vast masses already conveniently prepared for the catastrophe by a peculiar system of jointing.

The district is still subject to earthquakes. In 1854 and 1855 three shocks were felt at Schemnitz within the space of nine months, the attendant phenomena and effects of which were carefully noted by M. Russeger*. Each shock is said to have been attended with a loud noise, like the report of a cannon; and the whole town was violently shaken. The vibrations appear to have followed the line of the principal mineral vein of the district, but not to have extended to any very great distance from it. The secondary effects of the shocks seem to have gradually increased to greater depths, as was proved by a subsequent careful examination of the workings of the mines; and the maximum action appears to have been experienced at a depth of between 600 and 700 feet from the surface.

PART II.—*On the Interpretation of the Geological Structure of the Schemnitz District.*

Having now described the main features of this very interesting district, we will proceed to discuss the question of their true interpretation, and endeavour to define the exact relations and geological age of the several rock-masses of the central area; for on these points there have arisen, as we have before remarked, the widest diversities of opinion among geologists.

Without attempting to notice the works of all the earlier writers on Hungarian geology, it will be sufficient if in this place we make our retrospect of geological opinion on the questions at issue commence with the justly celebrated work of Beudant†, published in 1822. The distinguished French geologist, as is well known, de-

* "Das Erdbeben in Schemnitz am 31. Januar. 1855, von J. Russeger," Sitzungsber. Wien. Akad. xv. p. 368. "Bericht über das am 30. September, 1855, stattgefundene Erdbeben, von J. Russeger," *ibid.* xvii. p. 479.

† Voyage minéralogique et géologique en Hongrie pendant l'année 1818. 3 vols. Paris, 1822.

voted especial attention to the Schemnitz area; and the conclusions at which he arrived may be briefly stated as follows:—

Beudant seems to have regarded the outer girdle of andesitic rocks as being formed synchronously with the whole "Secondary series," while the syenite and greenstone of the central area he referred to the earlier "Transition period," and the metamorphic rocks of the same tract to the Primary. The rhyolitic and basaltic rocks he justly classed, in part at least, as Tertiary, although, through his unfortunate but not unnatural mistake of confounding the Pliocene *Congerina*-beds with the Eocene *Calcaire grossier*, he threw the whole too far back in time. The one point which all the earlier geological interpretations of the district appear to have had in common was the separation of the gneiss, granite, syenite, and diorite, which were classed as Primary and Transition rocks, from the trachytic and basaltic, which were grouped with the Secondary and Tertiary.

The more accurate study of the Tertiary faunas and floras, which was initiated by the labours of Lyell and Deshayes in Western Europe, and has been so admirably extended to the east of Europe by Hörnes, Suess, Von Hauer, Fuchs, and others, soon, however, led to the recognition of the fact that all the volcanic rocks of the Schemnitz area belong to the Tertiary period, and even to the latter half of it. Thus there was brought about a wide separation of the supposed ancient crystalline "granites, syenites, and diorites" from the evidently modern "trachytes."

But, at the same time, petrologists began to recognize the circumstance that the so-called old greenstones or diorites of the district not only presented the most remarkable points of resemblance to the Tertiary trachytes or andesites by which they were surrounded on all sides, but that in many instances the most perfect transition of the one rock into the other could be clearly traced. As early as 1848 we find Von Pettko* (to whose labours, next to those of Beudant, we are most indebted for the elucidation of the structure of the complicated Schemnitz area) making the declaration that "there is nothing to show that the greenstone of this district is older than the associated trachyte, while the frequent transition of the two rocks into each other, and their common local disposition, forming together the great ring-shaped mountain-ridge, decidedly point to their synchronous formation."

As this conviction of the intimate connexion existing between the Hungarian trachytes and the so-called diorites became more firmly established in the minds of geologists, the latter rocks acquired the name of "greenstone-trachytes." This view of the relations of the two classes of rocks was in part adopted by Richthofen, when, in 1860†, he made his general survey of the Hungarian volcanic rock-masses; and at a later date this author suggested, as we have already

* *Berichte über die Mittheilungen von Freunden der Naturwissenschaften in Wien*, Bd. iii.

† "Studien aus den ungarisch-siebenbürgischen Trachytgebirgen," *Jahrbuch der k.-k. Reichsanstalt Wien*, Bd. xi. S. 153.

seen, the name of "prophyllites" for the "greenstone-trachytes." Richthofen, however, in his later works, appears to have regarded his "prophyllites" as of slightly older date than the trachytes, though forming part of the same series of igneous outbursts during the Tertiary period.

At the present day, so convinced are some of the most eminent petrologists of the essential identity of these two classes of rocks, in Hungary, the Tertiary greenstones and the trachytes, that they make no distinction whatever in the terms which they apply to them—Tschermak and Doelter, for example, calling them both "hornblende-andesites," and Szabó designating them equally as "trachytes."

With regard to the stratified and metamorphic rocks, the discovery of fossils in some of the less crystalline schists and limestones has fully established their Triassic age. An isolated mass of limestone-conglomerate, which occurs near Eisenbach, is crowded with Nummulites, and therefore clearly belongs to the Eocene. With respect to the more altered and granitic rocks, namely the masses of gneiss, mica-schist, quartzite, crystalline limestone, &c., with the intrusive syenite and granite, it was suggested by Von Adrian in 1866* that they might belong to the Devonian, an opinion that was adopted with some hesitation by Von Lipold in 1867†; in the more recent publications of the Vienna Reichsanstalt‡, the probability of their being of Dyas or Permian age is entertained by Franz von Hauer. But all these identifications rest upon the insecure foundation of mere mineralogical resemblance, palæontological evidence being entirely wanting.

Dr. Daubeny, who paid a somewhat hurried visit to Hungary in 1823, appears to have been greatly impressed by the complicated relations of the granitic, dioritic, and trachytic masses of the Schemnitz area; and in 1848§ he made the remark that if the granitic rocks of this district could be regarded as of equally modern date with the trachytes, many difficulties in the interpretation of the geological structure of the area would thereby be removed. Unfortunately, however, he had no opportunity of revisiting the country, and of testing how far his suggestion might be tenable.

It is in this important suggestion of Dr. Daubeny, as I propose to show, that the true key to the correct understanding of the structure of the Schemnitz district is to be found.

Beudant is undoubtedly right in regarding the "granite and syenite" of the central tract at Schemnitz as being most intimately associated with the "greenstone," and, indeed, as forming part of the same mass. So strikingly is this the case, that in none of the geological maps of the district that have been published is there

* "Das südwestliche Ende des Schemnitzer-Kremnitzer Trachystockes," Jahrbuch der k.-k. Reichsanstalt Wien, Bd. xvi. p. 355-477.

† "Der Bergbau von Schemnitz in Ungarn," *ibid.* Bd. xv. p. 317-458.

‡ "Geologische Uebersichtskarte der österreichisch-ungarischen Monarchie, Blatt iii. Westkarpathen," *ibid.* Bd. xix. (1869) S. 512.

§ A Description of Active and Extinct Volcanos, 2nd ed. (1848) pp. 129, 130.

any thing like agreement as to the lines of separation between the "syenite" and the "greenstone"—rocks by one author assigned to the former being by others referred to the latter. And it is only necessary for the geologist to study the interesting series of sections exposed in the Eisenbach and Hodritsch valleys, to be convinced that the two classes of rocks pass into one another by the most insensible gradations.

But, on the other hand, it is equally certain, as is, indeed, I believe now universally admitted alike by petrologists and physical geologists, that the so-called greenstones, greenstone-trachytes, and trachytes are all merely varieties of the same rock, and constitute indeed portions of the same great eruptive masses.

Now, that the so-called trachytes (or andesites) are true volcanic rocks, erupted during the Miocene period, we have, as already shown, the most convincing proofs. Hence we are irresistibly led to the conclusion that all these igneous rocks of the Schemnitz area, "granites and syenites," "greenstone-trachytes," andesitic lavas and tuffs, are parts of the same great eruptive masses, and are of contemporaneous date.

The truth of this conclusion is borne out in a very striking manner by a comparison both of the chemical and microscopical characters of the three different classes of rocks in question. In the following table I place side by side analyses of typical examples of the so-called syenite, of the "greenstone-trachyte" and of the andesitic lava of the Schemnitz district.

	I.	II.	III.
Silica	61.73	60.26	61.62
Alumina	17.45	18.25	20.66
Oxides of iron and manganese	5.94	6.83	6.64
Lime	4.52	3.08	4.27
Magnesia	2.29	0.77	1.35
Alkalies	7.00	5.61	4.55
Loss	1.16	3.40	2.40

I. is the so-called syenite of Hodritsch, analyzed by Karl von Hauer.

II. the "greenstone-trachyte" of Gelnerowsky Wrech, analyzed by Von Sommaruga.

III. the hornblende-andesite of Rybnik, also analyzed by Von Sommaruga.

Allowing for the different degrees of decomposition, as shown by the amount of volatile material in each case, the rocks are seen to be almost identical in composition.

When we turn to the consideration of the microscopical characters of the so-called "syenite and granite" of Hodritsch, we find that, while offering the most marked points of contrast with all the undoubtedly ancient Hungarian granites, it presents some very remarkable features of agreement with the "greenstone-trachytes" and

“hornblende-andesites” of the same area, with which they are so intimately associated.

In all these rocks it is interesting to find that the prevailing felspar is always plagioclase; in all of them orthoclase occurs only as a subordinate ingredient, and hornblende and mica, or both of these minerals together, form the next most important constituents; and in all of them grains of free quartz occasionally appear in the mass, converting the “trachytes” into “dacites” and the “syenites” (diorites) into “granites” (quartz-diorites).

Rocks of precisely similar constitution to the so-called “granite and syenite” of Hodritsch are very widely diffused in Hungary and Transylvania, and in the countries lying southwards. In the Vlegyasza, Bihar, and Rodnaer ranges in Transylvania, Dr. Doelter has described the andesites and quartz-andesites as becoming highly porphyritic, and even granitiform in structure*. The rock of Illova Thal, which Richthofen compared with the “Nevadites” of the Rocky Mountains, appears from the examples of it which I was shown by Dr. Tschermak to be identical in character. In the Banat there occurs a precisely similar rock, to which Cotta applied the name of “Banatite;” and this forms intrusive masses which, as I am informed by Prof. Szabó, are of clearly younger date than all the members of the Cretaceous series. In the Euganean Hills we have quartziferous hornblende-andesites which are certainly as recent as the Eocene, if not of still later date. In the Alps we have the granitic mass of the Adamello, for the rock of which Vom Rath has proposed the name of “Tonalite;” and a rock of very similar character from Queensland has been described by Daintree. In order to illustrate the composition of these different granitic rocks, all distinguished by the presence of free quartz with a triclinic felspar as the predominating ingredient, I place side by side the following analyses:—

	I. Dacite (Quartz-Andesite) of Kis Sebes, Transylvania (Doelter).	II. Banatite of Szaska, Hungary, (Scheerer).	III. Tonalite of the Adamello Group in the Alps (Vom Rath).	IV. Quartziferous hornblende-andesites, Euganean Hills (Vom Rath).
Silica	66·32	65·84	66·91	67·98
Alumina	14·33	15·23	15·20	13·05
Oxides of iron and manganese ..	5·78	3·50	6·45	5·69
Lime	4·64	4·74	3·73	1·63
Magnesia	2·45	2·31	2·35	0·14
Potash	1·61	3·06	0·86	3·23
Soda	3·90	2·96	3·33	7·96
Loss	1·13	0·98	1·17	0·32

* “Zur Kenntniss der quartzführenden Andesite in Siebenbürgen und Ungarn, von Dr. C. Doelter,” Tschermak's Mineralogischen Mittheilungen, 1873, p. 51.

According to the analyses of Karl von Hauer, the felspar in the different varieties of the Hungarian rocks would appear to be usually either labradorite or some variety intermediate between that species and andesite. The results obtained by Szabó by a totally different mode of investigation are not very divergent from those arrived at by Von Hauer.

The microscopic examination, which proves that the mineralogical constituents of all these rock-varieties—the andesitic lavas, the “greenstone-trachytes,” and the “syenite and granite” of Hodritsch—are quite identical, consisting in each case principally of a plagioclase felspar with orthoclase, hornblende, mica, and sometimes quartz superadded, also demonstrates what are the real differences, namely those of structure, which serve to distinguish, though not by any hard lines of demarcation, the three several groups of rocks. The materials of the so-called granite and syenite are all distinctly crystallized; the “greenstone-trachytes” consist of a micro-crystalline or felsitic base, in which the crystals, often injured and broken, are imbedded; while in the andesite lavas the base is usually of a more compact texture, passing into a glassy condition. I hope to be able to show in the sequel that these variations of structure are fully accounted for by the differences of the conditions under which the several kinds of rocks can be shown to have become consolidated.

Having pointed out what appear to me to be the true relations of the several varieties of igneous rocks in this complicated district, I will now proceed to notice the different explanations which have been offered of its general physical structure. Beudant correctly described the volcanic rocks of Hungary as constituting five well-marked and more or less completely isolated mountain-groups—those, namely, of (1) the Schemnitz Mountains, (2) the Visegrad Mountains, (3) the Matra, (4) the Tokay-Eperies group, (5) the Vihorlat Mountains; and to these we must add, for Transylvania, two other groups (6) the Hargitta Mountains and (7) the Transylvanian Erzgebirge. Other similar masses of volcanic rocks of contemporaneous date and analogous composition stretch through the provinces of European Turkey, forming a link between the Miocene volcanic rocks of our continent and those of Asia. So enormously have the volcanic rock-masses of Hungary suffered from denuding causes, and so much more difficult is it to trace the relations between the isolated fragments of their short and bulky trachytic lava-streams, as compared with the wide-spreading plateaux constituted by the basaltic lavas of Auvergne, that it is not surprising to find Beudant altogether failing to perceive any connexion between the different isolated masses, and declaring that almost every separate mountain appears to be the result of a distinct eruption.

It is to Von Pettko, whose studies and writings have thrown so much new light upon the structure of the Schemnitz district, that we are indebted for the first clear exposition of the true relations of the different masses of volcanic rocks, and for some most valuable

suggestions as to the form and structure of the great volcano of which they constitute the ruins. He showed* that the mining-district of Schemnitz, a comparatively low-lying tract of oval form, about 20 miles long by 15 broad, was surrounded and overlooked on all sides by steeply scarped mountain-masses, rising to heights of from 3000 to 4000 feet above the sea. This encircling wall, as he pointed out, consists of great masses of andesitic lava, all exhibiting a slight dip away from the central depressed area, and alternating with enormous accumulations of tuffs and agglomerates, the whole being not unfrequently traversed by mineral veins; while in the central area rise numerous masses of rhyolitic and basaltic lavas and tuffs. Here, as the able Hungarian geologist clearly perceived, we have presented to us the characteristic features of a great volcanic cone, with a central crater of enormous dimensions; and he not inappropriately compared the Schemnitz crater with its central masses of acid rocks and its walls of more basic materials, to the well-known crater of Rocca Monfina with its enclosed bosses of rocks, forming the mountains of Santa Croce.

At the time when Von Pettko wrote (1848), the "elevation-crater" theory of Von Buch was almost universally accepted by foreign geologists, and the example of Rocca Monfina was regarded, on the authority of Abich, as affording a most signal illustration of its truth. It is not surprising, therefore, that Von Pettko should have adopted this view of the origin of the great crater of Schemnitz, and declared it to be a magnificent example of an "elevation-crater." The facts and arguments adduced in support of this once famous theory by Von Buch, Humboldt, and Elie de Beaumont have been so utterly demolished by the observations and reasonings of Lyell, Scrope, and Constant Prévost, that it would be mere waste of time at the present date to treat the theory as one still possessed of any vitality. But as regards all the other conclusions of Von Pettko concerning the Schemnitz district, I believe that they have been fully substantiated by further observation.

Riechthofen, who, at a somewhat later date, made a general study of the Hungarian volcanic rocks, arrived at some interesting conclusions as to their relations. He correctly defined their true sequence of eruption to have been as follows—first the trachytes, secondly the rhyolites, and thirdly the basalts; but, probably from failing to perceive and take account of the enormous amount of denudation which these volcanic masses had been subjected to, he was led to conclude that only the latter two classes of rocks could be regarded as having had a true volcanic origin. The vast masses of trachytic lavas with their tuffs he referred to a series of "massive-eruptions;" and not recognizing the essential identity in the chemical and mineralogical constitution between the "greenstone trachytes" and the ordinary trachytes of the district, he applied to the former the name of "prophyrites," and assigned their origin to an older series of

* "Erhebungskrater in der Umgebung von Schemnitz und Kremnitz," Berichte über die Mittheilungen von Freunden der Naturwissenschaften in Wien, Bd. iii. p. 199.

“massive-eruptions” than that which he supposed to have given rise to the latter.

I will now proceed to describe in detail the conclusions to which I have been conducted by a careful study of the volcanic rocks of the Schemnitz district, with the aid of the light thrown upon them by the labours of former investigators.

The epoch of maximum volcanic activity in Hungary was that true “age of fire” in our hemisphere, the Miocene period. So grand was the scale of the outburst of igneous forces at that time, so great the destructive effects on older deposits, and so enormous the accumulations of ejected materials piled above them, that the task of tracing the nature of the first symptoms and movements which heralded the appearance, and constituted the earlier stages of this tremendous manifestation of subterranean activity is a very difficult one.

The volcanic outbursts of the Miocene period were certainly preceded by a period of long and continuous, though irregular, upheaval throughout the areas in which they took place. The marine deposits of the Cretaceous and Nummulitic periods were succeeded by the wide-spreading estuarine and lacustrine sediments of the Oligocene, the latter formations consisting in Hungary and Transylvania of fresh- and brackish-water strata, having a thickness of several thousands of feet and containing beds of true coal, in one case of a thickness of 90 feet. Now various deposits of rocks of chemical origin testify to the fact that even before the close of the Eocene period, the subterranean forces were beginning to exhibit at the surface their most feeble manifestations, namely gaseous emanations and hot and mineral springs. But that even at this earlier stage some true volcanic fissures were formed, along which were thrown up a succession of cones, the isolated “necks” of teschenite and pikrite in Silesia, which have been so ably investigated by Hohenegger and Tschermak, abundantly testify. Nor is similar evidence wanting in Hungary. Dr. von Hantken, the Director of the Hungarian Geological Survey, pointed out to me that in the midst of the Visegrad group of mountains small deposits of tuff occur interstratified with the coal-series of the Oligocene; and this fact is recorded in the memoir which is published on this district by the Geological Institute of Hungary.

Dr. Szabó also suggested to me that some isolated masses of quartz-trachyte rocks near Buda-Pesth, which are totally different in composition and character from the widely spread andesitic lavas of the Miocene, might not improbably belong to this earliest stage of the great volcanic outbursts. It is not surprising, however, to find, both in Hungary and the adjoining countries, that the subsequent eruptions of the Miocene period on so grand a scale, and upon the same sites, have almost entirely destroyed the evidence concerning the first feeble manifestations of those forces which culminated in such tremendous displays of violence.

That the grandest of the Tertiary volcanic outbursts into Hungary and Transylvania—those namely which gave rise to the formation

of the vast masses of andesitic rocks—commenced at the beginning and continued during all the earlier portions of the Neogene period (that is to say, that they belong to the age of the Miocene proper, the Upper Miocene of Lyell), there is not the smallest room for doubt. At many points, as in the Piliser Gebirge, the tuffs and lavas of this volcanic series are found overlying even the highest members of the Oligocene formation, while the fine flora and fauna yielded by the tuffs themselves, and certain fossiliferous sedimentary deposits, which at some points are found alternating with the volcanic rocks, are quite sufficient to establish this conclusion as to the age of the latter.

An examination of the vast masses of lava, agglomerates, tuffs, and ashes themselves, as well as of the fossils associated with them, leads us to infer that the eruptions which produced them were of a *subaerial* character; and upon a review of the whole of the phenomena, we cannot escape the conclusion that during that great extension of the land-area which characterized the Miocene epoch in this part of the globe a chain of grand volcanos rose parallel to the great curved mountain-axis of the Carpathians. Of the still active volcanos of Europe, the only one which will bear comparison in point of dimensions with the great eruptive centres of Hungary is Etna. But during the period at which the Hungarian volcanos were formed, a complete girdle of volcanic mountains of almost equal dimensions, though pouring out various materials at different points, surrounded the whole Alpine system and stretched far eastward into Asia. At the same period another chain of equally grand volcanos stretched from the Arctic circle southward, through Iceland, the Faroes, the western side of the British Islands, and thence through the district which is now occupied by the Atlantic, to a latitude south of that of the Cape of Good Hope.

No mistake could, however, possibly be greater than to suppose that during this period of the tremendous paroxysmal displays of volcanic energy, there was any thing like an interruption of geological continuity in the area, or even to imagine that our portion of the globe exhibited the effects of more powerful subterranean action than can, at the present time, be witnessed upon other parts of its surface. On the contrary, we find the clearest proofs that these ejections of volcanic material which have produced such a vast aggregate result, were separated by very wide intervals of time, and that the whole continent, and even the slopes of the volcanos themselves, must have been clothed with that magnificent flora of which such interesting relics have been preserved for our study. We have also abundant evidence that innumerable lakes were formed among these old volcanos, and quietly filled with sediments, and that these were in turn buried under subsequent ejections from the igneous vents. Nowhere, indeed, can the vastness of the periods of time represented by the great Tertiary epochs be better appreciated than in Eastern Europe, where we find each of them represented by deposits several thousands of feet in thickness.

Confining our attention again more particularly to the Schemnitz

district, we find the andesitic lavas and tuffs ejected during the Miocene period gradually building up a cone of vast dimensions which eventually covered an area nearly fifty miles in diameter. That, as in the case of so many existing volcanos, eruptions took place sometimes from the summit, and at others on the flanks of the mountain, we have no room to doubt. The great volcano of Schemnitz then doubtless presented an appearance very similar to that of Etna at the present day; that is to say, it consisted of an enormous central mountain, upon the sides of which innumerable parasitical cones had been thrown up, each pouring forth its lava streams. Like Etna, too, the slopes of this old Hungarian volcano were covered by the magnificent forests characteristic of a warm temperate climate—gigantic Sequoias and pines, with oaks, beeches, chestnuts, planes, poplars, and willows, and an undergrowth of vines and herbaceous plants of subtropical character. And through these forests roamed the *Mastodon*, the *Dinotherium*, the *Anchitherium*, and the *Hyotherium*, with species of the Rhinoceros, Tapir, and many other forms, all of which are now extinct.

This period of most violent eruption in the great Schemnitz volcano appears to have been terminated by a paroxysmal outburst on the very grandest scale, which resulted in the formation of a prodigious crater of oval form. Vast as must have been the dimensions of this crater, they did not exceed those of some of the still active volcanos of the globe; and cavities of equal size have perhaps been produced by eruptions that have taken place during the historical epoch. The result of this tremendous paroxysm was to reduce the Schemnitz cone to a crater-ring of vast dimensions, one of those "basal wrecks" of a volcano, as Mr. Darwin so appropriately named the similar magnificent examples which are found among the islands of the Atlantic Ocean.

The great paroxysmal outbursts which produced this vast crater must have been succeeded, as is so frequently the case under similar circumstances, by a considerable subsidence of the whole mountain mass; and in consequence of this, not only were all except the highest portions of the crater-ring submerged beneath the sea, but the latter found its way into the interior of the crater. The wider-spread movements which had been taking place in Eastern Europe had resulted, as Von Hauer has so well shown, in the formation of a number of inland seas with which the waters of the ocean had not a perfectly free communication, and which are accordingly characterized by a stunted marine fauna. By a continuation of the same earth-movements the communication of these seas with the ocean was completely cut off, and a series of Caspians formed, characterized by a very remarkable brackish-water fauna. During these periods (those, namely, of the "Sarmatische Stufe," and of the "Congeria- and Inzendorf beds") the Hungarian volcanos rose as islands, still clothed with a flora very similar in character to that of the preceding period, but in which the mammalian fauna had undergone considerable change, through the disappearance of many of the old forms and the addition of such new and more modern types as *Hip-*

potherium, *Machairodus*, and *Antilope*, with species of *Sus* and *Hyaena*. The volcanic islands of Hungary must at this stage of their history have been very similar in appearance to those of the Grecian archipelago.

That during this period of subsidence the basal wreck of the Schemnitz cone underwent a vast amount of denudation we have the clearest proofs; the crater-ring was evidently breached at a number of points, and "barrancos" formed leading into it, the sea being thus permitted to enter it and to eat back the cliffs around it, with the same kind of action that Lyell and Darwin have shown to be taking place in the submerged volcanos of the Atlantic; and in this manner the extent of the vast "caldera" was probably greatly increased. Around the flanks and in the centre of the ruined volcano, deposits enclosing relics of the interesting fauna and flora of the period were accumulated—beds with marine, brackish-water, and freshwater shells alternating with lignites, formed by the numerous vegetable remains carried down into the lagoons, and with masses of tuffs ejected from the volcanic vents.

It was during this condition of the volcano that the last eruptions of the Schemnitz area took place; and these were almost entirely confined to the central lagoon occupying the crater hollow of the old volcano. The materials ejected during these later outbursts consisted in the first instance of quartz-trachytes (liparites or rhyolites) with the beautiful varieties of perlitic rocks which we have already referred to as having probably been formed for the most part under water and not constituting true pumice. The eruption of these highly acid rocks was followed by that of those of extreme basic character—the basalts. At this period of its history the appearance of the volcano of Schemnitz must have presented a most striking resemblance to that now exhibited by Santorin. The latter is a nearly submerged and greatly ruined crateral ring, the interior of which is occupied by the sea, in the midst of which a number of new and smaller cones are being gradually built up by the eruptions which are taking place at the present day. In the Schemnitz caldera the ejection of the rhyolitic lavas and tuffs was followed by that of the basalts, and a number of cones were formed which gradually rose above the surface of the central lagoon; and thus the eruptions that were at first submarine gradually became subaerial ones. By a continuance of these outbursts, the depression of the central area appears to have become eventually entirely filled up, and the sea excluded from it, the process being probably aided by a process of slow upheaval which the whole district was gradually undergoing.

It is impossible to pass by in silence the points of analogy in the succession of the different lavas of the Tertiary Hungarian volcanos and that of the more recent ones of the Lipari Islands*. In both cases the ejected materials which have formed the great mass of the volcanos, consist of rocks of composition intermediate between the acid and the basic types; and the eruption of these was followed,

* See Geological Magazine, Decade ii. vol. ii. p. 60.

after an interval of quiescence, by the final outbursts, first of a highly acid, and then of an extremely basic character. Have we here an indication that during a period of temporary rest in a volcano, the unejected materials below it may undergo a separation into two "magmas" of different composition and specific gravity, similar to those which, according to the well-known theory of Durocher, have been universally formed below the earth's crust?

The formation of the scattered basaltic cones within the great crater-ring of the Schemnitz volcano, and of a few similar ones ("pays") around its flanks, were the last great efforts of the igneous forces of the district. Subsequently their declining energies appear to have been equal only to the origination of fumaroles and hot springs or to the production of those earthquakes to which the region is still occasionally liable. The extent of the deposits, both siliceous ("sinter") and calcareous ("travertine"), formed by these springs shows clearly how long, even after the final extinction of the volcano, the subterranean forces retained a portion of their vitality, and how very slowly and gradually the igneous activity of this region sank into complete quiescence.

We have endeavoured in the preceding pages to investigate the several varieties of rocks of which the old Schemnitz volcano was built up, and, by the aid of the analogies of more perfect and still active volcanos, to reconstruct the history of the events to which its original features and its present condition are to be ascribed. Let us now proceed to inquire what are the appearances exhibited in the interior of this old volcanic pile as now exposed to us, which serve to illustrate the nature of the operations going on deep below the surface, synchronously with those phenomena which we ordinarily witness at the surface as the accompaniments of volcanic activity.

And although we have not here the remarkably clear sections afforded by sea-cliffs, as in the ancient Hebridean volcanos, yet in the great volcano of Schemnitz—the whole heart of which has been blown out by tremendous paroxysms, while the vast crater thus originated has been further enlarged by the action of the sea which entered it after the partial submergence of the mass—many valuable opportunities are afforded to the geologist for studying the relations of the originally deeply seated masses of the volcanic pile. Since the final upheaval of the district, too, the great rock-masses have been greatly reduced by subaërial denudation, and important sections of them exposed in the valleys; and, finally, the innumerable mining-works opened all over the central area, and a series of deep railway-cuttings have all served to throw light upon the relations which the different rocks of the district bear to one another. Aided by all these different kinds of exposures of the rock-masses of the Schemnitz area, we propose to describe the structure of the interior of this old volcano and to investigate the connexion between its internal mechanism and the operations which we have shown to have taken place at the surface.

We have already exposed the grounds on which we have been led to the conclusion that the so-called "granite and syenite," the

“greenstone-trachyte” and “dacite,” and the different varieties of andesitic rocks in the Schemnitz district are chemically and mineralogically identical, and that their variations in structure are simply the result of differences in the conditions under which they have been consolidated. That the hornblende- and mica-andesites were actual lavas poured out at the surface, we have the clearest proofs; and that the “greenstone-trachytes,” the dacites, and the “syenite and granite” constitute intrusive masses which have been forced, while in a plastic and highly heated condition, through the midst of the sedimentary rocks, is clearly shown by the phenomena presented at the planes of contact of the two classes of rocks, and by the dykes and veins which are seen proceeding from the one into the other.

The rocks of sedimentary origin, through which the igneous masses forming the centre of the old Schemnitz volcano have forced their way, have been supposed to include certain members of the Palæozoic series; and these rocks, which, as we have already pointed out, were at first generally referred to the Primary group, have been subsequently identified, though on very doubtful grounds, seeing that they contain no fossils, first as Devonian, and secondly as Dyas. They are supposed to be overlain by the Triassic and Nummulitic rocks of the district, which are unmistakably identified as such by the fossils which they contain.

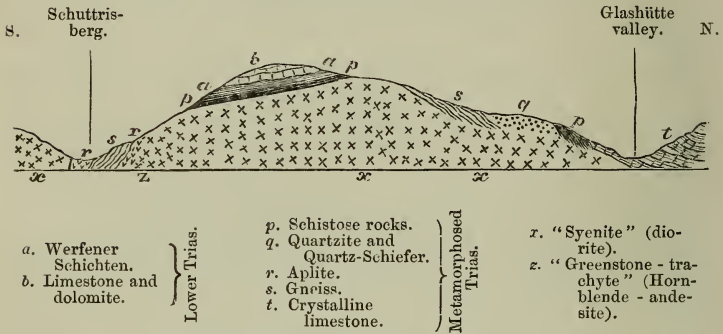
But after a very minute and careful examination of the central district of the Schemnitz volcano, I have been led to the conclusion that there exists within it no series of rocks of older date than the Trias, and that the supposed Palæozoic rocks—the quartzite and quartzschiefer, the crystalline and schistose limestone, and the schists, gneisses, and aplite—are nothing but the arenaceous, calcareous, and argillaceous beds of the Trias, metamorphosed by their contact with the Miocene intrusive masses.

I have already enumerated the chemical and petrological grounds on which I have been led to infer that the rocks of granitic structure in the midst of the Schemnitz volcano are identical in composition and age with the surrounding andesitic lavas. There are also several circumstances in connexion with the physical structure of the district which lend the strongest confirmation to this view. Were the igneous masses of Hodritsch, as is asserted, an old granitic boss upon which the so-called Permian and the Triassic strata have been deposited, the conglomerates associated with these latter could scarcely fail to contain pebbles of the granite and syenite. Such, however, is never the case, as I can testify after a most careful examination of the whole district, with a view to the determination of this point. Similarly, the absence of all pebbles of the metamorphic rocks (the quartzites, schists, and gneisses) of the district in the conglomerates of the Trias is quite inconsistent with the view that the former were in existence before the latter and constituted the basis on which they were deposited. Another proof that the rock of Hodritsch is not an old granite boss upon which the sedimentary rocks were unconformably deposited, is found in the circumstance that *the Triassic*

rocks are never seen resting directly upon a denuded surface of the granite*, but are always separated from it by a zone of highly metamorphosed rocks.

The most satisfactory method of determining the true relations of the igneous, metamorphic, and sedimentary rocks of this district is by studying their exposures along the Hodritsch, Eisenbach, and Glashütte valleys and in the mountain-masses of the Kohl-Berg (see fig. 1) and the Schwatzer Berg (see fig. 2) which separate

Fig. 1.—Section through the Kohl-Berg.



these valleys. Here we find, in innumerable instances, the limestones, sandstones, and shales of the Trias, wherever we approach a mass of "syenite" or "greenstone-trachyte," undergo a marked change and acquire by the most imperceptible gradations a more crystalline character, till finally they assume the condition of a crystalline or schistose limestone, of a quartzite or quartz-schist, or even of a gneiss or aplite (granulite). I believe that it is impossible for a geologist to examine all the interesting lines of junction between the igneous and stratified rocks without being fully convinced that the metamorphic masses which in every instance occur between them have been produced by the action of the Miocene intrusive rocks upon the Triassic strata which they have penetrated (see fig. 3).

I do not propose in this place to enter upon a discussion of the details of the interesting problems which are so admirably illustrated by these beautiful examples of *local* or *contact* metamorphism, and of their bearing on the wider question of the nature and causes of the phenomena of *general* metamorphism. On a future occasion I hope to lay before this Society the results at which I have arrived from the study and comparison, both in the field and in the cabinet, of the rocks which exhibit the most distinct and rapid transition from

* In this place, as in many other portions of this memoir, I have used the names by which the rocks of the district have been so long indicated, rather than those which I have endeavoured to show in the present paper would be more appropriately assigned to them, in order to make my line of reasoning more clearly manifest.

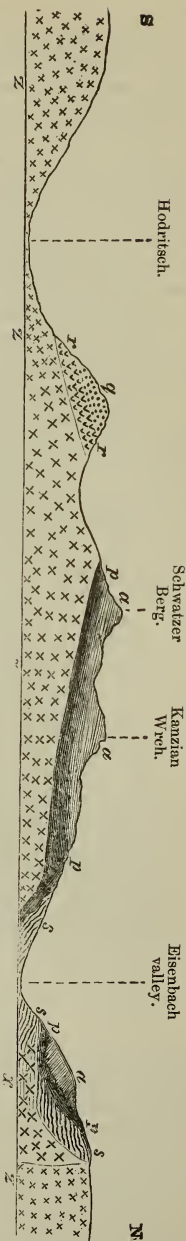


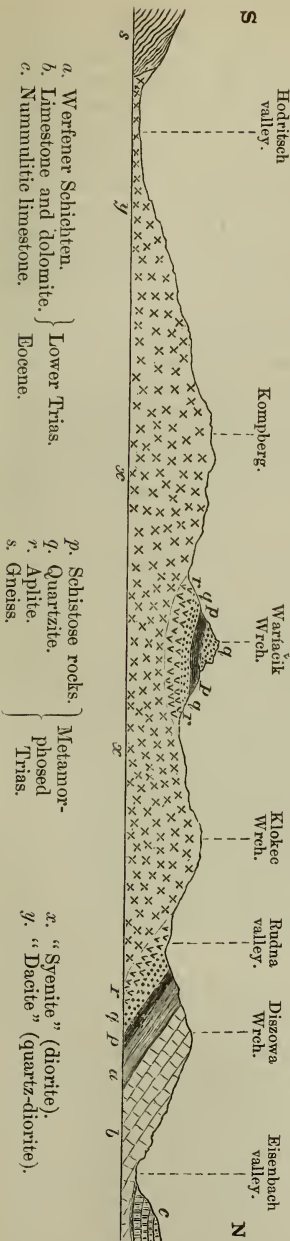
Fig. 2.—Section through the Schwarzer Berg.

a. Werfener Schichten
(Lower Trias).

p. Schistose rocks.
q. Quarzite,
r. Aplite,
s. Gneiss.

x. "Syenite" (diorite),
z. "Greenstone-trachyte"
(Hornblende-andesite).

Fig. 3.—Section from the Eisenbach valley to the Hodritsch valley (based on that of Von Adrian).



a. Werfener Schichten,
b. Limestone and dolomite.
c. Nummulitic limestone.

Lower Trias.
Eocene.

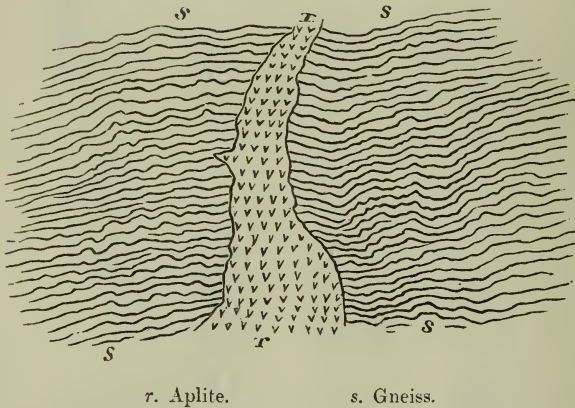
p. Schistose rocks.
q. Quarzite,
r. Aplite,
s. Gneiss.

x. "Syenite" (diorite),
y. "Dacite" (quartz-diorite).

the unaltered to the most highly metamorphosed condition in Scotland and Hungary, and of the light which they throw upon the important question of the origin of foliation. At the present time I propose only to notice the interesting relations of the rock called aplite, which appears to be the final product of metamorphism of some of the Triassic rocks. Upon the old theory that the granitic mass of Hodritsch was of ancient date, and that the Dyas and Trias strata were deposited upon it, the relations of the aplite rock appeared to be altogether inexplicable; while the views of the relations of the igneous, metamorphic, and sedimentary rocks of the Schemnitz area which I have endeavoured to enforce in the present paper suggest, as I hope to show, a remarkably simple explanation of the phenomena, which I think will commend itself to the minds of all geologists.

The aplite (a variety of granulite) is a crystalline rock composed of orthoclase and quartz, to which hornblende, tourmaline, and other minerals are sometimes added. It always occurs at the junction of the "syenite" and gneiss, and while it sometimes forms masses having a general parallelism with, and graduating insensibly into, the latter, it is not unfrequently found sending off veins into the gneissic rocks, and thus behaves like an intrusive rock, as von Lipold has well pointed out (see fig. 4).

Fig. 4.—*Aplite forming a vein in Gneiss at Schuttrisberg.*



At first sight the occurrence of this granulite, or "semi-granite" (as it is well called), at the junction of the granitic and gneissic masses might be thought to lend some support to the views entertained by several geologists of the metamorphic origin of the granitic rocks themselves. But a more careful study of the conditions here presented will be sufficient to convince us that, here at least, any such doctrine is altogether untenable. Microscopic and chemical examination alike demonstrate conclusively that the aplite cannot possibly be regarded as an intermediate stage between the gneiss and

the "syenite." Of the former it certainly represents the last stage of alteration; but with the latter it has absolutely nothing in common. It is a rock of far more acid composition, and it contains much free quartz and orthoclase felspar; while the igneous masses in contact with it have little or no free quartz, and the felspar is principally plagioclase.

The phenomena presented by these masses of aplite can only be explained, as it appears to me, by regarding the rock as the last stage of metamorphism of the Triassic sediments. That their particles must have attained the condition of almost absolute internal mobility is shown by the nearly perfectly crystalline character of the rock; and that, as a consequence of this, the mass was in a truly plastic state is shown by the fact that it was capable of being injected in the form of veins into the fissures of the surrounding masses. To the same cause (its perfect internal mobility), as I shall hereafter show, we must assign that disappearance of the foliation which distinguishes the surrounding gneissic rocks, into which it frequently passes, however, by the most insensible gradations.

We thus see that the examination of the ruins of the old Hungarian volcano leads us to results identical with those which we obtain by the study of the similar ones of the same age in the Western Isles of Scotland—namely, that portions of the same liquefied masses of rocks, which at the surface flowed in lava-streams or were scattered by explosions as scoriæ or ashes, consolidated at a great depth and under considerable pressure in the interior of the volcano, in a highly crystalline and even perfectly *granitic* condition. We have also shown that around these vast and slowly consolidating masses of intensely heated rock, a series of chemical changes were set up in the sediments which they penetrated, resulting in the transformation of the latter into schistose and highly crystalline rocks.

As in the case of the rock-masses of intermediate composition (the andesites and diorites) we find the more deep-seated portions assuming a highly crystalline and even granitic character, so we also have grounds for the conclusion that, under the same conditions, the rhyolitic and vitreous rocks of acid composition pass into highly crystalline quartz-trachytes, presenting precisely those characters which are regarded by some petrologists as belonging only to rocks of very ancient date. This highly porphyritic or semi-granitic form of the rhyolitic rocks is well exhibited by the great intrusive masses near Eisenbach and Königsberg.

Of the interesting minerals which result from the long-continued reactions taking place between masses of highly heated volcanic materials and the surrounding sedimentary rocks—and with which we are so familiar at Monzoni, an old volcanic vent in which they are seen lying in their original situation, and at Vesuvius, where they are continually being ejected from the crater—we find several very interesting examples in the case of the great Schemnitz volcano. Thus, near Hodritsch, a mass of Trias dolomite entangled in the dioritic rock exhibits, near the planes of its junction with the

igneous mass, beautiful examples of opicalcite; and in a similar situation at no great distance, masses of finely crystallized fassaite and pleonaste also make their appearance. Epidote, mica, garnet, and other minerals* are also found under similar conditions at several points in the district.

Although there are, as we have seen, so many points of resemblance between the volcanoes of Hungary and those of Scotland, yet there is one respect in which they afford a very remarkable contrast. In the case of the Scottish volcanoes we observe but little evidence of those hot and mineral springs and of those discharges of gas and vapour which usually constitute the final stage of volcanic activity; while of the existence and action of these, as we have seen, there are in the case of the Hungarian volcanoes most abundant proofs. Now when we come to examine the deep-seated rocks of each of these districts, we find also a corresponding difference. While the rocks which once formed the central masses of the old Scottish volcanoes have undergone comparatively little chemical change since their eruption, those in the midst of the Hungarian volcanoes have clearly been affected in the most powerful manner through the penetration of their mass by acid gases and vapours. Often the whole mass of rock over a considerable area is found to be completely decomposed and reduced to a white or variegated friable product, to which the name of "greenstone-tuff" has been sometimes, though erroneously, applied. At other times the change has been a more partial one; and over very considerable tracts the "greenstone-trachytes" or "propylites" are found to be charged with the sulphides of iron, copper, lead, and antimony, often containing some silver and gold. Where, however, fissures have existed in these rocks, these various metallic substances have been accumulated in greater abundance, and have given rise to the formation of those valuable lodes for which the district is so famous.

It does not of course fall within the scope of the present memoir to attempt to give any account of the great mineral deposits of the Schemnitz district, further than is necessary to show the connexion between the causes by which they are formed and the volcanic activity of the area in which they occur.

The fissures occupied by the Schemnitz lodes have a general direction from N.N.E. to S.S.W. They traverse the so-called granite and syenite, the "greenstone-trachyte," and the metamorphosed Triassic strata, and also extend into the midst of the trachytes and other rocks which surround the centre of the old volcanic mountain, the most productive portions of the lodes appearing to be always situated in the central masses of "greenstone-trachytes." According to Von Pettko there is evidence that in some cases the infilling of the mineral veins is even of later date than the eruption of the basalts.

The phenomena which we have described as being exhibited by the old volcano of Schemnitz find a very close parallel in the other great centres of igneous activity in Hungary and Transylvania. In each case we find a great circular or, sometimes, linear group of

* Jahrbuch der k.-k. Reichsanstalt, Bd. iv. (1855) p. 183.

mountains (the centre of volcanic activity sometimes showing clear evidence of having shifted along a line of fissure), which has been formed by enormous and frequently repeated eruptions of andesitic lavas and tuffs. In every instance we find proofs that the more deeply seated masses of andesitic lava have, in consolidating, assumed a highly porphyritic or granitiform structure, and that the action upon these of acid gases and vapours has resulted in the decomposition of the mass, with the diffusion of valuable metallic ores throughout the substance of the rock and their accumulation in considerable quantities wherever a suitable fissure occurred in it. In each of these volcanos, too, the eruption of the andesitic lavas appears to have been followed, after an interval of subsidence, by the extrusion of highly siliceous rocks (rhyolites) and, finally, of extremely basic ones (basalt and augite-andesite) on a much more restricted scale than in the case of the older ejections. The fossil remains associated with the masses of tuffs at the several volcanic centres show that the ejection of the different classes of lavas took place at periods which were approximately contemporaneous in each case; and at every point the decline of volcanic activity was marked by the appearance of hot and mineral springs and fumaroles.

Conclusion.

The more important results to which we have been led by the facts and arguments of the foregoing memoir may be briefly summed up as follows:—

(1) The igneous masses which in Hungary and Transylvania have been poured forth at the surface, in the form of andesite and quartz-andesite lavas, have, where undergoing consolidation at some depth from the surface, assumed a most perfectly granitic character ("syenite" and "granite" of most authors, or, more properly perhaps, diorite and quartz-diorite). There is the most complete and insensible transition from these granitic rocks to the true lavas; and the whole of them are of Miocene date.

(2) Around each of the intrusive masses which constitute the links between the volcanic rocks poured forth at the surface and the subterranean reservoirs from which they have been derived, various chemical actions have been set up in the masses of Triassic sediments through which these have been extruded; and these actions have resulted in the production of highly crystalline and foliated rocks which are identical in petrological character with materials constituting widely spread metamorphic areas.

(3) But, while there appears to be at first sight a gradual passage from the stratified rocks through these metamorphic masses into the truly granitic rocks, yet the phenomena displayed by this district really afford no support whatever to the theory that the granitic masses are not truly intrusive at all, but represent sediments which have undergone their final and most extreme metamorphism *in situ*. On the contrary, not only is the chemical and mineralogical constitution of the granitic masses far too uniform throughout and too

different from that of the surrounding stratified rocks to admit of any such interpretation, but the final product of metamorphism of the Triassic rocks is actually seen in the aplite—which must have been reduced to a liquefied condition, and graduates most insensibly through the gneissose and schistose rocks into the sedimentary masses; and yet the distinction in character and composition between the aplite and the dioritic rocks is most clear and unmistakable.

(4) The mineral veins of Hungary and Transylvania, with their rich deposits of gold and silver, cannot be of older date than the Miocene, while some of them are certainly more recent than the Pliocene. Hence these deposits of ore must all have been formed at a later period than the clays and sands on which London stands; while in some cases they appear to be of even younger date than the gravelly beds of our Crag!

EXPLANATION OF PLATE XX.

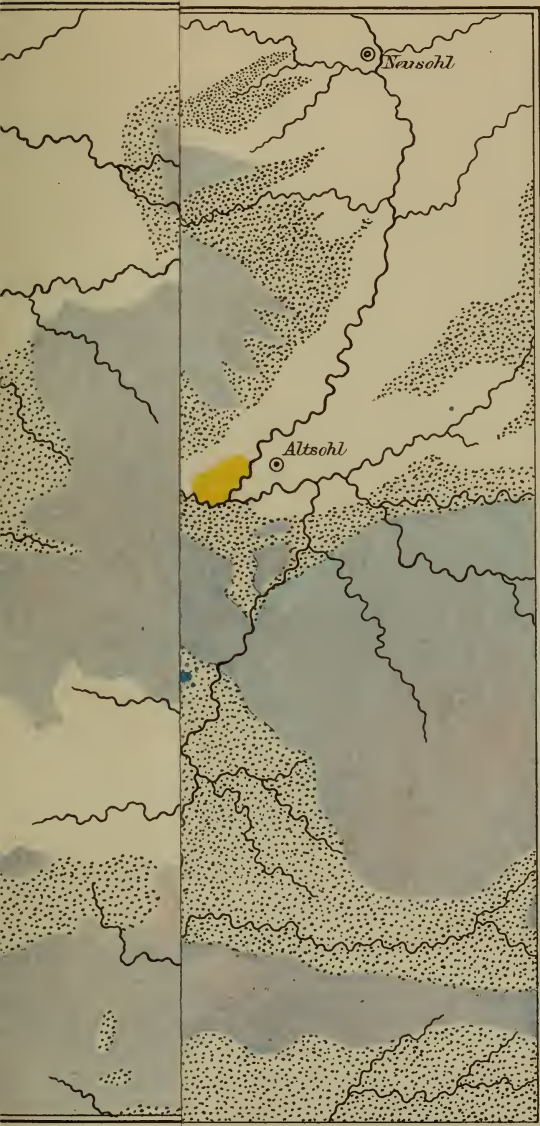
In this Plate the same plan of colouring has been adopted as in those illustrating the paper "On the Ancient Volcanoes of the Highlands," published in vol. xxx. of this Journal. The distinctive chemical character of the several volcanic rocks is indicated by different colours—blue representing the basic lavas and red the acid, while the varieties of intermediate composition are distinguished by shades of purple. The *depth of tint* in each case indicates the more or less highly crystalline character of the several rock-masses; thus dark purple represents the granitic andesite, or diorite, and fainter tints the ordinary andesitic lavas. The same plan of colouring is adopted both in the map and section. In the former the broken line shows the approximate boundary of the great "Caldera" to which the crater of Schemnitz was reduced by prolonged denudation; the continuous line is the direction of the section below, which is drawn on a true vertical and horizontal scale, twice as great as that of the map. The scale of the map is about one inch to six English miles; that of the section one inch to three miles.

DISCUSSION.

The PRESIDENT (Prof. Duncan) remarked that it was curious to note that the same volcanic rocks had been ejected in past times as were being thrown out at the present day; whilst, on the other hand, in two neighbouring districts volcanic rocks of completely distinct natures were being ejected at the same time. He did not consider plants to be a safe guide to the age of beds, as they are known to extend through long periods.

The DUKE OF ARGYLL expressed his personal thanks to Mr. Judd for the light he had thrown on volcanic rocks, more especially those of Scotland. The most important point was the identity of rocks hitherto considered distinct. In the Isle of Mull granite had been found passing insensibly into porphyritic and volcanic rocks.

MR. W. W. SMYTH said that formerly the rocks of this district were divided into metalliferous and non-metalliferous. In going over this spot with Von Hauer and others, he had pointed out Nummulites at Eisenbach, and had then maintained that the crystalline rocks there were metamorphosed Nummulitic Limestone. A map of part of this region, which he had drawn at that time, agreed in most re-



Aqueous Rocks.

Neogene Strata

Eocene (Nummulitic) Rocks.

Triassic Rocks metamorphosed in places and passing into Quartzite Schist, Gneiss & Aplite

Igneous Rocks

Age

Basaltic tuffs
Basalt and Andrite andesite lavas.

Cingirian Strata

Rhyolitic and Pumice tuffs
Quartz porphyry and Rhyolitic lavas

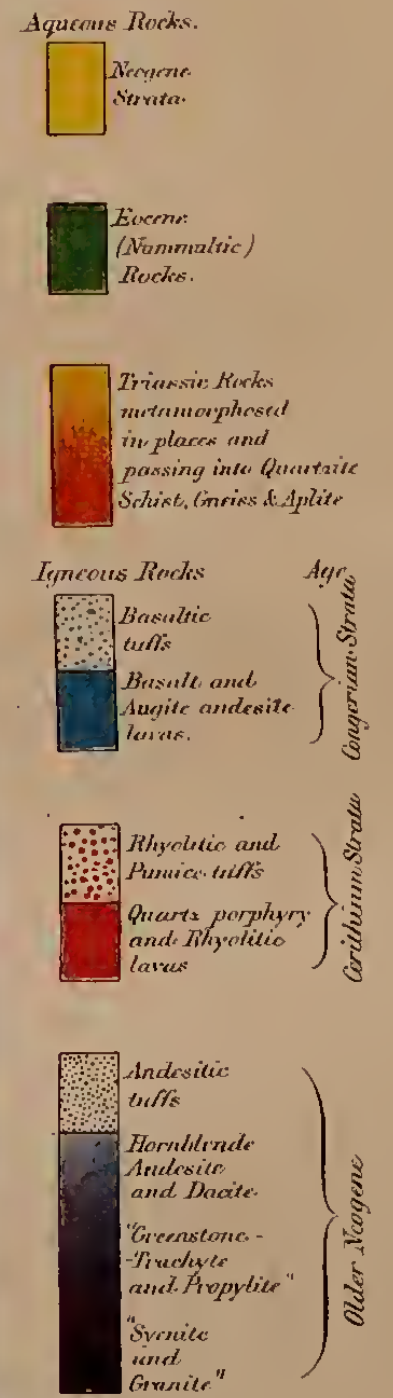
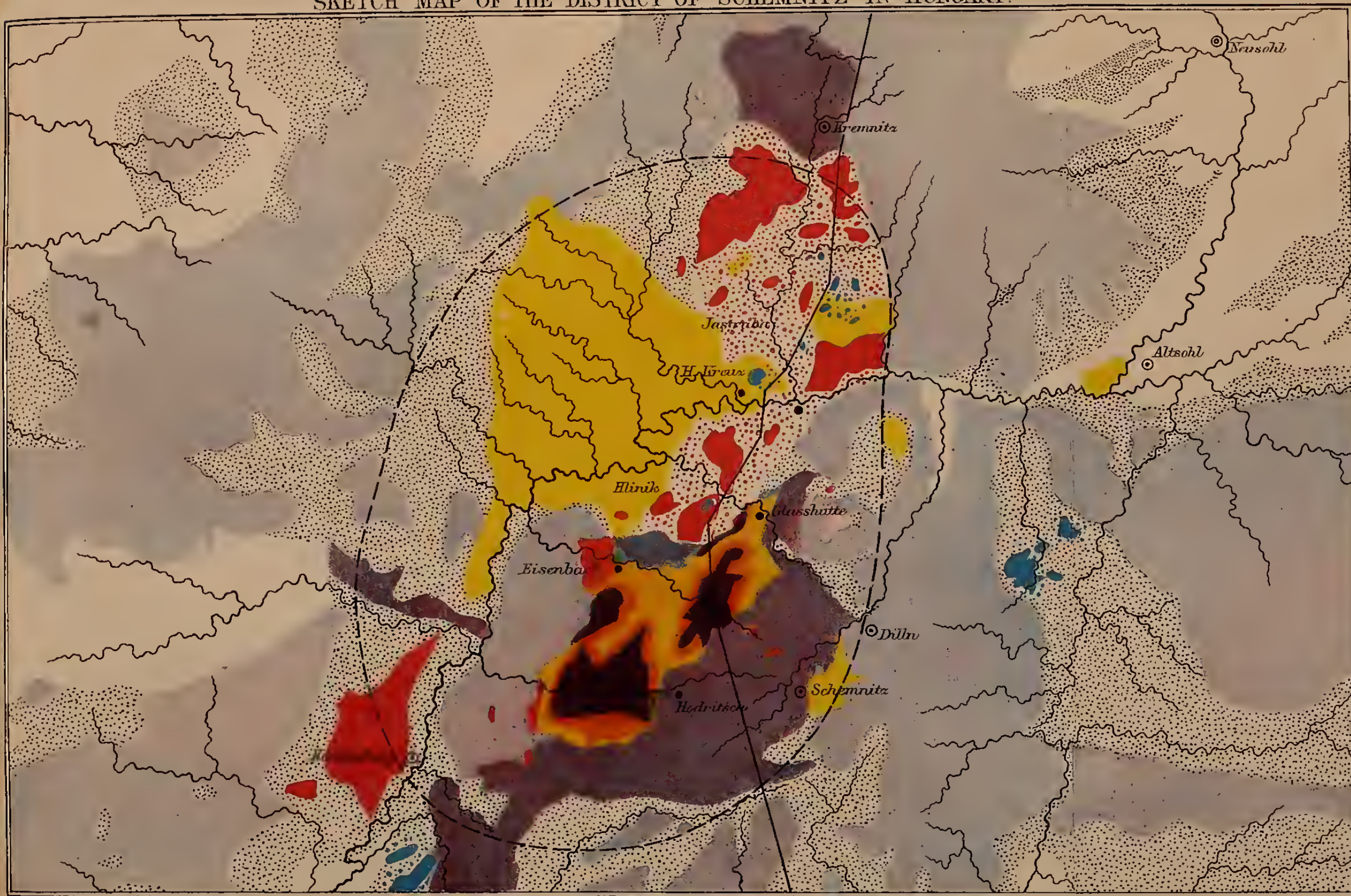
Cirithium Strata

Andesitic tuffs
Hornblende Andesite and Daate
"Greenstone - Trachyte and Propylite"
"Syenite and Granite"

Older Neogene



SKETCH MAP OF THE DISTRICT OF SCHEMNITZ IN HUNGARY.



SECTION ACROSS THE GREAT CRATER OF SCHEMNITZ.

spects with Mr. Judd's; but Mr. Judd had greatly simplified our notions of what had hitherto appeared to be an excessively complex district.

Mr. JUDD, in reply, stated that marine shells had been found along with the plant-remains in the beds associated with andesitic lavas, and these had borne out the views held by botanists with regard to the age of these lavas. The Duke of Argyll's discovery of the leaf-bed in the Isle of Mull constituted the starting-point for all our knowledge of the age of the volcanic rocks of the Western Isles. The transition of granite into the volcanic rocks was very marked in that island. The difference between the rocks with glassy plagioclase and the earthy rocks in the Schemnitz district was possibly connected with the presence or absence of metallic deposits. In Scotland the rocks were destitute of ores; but in Hungary they had evidently been subjected to the action of acid gases, and valuable metalliferous minerals are found abundantly in them.

35. *On two CHIMÆROID JAWS from the LOWER GREENSAND of NEW ZEALAND.* By E. TULLY NEWTON, Esq., F.G.S., of H.M. Geological Survey. (Read June 7, 1876.)

(By permission of the Director-General of H.M. Geological Survey.)

[PLATE XXI.]

HAVING been working for some time past at the Cretaceous Fishes, my interest has been especially centred in the group of the Edaphodontidæ; for the specimens belonging to this group, which have been brought to light within the last few years, have much enlarged our knowledge of these peculiar forms of fossil fishes. The general results of my examination of this group, will shortly be published; and in the present communication it is only proposed to consider two specimens from the Lower Greensand of New Zealand, which have been deposited in the British Museum by Dr. Hector. My attention was first directed to these specimens by Mr. W. Davies, of the British Museum, when I was examining the fine series of Chimæroid jaws now in the national collection.

One of these New-Zealand specimens is the right mandible of a species of *Ischyodus* already known to us from the Gault of Folkestone; and the second is a small right maxilla, which is altogether new and appears to be generically distinct from any of the fossil forms hitherto described.

Before considering the peculiarities of the mandible, it will be necessary to enter into some explanation and description of the species to which it is referred.

It appears that the late Prof. Agassiz, some years ago, saw in the Earl of Enniskillen's collection of fossil fishes, a Chimæroid mandible from the Gault of Folkestone, which he named, in manuscript, *Chimæra brevisrostris*. Subsequently, in his 'Poissons Fossiles' (1843)*, he alluded to this specimen under the same specific name, placing it in his subgenus *Ischyodon* †; but, most unfortunately, he gave no description or figures. Since the publication of that standard work of fossil ichthyology, several examples of *Ischyodus*-mandibles have been obtained from the Gault, nearly all of which appear to belong to one species. These mandibles have generally been referred to Agassiz's *I. brevisrostris*, simply because they were the only forms of *Ischyodus* known from the Gault; but the want of a figure or description of the original specimen left the matter in great uncertainty.

At the request of my colleague, Mr. Etheridge, the Earl of Enniskillen has very kindly sent the original type specimen of Agassiz's *I. brevisrostris* to the Museum of Practical Geology for examination and comparison; and I am now therefore enabled to give for the first

* Recherches sur les Poissons Fossiles, iii. p. 344.

† Agassiz provisionally adopted Sir Philip Egerton's genus *Ischyodus*, with the above modification.

time a figure of the type of this species (Pl. XXI. fig. 4). Although the specimen is much broken, there can be no doubt of its specific identity with those mandibles which have been more recently obtained from the same horizon, and in a more perfect condition.

Among the fish-remains from the Cambridge phosphatic deposits, examples of *I. brevirostris* (which can now be definitely determined to be this species) are not uncommon; and one of the varieties there found agrees very closely, not only with the type specimen from the Gault of Folkestone, but also with the New-Zealand Lower-Greensand example, which forms, in part, the subject of the present communication.

As *I. brevirostris* has never been described, it is proposed here to give the chief peculiarities of the mandible; and considering the fragmentary character of the type specimen, it is thought better to describe a more perfect example, and afterwards to compare with this, first the original type specimen, and then the one from New Zealand.

Good evidence of the form of the maxilla and præmaxilla of *I. brevirostris* has now been obtained; but as these parts are not required here for comparison, I do not purpose describing them.

ISCHYODUS BREVIROSTRIS, Agassiz. (Plate XXI. figs. 1-5.)

The specimen of a right mandible, represented by fig. 1, has been chosen for description on account of its being extremely like Agassiz's type specimen, and also because it is intermediate in form between two or three extreme varieties, this species being, like others of the family, very variable in form. The general appearance of the jaw will be best understood by a reference to the figure. It is somewhat more triangular in outline than is usually the case in this genus, or even in other specimens of the present species. The oral margin (*a* to *d*) is seen to be deeply indented anteriorly and posteriorly. The front or symphyseal margin is slightly convex. The posterior margin is irregular in outline, being always more or less broken. It is evident from the form of these jaws, that they were continually growing at the hinder part, and being thrust forward as the anterior portions were worn away; from this arrangement it is obvious that at the hinder part the bone would be only imperfectly ossified, and consequently easily broken; and as a matter of fact the hinder part of these fossils is always more or less broken.

Viewed from the inner side, as in fig. 1, the oral surface (*os*) of this mandible is seen to be armed with five of those peculiar dental surfaces which have been sometimes termed *tritons*, but which will be alluded to in this paper as teeth (fig. 1, *abcde*). The first of these is placed at the end of the beak (*a*). The dental substance of which this is composed is arranged in a series of plates or lamellæ, set somewhat obliquely to the anterior border. These lamellæ are not seen in fig. 1; but in specimens with the outer surface denuded they are seen to extend along near the front margin as in fig. 2. The dental substance of which the other four teeth are composed is not arranged in lamellæ, but each tooth consists of a

number of tubes (filled with dark substance), generally set perpendicularly to the surface, around which the dentinal substance is deposited. A surface-view of a portion of one of these tubular teeth is shown in fig. 3. The tooth *b* (fig. 1) is small, and placed at the anterior end of the upper margin of the symphysis. The tooth near the letter *c* causes the projection upon the oral margin, and extends inwards almost to the large central one, *e*. The posterior and outer tooth, *d*, extends for some little distance near to the margin of the bone. The median tooth, *e*, is much larger than either of the others; in this species there is always a space between it and the symphy-sial tooth, *b*. Below and behind the teeth the bone is covered by a delicate layer of enamel-like substance, which is smooth and shining and shows definite lines of growth. The symphy-sial surface (*sy*) is slightly convex; but towards its oral margin it is marked by a deep groove with a rounded and projecting ridge immediately above it.

If Agassiz's type specimen (fig. 4) be compared with the more perfect one described above (fig. 1), the close resemblance in every particular will, I think, be obvious, the greatest difference being that the middle tooth (*e*) is larger in the type (fig. 4); this difference, however, must be regarded as of little importance, as it is almost wholly due to the fact that the bony covering is more broken away in the latter.

It might be thought that the differences in general outline and in the form of the teeth between the two specimens represented by figs. 1 and 4 would justify their being referred to different species; but the examination of a large series from the Gault and Cambridge deposits has convinced me that *I. brevirostris* varies to a far greater extent than is shown in these two specimens. In some instances the tooth *e* is narrower than it is in fig. 1, and extends almost to the oral margin at *c*; in other cases the same tooth will be proportionally much wider, and placed further back. The extent to which the oral margin is indented also varies much, being sometimes more, and sometimes less than in fig. 1. The proportional length of the oral margin from *a* to *d* likewise varies.

The New-Zealand specimen (fig. 5) has the outer surface imbedded in the matrix, and a portion of the beak broken off; but still the fossil is sufficiently perfect to allow of a very close comparison. The description of the Cambridge mandible given above would answer equally well for this one from the Antipodes; but a comparison of the two (figs. 1 & 5) will show that there are some differences. When, however, the variations which are known to occur among the Gault specimens belonging to this species are duly considered, these differences will be regarded as of minor importance. The greatest dissimilarities are these: in the New-Zealand specimen the oral margin was probably shorter and less indented, the margin from *d* to *x* is proportionally longer, and the middle tooth *e* is larger, and extends further forward and nearer to the symphy-sial tooth, *b*. If now the figs. 1, 4, & 5 be compared, it will, I think, be acknowledged that there is as great a difference between the Cambridge and the Folkestone specimens (figs. 1 & 4)

as there is between the New-Zealand form (fig. 5) and the original type specimen of *I. brevirostris* (fig. 4).

*CALLORHYNCHUS** *HECTORI*, nov. sp. (Pl. XXI. figs. 6-9.)

The second Chimaeroid jaw, alluded to above as having been brought from New Zealand by Dr. Hector, is a small right maxilla which presents certain peculiar and interesting characters.

This maxilla measures little more than an inch in length, and not more than three fourths of an inch in width at its widest part. The oral surface of the specimen is exposed, the upper portion being imbedded in the matrix. The entire bone is much depressed, as shown in figs. 8 & 9; and this is evidently its natural form, for there is not the slightest evidence of its having been distorted in the process of fossilization. It is narrowest in front, and widens out at the hinder part, the outer angle being produced backwards, downwards, and outwards, so as to form a conspicuous process. The oral surface is provided with but one tooth, composed of the tubular kind of dentinal substance; this one, however, has a peculiar form. Posteriorly the tooth appears to pass into the substance of the bone, as in the other forms of the *Edaphodontidæ*; and at this part it is proportionally wide, occupying the greater part of the width of the bone; passing forwards it is seen, at a distance of about $\frac{1}{4}$ of an inch from its hinder border, to separate into two processes: one of these passes along the inner side near the symphysis, almost to the anterior end of the maxilla; the other extends along the outer margin for some little distance, but does not reach so far forward as the inner one. Between these two processes there is a depressed space, the inner process standing up in relief as a rounded ridge. Both sides of each of these processes appear to have been worn by attrition against the teeth of the mandible. Judging from the manner in which this maxillary tooth is worn, it seems at first sight that there must have been at least three teeth in the mandible—one to cut out the central groove in the maxillary tooth, and a second and a third to wear away the inner and the outer sides. But a study of the recent *Callorhynchus* shows that the mandible was probably provided with but one tooth.

It will be remembered that the maxilla of *Edaphodon* is characterized by three teeth, that of *Ischyodus* by four, and that of *Elastomodus* by possessing two elongated teeth and a series of dental laminae upon the outer margin. In the young condition it appears that the two long teeth are joined posteriorly and rolled in a peculiar scroll-like manner. In general appearance this tooth resembles that of the New-Zealand maxilla (compare Pl. XXI. fig. 6 with

* When the paper was read before the Society, this specimen was described as the type of a new genus under the name of *Upsilonodus*; but some remarks made by the referee induced me to reexamine the matter. Through the kindness of Dr. Günther, I have had the advantage of studying the recent *Callorhynchus antarcticus*, and have convinced myself that there are no such important differences between its maxilla and this fossil as, from descriptions alone, I had supposed to exist. I have therefore felt compelled to refer the fossil maxilla to *Callorhynchus*.

Geol. Surv. Dec. 6, pl. i. fig. 8); but this resemblance is more apparent than real.

Concerning the maxilla of *Ganodus*, one would like to be better informed. Agassiz says ('Poissons Fossiles,' vol. iii. p. 339) "that the upper jaw of this genus resembles that of *Callorhynchus*; but its external face, in place of being entirely concave, presents only a deep groove along the external part, and the remainder is convex." The New-Zealand specimen does not agree with this description, nor with the figures which are given. Concerning the mandibular teeth Agassiz goes on to say that they are near together and united into a protuberance covered by a bony layer, and that they are placed so obliquely as to be parallel with the dentary margin.

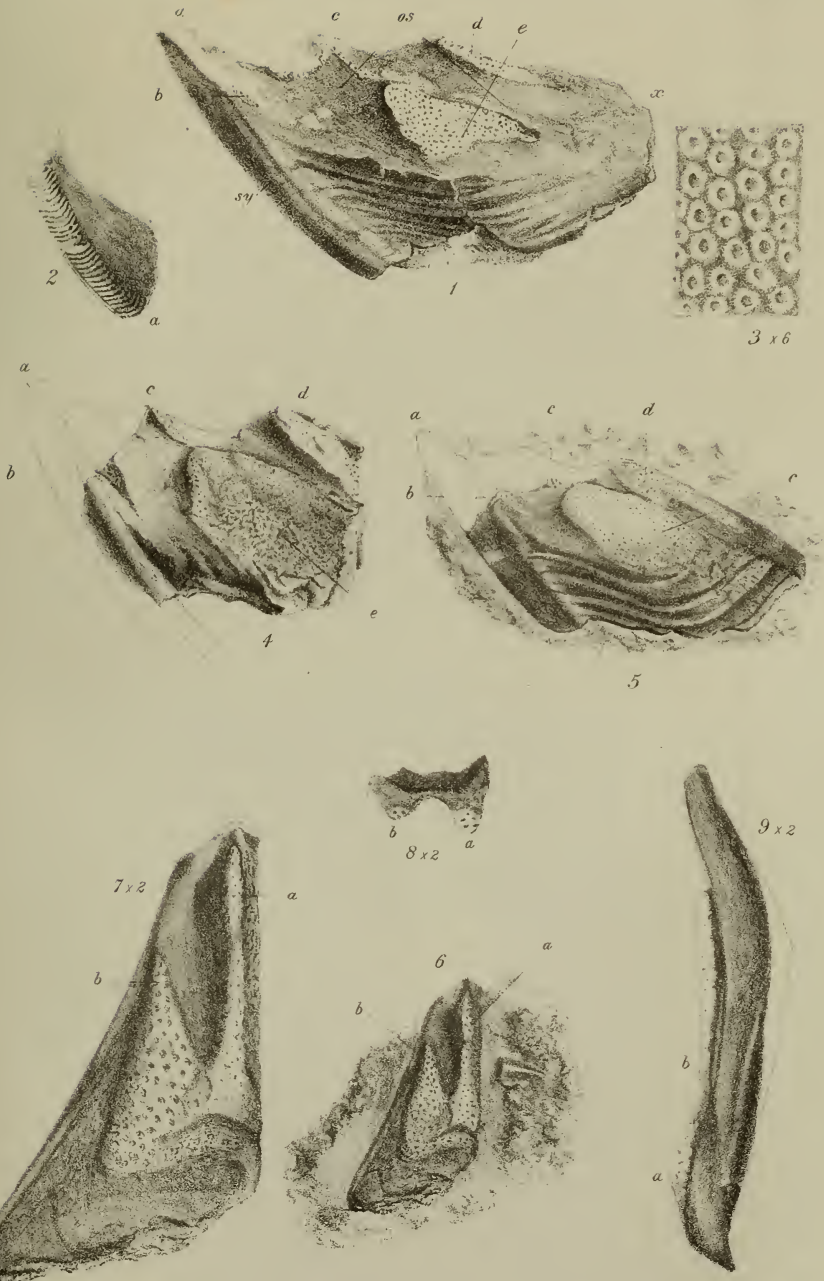
From these considerations, I think it will be obvious that the New-Zealand specimen cannot be referred to either *Ischyodus*, *Edaphodon*, or *Elasmodus*, and also that we should not be justified in placing it in the genus *Ganodus*; for it seems extremely improbable that teeth placed obliquely in the mandible should wear a single maxillary tooth into longitudinal grooves.

A comparison of the New-Zealand specimen with the maxilla of *Callorhynchus antarcticus* shows that, although there are minor differences, yet in all their chief points they are remarkably alike. Their general form and size closely agree. In both there is but a single tooth, forked anteriorly and covered by the bone posteriorly. The greatest differences between the two are these: the tooth of the New-Zealand maxilla is flatter, larger, and has longer anterior processes than that of *C. antarcticus*, the tooth of the latter being more rounded and not approaching so nearly to the borders of the bone, while the anterior portion is much less deeply indented.

Each mandible of *C. antarcticus* possesses but one tooth; and it is this which cuts out the indentation in the front of the maxillary tooth, thus forming the two processes. The outer margin of the mandible, although not armed with teeth, is trenchant and wears away the outer surfaces of the maxillary bone and tooth. The inner or symphysial edge of the maxillary tooth stands above the surface of the bone, so that when the two maxillæ are together there is a groove between the teeth. This conformation is markedly shown in the New-Zealand maxilla.

The differences above-mentioned between the maxilla of *C. antarcticus* and the New-Zealand fossil are of such a character that they can scarcely be regarded as of more than specific value; and it is suggested that the name of the Director-General of the New-Zealand Survey, who brought the specimen to this country, should be associated with it as a specific appellation, and that this Chimæroid fish should be known as *Callorhynchus Hectori*.

With regard to the geological horizon from which the two specimens constituting the subject of the present communication were derived, the only information I have been able to obtain is, that they were found, together with other fish remains, imbedded in a fine conglomerate, believed to be of Lower Greensand age, which occurs at Amuri Bluff, New Zealand.



Sharman adnat. del. et lith.

M & N. Hanhart. imp.

CRETACEOUS CHIMEROZOOIDS

DESCRIPTION OF PLATE XXI.

· *ISCHYODUS BREVIROSTRIS*, Ag. Figs. 1-5.

- Fig. 1. A right mandible, from the Cambridge phosphatic deposits, seen from the inner side: *a*, laminated tooth at extremity of beak; *b*, symphyseal tooth of tubular dentine; *c*, anterior and outer tooth of tubular dentine; *d*, posterior and outer tooth of tubular dentine; *e*, median tooth of tubular dentine; *os*, oral surface; *sy*, symphyseal surface; *x*, posterior angle. In the Museum of Practical Geology.
- Fig. 2. A portion of the beak of a left mandible from Cambridge, having the outer surface ground away to show the laminated structure of the tooth. In the Museum of Practical Geology.
- Fig. 3. A portion of the surface of one of the tubular teeth, enlarged six diameters, showing the central tubes and the surrounding dentine. In the Museum of Practical Geology.
- Fig. 4. A right mandible from the Gault of Folkestone. The original type of the species alluded to in Agassiz's 'Poissons Fossiles,' iii. p. 344. In the collection of the Earl of Enniskillen. Letters as in fig. 1.
- Fig. 5. A right mandible from the Lower Greensand of New Zealand. In the British Museum. Letters as in fig. 1.

CALLORHYNCHUS HECTORI, sp. nov. Figs. 6-9.

- Fig. 6. A right maxilla from the Lower Greensand of New Zealand, showing the lower or oral surface: *a*, the inner spur of the tooth; *b*, the outer spur of the tooth. In the British Museum.
- Fig. 7. Same specimen, enlarged.
- Fig. 8. Same specimen, enlarged, front view.
- Fig. 9. " " " outer side.

DISCUSSION.

Mr. ETHERIDGE stated that he had been called upon to examine carefully the large series of fossils brought from New Zealand by Dr. Hector, and that he had been much struck with those associated with the specimen of *Ischyodus* noticed by Mr. Newton. These were undoubtedly of Cretaceous type; and the deposit, in its general conditions, appeared closely to resemble the remarkable beds of Upware and Farringdon. Mr. Newton's paper was of great importance, as throwing much light upon the distribution in time and space of so interesting and remarkable a group as the Chimæroid fishes.

Sir PHILIP EGERTON was gratified to find that the divisions established by him in this group of fishes some twenty years ago still held good. Mr. Newton's determination of the *Ischyodus* was certainly of great interest, as demonstrating the occurrence in New Zealand of a species belonging to our own Greensand.

The AUTHOR stated that the nearest ally of his new form appeared to be the living *Callorhynchus*. The maxilla was remarkably well preserved; and its single tooth seemed to furnish evidence of the existence of three teeth in the lower jaw.

36. *On a BONE-BED in the LOWER COAL-MEASURES, with an ENUMERATION of the FISH-REMAINS of which it is principally composed.*
By JAMES W. DAVIS, Esq., F.G.S., F.L.S. (Read June 7, 1876.)

NEAR Bradford and Clifton, in Yorkshire, a peculiar stratum of shale, which contains so great a number of remains of fossil fishes that I venture to call it a bone-bed, occurs immediately above the Better-bed coal, and is known to extend over a surface four or five miles in length by about two in average breadth.

The Better-bed coal is a member of the Lower Coal-measures, or Gannister series. It occurs about 700 feet above the Rough rock, the uppermost bed of the Millstone grits, and is separated from the Black-bed coal by overlying strata of an average thickness of 120 feet. It is extensively worked by the Low-moor Iron Company, and used by them in smelting the clay-ironstone of the district. It is peculiarly valuable for this purpose on account of its freedom from sulphur, the excellence of the iron manufactured by this firm being in a great measure ascribed to the use of the Better-bed coal.

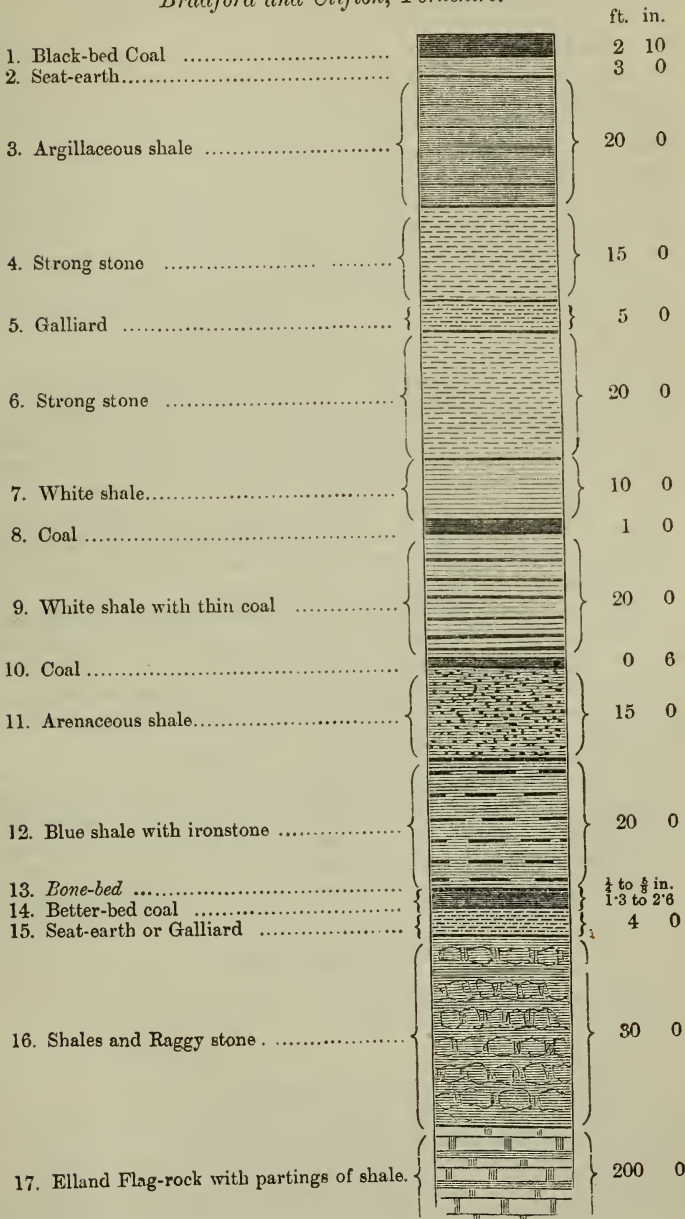
The following section (p. 333) will explain the position of the bone-bed. The section extends from the thick series of sandstones known as the Elland Flag rock, below the Better-bed coal, to the Black-bed coal above.

The beds vary very much in thickness within even a small area, the sandstones and shales often thinning out from a thickness of from twenty to forty feet in less than a mile, and altogether disappearing. The most persistent beds are the coals and the fire-clays, or seat-earths on which they rest. The section may be taken as a fair average in this locality.

The bone-bed rests immediately on the surface of the coal, and varies from a quarter to five eighths of an inch in thickness. Above is a thick bed of blue argillaceous shale containing layers of ironstone nodules, the only organic remains found in it being those of plants. The bone-bed is composed in a great measure of comminuted bones, principally of fishes, though remains of Labyrinthodonts are sometimes found; mixed with these are minute fragments of coal, often in thin layers of small extent. The whole presents the appearance of a brownish-black, argillaceous shale, and is easily distinguished from the light-bluish shale above. It is continuous over a large area, being invariably found (where the coal has been worked) from the north-west of Wyke, near Bradford, to Clifton. Nearly all my specimens are from the latter district.

I would briefly draw attention to the section, in order to point to the probable circumstances attending the aggregation and deposition of the strata composing it. Beginning with the Elland Flag-rock, we find it composed of a great thickness of sandstones, with intercalations of shale, which were probably of littoral origin, or may have been the estuary of a large river. A gradual elevation of

Diagram Section of Strata to show Position of Bone-bed near Bradford and Clifton, Yorkshire.



the land took place and was in course of time covered by a dense vegetation, which ultimately formed the Better-bed coal. The roots of the plants are found in the seat-earth below the coal, from which the inference may be drawn that they grew and decayed where they are now found, and were not washed from a distance. The land became again submerged, probably forming an estuary, whilst the materials forming the bone-bed were deposited on the coal. That it was an estuary-deposit receives confirmation from several sources. The fish-remains found imbedded in it belong to two distinct groups: the Elasmobranchii, of which the sharks and rays are existing representatives, are chiefly confined to salt waters; whilst a second group, the Ganoidei, have several living representatives which are only found in fresh water, as the *Lepidosteus*, *Amia*, and *Calamoichthys* of the rivers of America and Africa, whilst others, as the sturgeon, can live either in salt or brackish water. It is by no means certain that the habits of the fish during the Carboniferous period were exactly similar to those of their descendants; but supposing that they were so, it is not difficult to conceive, when the land was lowered sufficiently for the formation of an estuarine deposit, that the detached teeth and spines of the Elasmobranchs might be washed towards the shore by the tides, and there mixed with the remains of Ganoids from the river. This also appears probable when the broken and fragmentary condition of the fossils is considered; for being constantly subject to attrition by each succeeding wave, the state in which they are found would be the natural result.

After some time, the land was lowered still more, and the mud brought down by the stream, being deposited in deeper water, formed the bed of blue shale resting upon the bone-bed. The overlying strata of alternating beds of coal, shale, and sandstone lead to the inference that the elevation and subsidence of the land occurred repeatedly.

Before proceeding to the enumeration of the fish-remains I have been able to identify from the bone-bed, I wish to acknowledge my indebtedness to the Earl of Enniskillen, Sir Philip de M. Grey Egerton, and W. P. Sladen, Esq., who have kindly placed their collections at my disposal for comparison with my specimens, and also to L. C. Miall, Esq., who identified the remains of Labyrinthodonts.

ELASMOBRANCHS.

1. *GYRACANTHUS FORMOSUS*, Agass.
2. *G. TUBERCULATUS*, Ag.

Pectoral and dorsal spines of this genus are frequently met with. The bones of the pectoral arch are also found, and occasionally patches of shagreen covered with small tubercles.

The gyrating lines of *G. formosus* are sometimes found divided into tubercles, which are characteristic of the second species, *G. tuberculatus*: but as the various intermediate stages can be traced in a

series of the spines, I infer that there can be no sufficient grounds for considering the latter more than a variation from the original type.

3. CTENACANTHUS HYBODOIDES, Eg.

Tolerably abundant. In good state of preservation. Spines 12 to 15 inches long.

4. CTENACANTHUS, sp. ?

Straight. Ridges much broader than in *C. hybodoides*, and much fewer in number, being only 5 or 6, whilst *C. hybodoides* has 16 or 18. The spine presents a fibrous appearance, as though the ganoine had been dissolved away, exhibiting the bony structure underneath. Its length is from 4 to 6 inches.

5. CTENACANTHUS, sp. ?

This spine differs from the preceding in being more curved, with the ridges symmetrical, and not branching into each other, and closer and finer in appearance. It is $5\frac{1}{2}$ inches long, $\frac{3}{4}$ inch broad at the base, and tapers to a fine point.

6. LEPRACANTHUS COLEI, Egerton.

Was described by Prof. Owen in the 'Geological Magazine' for 1869, p. 481, from a single specimen found by the Earl of Enniskillen in the coal-shale at Ruabon. The species occurs in the bone-bed, about a score of specimens having been found. The largest measures $3\frac{1}{2}$ inches in length, and $\frac{3}{16}$ of an inch in width, being an inch longer than the one described by Prof. Owen. He says, "The spine is gently curved, moderately compressed, with the back or convex border rounded; the thinner concave border is armed by relatively large recurved pointed denticles, subcompressed and strengthened by an almost ridge-like swelling along the middle of each side. These denticles are few in number compared with most similarly barbed fossil fish-spines: four project from about one third of the length of the body of the spine; and not more than seven are traceable in the present specimen." In one or two of the specimens from the bone-bed, which have left the matrix without being fractured, the spine is seen to have been hollow, with a row of denticles on each side of the concave border; these are placed alternately, and not opposite to each other, so that there are 13 or 14 denticles, in place of seven as seen by Prof. Owen, one half of the type specimen being hid in the matrix.

7. ACANTHODES WARDI, Egerton.

Spines of this species are common. They range in size from an inch and a half long, and one eighth of an inch broad, to 7 or 8 inches in length, and fully half an inch in breadth. All are characterized by the deep furrow running parallel to the convex portion of the spine.

8. *PLEURACANTHUS LÆVISSIMUS*, Agass.

Very rare. One specimen very perfect, nearly 8 inches in length, and five eighths broad at the base, gradually tapering to a blunt point. A double row of denticles extends, on each side from the point, five inches along the spine.

9. *ORTHACANTHUS CYLINDRICUS*, Agass.

The specimens of this species are generally small, rarely exceeding three or four inches in length. They are found rarely in the bone-bed.

10. *DIPLODUS GIBBOSUS*, Agass.

Teeth rare. They are probably the teeth of *Pleuracanthus* or *Orthacanthus*. Sir P. Grey Egerton has established their connexion with the former; and Dr. Newberry has found the spines of the latter associated with the teeth of *Diplodus* in such a manner as to leave no doubt that they belonged to the same fish. Both spines were cephalic and nearly related. It is probable that different species of *Diplodus* belong to each of these genera.

11. Gen. nov.

A spine hitherto undescribed. It is $4\frac{3}{8}$ inches in length, with a diameter of $\frac{1}{5}$ of an inch. The only specimen I have is crushed from the base for $\frac{2}{3}$ inches towards the apex; the remaining portion is round, without any hollow for the insertion of fin-rays, and gradually tapers to a point. It is slightly curved, principally on the convex or posterior portion of the spine. The surface presents a fibrous appearance; otherwise it is quite plain and smooth. On the concave surface of the spine are eight denticles, separated from each other by about $\frac{1}{4}$ of an inch, the intervals between those nearer the base being wider and gradually becoming smaller nearer the point. The denticles are comparatively large, flattened, and blunt, and extend from the spine nearly $\frac{1}{8}$ of an inch. A second specimen, in the cabinet of W. P. Sladen, Esq., is completely separated from the matrix; it is nearly straight, and shows no evidence of a second row of denticles. A transverse section, cut from the spine about one third its length from the base and magnified twenty diameters, shows the internal part to be rather more than half the diameter of the spine, and apparently hollow. The bony structure surrounding the central part is composed of numerous ridges without definite arrangement, between and amongst which are pits or vacuoles, the whole presenting a labyrinthoid appearance. The bony part of the section has been cracked both from the external and internal margins. The cracks are filled up with iron pyrites.

It is probably a cephalic spine allied to *Pleuracanthus*.

12. *HOPLONCHUS*, gen. nov.

Three or four spines found in the bone-bed present characters differing from any previously described. They are $1\frac{1}{2}$ inch long and $\frac{3}{8}$ broad at the base. They are straight except a slight curve

on the anterior margin towards the point. From the apex to $\frac{1}{4}$ of an inch from the base the side of the spine is ornamented by longitudinal enamelled ridges, six in number; the remaining portion has been imbedded in the integument of the fish. The line dividing the two parts lies obliquely across the spine, the posterior border being the shorter one. The ridges in one or two instances, by running into each other, present a bifurcated appearance. The whole of the spine is slightly compressed. Along the posterior margin is a series of minute denticles scarcely distinguishable without the aid of a magnifying-glass.

The two genera to which these spines are most nearly allied are *Onchus* and *Homacanthus* of Agassiz. They differ from the former in having denticles, the genus *Onchus* being described by Agassiz in the 'Monographie des Poissons du Vieux Grès Rouge' as "comprehending only the Ichthyodorulites which are straight or feebly arched, with longitudinal, smooth, and uniform furrows, and having the base bevelled;" whilst in the same monograph *Homacanthus* is described as including very small Ichthyodorulites "armed with crenulations on their posterior border, and their sides ornamented by homogeneous longitudinal furrows." The only specimens known are named *H. arenatus* "from the arched form of the spines, which are curved like a sickle." The spines from the coal-measures differ from *Homacanthus* in being straight and having the ridges bifurcating.

Sir Philip Egerton, who has a specimen of the spine, suggests the generic name "*Hoplonychus*" as signifying the character distinguishing them from *Onchus*, which appears to be their nearest relative.

13. PLEURODUS RANKINII, Agass.

14. PLEURODUS AFFINIS, Agass.

I have nearly two hundred teeth of these species from the bone-bed. They differ very much in form, size, and character. Some have broad wing-like processes spreading from the main ridge of the tooth; others are narrow and elongated. Many are ornamented with a series of well-defined striæ running across them transversely, whilst the majority are smooth and plain or slightly punctured. The size ranges from two tenths of an inch to seven tenths. Prof. Agassiz named the two species, but did not describe them. Judging from the manner in which the species run into each other in specimens in my cabinet, it will probably be found, when the fish is well known, that the teeth are from different parts of the mouth of one species rather than belonging to separate ones.

15. HELODUS SIMPLEX, Agass.

Rare. Two or three teeth.

16. HELODUS, sp. ?

Rare. Two teeth.

17. CLADODUS MIRABILIS, Agass.

Not common. Teeth.

18. PÆCILODUS, sp. ?

Teeth.

19. PETALODUS HASTINGSIÆ, Owen.

Not uncommon. Teeth.

20. HARPACODUS, sp. ?

Teeth.

21. CTENOPTYCHIUS APICALIS, Agass.

Teeth.

GANOIDS.

22. MEGALICHTHYS HIBBERTI, Agass.

The remains of this fish are abundant. The scales are usually found detached; occasionally masses are discovered connected; teeth, vertebræ, and head-bones are common. The fish varied much in size. One large specimen measures 2 feet 6 inches in length without the head and tip of the tail, which are unfortunately wanting.

23. HOLOPTYCHIUS SAUROIDES, Agassiz.

24. STREPSODUS SAUROIDES, Huxley.

Scales of the former and teeth of the latter are found in tolerable abundance, nearly always detached. One or two large teeth, probably belonging to *Strepsodus*, are anchylosed to the bone of the jaw.

25. ACROLEPIS, sp. ?

Rare. Very beautifully preserved scales and broken head-plates.

26. PLATYSOMUS, sp. ?

Rare. A mass of scales is the only example I have seen.

27. ACANTHODOPSIS EGERTONI, Hanc. & Atthey.

Part of a jaw with teeth.

28. AMPHICENTRUM, sp. ?

A tooth and a spine attached to dorsal fin ?

29. RHIZODOPSIS, sp. ?

Very rare.

30. CYCLOPTYCHIUS, sp. ?

Rare. Part of a jaw.

31. GYROLEPIS RANKINII, Agass.

One of the few examples from this bed of a fish being found with the fins and scales *in situ*. It is 5 inches long, and exhibits part of the head, two dorsal fins, and a mass of small scales.

32. PALÆONISCUS.

I have found no good specimen of this usually abundant genus; occasionally detached scales and teeth are found which exhibit its peculiarities.

33. CÆLACANTHUS LEPTURUS, Agass.

The remains of this species are fairly numerous, and indicate a fish from 12 to 15 inches in length; and as the specimens figured by Prof. Huxley in dec. xii. of the 'Memoirs of the Geological Survey' are only 4 to 5 inches long, the present examples may be regarded as large. All my specimens are disarticulated; as single bones they are very perfect; and many of the external ones exhibit most beautifully the sculpturing peculiar to the genus. Of the bones forming the head are found the hyomandibular and palato-quadrate jugular plates, ramus of lower jaw with teeth, opercula and frontal bones, bones forming the pectoral arch, and large interspinous bones connecting the unossified vertebræ with the dorsal fin-rays. A number of bones presenting very much the appearance of vertebræ, but of a more cruciform shape, were doubtless the ossified centres from which were suspended the branchiostegal rays; some examples show the rays *in situ*. Fragments of the rays exhibit ossified processes developed along the two flattened edges of the ray, which possibly served to support the gills. The ossified walls of the air-bladder are occasionally found; one specimen measures 6 inches in length by 3 in breadth.

34. CTENODUS ELLIPTICUS, Hanc. & Atthey.

Rare. Two or three teeth, a few head-bones, and ribs.

35. CTENODUS TUBERCULATUS, Hanc. & Atthey.

Teeth.

LABYRINTHODONTS.

36. Vertebræ and other bones of Labyrinthodonts, recognized by L. C. Miall, Esq., as those of *Loxomma*, have been found. They are rare.

DISCUSSION.

Sir PHILIP GREY EGERTON remarked upon the advantage accruing to geological progress by the activity of local observers, as furnished by the detection and thorough working-out of this bone-bed, which, being only half an inch thick, would in all probability have entirely evaded the notice of geologists not resident in the immediate district. Local observers (he did not mean mere collectors, but men who knew how to follow out a course of investigation indicated by the local phenomena noticed by them) ought in every way to be encouraged. He said that *Onchus*, as now restricted, is essentially an Old-Red type, but extends up into the Carboniferous Limestone,

and even into the Coal-measures, from which Agassiz described one species under the name of *O. subulatus*. This will in all probability prove to belong to Mr. Davis's new genus *Hoplonchus*. He approved of the author's proposed union of the two supposed species of *Gyracanthus*, and agreed with him in his determination of the Ctenacanth. To show the generality and wide distribution of the characteristic forms of this formation, he mentioned that M. De-walque had recently furnished him with examples of several of the species from Central Russia.

Mr. ETHERIDGE remarked that the relation of the Bone-bed to the Better-bed coal gave it a perfectly definite geological horizon.

37. *On some FOSSIL REEF-BUILDING CORALS from the TERTIARY DEPOSITS of TASMANIA.* By PROFESSOR P. MARTIN DUNCAN, M.B. Lond., F.R.S., &c., President. (Read May 10, 1876.)

[PLATE XXII.]

A DESCRIPTION of a very remarkable species of *Dendrophyllia* from the Tertiary deposits of Table Cape, in North Tasmania, was read before this Society on June 9, 1875*; and shortly afterwards I received a parcel of other kinds of corals from the same locality, accompanied by a request from the Royal Society of Tasmania that I would undertake their examination. I was then made aware, from an abstract of a paper read before the Royal Society of Tasmania, that all these corals had been under the careful hands of the Rev. Julian Woods, to whom the palæontology of the Australian province is so much indebted.

The Rev. Mr. Woods gave his reasons for believing the Table-Cape deposits to be of the same Lower Cainozoic age as that which I had given them, and supported his opinions by references to the similarity and identity of the species of Echinodermata, Mollusca, and Corals found in them and in the Lower Cainozoic deposits of the mainland. As my inferences were derived second-hand from Mr. Woods, he clearly has the priority of having decided the geological position of the Table-Cape beds. He stated that, after a comparison of the Tasmanian and Australian specimens, he found in the deposits of both countries such well-known forms as *Hemipatagus Forbesi*, Woods & Dunc., *Cellepora gambierensis*, *Pectunculus laticostatus*, *Cucullæa concamerata*, *Dentalium Hicksii*, *Trigonia semiundulata*, *Corbula sulcata*, *Cypræa eximia*, *Voluta Hannafordii*, *Voluta antiscalearis*, *Conotrochus M'Coysi*, and a large *Placotrochus deltoideus*. This is a fauna which is characteristic of the Muddy-creek series in Hamilton, Victoria, and partly of the Mount-Gambier limestone, deposits which are low down in the Australian Cainozoic series (Miocene of some geologists).

In noticing one of the corals the description of which forms part of this communication, Mr. Woods considered it to belong to the genus *Isastræa*, explaining that it was new to science, and that its presence indicated that there was evidence of a deeper sea and warmer climate than now existed on the area.

The examination of the coral in question and of some other specimens from the same locality, whilst it necessitates the rejection of the generic nature of Mr. Woods's species and of its bathymetry, quite confirms his opinion regarding the former climate of Tasmania.

The specimens about to be described are included in the group of compound Astræida, called the Astræacæ by Milne-Edwards and Jules Haime, and belong to the genera *Heliastrea* and *Thamnastræa*.

Heliastrea, a large genus, culminated during the Miocene, and

* Quart. Journ. Geol. Soc. vol. xxxi. p. 673.

was, and is at the present day, a reef-building and not a deep-sea group. *Thamnastræa*, so common in the Jurassic ages, was then a reef-builder and a littoral form, and after a great number of species had been evolved, it became rare in the Nummulitic period, and died out in the subsequent geological age in the Australian region, having been probably destroyed in the European areas by the changes which ensued upon the destruction of the Eocene reefs.

List of species from Table Cape, Tasmania :—

1. *Dendrophyllia epithecata*, *nobis* *
2. *Heliastrea tasmaniensis*, sp. nov.
3. *Thamnastræa sera*, sp. nov.

Genus HELIASTRÆA.

HELIASTRÆA TASMANIENSIS, sp. nov. Plate XXII. figs. 1–3.

The corallum is incrusting, and the corallites are subcylindrical and distant. The calices project but slightly, and differ much in size; the fossa varies in depth, being in some instances slight and in others more than equal to the diameter of the calyx; and the margin is thin. The septa are alternately long and short, are straight and thin, and are marked with separate granules or with linear groups of them. They are not exsert, and are only slightly thicker at the wall than elsewhere: their arrangement is irregular; for in the largest corallites there are four cycles in six systems, and a few members of the fifth cycle in one or two also, whilst in the majority the fourth cycle is incomplete, there being three cycles in six systems, and in one or two members of the fourth. In some calices the quaternary arrangement of the septal numbers exists, there being only four primaries and four cycles in four systems. The distinction between the primary and secondary septa is slight; but the existence of a very small septum between two much larger ones is very decided. The large septa reach far inwards and are entire. The columella is very small, and is formed of trabeculæ between the septal ends. The wall is thin, and in some instances more so than are the larger septa. The endotheca is largely developed, and the dissepiments are thin, long, and curved downwards.

The costæ of the large septa are well developed; and they are either long and wavy over the cœnenchyma, or are short and restricted to the corallite; those of the small septa are rudimentary, and exist either as faint projecting lines or as spines; and their presence between the more prominent ones is very marked; they are all thin and delicate. The exotheca is greatly developed and is largely cellular, the direction of the upper parts of the cells being nearly horizontal; but all parts of it, including the vertical partitions, are thin.

The diameter of the calices is under $\frac{1}{5}$ inch, and their distance apart is rather more or slightly less.

The species is remarkable for the tenuity of the whole of the struc-

* Quart. Journ. Geol. Soc. vol. xxxi. p. 677.

tures of the corallum, the great development of the exotheca, the long filiform continuations of the greater costæ which connect the corallites, and their occasional absence, and also for the small columella and indefinite septal number. The presence of corallites with the quaternary arrangement is very suggestive.

Alliances. The species is eminently *Solenastræan* in its aspect; and were it not for the costal development, it would be associated with that genus. In some parts of the corallum the distinction between the structures and peculiarities of the genera *Heliastrea* and *Solenastræa* are by no means decided; but in others the long wavy costæ mix in and amongst the exotheca, and unite with those of the neighbouring calices. The alliances of this *Heliastrea* must be sought amongst those with long costæ, much exotheca, a fair amount of endotheca, and a small columella. Species thus distinguished are not found amongst the recent reef-building coral faunas. The nearest allies of the new species have been found in the same strata as the congeners of the Australian *Placotrochi*, namely in the Miocene of the West Indies; but in estimating the value of this remote connexion, it must be remembered that there is hardly any palæontological evidence relating to the Tertiary reef-corals of the Pacific area.

The species differs much from the *Heliastrea* I described from the Tertiaries of Java*.

Heliastrea immersa, Reuss. †, from the older Tertiaries of Monte Grumi, near Castelgomberto, is of the same general type as the new form, as it has distant corallites, a peculiar septal number, long wavy costæ, and apparently a thin wall and a small columella.

The new species, when compared with the *Heliastrea*s of the Ootator group of the Cretaceous formation of Southern India, presents remarkable affinities with *Heliastrea cortica*, Stol. ‡; for this interesting Indian reef-coral has all the characters of the Tasmanian form, but differs in possessing thick costæ, those of the small intermediate septa being large. Even the other species from these Indian rocks (*Heliastrea rotunda*, Stol.) is not without its resemblance to the Tasmanian species.

THAMNASTRÆA SERA, sp. nov. Plate XXII. figs. 4-6.

The corallum is solid and short, being about $\frac{6}{10}$ inch in height; and the base is incrusting; the upper surface is subplane; and the corallites are distant and widely apart. The calices are slightly depressed below the level of the long and numerous costæ; their fossula is small and shallow; and the columella is papillary, being formed by oblique and rounded processes from the free ends of the septa. The septa are continuous with the costæ, and are at the margin of the fossula about twenty-six in number; they are subequal,

* Quart. Journ. Geol. Soc. vol. xx. 1864, p. 72.

† Reuss. Pal. Stud. über die ält. Tertiär. der Alpen, 1868, 1. Abtheil. p. 30.

‡ Stoliczka, Palæontol. Indica, vol. 14, 4 ser. pl. viii. f. 4-8; The Corals or Anthozoa, Mem. Geol. Survey of India, 1873.

and their upper edge, finely dentate, dips down very slightly towards the columella. Some septa are continued on to long and wavy costæ, which become thickened halfway between the calices; and others soon unite to two or even more costæ, or simply bifurcate in their path towards the nearest corallites. Occasionally there are three costæ united to one septum. The costæ are long, slightly wavy, slightly exsert, narrow, except midway, and are dentate at their free edge. The small spiny dentations, when removed, leave open pits on the surface of the costæ, which give them a very characteristic appearance. The costæ are also finely and distinctly granular laterally; but the tips of the grains do not meet. There are eighty costæ in connexion with the calicular septa in the largest corallite.

The sides of the septa are marked with closely packed, large, but flat granules, as are those of the costæ (as seen in sections); and the endotheca is largely developed, being close, and curved both upwards and downwards. It reaches to the columellar space, across it, and high up in it.

The wall appears to be rudimentary; and the costæ are united by exotheca and by a growth from their sides. Synapticulæ barely exist; for it is very rare to find a few of the lateral granules of the costæ and septa attached by their ends.

Diameter of largest calice $\frac{6}{10}$ inch.

Alliances. This is a well-marked species, and has large calices, long dentate costæ, and largely developed endotheca and exotheca, the synapticular element being very small. It is the only form of the genus which has hitherto been discovered in deposits later in age than the Nummulitic; and it does not closely resemble those from that series*. Very Jurassic in its appearance, the coral would almost pass for *Thamnastræa Walcottii*, nobis†, from the Inferior Oolite of England; and it has no alliance, except that of a generic nature, with the species from the Indian Cretaceous rocks.

THAMNASTRÆA, species.

A much-worn specimen of a *Thamnastræan*, greatly resembling and probably identical with the last-described species, was cut, and microscopical sections were made. One section passed through several corallites at a slight distance from the surface; and another was taken in a longitudinal direction and parallel with the septa. A wall separating the corallites is not to be found, and the costæ are continuous with the septa of different calices, the laminæ being bound together by their sides. The septa and dissepiments, especially the former, are marked by opaque and either rounded or more or less elongate spots, which apparently coincide with the large granules which constitute the beauty of the ornamentation of the septa. These granules are very numerous and evidently are of more importance than simple ornaments; for the microscope shows them to be centres of sclerenchymatous spicular growth. They are probably ill-developed synapticulæ.

* Consult D'Achiardi, *Coralli Eocenici del Friuli*, 1875.

† *Pal. Soc. Supplement to Brit. Foss. Corals*, Oolitic part.

The sclerenchyma, as a whole, may be said to consist of spicules radiating from centres in more or less linear series; and each spicule is joined laterally and before and behind to its fellows. The whole coral is infested with the tube-like penetrations and ramifications of a parasitic unicellular Alga; and this has been described in a former communication (see Quart. Journ. Geol. Soc. vol. xxxii. p. 205).

Remarks on the Species.

The Heliastreaean just described was evidently a rapid grower, and a true reef-building form, having its bathymetrical distribution restricted to 20 fathoms; and the Thamnastraean (so solid, yet so abundantly supplied with endothecal structures) appears to have had a corresponding habitat. They required the external conditions peculiar to coral-reefs.

In considering how these physical conditions could be found on the area from which their absence is now so conspicuous, the general physical geography of the Australian seas during the Cainozoic periods must be considered. This was attempted to be explained in 1870 (Quart. Journ. Geol. Soc. vol. xxvi. p. 284), by the author of this communication; and the relation of the past and existing coral-faunas of Southern Australia, and the former distribution of land and sea, were noticed in the concluding parts of his essay on the fossil corals of the Australian Tertiary deposits. As there is no reason for altering the opinions therein expressed, reference must be made to that communication; and the bearings of the suggestions therein contained will be found to be explanatory of the existence of reefs in Tasmania. The open sea of the vast area to the west of Cape Howe, running up into the tropics, would place the old hills of Tasmania and those of Eastern Australia in the midst of an ocean, even if the Australian land were prolonged away to the north-east, as it probably was in those days. But even admitting that probable insular distribution of land in the South Pacific during the Miocene epoch which has been so frequently suggested by zoologists, botanists, and geologists, the fact of the sea-temperature being sufficient for the development of reefs in Tasmania is insufficiently explained.

There is a faint relic of the old reef-fauna still lingering on the Tasmanian shores in the form of *Echinopora rosularia*, Linn. It forms thin incrusting layers, and not masses of limestone; but it is clearly a relic of that reef-building coral-fauna which has long since died off from the area. Even the hardiest of the Pacific corals, the stronger forms of *Porites*, are absent. In fact, the only surface-water coral lingers on in a temperature in which *Porites* could neither exist nor propagate.

Evidently the reefs around Tasmania, now long extinct, existed amidst all the physical conditions peculiar to coral-growth on a large scale. Pure sea-water in rapid movement and having a temperature of not less than 74° Fahrenheit, was as necessary to them as it is to those far away to the north and north-east at the present day.

The coral-isotherm would have to be 15° of latitude south of its present position in order that reefs should flourish south of Cape Howe; and this could only be produced by a different distribution of land and sea, and by a different position of the polar axis to that which now prevails.

A south-polar continent reaching, in the Miocene age, northwards to 50° S. lat., would meet the requirement of a land reflecting the equatorial currents and tides and adding in no way any great amount of cold water; and large islands off its coast extending to the American and African coast would satisfy most of the biological requirements of the period. To the north and north-east there existed then the land whose memorials are the atolls and fringing reefs of the great Pacific. On the other hand there was the open sea, already noticed, of Central Australia, and to the north the great volcanic islands were sea-floors on which Miocene detritus was accumulating. 'Lemuria' may be assumed to have existed.

Vast surfaces of South and Central America, and some of North America, were sea-floors; and the ocean and coral-tracts prevailed over a great space in Europe and Western Asia. Much of North Africa was still submerged. On the other hand there was probably an Atlantis, and a huge continent existed in the north of Central Asia, N. America, and N. and Central Europe. In those days and before, even during the Nummulitic period, the coral-isotherm of 74° F. reached fully 25° N. of its present possible position in the portion of the globe antipodean to Tasmania; and the winter's cold could not have been sufficient to chill the surface-water in the latitude of Vienna and N. Italy. The question arises,—Could the temperature of this broad belt of warm water be maintained by geographical causes alone? and a second question requires a satisfactory solution, bearing as it does on the question of alternations of season and of light and darkness,—Could such geographical causes as the distribution of the land in polar masses and in central islands overcome, in high latitudes, the effects of the position of the globe in relation to the sun in perihelion and aphelion? It appears to me that they might to a certain extent modify the severity of climate, but not sufficiently to permit of important reefs existing in Western, Central, and Southern Europe, and in Tasmania synchronously. That the reefs were contemporaneous, there is every reason to believe.

An examination of the flora which underlies the marine Cainozoic deposits of the mainland of Victoria has shown that the plants found there resemble those of Tropical rather than of Extra-tropical Australia; and as will be noticed in a communication about to be presented to the Society, the Echinodermata of the succeeding strata afford the same kind of evidence.

The proofs of the existence of higher temperatures, and of the absence of the long and dark months in the Arctic regions, are abundant from the age of the Carboniferous formation to the Miocene. During all the ages of the globe down to that period when such vast alterations in the relative level of land and sea occurred, there is found evidence in favour of the theory that perpetual frost

and snow and months of darkness did not exist in the Arctic regions. Contemporaneously a corresponding genial climate existed in the southern hemisphere. It is perfectly certain that, under the existing astronomical arrangements, there must be prolonged day and prolonged night at the poles and for a certain number of degrees in the equatorial direction; and the inclination of the polar axis to the plane of the ecliptic necessitates the perpetuation of the present arctic and antarctic climates. The astronomical conditions under which a sufficient amount of light could be given to the plants within twenty degrees of the pole are not those which now prevail; but were the polar axis at right angles to the plane of the ecliptic, and were there no greater node than at present, there would be equal day and equal night. The biologist claims this as the earliest position of the globe. The arguments against such an inference relate, of course, to the nature of the forces which could bring down the north pole, or rather which would incline the polar axis, and to the amount of solar heat which would reach the polar regions. Probably no force acting on the globe as a mass, such as gravitational energy, could alter the position of the poles as they are now, with reference to the ecliptic; for after a very slight inclination had been produced, the force would produce no more obliquity, but only a more or less rapid precessional movement.

Nor is it possible to understand how any external force could cause the approach of one pole to the sun and the recession of the other, the globe being comparatively homogeneous, for the sake of argument, and the polar axis being supposed to be at right angles to the plane of the ecliptic.

But it would be possible if a vast alteration in the relative distribution of land and sea occurred, in one hemisphere especially. It is perfectly reasonable to infer that the great subsidences of the Miocene lands, and the formation of the Southern Ocean, whose area is greater than that of all the land to the north, and the vast upheaval of the Central-Asian, Caucasian, and Alpine and other areas, producing great alterations in the homogeneous condition, brought the land-surfaces of the north with their higher specific gravity and great mass within the influence of the gravitational energy of the sun. From that time dated the long winter's night and the presence of perpetual ice and frost in the highest latitudes; and those changes in the climatal conditions of the northern and southern areas, where reef-corals had built and the light-requiring floras had flourished. The objection regarding the small amount of heat which would be granted to the high latitudes under the conditions of a vertical polar axis are of the nature of those which sadly troubled our science with respect to the impossibility of animals living at very great depths in the sea in consequence of the pressure to which they would have to submit, and to the warm temperatures which must prevail in the oceanic abyss.

The presence of land in the extreme north or south on which no perpetual ice rested except on the high hills, would introduce an element into the argument which would suffice to demonstrate a tem-

perate zone. Oblique as would be the path of many solar rays, still the corresponding loss of temperature would be compensated for by the warming of the atmosphere by the radiation from the masses of the land-surfaces to the north and south. It is, moreover, reasonable, according to the principles of thermodynamics, to assert that the sun was then producing more heat, and that the internal temperature of the globe was greater than now; and this may have had some slight influence.

In bringing these theories before you, which have been in the minds of so many geologists, and which have been brought forward by succeeding generations of us, Belt and Woodward being their last supporters, my excuse must be that possibly they may be improved upon by those physicists who will admit the necessity of comprehending biology in their dynamical and kinetic arguments, —or that in the true interests of science they may be disproved, so that we may seek explanations of the facts brought forward in this and other cognate essays in other directions.

Note.—This communication was forwarded to the Society before my predecessor in the Presidential office read his admirable Address. I now refer the reader to his remarks on those questions of astronomical interest which I have introduced in this paper. (See Anniversary Address of the President, John Evans, Esq., F.R.S., Quart. Journ. Geol. Soc. vol. xxxii. Proc. p. 101 *et seq.*)

EXPLANATION OF PLATE XXII.

- Fig. 1. Corallum of *Heliastrea tasmaniensis*, sp. nov.
 2. Calice, magnified 3 diameters.
 3. Costæ and exotheca, $\times 3$.
 4. Calices of *Thamnastræa sera*, sp. nov.
 5. Longitudinal section of corallum.
 6. Details of septa, $\times 3$.

DISCUSSION *.

MR. EVANS was glad to find that this subject, concerning which he had lately expressed his own views, had been taken up by the author; but he thought it possible that Dr. Duncan would, on further consideration, be inclined to modify somewhat the theory promulgated in this paper in favour of some other view. In order to account for the occurrence of reef-building corals of Miocene age in latitudes now too cold for them, the author had reverted to the old idea of the vertical position of the poles. If the interior of the earth is fluid, a sliding crust such as the speaker had formerly suggested is possible, though it would be difficult to prove the existence of a fluid interior, and still more difficult, did that exist, to prove that the crust would slide on it. But even supposing the earth to be a nearly solid body, elevations and depressions enough

* This discussion relates also to Prof. Duncan's paper "On the Echinodermata of the Australian Cainozoic Deposits."

must take place on the surface to alter the relative positions of the poles with regard to the surface of the earth. Because there were proofs of warmer climate having existed in Miocene times in Greenland, near the one pole, and in New Zealand near the other, there was no need to suppose that belts of warmer temperature had extended nearer the poles than at present, for the same sliding of the crust that brought Greenland nearer the equator would also bring New Zealand nearer the tropics, both being on nearly the same meridian, but on opposite sides of the globe. The subject was one that deserved the attention of geologists, as it lay at the root of many important questions affecting the past history of the earth.

Professor HUGHES believed implicitly what the astronomers told him *must be*; and if observations on the distribution of life necessitated any thing more than such alterations of climate as could be accounted for by geographical changes and modification and adaptability in the forms of life, he would prefer to leave it as one of the many things he could not explain, than accept an explanation inconsistent with accepted astronomical theories. If, as explained by Sir John Herschel, the transference of large masses from one part of the earth's surface to another would disturb the equilibrium, we must remember that this action would be mostly compensative; and if the cumulative effect of many such disturbances might be a partial readjustment of the mass, we must regard such movements only as a tendency to keep the whole mass and its axis of rotation as it was in spite of the transference of portions from one place to another by denudation. Moreover he disputed the data on which the views advocated by both the present and the late President were founded. He asked whether we should say that the climate of the period of our older river-gravels was that of Egypt or of Northern Siberia, seeing that the *Corbicula fluminalis* and *Unio littoralis* were now found only much further south; while the hairy elephant and reindeer, which had once lived with them, were now held to prove an arctic climate. When we know that flowering plants and evergreens now live in Alpine regions, where they are buried in total darkness under snow for four months, shall we say that the absence of light would render it impossible for evergreens and flowers to have flourished where the arctic winter-night is four months long, even though we could account for a milder climate by geographical changes.

Mr. WOODWARD remarked that as it was not merely a question of *one* fauna and flora, Mr. Hughes's statements must be received with caution. There were evidences in northern latitudes, not only of a Miocene, but also of a Carboniferous, a Jurassic, and a Cretaceous flora. Nor was it a question merely of lowly organized plants which would be more likely to withstand the climate; for Prof. Nordenskiöld had found tree-trunks standing erect in the soil in which they grew, and it was impossible for them to have grown in a climate so rigorous as now exists at that latitude. If the geologists are wrong in the conclusions they have drawn from these facts, let the astronomers show

them how to account for the occurrence of fossils indicative of such a warm climate in such high northern latitudes; for the absence of cold must be accounted for to explain the growth of these trees in that spot.

Prof. ANSTED maintained that the geologists had certain natural-history facts on their side with regard to the occurrence of fossils near the poles; it remained, therefore, for the astronomers and physicists to find a new theory to account for these facts.

Prof. GREEN thought that the astronomers should be asked if the change of axis was a possible explanation, and to calculate what would be the result of a change in the distribution of land and sea, and how would such a change affect the position of the poles. The question was one of mechanics.

Mr. SORBY considered that the amount of heat and light received from the sun should also be taken into account, and the fact that this may have varied at different periods.

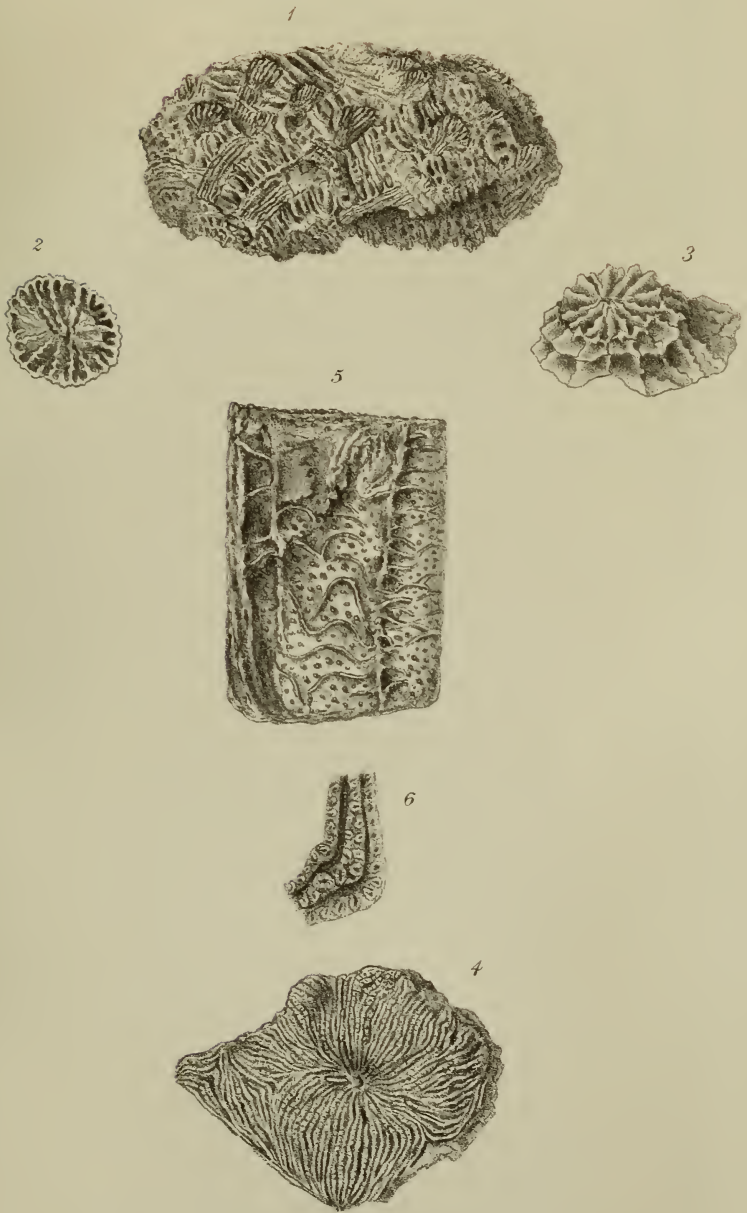
Sir ANTONIO BRADY stated that there were many facts which tended to prove that the sun had varied in heat &c.; but the sun had probably little to do with the warmer climate of the poles in past ages. The heat of the earth in its various stages of cooling would be sufficient to account for these changes of climate on the surface of the globe.

Prof. RAMSAY could not agree with the last speaker in thinking that radiation in cooling would produce any palpable effect on the surface of the globe. So far from there being any proof that the climate had been gradually growing colder from the earliest times down to the present date, there was every evidence to show that glacial periods had recurred at different periods in past time. Dr. Duncan and Mr. Evans had merely given suggestions, but had not attempted to solve the problem. The poles probably occupied the same position in Miocene times that they do to-day. Darwin and Dana were both agreed in thinking the present continents to be of extreme antiquity. Great elevations of land had taken place prior to the Miocene epoch. The Alps and the Himalayas were both pre-Miocene, and were probably higher in pre-Miocene times than at present, having been subjected to great denudation.

Mr. GWYN JEFFREYS pointed out that certain species of shallow-water mollusca now found in the Arctic Ocean had formerly in post-Tertiary times lived as far south as Sicily.

Dr. WRIGHT remarked that there was a wonderful similarity between the Miocene echinoderms from Australia and those found at Malta.

Prof. MORRIS considered the abundance of echinoderms belonging to the Spatangoid group in these Australian beds to be very interesting. The feature presents itself in the New-Zealand Tertiaries, where forms allied to *Arachnoides* occur. The distribution of these echinoderms in New Zealand was excessively complex and difficult to understand. There was a remarkable similarity between the Miocene floras of Greenland and Central Europe; and the question to be asked was, Did they spread over a continent formerly existing



Foord lith.

M&N.Hanhart imp

TASMANIAN CORALS.

between these points, or had they emigrated from some one central spot ?

Dr. DUNCAN, in reply, stated that it was only by the united investigations of all students of geology that the question could be in any way settled. The belief in the recurrence of glacial epochs was founded on some erroneous conclusions drawn from beds in England, South Africa, and in India, which were related to local glacier action or to volcanic agglomerates. The Miocene plants could not have existed without sufficient light; and severe frost would have destroyed them; and therefore they could not have extended so far north under conditions similar to the present. The Echinoderms did certainly present a striking resemblance to those found in the Miocene beds of Malta; but there were still sufficient specific and generic differences to justify him in describing them as distinct.

38. EVIDENCES of THERIODONTS in PERMIAN DEPOSITS elsewhere than in SOUTH AFRICA. By Prof. OWEN, C.B., F.R.S., F.G.S. (Read May 24, 1876.)

A FEW days ago Mr. W. Davies brought to my notice the cast of a fossil which had been purchased by the British Museum in 1865 of Krantz, the dealer, with the label "*Eurosauros uralensis*, H. v. Meyer, *Brithopus priscus*, Kutorga. Permischer Sandstein von Perm."

The subject of this cast is that of Kutorga's plate i., and is, as he truly describes it, the lower end of a humerus, with the perforation or canal above the inner condyle, on which character he mainly rests his determination of the fossil as evidence of an extinct mammal and as the basis of his genus and species *Brithopus priscus* *.

The discovery of that character in the humerus of *Cynodraco* † and other genera of South African reptilia, led to the rescue of the cast in question from the obscurity in which it had remained since its acquisition, and to the present retrospect of the circumstances under which Kutorga's contribution to Permian palæontology has been thrown into the background, and his supposed mammalian genera systematically ignored.

Kutorga, accepting the evidences summed up, in 1831 ‡, of the mammalian nature of *Thylacotherium* and *Phascolotherium*, and the proofs of the Oolitic age of their matrix, saw no geological objection to the remains of that class being discovered in the Permian deposits.

With respect to the most conspicuous test-character of the fossil humerus §, he truly states that such character was known only (in 1838) in that bone of certain unguiculate mammals; and he quotes the instances given by Cuvier ¶, out of which instances, by reason of the breadth of the condylar part of his fossil, and the high position of the canal, he adopts the Edentate genera as those to which his *Brithopus* was most nearly allied, and proposes to place his extinct mammalian genus between *Bradypus* and *Dasyppus* ¶¶.

* Beitrag zur Kenntniss der organischen Ueberreste des Kupfersandsteins am westlichen Abhange des Urals, von Dr. Stephan Kutorga, &c., mit vii. Steindrucktafeln (8vo, St. Petersburg, 1838), p. 9.

† Quart. Journ. Geol. Soc. vol. xxxii. p. 95, pl. xi. figs. 6-9.

‡ Buckland, Bridgewater Treatise, vol. i.: supplemented by papers in Proceedings of the Geological Society of London, December, 1838, vol. iii. p. 17: and Transactions of the Geological Society, 2nd Series, vol. vi. p. 58.

§ "Das am meisten im Auge fallende Kennzeichen dieses Knochens, ist das grosse ovale, über dem '*Condylus internus*' stehende Loch, welches zum Durchgange der *Arteria ulnaris* diene."—*Op. cit.* p. 10.

¶ Leçons d'Anat. Comp. ed. 1835, vol. i. p. 384.

¶¶ "Aus allem oben Gesagten ergibt sich, dass das Thier, dessen Oberarmknochen theil wir vor uns haben, zur Ordnung der Edentaten gehörte, und zwar zu einer neuen, zwischen *Bradypus* und *Dasyppus* zu stellenden, jedoch mehr mit der ersten verwandten Gattung."—*Ib.* p. 13.

For the generic distinctness of *Brithopus* he specially urges the presence of a second perforation or canal, near the upper part or beginning of the supinator crest, which canal he calls the *foramen condyloideum externum*, and conceives that it may have served for the passage of the *arteria radialis* *. This canal, Kutorga states, had not been previously observed in the humerus of any vertebrate animal; and at that date (1833) the statement was true.

I may not be mistaken in supposing that the reduced copy of Kutorga's figure of the above-defined Permian fossil will be acceptable, to which I have added (Cut, fig. 1) letters indicative of the

Fig. 2.

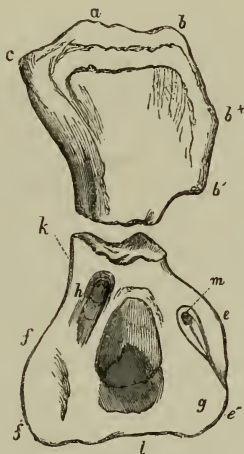


Fig. 1.

Fig. 1. *Brithopus priscus*, Kut.Fig. 2. *Orthopus primævus*, Kut.

same parts as in figs. 6–11, pl. xi., Quart. Journ. Geol. Soc. vol. xxxii. The significance of the foramen marked *m* will thus be appreciated.

Kutorga finds evidence of a second mammalian genus in another fossil from the same locality and formation, which he describes and, fortunately, figures in the same treatise †. Conceiving this fossil to be the lower portion of a humerus, with also the characters of the *foramen condyloideum internum*, he indicates differences which support his conclusion that it formed part of a distinct mammalian genus and species, for which he proposes the name *Orthopus primævus*.

* "Die Basis dieses Kammes ist schräge von oben nach unten mit einem cylindrischen Kanale durchbohrt, der in seinen beiden Enden in flachovale Gruben übergeht, und eine Arterie, wahrscheinlich die *arteria radialis*, im oberen Theile ihres Verlaufes beherbergte."—*Ib.* p. 11.

† *Op. cit.* p. 15, Taf. ii.

This fossil, however, is the upper (proximal) portion of a reptilian humerus, and most probably of the same species, if not bone, as that on which the genus *Brithopus* is founded. Figured upside down, as in Kutorga's plate ii., the articular head of the humerus, (*a*, *b* in Cut, fig. 2) is made the "trochlea;" the entotuberosity (ib. *c*) becomes the "condylus internus;" the ectotuberosity is the "condylus externus;" the delto-pectoral plate (ib. *b*^x, *b'*) is the "supinator ridge" ("der über diesem Condylus stehende kamm"); while the groove at the inner part of the fractured shaft, rightly referred to as evidence of a "foramen condyloideum internum," is the upper (proximal) commencement of that canal, which is shown in its entirety and with its lower (distal) outlet in what I hold to be the distal portion (Kutorga's pl. i.) of the humerus of the same species or individual (Cut, fig. 1).

The humerus of *Orthopus* being reversed in position, as in Cut, fig. 2, and being juxtaposed to fig. 1 (*Brithopus*), the characters of the reptilian humerus, under theriodontal modifications, come out unequivocally; and the proportions are nearer those of the perforated humerus of *Galesaurus* and *Dicynodon* than of *Cynodraco*.

The proximal articular convexity, or head, of the bone (Cut, fig. 2, *a*) is a narrow semi-ellipse, its long axis transverse to that of the shaft, its curved border being due to the usual production of this articular surface backward, or anconad, in Reptiles. The entotuberosity, *c*, is more definitely marked than in *Cynodraco*. The ectotuberosity, *b*, is represented by the angle formed by the outstanding of the delto-pectoral crest as it descends from the axial line of the head of the humerus to *b'*. The outer border of this large and characteristic crest forms a low angle about halfway down at *b*⁺; then forms a second (almost right) angle at *b'*, where it returns to subside on the shaft of the humerus. The forward (thenal) bend of the crest is not so marked as in *Dicynodon*; it does not exceed that shown in the humerus of *Cynochampsia* and *Cynodraco*. The shaft of the humerus between the delto-pectoral and supinator crests is as short and as contracted, compared with the proximal and distal expansions of the bone, as in *Cynodraco* (*loc. cit.* pl. xi. figs. 6, 7). The reptilian character of the distal portion of the *Brithopus* bone (Cut, fig. 1) is shown by the shallow ill-defined olecranal depression, by the absence of the definite trochlear character of the distal articulation for the ulna, and by the presence of the ectocondylar perforation, *m*.

There is thus satisfactory evidence of an extinct reptile in the Permian deposits of the Ural, with a humerus showing the same mammalian entepicondylar perforation as in certain extinct reptiles of the Karoo series of South Africa, and with other modifications in which it more nearly resembles the Theriodont species of those deposits.

Brithopus priscus, Kutorga, as represented by the plaster cast, is superseded by *Eurosaurus uralensis*, H. v. Meyer; and I next proceed to give the results of investigation of the ground of this supercession and synonymy in the printed label of the dealer Krantz.

The earliest ascription of the generic term *Eurosaurus* to Permian fossils I find in a paper by Fischer von Waldheim, in tome xv. 1842, of the 'Bulletin de la Société Impériale des Naturalistes de Moscou'*. Fischer there states that he has several portions of bone (not named) belonging to the same Saurian. A striking character, he remarks, is the great breadth of the articular head compared with the insignificant length of the bone, "as if," he says, "that articular end ('Gelenkkopf') of the bone had been provided with an aliform process;" and he proposes for the new Saurian, so indicated, the name of *Eurosaurus*. No other characters of the genus nor any figure of the fossils are given. We recognize, however, in this curt notice, a characteristic of the proximal portion of the humerus of Kutorga's *Orthopus*.

The author next cites a "remarkable humerus distinguished by its broad processes and the perforated articular surface for the reception of the ulna, from the same locality as that in which the mandible of the reptile called *Rhopalodon* was found;" and this humerus, the perforated character of which is perhaps more accurately described by Kutorga in his *Brithopus*, Fischer thinks may belong to his genus *Rhopalodon* †.

It is significant, and probably by reason of the insufficient grounds assigned by Fischer for his genus *Eurosaurus* of 1842, that Agassiz has omitted it in the list of Reptilian genera in his 'Nomenclator Zoologicus,' 4to, 1842, and in the 'Addenda,' 1846. He gives amongst the mammalian genera Kutorga's *Brithopus* and *Orthopus*, but adds "Reptilia?" after each entry.

Fischer's *Rhopalodon Wangenheimii* was founded on a portion of a mandibular ramus, $2\frac{1}{2}$ inches in length, containing "nine molars with short, thick, pointed, subcompressed crowns having two trenchant and serrate borders;" and, further, "at the anterior fractured part of the fossil was the implanted base of a large canine." A figure of the fossil is given by Eichwald in the 'Lethæa Rossica,' 1860, pl. lviii. fig. 9. So far as the characters are noted they are "theriodont."

In 1858 Hermann von Meyer described a fossil skull, presented by Major von Qualen to the 'Mineralien Kabinet' at Berlin, as from the Permian system of West Ural, probably from the same locality as the fossils described by Fischer. A skull from this locality had previously been described by Eichwald under the name of *Zygosaurus lucius*; but v. Meyer's subject is referred by him, under the name of *Melosaurus uralensis*, to the section of the Labyrinthodonts with embryonal vertebral column ‡. The specimen

* "Zweiter Nachtrag zu den von Hrn. Major von Qualen am westlichen Abhange des Urals gesammelten Versteinerungen," p. 463.

† "Ein merkwürdiger *Humerus*, ausgezeichnet durch seine breiten Fortsätze, und die durchbohrte Gelenkfläche zur Aufnahme der *Ulna*, ist in derselben Gegend gefunden worden, und scheint dem *Rhopalodon* anzugehören."—*Ib.* p. 464.

‡ "Bei diesen Abweichungen habe ich den zweiten Schädel aus den Ural unter der Benennung *Melosaurus uralensis* zu den Labyrinthodonten mit embryonaler Wirbelsäule gestellt."—*Neues Jahrbuch für Mineralogie, &c.*, von K. C. von Leonhard und H. G. Bronn, Jahrgang 1858, p. 301.

is figured, of the natural size, by Eichwald in pl. lvii. fig. 25, *op. cit.* In the text of this work the genus *Melosaurus* of von Meyer, together with the genera *Brithopus* and *Orthopus* of Kutorga, are made synonyms of the *Eurosaurus* of Fischer*: no characters of the Permian humeri are pointed out to show the reptilian nature of Kutorga's fossils; but Kutorga's determination of their homology is called in question; they are affirmed to be portions of the coracoid bone of *Eurosaurus*; and the perforations in the bone assigned to *Brithopus* are homologized by Eichwald with those in the coracoid of *Ichthyosaurus* and *Hylæosaurus* †.

The three folio plates of Eichwald's 'Lethæa Rossica' are devoted to the reptilian fossils of the Permian deposits in the Ural. Long bones and portions of long bones are figured, as of *Eurosaurus wralensis*, but give not any indication of correspondence with such bones from the Karoo beds.

The characters described and figured of the skull of the *Melosaurus*, v. M., are Labyrinthodont. The strong mandible and its canine-like anterior teeth suggest the need of as firm a junction of the head to the trunk as in the *Salamandroïdes* of Jaeger ‡. Whether the occiput in the subject of v. Meyer's description be in such a state of preservation as to support the conclusion that the basioccipital had not advanced beyond its embryonic notochordal state, may be worthy of fresh scrutiny of the specimen in the "Mineralien-Kabinet." With whatever result, it would give no support to Eichwald's reference of Kutorga's *Brithopus* and *Orthopus* to such Labyrinthodont genus, or to the synonymy of *Melosaurus* with Fischer's *Eurosaurus*.

The homology and reptilian characters of the portions of Permian fossils described and figured by Kutorga being now beyond question, it is to the Theriodont, not the Labyrinthodont order that such humerus must be referred. I say "Theriodont" rather than "Anomodont," because of the indication of the more powerful muscles working the forearm and paw which is afforded by the degree of development of the "supinator" or "ectocondylar" crest in *Brithopus*, as in *Cynodraco*. A minor development differentiates the humerus in the genera *Dicynodon* and *Oudenodon*.

I therefore proceed to seek for other evidences of Theriodontia in Permian fossils of the Ural.

* *Lethæa Rossica*, 8vo, 1860, p. 1621.

† "L'os coracoïde" de l'*Eurosaurus* "a été pris¹ antérieurement pour la partie inférieure de l'humerus d'un Mammifère; il semble plutôt se rapporter à l'os coracoïdien de l'omoplate, qui offre une forme très-large dans l'*Ichthyosaurus* et surtout dans le *Hylæosaurus Mantelli*."... "L'os coracoïde de l'*Hylæosaurus* est perforé d'un trou artériel et nerveux; le coracoïde de l'*Eurosaurus* en offre deux, un trou large, percé de chaque côté de sa partie rétrécie par laquelle passaient des artères et des nerfs de l'extrémité antérieure."

¹ Kutorga die organ. Ueberreste des Kupfersandsteins, &c. pl. i. fig. 1-3" (*Eichwald, op. cit.* p. 1626). "M. Kutorga a décrit un autre os fragmentaire comme 'pars condyloidea humeri' d'un Mammifère inconnu; je préférerais le nommer aussi l'omoplate, en l'ajoutant à l'os coracoïde" (*ib.* p. 1626).

‡ Fossile Reptilien im Württemberg, 4to, 1828, p. 38, Taf. v. figs. 1 & 2.

So long as such evidence afforded by the arm-bone remained unrecognized, the third fossil which Kutorga figures (in his Taf. iii. fig. 3, A, B, C, D, E), and describes (p. 19) as the representative of his Pachydermal genus *Syodon*, had little chance of being extricated from the neglect and oblivion into which it had fallen. This fossil is a recurved subcompressed caniniform tooth, 3 inches in length, (following the convex curve), 7 lines in antero-posterior basal breadth 4 lines in transverse basal breadth, which diminishes more rapidly than the antero-posterior one to the point; both fore and hind margins are trenchant, and need only the fine serrations, which may have been overlooked, to make the correspondence of this Permian tooth with the upper canine of *Cynodraco* instructively close. Kutorga's fossil is certainly more like that reptilian tooth than the tusk of a wild boar or other porcine species.

A more decisive dentary evidence of a Permian Theriodont is afforded by the *Deuterosaurus biarmicus* of Eichwald*. This species is represented by the fore part of both upper and lower jaws, which are remarkable for the predominance of the vertical over the transverse diameter. The disproportionate development of the canines, especially of the upper pair, is noted in the generic character:—"les canines etaient très-longues, surtout celles de la machoire supérieure" (l. c. p. 1608). I submit a reduced copy of Eichwald's figures of the fossils (Cuts, figs. 3 & 4, p. 358), which indicate the following incisive-canine formula:—i. $\frac{5-5}{4-4}$, c. $\frac{1-1}{1-1}$. The lower canine crosses in front of the upper one.

One small molar (fig. 4, *m*) is shown at a short distance behind the upper canine, and a still smaller one (ib. *m'*) behind the lower canine in the postcanine portion of the fragment of skull. All the teeth have conical acuminate crowns with denticulate or crenulate trenchant borders. In the incisors the fore-and-aft diameter prevails at the base of the crown chiefly through a posterior protuberance of that base: in the canines the antero-posterior diameter is greatest at the base of the crown.

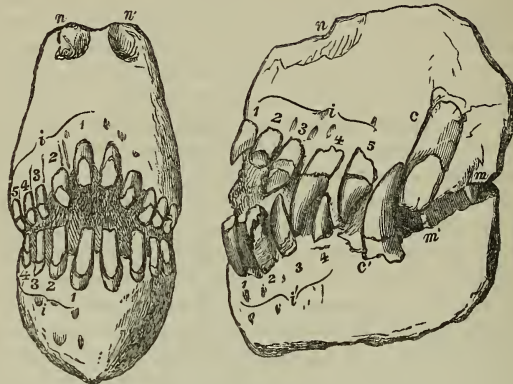
In all the more essential characters there is a close agreement between *Deuterosaurus* and *Cynodraco*; the incisive-formula is the same (Cut, fig. 5, *Cynodraco serridens*, from Karoo beds, Fort Beaufort). In the more compressed form of both upper and lower jaws, the *Lycosaurus* of the Karoo beds of the Sneewberg range (Cut, figs. 6, 7) more resembles the *Deuterosaurus* of the Ural Permian. But the incisive-formula of *Lycosaurus* is $\frac{4-4}{3-3}$. The canines of *Deuterosaurus*, though large in proportion to the contiguous incisors and molars, appear relatively less than in *Lycosaurus* or *Cynodraco*. The postbasal swelling, or partial "cingulum," in the incisors of *Deuterosaurus*, and the greater relative depth of the mandibular ramus behind the canines compared with that of the symphyseal part supporting the incisors, preclude a reference of the Cape species of Theriodontia to the genus of that reptilian order from the

* *Lethæa Rossica*, p. 1607, tab. lviii. figs. 1, 2, 3.

Ural. But their ordinal affinity is as satisfactorily manifested by the maxillo-mandibular and dental characters as by the humeral ones.

Fig. 3.

Fig. 4.

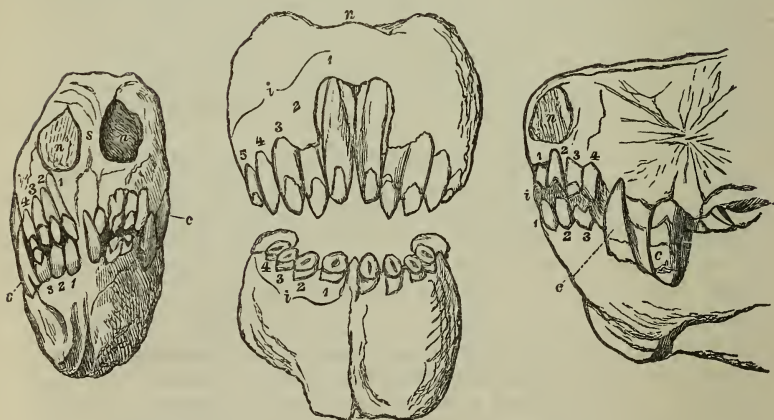


Deuterosaurus biarmicus, Eichw.

Fig. 6.

Fig 5.

Fig. 7.



Lycosaurus, Ow.

Cynodraco serridens, Ow.

Lycosaurus, Ow.

I submit, therefore, as a result of the foregoing analysis of the accessible records and representatives of the Permian fossils of the

Ural, that we have an additional and weighty evidence of the palæozoic date of the "Karoo series" of South Africa.

I next propose to offer evidence of a Theriodont reptile affined to *Lycosaurus*, from a probably Permian deposit in North America.

In a "red-sandstone formation" in Prince-Edward Island, a portion of the skull of a reptile, including the left maxillary (21), premaxillary (22), and nasal (15) bones (Cut, fig. 9), was discovered

Fig. 8.

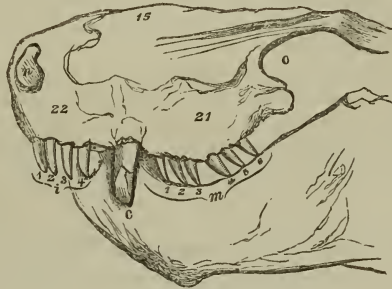


Fig. 9.

Fig. 8. *Lycosaurus*, Ow.

Fig. 9. *Bathynathus*, Leidy.

and has been described and figured by the eminent palæontologist, Joseph Leidy, M.D., in the 'Journal of the Academy of Natural Sciences of Philadelphia'*

The teeth, of which seven are preserved, are implanted in distinct sockets, and have subcompressed, recurved, conical, acuminate crowns, with anterior and posterior trenchant borders, of which the latter is minutely crenulated †. Of these teeth the foremost in the maxillary bone, protruding close to the maxillo-premaxillary suture, claims by

* Vol. ii. p. 327, plate xxxii.

† Ib. ib.

its superiority of size and length of crown to be regarded as a "canine" (Cut, fig. 9, *c*). It is followed by five much smaller but similarly shaped teeth, to be classed by position as "molars" (ib. *ib. m*). In the premaxillary bone but one incisor has been preserved (ib. *i*): "its anterior border is obtuse and not crenulated, while the posterior border is acute, but is too much broken to judge whether it is crenulated; the enamelled crown has been about 9 lines long by 4 lines in breadth at its base. The fang of the tooth, like that of the other ones, is oval in section"*. This incisor is separated by a diastema an inch in extent from the canine. The length of the crown of the tooth is 1 inch 9 lines, with a breadth of base of 7 lines. "Its fang can be seen in the wide fissure of the jaw extending two inches from the alveolar border"†.

The foremost molar, with a visible crown 6 lines in length, protrudes at a distance equal to its own antero-posterior breadth from the canine. The crown in the succeeding molars, which are completely protruded, is 9 lines in length. Dr. Leidy describes a minute crenation of the anterior as well as posterior trenchant borders of the crown ‡.

On the hypothesis that a portion of the upper jaw is here described, I see in a semicircular notch more than an inch across the base, at the upper anterior angle of the fossil, evidence of an external nostril (Cut, fig. 9, *n*). Dr. Leidy, however, has described and figured this fossil as "the right dental bone" of the lower jaw. The grounds of the contrary homology, which I here submit, are afforded by an almost complete skull of a *Lycosaurus*, from the Karoo series of S. Africa (Cut, fig. 8).

In this, as in other Theriodonts, a well-marked canine (ib. *ib. c*) divides a series of small incisors (ib. *ib. i*) from a similar series of small molars (ib. *ib. m*). The diastema between the canine and incisors is rather longer than between the canine and the molars. The crowns of all the teeth have the same general shape, even to the "minutely crenulated" hinder border, as in *Bathygnathus*, Leidy; the incisors also show the distinction of the "more obtuse anterior border."

Both fossils are remarkable for the depth or vertical extent of the upper jaw, 21; and, in both, the alveolar border of the maxillary describes a moderate convex curve. This seems to me to be fatal to the mandibular hypothesis. I exhibit an impression of the plate (lxviii.) of my 'Catalogue of S. African Reptilia,' giving a side view of the skull of *Lycosaurus curvimola*, also an impression of Leidy's plate xxxiii. of his *Bathygnathus borealis* (reduced in Cuts 8 & 9), from which may be better appreciated the comparisons leading me to refer *Bathygnathus* to an allied genus of the Theriodont order of Reptilia.

If the proposed homology and affinity be accepted, then the students of the South-African fossils have a new interest in the determination of

* *Op. cit.* p. 328.

† *ib. ib.*

‡ This character is repeated in certain teeth of *Cynodraco serridens*, 'Catalogue of S.-African Reptilia,' 4to, 1876, pl. xvii. fig. 7.

the horizon of the Nova-Scotian deposits in which the *Bathynathus borealis* was discovered. On this subject the experienced geologist Principal Dawson, F.R.S., F.G.S., adds a note to Dr. Leidy's paper, a quotation from which may not be unacceptable. "The fossil was found at New London, on the northern side of the island, imbedded to the depth of 9 feet in red sandstone with calcareous cement. The total depth from the surface was 21 feet 9 inches; the discovery was made when digging a well. The sandstone in question belongs to a formation which occupies nearly the whole of Prince-Edward Island, generally dipping at a small angle to the northward. It includes thin beds of coarse concretionary limestone; and at the southern side of the island, where the oldest beds of the formation appear, there are beds of grey clay or soft shale, and brown and grey sandstone, containing silicified trunks of *coniferous trees*, with indistinct vegetable impressions, perhaps *Calamites*. These beds may either belong to the top of the Carboniferous system or to an overlying deposit of the Permian or Triassic age; and in either case the red sandstones which conformably overlies them will be equivalent to the New Red of western Nova Scotia* and Connecticut, and are probably Triassic or Permian." To this note there is the following rider:—"Mr. Lea states he agrees with Mr. Dawson in supposing these Red Sandstones to be equivalent to those of Connecticut," &c.; and he further observes, "there are many reasons in favour of referring them to the superior strata of the Permian series." However this question, viz. as between Permian and Trias, may be decided, no fact is elicited in the foregoing survey indicative of a Liassic age, and the majority of instances weighs in favour of a Permian period. If the affinities of the Ural and Prince-Edward-Island fossils have been correctly determined, we have evidence already of the wide geographical range (North America, Europe, South Africa) over which the Reptilia distinguished by certain mammalian structures extended.

The Saurians which have been referred to the family of Thecodonts, the remains of which have been obtained from the dolomitic conglomerate of Bristol, have not only the teeth implanted in distinct sockets, but have crowns, conical, compressed, acuminate, with an anterior and posterior finely serrated edge†. A similar type of tooth (*Cladiodon*) has been discovered in the red sandstone of Warwickshire. These "thecodonts" may form a family in the Theriodont order, if less fragmentary evidences than we now possess do not show even a closer similarity in their dentition to the type genera of the Karoo beds.

The steps leading to the above results may be summed up as follows:—

To Kutorga belongs the merit of having first pointed out and figured the humeral characters which he terms "foramen condyloideum internum" and "foramen condyloideum externum," but under the belief that both were mammalian characteristics. In the

* *Op. cit.* p. 329.

† 'Odontography,' 4to, 1840, p. 266.

'Descriptive Catalogue of the Osteological Series contained in the Museum of the Royal College of Surgeons,' it was first shown that the "foramen condyloideum externum" was a character of a reptilian humerus*.

Professor Huxley was the first to figure the canal homologous with Kutorga's "foramen condyloideum internum," under the term "supracondyloid foramen or canal," in a humerus of a *Dicynodon* from the Panchet rocks of India, and in the humerus of a *Dicynodon* from the Karoo series of the Cape, in elucidation of which character he remarks:—"A supracondyloid foramen occurs not unfrequently among Lacertian Reptiles, but not with the precise form and proportions which it presents in these two humeri" †.

The determination of the homology of the supracondyloid foramen in the humerus of the *Dicynodonts* and *Theriodonts* is given in the 'Catalogue of S.-African Reptilia' ‡, and in the paper on *Cynodraco* §. It illustrates the mutual affinity of the two extinct groups, and their common possession of a mammalian structure. A like determination of the homology of Kutorga's "foramen condyloideum externum" converts into certainty the suspicion expressed by Agassiz of the reptilian nature of *Brithopus* and *Orthopus*. An ectepicondylar foramen or canal has hitherto been seen only in the humeri of cold-blooded vertebrates; an "entepicondylar foramen or canal," characteristic of many genera of Mammalia, is also characteristic of the humerus in certain *Reptilia*, but has hitherto been found only in extinct genera and species of Palæozoic or Permian age.

Thus is exemplified the value of close study and comparison of small and seemingly insignificant foramina and other minute characters of fossil bones, the advantage of defining such characters, their homologues being determined under distinct names, and the indispensability of such labour in all who would contribute to "the progress of sound palæontology" ||.

DISCUSSION.

Professor SEELEY could not realize Prof. Owen's new order. It seemed to him to rest upon the collocation of specimens, for which there seemed to be no sufficient evidence to justify the foundation of a new order upon them. It seemed to be stretching a point a very long way to refer all these isolated specimens to a new order of which we know so little. The Bristol specimens of *Palæosaurus*

* 4to, vol. i. p. 184, no. 943 (1853).

† "On Vertebrate Fossils from the Panchet Rocks," &c. in 'Memoirs of the Geological Survey in India,' 4to, 1865, p. 10, figs. 3 A, B. See, however, the remarks in the Quart. Journ. Geol. Soc. vol. xxxii. p. 98.

The figure and description of the left humerus of the *Dicynodon Murrayi*, Huxley, in 'Quart. Journ. Geol. Soc.' vol. xv. 1859, exemplify the difficulty attending the investigation of fossils from the dark hard matrix of the Karoo beds.

‡ Quarto, 1876, pp. 35, 43, 53; Nos. S. A. 59, S. A. 72, S. A. 88; pls. xxvii. xli., xlii.

§ Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 96, pl. xi. figs. 6-11.

|| Quart. Journ. Geol. Soc. vol. xxvi. (1869) p. 32.

did not seem to him to warrant the removal of that genus from the Dinosauria.

The PRESIDENT (Prof. Duncan) remarked on the interesting mode in which these Reptilian jaws seem to foreshadow those of the Mammalia. During the existence of the great land surface which persisted through the Carboniferous, the Permian, and the Trias, many land reptiles lived upon it, and doubtless developed those characters which seem to be Mammalian, just as in more recent times we have similar characters developed under similar conditions in the Marsupial Mammalia.

Mr. ETHERIDGE stated that the deposits from which the Bristol Saurians were obtained certainly belonged to the middle of the British Triassic series, forming the base of the Keuper.

The AUTHOR stated that the teeth of *Megalosaurus* among the Dinosaurs approached nearest to those of his Theriodontia, but they are not Thecodont. *Megalosaurus* had amphiplatyan vertebræ, whilst those of the Theriodonts were biconcave. Considering the fragmentary evidence upon which the order Dinosauria was first established, and the fact of its being now generally accepted, he did not think that the argument from imperfect evidence against the order Theriodontia was of much value.

39. *Appendix to "NOTE on a MODIFIED FORM of DINOSAURIAN ILIUM, hitherto reputed SCAPULA."* By J. W. HULKE, Esq., F.R.S., F.G.S. (Read June 9, 1875.)

A RECENT discovery of *Iguanodon*-remains in the Isle of Wight by the Rev. W. Fox has solved the riddle of the bone which, in the above note, I brought under the Society's notice towards the close of last Session*, and it has also completed our knowledge of the pelvic elements of Mantell's *Iguanodon*. It will be remembered that Mantell and, later, Owen had regarded the bone as a scapula, first of *Iguanodon*, and afterwards of some unknown reptile, that this decision seemed to be untenable, and that the balance of all the evidence I could up to that time collect respecting it favoured its being an ilium.

This fresh material, which Mr. Fox has courteously permitted me to examine, consists of a series of vertebræ, of fragments of large flat bones which cannot be any thing else than pieces of the ilia, of a pair of ischia, the former clavicles, and a pair of the bones in question.

The vertebræ comprise the sacrum and a few of the adjoining lumbar and caudal vertebræ. Their form, and also that of the ischia, agree so closely with those of the types of Mantell's *Iguanodon* in the British Museum as to leave no doubt of their generic identity. The third pair of bones in the pelvic girdle, which are neither ilia nor ischia, must be pubes (fig. 1, P). Their shape closely repeats that of the smaller of the two specimens illustrating my note (pl. xxxii. fig. 1, vol. xxx.). Inverting the bone there figured, its long slender process (*Spp'*) is easily identified with the thin elongated rod which, in the Mantell-Bowerbank specimen of the nearly allied *Hypsilophodon*, Prof. Huxley recognized as the pubis (*Pb*, pl. ii. Quart. Journ. Geol. Soc. vol. xxvi.). This identification roughly gives the direction of the whole bone. Its long slender branch slanted downwards and backwards parallel to the ischium; and the little process detached from its posterior surface meeting a corresponding process observable in all well-preserved ischia, converted the upper end of a long narrow obturator-space into a foramen having the position of that which in birds (Ostrich) transmits the tendon of the *obturator internus* muscle (figs. 1 & 2, *obt*). The process marked *i* in the figure (pl. xxxii. vol. xxx.) joined the ilium, and that marked *p* the ischium; the smooth intermediate arc formed the lower and front part of the acetabulum, whilst the broad blade-like part sloped ventrally inwards and forwards (figs. 1-3, *p*). I am inclined to think that the free end of this part met the corresponding extremity of the *os pubis* of the other side in a median symphysis; but I have not yet any positive evidence of this in *Iguanodon*.

In respect of its large contribution to the acetabulum, the pubis of Mantell's *Iguanodon* resembles that of existing Lacertilia, as it

* Quart. Journ. Geol. Soc. vol. xxx. p. 521, pl. xxxii.

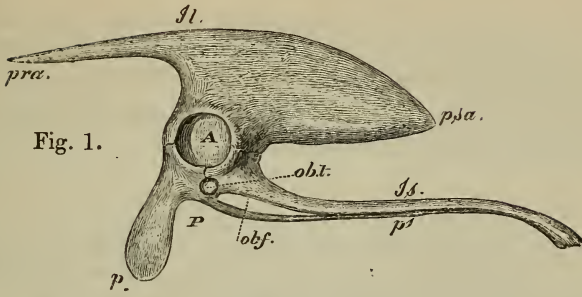


Fig. 1.

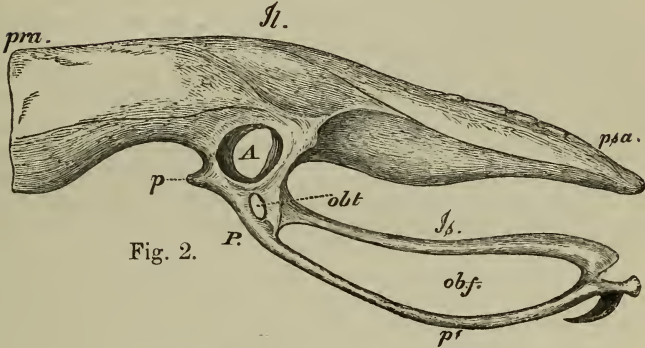


Fig. 2.

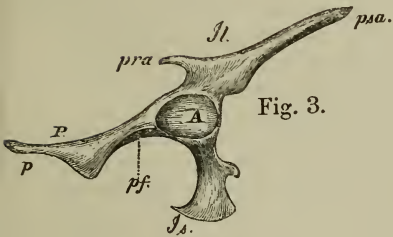


Fig. 3.

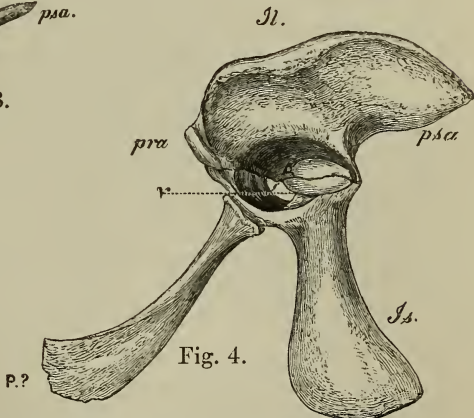


Fig. 4.

- Fig. 1. Restoration of Iguanodon's pelvis, about one fourteenth natural size.
 „ 2. A corresponding view of pelvis of Ostrich.
 „ 3. A corresponding view of pelvis of an existing species of South-American Lizard, about twice natural size.
 „ 4. A corresponding view of pelvis of *Crocodilus niloticus*, about one fifth natural size.

The homologous parts in each figure are indicated by the same letters, viz. *A*, acetabulum; *Il.*, ilium; *pra.*, its præacetabular process; *psa.*, its postacetabular part; *Is.*, ischium; *P*, os pubis; *p.*, the part directed beneath the belly where in the Lizard it meets its fellow in a mesial symphysis; *p'*, its postacetabular part directed backwards parallel with the ischium, wanting in Lizards and Crocodiles; *ob.f.*, obturator foramen; *obt.*, foramen for the transmission of the tendon of the musculus obturator internus.

does also in respect of its broad ventral extension and probable median symphysis (compare figs. 1 & 3); whilst its long slender branch repeats the avian resemblance noticed by Prof. Huxley in *Hypsilophodon* (figs. 1 & 2).

My warmest thanks are due to the Rev. W. Fox for allowing me to study these very instructive fossils.

DISCUSSION.

Prof. SEELEY said he thought this paper was one of the most important contributions to the osteology of the Dinosauria that had been laid before the Geological Society within his memory. He entirely agreed with the interpretation which Mr. Hulke had given of the bones. He said that in the *Apteryx* the præpubic process of the pubis is more developed than in any other known bird, while the whole pelvis in other respects approximates closely to that of *Iguanodon*. It was of great interest to find the fossil showing that this process attained at least as great a development as in the Chelonia and Lacertilia, because it showed that the pelvis of Dinosaurs was not entirely Avian, but, like the remainder of the skeleton, showed a blending of Avian and Reptilian peculiarities.

40. *On the TRIASSIC ROCKS of SOMERSET and DEVON.* By W. A. E. USSHER, Esq.,-F.G.S., of the Geological Survey of England and Wales. (Read June 7, 1876.)

(Communicated by permission of the Director of the Geological Survey.)

CONTENTS.

- I. The Mendip Area.
- II. Polden Hills, Bridgewater and Taunton Vale.
- III. West-Somerset and Devon Area.

INTRODUCTION.

THE Triassic areas of Devon and Somerset may be divided into three lithological districts:—the first, on the north and north-east of the Polden Hills; the second, on the north-east, east, and south-east of the Quantocks; the third, comprising the rest of the Triassic area, lies between Watchet and the south coast of Devon, being bounded on the west by the Devonian and Culmiferous highlands, and on the east by the Quantock and Blackdown ranges.

The first of these districts is too well known to call for more than a general description in this place. In the Geological-Survey Memoir on the Bristol Coalfield it has been already treated of, the labours of Conybearc and Phillips, De la Beche, and the late Mr. Wm. Sanders, with those of Messrs. Moore and Etheridge having left little to be desired as far as the description of the Triassic strata is concerned. With reference to the last-mentioned districts, of which we purpose to give a more detailed though far from exhaustive description, it is different, the relations of the Trias not having been before established, except so far as might be inferred from a study of the splendid section along the coast between Seaton and Torquay.

Sir Henry De la Beche, in his report upon the geology of Devon and Cornwall, gives a very general description of the Trias, without attempting a classification of its component marls, sands, and conglomerates, which the greater time occupied in the resurvey of the district has enabled me to make, and, by the kind permission of the Director of the Geological Survey, to lay before the Society. A general description, adducing only such evidence as becomes necessary to prove the sequence which we have adopted, and to the exclusion of such details as must be reserved for Geological-Survey publication, is here attempted.

I. *The Mendip Area. Trias North of the Polden Hills.*

Throughout the districts occupied by Triassic strata between Bristol in the north and Glastonbury and Shepton Mallet in the south, and between the mouth of the Severn in the west and Frome in the east, their lithological characters seldom vary, the major part consisting of red and greyish green marls, in the neighbourhood of Palæozoic hills resting upon or dovetailing into conglomerates with a dolomitic matrix, which from their marginal nature are but locally observable and superficially occupy a very limited area.

The variegated marls outcropping from beneath the Liassic strata in the east occupy the lowest tracts of land covered by the secondary rocks, capped here and there by Liassic beds, where hills of sufficient height to allow of their presence occur, or where exceptional cases of fault have rendered both equally susceptible to the forces of denudation. The scanty herbage sometimes permits the junction between the marls and overlying Rhætic beds to be seen, even at a considerable distance, on the slopes of these outliers, the grey and cream-coloured marls of the Rhætic offering a marked contrast to the green-, grey-, and red-banded marls of the Trias.

As a general rule, greenish and bluish grey tints are most prevalent in the upper portions of the marls. Bands of greenish grey calcareous stone are frequently met with, sometimes occurring in laminae, upon the surfaces of which pseudomorphs of crystals of rock salt have been occasionally discovered. Mr. Bristow found a specimen in the railway-cutting between Shepton Mallet and Wells during my noviciate in field-work. Bluish mottling and banding is not uncommon in the marl.

Sandstones appear to be intercalated with it, but in very exceptional cases, where we were unable to ascertain their thickness or relations to the underlying beds.

At Claverham, near Yatton, grey sandstones occur which are much used in the neighbourhood for building-purposes, owing to their durability and hardening on exposure. The local epithet for these beds is Clar'ham stone; but whether they occur as a small lenticular patch in the marl, or as a boss of a subjacent extensive bed, there only brought to the surface, we are unable positively to say, though from the proximity of Carboniferous sandstones capable of furnishing them, and the fact that similar beds have not been traced, we are inclined to the former hypothesis.

At Ridge Hill, on the west of Chew Stoke, beds of soft sandstone are shown under the marls in a road-cutting. Here again the proximity of a patch of Millstone Grit at Leigh Down, about half a mile to the northward, is sufficient to explain their presence; but their vicinity to the conglomerates on the north, and the occasional presence of arenaceous beds at the base of the marls, render it difficult to determine whether they do or do not rest on the conglomerates directly, their junction with them being concealed by an overlap of marl.

Arenaceous beds outcrop at the base of the marls, near Backwell, between Brockley Elm and Yatton, between Yatton and Wrington, and also at Churchill; they are best developed near Roddy to the north of Congressbury, and at Churchill.

The irregular junction sometimes noticeable between the marls and conglomerates, and the very unequal breadth of outcrop exhibited within short distances by the latter, render it probable that these sandstones may represent portions of arenaceous deposits thrown down further from the old Triassic shores, and subsequently overlapped by muddy sediments, as a progressive subsidence narrowed the limits of the existing land.

We do not know of the occurrence of similar sandy beds on the flanks of the Mendips; superficial evidence confines them to Broadfield Down.

With very few exceptions the old Triassic coast line in this area is fringed with conglomerates, sometimes occurring superficially as very thin fringes resting on the Palæozoic rocks, as on Banwell Hill, Sandford Hill, &c., sometimes occupying considerable local superficies, as near Wrington, Blagdon, Shipham, Chilcompton, Mells, Croscombe, &c. (in which places they occupy high grounds sloping towards the principal valleys, with minor hills and undulations of their own), sometimes rising in bold hills wrapping a nucleus of Mountain Limestone which is here and there uncovered, as at Churchill and Decoy Nyland, near Cheddar, sometimes as inliers in valley bottoms as at Midsomer Norton, sometimes as outliers on the older rocks, as at Slab-Ho (north of Dinder) and near Binegar and Nettlebridge. In all cases where it rests upon the older rocks the conglomerate fills the inequalities in their outline, presenting a very irregular junction with them in places where the old coast was much indented.

De la Beche thus describes the composition of these conglomerates (Mem. Geol. Surv. of Gt. Brit. vol. i. p. 240):—"The lowest part of the poecilitic, or new red sandstone series in our district has generally been considered as composed of a conglomerate formed of rounded portions or fragments of the subjacent rocks cemented by carbonate of lime, mixed occasionally with so much carbonate of magnesia that the name magnesian conglomerate was applied to it, and magnesian limestone to the limestone into which it sometimes graduates by the disappearance of the pebbles of the subjacent rocks, and the presence of little else than the matter of the cement. Instead of these terms the names of dolomite conglomerate and limestone were suggested by Dr. Buckland and Mr. Conybeare, they at the same time observing that the cement or limestone, in the absence of pebbles and fragments, was sometimes dolomite (carbonate of lime and magnesia) mixed with carbonate of lime, at others merely carbonate of lime. They also pointed out that the pebbles and fragments in the conglomerate or breccia were those of the nearest hard rock, fragments of coal sandstones being scarce, probably from their texture being commonly too friable to resist the friction to which the other pebbles had been exposed."

De la Beche (*ibid.* p. 241), after mentioning the irregular projection of the conglomerates from the margin at intervals into the marl (of which we recall to mind an instance at Dunyate, near Axbridge, on the south side of the Mendip hills), proceeds to say:—"It will be evident that whenever conditions may arise for the deposit of the carbonate of lime, or of carbonate of lime and magnesia, as the case may be, without including the pebbles, the travertino, for such it would be, would cover up the conglomerate beneath. In supposing, therefore, that these dolomitic conglomerates may often have been beaches skirting the land of the time, rising higher and higher up its flanks as such land became depressed

relatively to the sea, we do not suggest a mode of explanation at variance with the manner in which such things may happen at the present time, but on the contrary, one in accordance with it."

He says further (*ibid.* p. 246), "The conglomerate of the Vale of Westbury is pointed out as containing an abundance of sulphate of strontia, forming part of the matter cementing the pebbles and fragments together. The frequent occurrence also of nests of sand in many places, the irregular cavities filled with rock crystal, chalcedony, carbonate of lime and other minerals, and which, when detached from the matrix surrounding them, are locally known as Potato-stones, is mentioned (*Geol. Trans.* vol. i. pp. 212, 291-294, &c.; *ibid.* 1st ser. vol. iv.). These cavities so filled, and shown to be particularly abundant near Mells (Mendip Hill district), are of the same kind as those noticed at Kenfig Point, Glamorganshire," where the most westerly patch of conglomerate occurs.

On p. 249, De la Beche notices intercalations of flesh-coloured dolomitic limestones with the marls, on the south of the Mendips, near Croscombe. They seem to be passage-beds into the underlying dolomitic conglomerate. The presence of arenaceous matter in the lower part of the Trias, in neighbourhoods where Palæozoic sandstones occur, has been already noticed; it might be of interest, however, to quote an instance at Portishead, given by De la Beche in the work before referred to (pp. 248, 249*), the beds being given in descending order:—

1. Conglomerate.
2. Layers of red and buff-coloured sandstone.
3. Conglomerate.
4. White crystalline dolomite.
5. Buff-coloured sandstone.
6. Conglomerate reposing on the edges of the coal-measure sandstone (Pennant grit).

In fact, throughout this district, the general absence of arenaceous matter of Triassic age may be accounted for by the great quantity of calcareous sediments afforded to the denuding agents of that period, through the prevalence over the area of Carboniferous limestones. Even in cases where the shores were wholly composed of Carboniferous sandstones the transport of calcareous matter from adjoining limestone coast-lines prevented the representation of the marginal deposits by sandy beds alone, but produced an intercalation of sandy and calcareous matter, according as the degradation of the sandstone cliffs was counteracted by the interception of beach materials, or counterbalanced by the influx of calcareous sediment from the vicinity.

The reverse is the case in the Devon area, where the shales and grits of the Devonian and Culm-measure strata afforded a mass of arenaceous sediment, in which the occasional limestones occurring in them were in their degradation unable to produce any marked

* *Vide* Moore, "Abnormal Secondary Deposits," *Quart. Journ. Geol. Soc.* xxiii. p. 456: a gallery driven in search of manganese, through conglomerates with intercalated masses of bluish and variegated marl, at Croscombe.

change, or to afford intercalations of calcareous matter other than is locally to be seen in certain of the lowermost breccio-conglomerates in the neighbourhood of Sampford Peverell (*vide* Conybeare and Phillips, 'Outlines of Geology of England and Wales,' p. 308), and in the vicinity of Paignton and Teignmouth, in the middle series of conglomerates near Wiveliscombe, Milverton, and Vellow (near Stogumber), and the marlstones between Bishops Lydeard and Crowcombe Heathfield, and the calcareous nodules and beds in the same sandstones in other places. The fragments contained in the conglomerates are principally composed of Carboniferous limestone, exhibiting various degrees of attrition, from well-rounded boulders and pebbles to nearly angular fragments.

At Wrington (near Yatton) and Draycot (near Cheddar) beds rather approaching to the character of a breccia than a conglomerate occur, and in the latter locality form a very serviceable building-stone.

Organic Remains.—Sir H. De la Beche, in the work before cited (p. 268), says:—"In the dolomitic or magnesian conglomerate of Redland, near Bristol, Dr. Riley and Mr. Stutchbury have found the remains of two Saurians, to which they gave the names of *Thecodontosaurus* and *Palaeosaurus*." (*Vide* Moore, "Abnormal Secondary Deposits," *l. c.* p. 456.)

We may therefore infer that, from its first known appearance in the Coal-measures, Sauroid life had continuously progressed through the Triassic period (of which Mr. Lavis's recent interesting discovery at Sidmouth affords further proof) wherever the waters of that period were favourable to their existence, till in the Liassic age more suitable conditions for their preservation, if not for their increase, prevailed.

Thickness.—According to Conybeare and Phillips (p. 299), "At Pucklechurch, in Gloucestershire, shafts have been sunk from the Lias to the coal-measures;" the Trias was found to be 153 feet in thickness.

In a section of a coal-pit, $\frac{3}{4}$ mile south-east of the village of Paulton (*ibid.* p. 429), the Trias underlying Liassic and Oolitic beds was found to consist of—

	ft.	in.
Red marl and sand	132	0
Calcareo-magnesian conglomerate, called millstone	6	0
Total thickness of Trias...	138	0

In a pit-section at Chilcompton, given by Messrs. Buckland and Conybeare (in observations on the south-western coal-district), the dolomitic conglomerate continued for 138 feet from the surface. (It should be mentioned that the major part of the formation in this locality is represented by conglomerates, and that, in places, the Rhætic beds appear to rest directly upon them, so that the formation of conglomerate appears to have been locally continuous and contemporaneous with that of the upper beds of marl.)

The same observers give a section of a pit at Welton, to the north of Midsomer Norton, which was sunk through 114 feet of red marl, resting on 6 feet of dolomitic conglomerate.

“There is a large development of this conglomerate at Stratton-on-the-Fosse, where it comes in contact with the exposed edges of the Coal-measures, and again at Mellis, whence a narrow belt passes beyond the village of Elm, skirting the limestones to Vallis. Conglomerates are also found continuously along the limestone escarpments, filling up the inequalities of the surface on both the north and south flanks of the southern portion of the Mendips. . . . Few if any organic remains of a locality so disturbed as were the probably local coast lines on which these pebbly deposits were laid down can be expected to have been preserved.” (Moore, “Abnormal Secondary Deposits,” *l. c.* p. 455.)

Mr. Moore says the dolomitic conglomerate is found to vary from 3 to 60 feet in thickness.

Mr. Moore (“Abnormal Secondary Deposits,” *l. c.* p. 498) gives the following representation of the Trias in the Mangotsfield railway-cutting :—

Under Rhætic Beds.

Keuper, consisting of variegated red and blue marls with sulphate of strontia, passing into regularly bedded New Red Sandstones without organisms	ft. in. about 25 0
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Resting on Pennant Rock.

In the same paper (*ibid.* p. 458) he says :—“It will be seen that within this part of the Somersetshire coal-basin the Triassic rocks are reduced to a little over 50 feet, whilst south of the Mendips, and where only partially proved, they attain a thickness of 609 feet.”

He says further (p. 476), “Comparing the greatest thickness ‘of the Trias’ without the coal-basin with the greatest reduction above the coal-measures within it, we arrive at the following remarkable result.”

	Without the Coal-basin.		Within the Coal-basin.	
	ft.	in.	ft.	in.
Triassic beds ..	2000	0	50	0

Mr. Moore gives the thickness of the Trias at the Tynning Pit (near Radstock) as 186 feet, of which 19 feet at the base consist of dolomitic conglomerate.

At Norton-Hill Pit the marls are given as 118, and the conglomerates 54 feet in thickness.

At Batheaston a pit, in 1812, showed 54 feet of Trias under Rhætic beds.

The red marls of the northern area were deposited continuously with the upper portions of the marls, upon which the Blackdown greensands to a great extent rest directly.

The same general description is applicable to the latest stage of deposition in the three districts under consideration; but the great attenuation exhibited by the Trias of the northern district precludes any attempt at correlation as regards time with the much greater development of marls which in South Devon form only the upper part of the Trias.

As we have no reason for inferring that deposition was more

rapid to the south than to the north of the Mendip hills, and certainly could never have been so unequal as to cause the sediments formed in the northern area to bear so small a proportion to those thrown down in the southern districts, on the assumption that deposition took place contemporaneously in both, we have every ground for inferring with Sir H. De la Beche that "deposits were not effected over the northern area to any great extent until the period when the red marls prevailed, when the waters of the time evidently overspread a considerable portion, there being a free passage of sea between Wales and Devon, with outstanding islands."

II. Area of the Polden Hills, Bridgewater and Taunton Vale.

(a) Bridgewater District.

We have placed this area second in order, not only because it separates the northern from the southern area, but because it seems to present a transition stage between the simple uniformity of the Triassic deposits in the one, and their more complex and variable nature in the other.

We include in this district the country on the south of the Quantocks as far west as Taunton. It is therefore bounded on the south by the Liassic tableland (on the north-eastern side of the Blackdown Range), on the east by the Polden hills, and on the north by the Otterhampton Liassic strata, the beds resting upon the slopes of the Quantocks upon their north-east, east, and south flanks.

The Trias in this area, east of a line drawn north and south through Bridgewater, and south of a line drawn in an east and west direction through Monkton Heathfield, appears to consist entirely of red variegated marls of the same character as those on the north; that is, everywhere marls are at the surface; but whether they rest directly on the older rocks or conceal lower beds of different characters, we are, through the want of sufficiently deep excavations, unable to say—though, from the presence of arenaceous beds in places on the south slopes of the Quantocks, we are inclined to believe that an intercalation at least of arenaceous matter with the marl occurs near the base of the Vale-of-Taunton Trias, marking the marginal accumulations of a coast receding with gradual subsidence.

This view is in a measure borne out by the observations of Mr. Moore, to whom we are again largely indebted. He gives a section at Ruishton, north of Taunton*, 21 feet 5 inches in depth, consisting of—

	ft.	in.
Red, bluish green, and grey marls.....	9	7
Gritty conglomerate with occasional sandy bands and intermediate layers of marl, with Fish, Reptile, and Batrachian remains (including teeth of <i>Labyrinthodon</i> ,? <i>Belodon</i> , <i>Acrodus keuperinus</i> , <i>Estheria minuta</i> , &c.)	1	2
Sandstone.....	0	2
Fine sandy bed	0	6
Bluish and red marls	10	0

At North Curry, under an undetermined thickness of variegated marls, Mr. Moore notes the occurrence of various beds of dull grey

* Quart. Journ. Geol. Soc. vol. xxiii. p. 468.

and brown sandstone, enclosing nodules of marl, and containing *Esteria*, plants, traces of fish-scales, and a Reptilian bone—in all 3 feet 6 inches thick, and resting upon marls exposed to a depth of more than 50 feet.

At Knap, he gives a section of beds to which he assigns a lower position than those exposed in the North-Curry section:—

	ft.	in.
Variogated marls with a hard grey band of stone 2 inches thick	10	9
Grey sandstone in thin courses.....	3	0
Sandstone.....	1	10
Red marl.....	1	10
Grey sandstones	10	11
	28	4

Near Stoke St. Mary, Mr. Moore noticed thin beds in the Keuper containing *Posidonomya minuta*.

Upon the south-eastern flanks of the Quantocks, between North Petherton and Durston, beds of rock-sand rest upon the Devonian strata, and attain their greatest superficial breadth (of one mile and a half) between St. Michael's church and Thurloxtou. From North Petherton they gradually diminish in superficial breadth upon the north-eastern flanks of the Quantocks; and at Enmore, where they are in parts slightly brecciated, they disappear beneath the overlying marls, which rest directly upon the older rocks for a distance of three miles. At this point a deep valley has been cut through the marls, exposing sandstones resting upon the older rocks and continuing for a mile down the valley to a point beyond Spaxton, where they are apparently cut off by a fault bringing down marls.

The area between Bridgewater and the Quantocks is characterized by the presence of numerous inlying hills of Devonian grit, and by the prevalence of faults in an easterly and westerly direction; three of these to the north of Bridgewater are especially noticeable, as they intersect the Triassic area, affecting its component marls and sandstones on the alluvial flats of the river Parret and the slopes of the Quantocks.

The Devonian inliers are frequently flanked by beds of sandstone, as at Cannington and Radlet farm; but the overlying marls seldom allow more than a partial exposure (of sandstone) upon their flanks.

Between Charlinch and Cannington, beds of sandstone are intercalated with the marls, and are either passage-beds between them and the marginal sandstones upon the Quantock slopes, or a local modification caused by the interchange of calcareous matter as fine mud with arenaceous sediment.

Upon Wembdon Hill another modification of the Bridgewater Trias is shown in the occurrence of hard bedded breccia, consisting of subangular and occasionally rounded fragments in a matrix of calcareous sandstone, and containing beds of sandstone unbrecciated. These breccias are of very local occurrence; as far as we can judge by superficial evidence, they appear to occupy a position at the base of the sandstones, as they are always found to pass upwards into them; but the relations of the Wembdon sandstones to the marls on the north and south, against which they are faulted, cannot be definitely fixed, nor can we at present say whether the

breccia rests directly upon the older rocks, though we are inclined to consider its position as indicative of a nucleus of older rock, brought up by faults, but not exposed, through the greater durability of the Triassic beds thrown down upon it.

To continue the thread of our notice of the marginal sandstones on the Quantock slopes, interrupted by this necessary digression,—between the Spaxton valley and Over Stowey we find sandstones fringing the older rocks, but superficially forming a band of no great breadth. At Nether Stowey, however, we find the sandstones flanking the older rocks, and at Doddington overlain by marls which continue to the Liassic districts on the north, extending for some distance from their margin, and connecting sandstone beds, in places flanking the Devonian inlier of Radlet Farm, with the marginal sandstones on the Quantock slopes. The southern boundary of this exposure of sandstone is formed by one of the three great faults before mentioned, bringing up marls on the south.

Upon the north side of the most northerly of these three great faults, the sandstones of Doddington appear to the south of Fiddington, in a small valley between that point and Cannington Park, and to the south of Cannington Park, proving their continuity in that district under the marls.

By similar reasoning, into which we cannot now enter, we are led to infer that the sandstones flanking the Quantocks are of the same age with those brought up here and there by faults and exposed on the sides of Devonian inliers. Whether, when the area of Bridgewater first came within the influence of Triassic waters, breccias were thrown down over a much larger area than the vicinity of Wembdon Hill and subsequently overlapped by sandstones, or formed merely a local variation of arenaceous beds at first deposited, we are unable to say.

(β) *Vale-of-Taunton District.*

In the vale of Taunton we find, superficially at least, an order of deposition and mode of occurrence in the Triassic strata as simple as that exhibited in the Mendip country; but on either side of it the relations of the beds are more obscure, owing to the greater lithological differences observable and the occurrence of numerous faults; yet when we trace the marginal sandstones on the Quantocks from Durston westwards, as we have already done in the Bridgewater district, we shall find that they form a connecting link between the deposits of the Bridgewater area, and the more complicated divisions of west Somerset and Devon,—in other words, that a contemporaneous deposition of arenaceous material took place in the Watchet-valley, Vale-of-Taunton, and Bridgewater district. From Durston these sandstones gradually attenuate at the surface, being concealed by marl resting directly on the older rocks to the southeast of Hestercombe; at Cheddon Fitzpaine they reappear, being brought up by fault, and, with an average breadth of half a mile, continue to within a mile of Kingston (north of Taunton). Here marls rest upon the older rocks. To the west of Kingston, however, sandstones reappear and exhibit some superficial development;

at Yawford they are concealed by marl, but at once emerge, and thence continue along the southern flanks of the Quantocks at Bishops Lydeard and in the Watchet valley, finally becoming portions of the Upper Sandstone division of the Devon and West-Somerset Trias, hereafter to be treated of.

Thickness.—Considerable difficulties exist in estimating the thickness of the Trias in this area. Mr. Moore ("Abnormal Secondary Deposits," *l. c.* p. 458) mentions a boring made at Compton Dundon, south of Street, through a small thickness of Rhætic beds, in which the base of the Keuper was not reached at a depth of 609 feet. If we allow a persistent dip of 3° in the Bridgewater Trias, measuring its outcropping breadth from the Rhætic beds on the Polden Hills, near Puriton mill, to the Quantocks near north Petherton, we get a thickness of about 1200 feet; but the conditions for forming such an estimate are too unfavourable to allow of its being put forward except as a theoretical possibility. In the Vale of Taunton, De la Beche allowed a thickness of nearly 300 feet for the Trias; but it is plain that the materials for forming an estimate are equally wanting there; for the vicinity of the district to the Watchet and Wellington areas, where a very much greater thickness and more variable composition are exhibited, and the uncertainty as to the depth of the old rock floor under Taunton render it possible that the marls, superficially constituting the Trias, may conceal beds of a different character, of the same age as the conglomerates or lower marls of the Watchet and South-Devon area.

We can only partially account for so small an estimate of the thickness of the Vale-of-Taunton Trias by assuming that the rocky floor on which it rests formed, as a ridge extending southwards from the Quantocks, a barrier to the incursion of Triassic waters during the deposition of the breccias, lower marls, and conglomerates in the area between Watchet and the south coast of Devon, and during the earlier deposition of sandstones in the Bridgewater district, not finally coming within their influence till the later stages in the deposition of the Upper Sandstones of West Somerset and Devon. Even on this assumption, allowing a persistent dip of 3° , and estimating breadth of outcrops from the base of the Rhætic beds north of Stoke St. Mary to the Quantocks at West Monkton, the resultant 700 feet can scarcely be considered excessive.

Concluding remarks.

We have hitherto been considering districts in which the Trias of Somerset presents its simplest form, being mainly divisible into two portions, the lowermost of which appears to be far the least developed.

In the Mendip area we find:—(1) Variegated marls occasionally arenaceous or passing into sandstones at and near their base, overlying or dovetailing into (2) Dolomitic conglomerate, which though apparently the first deposit of Triassic times in the area, has, in places, as a marginal deposit, continued during the entire deposition of the marls.

In the Bridgewater district, and in the area between Taunton and the Polden Hills (as far as we can judge by superficial evidence) we find:—

(1). Variegated marls occasionally containing arenaceous beds.

(2). Sandstones, or rock sands, apparently forming the marginal deposit, marking, with few exceptions, the first stages of deposition in these areas, passing upwards, in places, by intercalation into the overlying marls, at Wembdon passing downwards into hard bedded breccio-conglomerate.

If the Wembdon breccias should prove persistent beneath the sandstones in the Bridgewater district, a threefold division of (1) marl, (2) sandstone, (3) breccia, would be necessary, presenting some slight affinity to the (1) marls, (2) sandstone, (3) dolomitic conglomerate flanking Broadfield Down (to the north of the Mendips).

III. *West-Somerset and Devon Area.*

The area now to be treated of is bounded on the north by the Bristol Channel, on the south by the English Channel, whilst the Quantocks, Taunton Vale, and the Blackdown range form a provisional boundary on the east; the Devonian and Culmiferous highlands, stretching south from the Brendon Hills, define its western limits.

Much has already been written about the Trias of Devon as shown in its greatest exposure on the south coast. The whole section has been described by Mr. Pengelly, and attention has been specially directed to individual divisions, to the marls and sandstones between Exmouth and Straight Point by Mr. Ormerod, to the Pebble beds of Budleigh Salterton by the late Mr. Salter and my friend Mr. Vicary of Exeter, to the Upper Sandstones by my friends Messrs. Lavis and Whitaker; so that in the following brief notice my object is rather to prove the maintenance over the area under consideration of the sequence observable in the south-coast section, and to observe the relations of the beds in that section, than to attempt any detailed account of the lithological characteristics of separate divisions. Inasmuch as one section of any set of beds, be it ever so clear, cannot be taken without further research as the absolute and unvarying type of the whole, I propose, by the correlation of the beds in four distinct parts of the area and by a glance at the structure of each, to endeavour to prove the persistence of the south-coast divisions throughout the area, and that any hiatus is rather due to concealment by faults or overlap* than to impersistence, and, whilst showing the difficulties in the way of forming estimates of their thickness through the prevalence of faults repeating and (in some cases) cutting out the beds, to attempt an approximation to the thickness of the several divisions.

I made my first acquaintance with the Trias of this area at Wellington, in the year 1871, and was then led to make, with one exception, the same divisions as are displayed in the South-Devon coast. In the year 1872, the division underlying the conglomerates was indecisively indicated; but the discovery of its true character in the following year necessitated a reinvestigation of its boundaries, in doing which considerable light was thrown upon the relations of

* By the term *overlap* no unconformity is here meant, but the concealment of lower beds by the extension, through a progressive subsidence, of those next in time upon the old rocks.

the other divisions, and the distinction between natural and faulted boundary-lines became apparent.

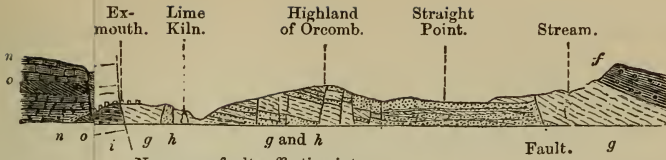
In the correlation of the divisions displayed in the south-coast section with those inland, we should hardly expect to find the same identical lithological characters or identification tests throughout. Nor is this the case; for, with the exception of two divisions, both marls, we find considerable local variations, distinct derivation, and in the members of the lowest division, much horizontal change or replacement.

The subjoined is a rough table of the Triassic beds in four distinct and typical localities, between Watchet and the south coast of Devon*.

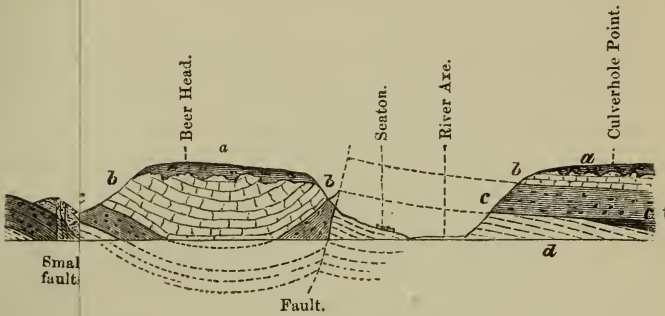
COAST SECTION.	BURLESCOMBE.	MILVERTON.	WILLITON.
1. (Upper) red variegated marls, veins of gypsum, calcareous in upper and middle beds, loamy and sometimes passing into rock-sand in bottom beds.	Ditto, but no gypsum observable.	Ditto. Brickpits in marls at Taunton, and in marl bottom beds at Wellington.	Ditto. Brickpit at Blue Anchor; gypsum veins on coast.
2. (Upper) red sandstones and rock-sand, in places with calcareous nodules, mottled greyish, and containing bands and pockets of red clay; slightly conglomeratic at about 50 feet from bottom.	Red rock-sand, sometimes buff and grey, and occasionally containing seams of clay.	Red rock-sand and sandstone with calcareous nodules in places, and grey mottling in streaks and spots.	Red, buff, and grey rock-sand and sandstones; between Bishop's Lydcard and Williton very calcareous, almost a marl-stone in places.
3. Pebble-beds of Budleigh Salterton, large ellipsoidal pebbles, mostly quartzite (foreign derivation) in red-sand matrix, with impersistent beds and bands of rock-sand.	Small quartz pebbles in red-sand matrix, occasional impersistent strips of sand, sometimes compacted, with grit pebbles locally predominant.	Conglomerate of limestone grit and quartz pebbles, in hard sandstone matrix, often thick-bedded. Near Whiteball-Hill tunnel, north of Burlescombe, seems to be passing into pebble-beds.	
4. Red variegated marls slightly calcareous above, loamy below, and containing beds of sandstone often impersistent. Brickpits in soil at Exmouth.	Ditto; structure not observable, owing to a thick loamy clay soil, in which are brickpits.	Ditto, much faulted; whole thickness not shown by the outcrop.	Ditto.
5. Faulted against 4. Breccias of angular stones in red rock-sand, as at Exmouth and Dawlish; with intercalated rock-sands near the latter, and underlying rock-sands at Dawlish. Hard thick-bedded (compare Heavitree) breccias of Teignmouth, breccias, breccio-conglomerates, and variegated sands of Torquay and Paignton. (At Exeter brecciated loamy clay with beds of sandstone.)	Either faulted out or concealed by 4. In places a little breccia of shale fragments in sand and dark-coloured sandstones. At Tiverton breccia and breccio-conglomerate, hard-rock-sand, shale breccia in sand. At Bradninch gravelly breccia of gritstones with intercalated beds of red rock-sand. Gravels near Tiverton, &c.	Red and blackish rock-sand, in places slightly brecciated in lines of false-bedding. Near Wiveliscombe hard breccia, sometimes slightly conglomeratic, and red sandstones, red and blackish rock-sands.	Breccia of angular fragments in red sand; hard breccias; red and blackish rock-sand and sandstone, occasionally slightly calcareous. Breccias of shale fragments in sand and loam.

* The relations of the divisions in the coast section, Burlescombe district, and the Williton neighbourhood are shown in figs. 1, 2, and 3 respectively, the sections accompanying this paper. The similarity of the Milverton and Williton districts renders a section illustrative of the former unnecessary.

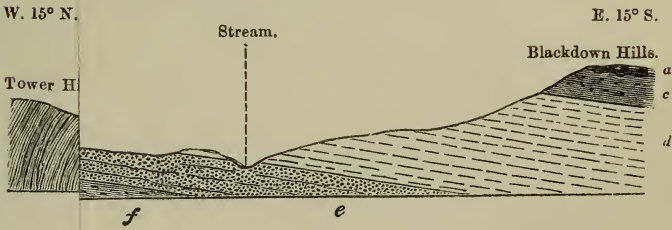
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Numerous faults affecting intercalated marl and sandstone beds.

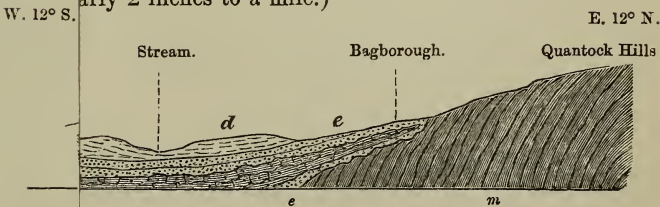


nches to a mile.)



Gravelly T

arly 2 inches to a mile.)



- a. Blue Limestone.
- b. Shales and Grits.
- c. Cherts and Shales.
- d. Sandstones.

- e. Greenstone.
- * Red clay, probably belonging to the lowest Triassic series.
- † Rhætic beds.

Fig. 1.—South-Devon Coast Section. (Horizontal scale about $\frac{6}{10}$ inch to a mile.)

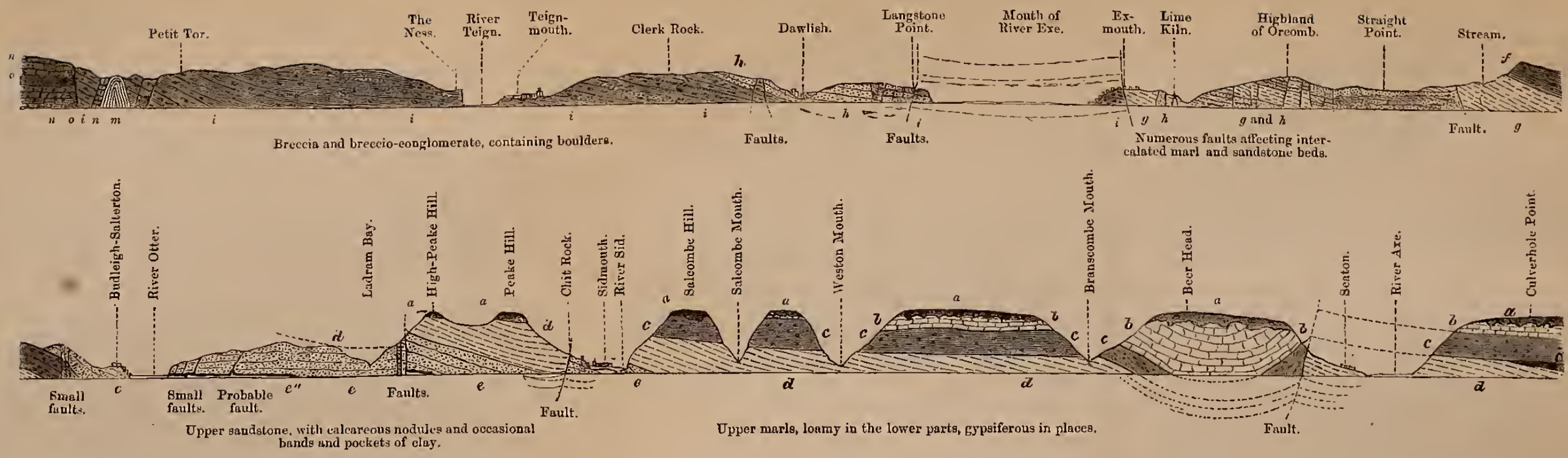


Fig. 2.—Section across the Triassic Valley near Burlescombe. (Horizontal scale nearly 2 inches to a mile.)

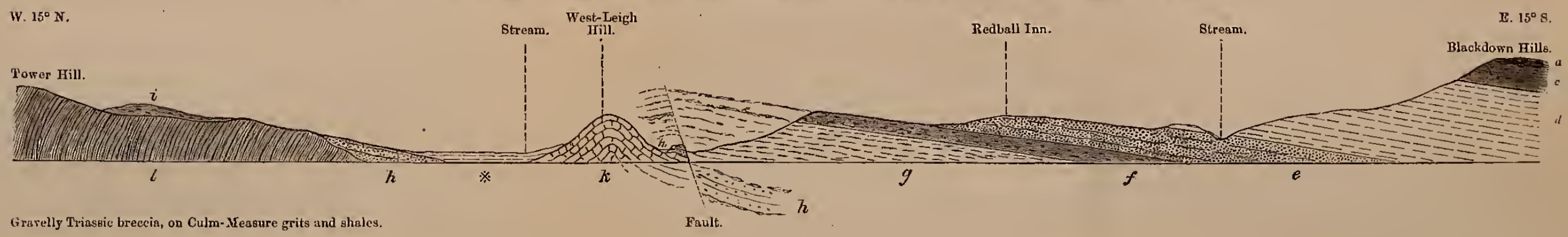
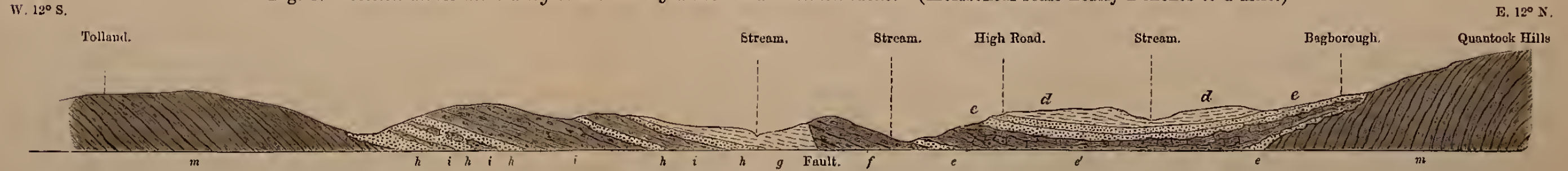


Fig. 3.—Section across the Valley between the Quantock and Brendon Hills. (Horizontal scale nearly 2 inches to a mile.)



- | | | | | |
|--------------------------------------|--|----------------------|-------------------------------|---|
| a. Clay with flint or chert nodules. | d. Upper Marls. | g. Lower Marls. | k. Culm-Measure Limestone. | o. Greenstone. |
| b. Chalk. | e. Upper Sandstones: e', calcareous; e'', conglomeratic. | h. Lower Sandstones. | l. " " Shales and Grits. | * Red clay, probably belonging to the lowest Triassic series. |
| c. Upper Greensand. | f. Pebble-beds and Conglomerate. | i. Breccia. | m. Devonian Grits and Shales. | † Rhætic beds. |
| | | | n. Devonian Limestones. | |

Here, then, we have five distinct and mappable divisions of the Trias, occupying an area of about 500 square miles—that is, between Watchet and Minehead on the north and Paignton and Axmouth on the south, and between Durston on the east and Wiveliscombe on the west. Of this area, however, the only member of the Trias of Devon and Somerset that we can speak confidently about, regarding persistence, viz. the Upper Marls, occupies about a half. Whether borings made at Taunton or Axmouth would cut through all the other divisions in vertical succession, beneath the Upper Marls, or subsidence over the whole area proceeded unequally, so that the other divisions were local, and conformably overlain in some places, and overlapped in others, by the marls resting on the older rocks, as we proceed eastwards, is entirely conjectural.

We will now treat briefly of each division in descending order, beginning with

The Upper Marls.

These, from their outcrop beneath the Penarth, or Rhaetic beds, cover a larger area, superficially, than any other member of the series. Between Durston and Langport, East Ninehead (north of Wellington), and the Lias plateau of Hatch Beauchamp, Sidmouth and Axmouth, they extend, concealed by the overlapping Upper Greensands of the Black Downs, over many places between Taunton and the coast.

They consist of red marls, variegated greenish grey, sometimes with slightly bluish bands in their upper portions—locally, as at Dumpdon, north of Honiton, greenish grey, mottled red. In the coast sections of Watchet and South Devon they are intersected, in places, by numerous gypseous veins; occasionally, as on the coast* west of Sidmouth, potato-stones are to be found in them. In the coast section, in their lower beds, we find them retaining their marly structure, but losing their calcareous nature, and in the beds immediately overlying the sandstones, in places, almost passing into rock-sand; in the cuttings north of Sidmouth, on the branch line, a thick bed or two of sandstone occurs in them near their junction with the underlying sandstones. Many disused marl-pits are to be met with over the area they cover.

Thickness.—In estimating the thickness of these beds we cannot take a persistent dip across the wide area they cover, ignoring probable undulations and faults; this would give an enormous thickness, in excess even of that which we should infer from their exposure on the coast, where we have a distance of about 8 miles between their outcrop south of Axmouth and the mouth of the river Sid, where they overlie the sandstones. In this distance their continuity is broken by a large fault at Whitecliff, near Seaton. A considerable allowance must be made for the synclinal trough which

* Pseudomorphs of rock-salt crystals have been obtained between Peak and High-Peak Hills and near Salcombe mouth in the coast-section marls by Mr. Ormerod, the author, and others.

lets down the Chalk and Upper Greensand, between Whitecliff and Branscombe Mouth. In assigning a dip of 3° , persistent over an area of 5 miles, allowing a deduction of 3 miles for the synclinal at Beer, &c., we are scarcely making an underestimate. This would give a thickness of about 1350 feet. I do not think they exceed 1000 feet further inland.

The lower beds, sandy marls, lead us by an easy conformable passage to the consideration of the next member of the group.

The Upper Sandstones.

These consist of sandstones and rock-sands, red in the coast section; generally red but often yellowish, buff and grey, resembling the Upper Greensand in colour in the interior; locally mottled grey, in spots and streaks as at Ninehead, near Wellington; containing pockets of red clay in parts of the coast section, and in the railway-cuttings north of Sidmouth lenticular bands of marl in the top beds, and near Milverton and Wellington beds of clay in their lower portions (= WATERSTONES).

At Otterton Point they contain two or three conglomeratic beds, and a few pebbles in false-bedding lines, also observable near Harford, 5 miles north of the Point.

Calcareous nodules, and veins and nodules of ironstone occur in them on the coast, and in many localities inland. Between Crowcombe-Heathfield station (south of Watchet) and Bishops Lydeard these beds become exceedingly calcareous; about the middle of the division they present a nubby appearance and bluish grey colour with occasional red spots, and might locally be almost considered a limestone. From a minute investigation of the Watchet district, my colleague, Mr. Blake, suggested the possibility of these marlstone beds representing a portion of the hitherto unfound Muschelkalk; but from an acquaintance with the whole area where the Upper Sandstones are present, I can only regard the local variation the beds here assume as an intensified form of the calcareous bands and nodules to be met with in many places between Bishops Lydeard and the south coast.

The discovery of organic remains in the South-Devon and West-Somerset Trias seems to be confined to this division, the respective finds of my friends Messrs. Lavis and Whitaker being in its upper and lower beds.

A conglomeratic bed occurs in the sandstone at Ninehead (near Wellington), but apparently much higher up than the beds of Otterton Point. The Otterton beds were observed and commented on by Mr. Pengelly and many other able observers long before I knew of their existence, and have become of peculiar interest as the site of the *Hyperodapedon* found by Mr. Whitaker.

On Woodbury Common, north of Exmouth, the rock-sands very much resemble Greensand in colour, and in the older Survey map have been mistaken for it.

These sandstones frequently exhibit false-bedding.

Extent.—With one exception south of Williton, where these beds are faulted out, they run with an average breadth of outcrop of $1\frac{1}{2}$ mile, between Williton and Otterton Point, a distance of over 30 miles: in sheet 22 of the Ordnance map, north of Otterton Point their breadth of outcrop appears to be from 3 to 4 miles; but this is probably due to repetition by faults.

Economic Uses.—At Watt's Bridge, near Bishops Lydeard, some hard thick-bedded sandstones, used for building-purposes, occur in this division. Between Bishops Lydeard and Crowcombe the calcareous sandstones are largely quarried to burn for lime.

Thickness.—In estimating the thickness of these beds we cannot allow more than a mile and a half of outcrop, north of Ottery St. Mary, which, with a dip of 3° persistent, would give a thickness of about 400 feet. If we take the coast section, it is plain that an estimate made at right angles to the strike, measuring outcrop from their junction with the last capping of marl (supposing the absence of disturbances) to the outcrop of the pebble-beds of Budleigh Salterton, would give the true thickness.

Estimates have been previously made ignoring any disturbances in these rocks as displayed on the South-Devon coast, on the ground that the beds cut out by faults, would balance those repeated: a glance at the section of these sandstones made from close observation of the coast will, at least as far as this division is concerned, show the fallacy of this reasoning. The fault at Chit Rock brings down about 200 or 300 feet of Upper Marls—the same sandstones there cut off appearing again at the base of the cliff south of Peak House, and again outcropping on the surface south of High Peak, but not finally, as a fault with a downthrow of about 50 feet again brings down Upper Marl a little to the north of the Preventive Station at Ladram Bay. About 80 yards further south the first cutting-out fault occurs, which disposes of about 5 feet of marl; but this is more than counteracted by another fault not 80 yards further south, which throws down about 14 feet of marl, the sandstone finally emerging from the last capping half a mile south of the road to the beach, at Ladram. Even from this point we cannot take the coast section, as it frequently represents the strike of the beds, and in many places they appear perfectly horizontal, whilst in one place, as may be seen in the section, either a fault or a crack (I have not yet succeeded in ascertaining which) by inland evidence occurs. So, allowing the coast-section sandstones an outcrop of $2\frac{3}{4}$ miles, and a persistent dip of 2° , we have a thickness of about 530 feet—if any thing, an excessive estimate.

Both from a better acquaintance with these beds as shown on the coast, and to point out a few of the difficulties in the way of estimating the thickness of the divisions, even where the relations between the under and overlying members are observable, I have gone into their occurrence in the coast sections at greater length.

The traces of conglomerate at Otterton Point may be considered indicative of a passage into the next series—

The Pebble-beds of Budleigh Salterton and of Burlescombe, and the Conglomerates of Milverton.

This division affords 3 distinct lithological types, passing from one to the other, I believe horizontally; but, owing to this being the thinnest member of the Trias of Devon and Somerset, it is the most affected by faults, so that the changes in composition cannot be always traced.

We will commence with the coast, as the conglomerate in the Williton district is so much faulted where present and so often absent, owing to the same cause, as well as so similar to that of Milverton and Wiveliscombe, that it would form a bad starting-point.

The following are general characteristics of all three types—well-worn nature of contained fragments, impersistent strips and beds of rock-sand and sandstone intercalated, and general thickness of beds.

At Budleigh Salterton the pebble-beds form, for nearly 20 chains, the substratum of the beach, dipping conformably under the Upper Sandstones and overlying Marls which dip towards the north-east at an angle of 5°. They consist of about 100 feet of large ellipsoidal quartzite pebbles of foreign derivation (as far as at present known)* in red sand, and containing impersistent strips and beds of rock-sand. As far as I have yet seen, the quartzite pebbles seem to give way gradually to grit and quartz, and to become smaller north of Aylesbere Hill, between Whimble and Ottery St. Mary. Between Tallaton and Uffculm, though the feature is generally persistent, the pebble-beds are present only at intervals along the line of feature, but sufficiently close to justify me in considering their absence due to faults. Thus they are shown at Blue Anchor, Higher Tale, Clist, William's Cross, Kentisbere, Pirzwell, Higher South Hill, and Bull Moor, near Uffculm. In most of these patches the pebbles are smaller than those south of Tallaton. At Uffculm and Uffculm Down they consist of pebbles of grit and quartz (in some places compacted by ironstone into comparatively hard beds), in a red-sand matrix, and containing strips of sand. At Burlescombe they exhibit the appearance of a loose gravel of small quartz pebbles in sand. Between Uffculm and Whiteball Hill their absence in one or two places is manifestly due to faults. Near Thorn St. Margaret, they appear to be passing into a hard rock, but the immediate change into the conglomerates, faulted against them, cannot be observed. The conglomerates of Thorn St. Margaret, Milverton, Castle Hill, near Wiveliscombe, Combe Florey, &c. contain pebbles (generally large) of limestone and Old Red Sandstone, and smaller ones of quartz (the limestone pebbles being in excess of or less than the others in different places) in a matrix of hard red sandstone, generally slightly calcareous. The beds are generally massive; but those at the top of sections often appear much thinner than the rest. Subangular fragments of grit and

* Mr. Peach advocates their derivation from certain quartzites in Cornwall.

quartz sometimes occur in the matrix, and give the beds the slightly hybrid character of a breccio-conglomerate, as at Vellow near Stogumber.

It is possible that the thick-bedded breccias of Wembdon, overlain as they are by sandstones, and containing intercalated beds of sandstone, may prove to be the representative of the conglomerate division in the Bridgewater area.

Thickness.—As the conglomerates and pebble-beds seldom exceed 100 feet in thickness, and both contain intercalated beds of sandstone, so that in some places a section might display more sandstone than conglomerate, it is probable that the local absence of this division may be due to replacement, and the sandstone beds traced from Otterton Point (between the conglomeratic bed there and the pebble-beds) pass into conglomerate in other parts of the district.

Mr. Pengelly noticed the feature made by the pebble-beds of Budleigh Salterton, being the line of hills running thence to Tallaton. In tracing the conglomerates from Wellington southwards, I found that feature maintained, even where the beds themselves were absent, indicating a fault junction between Upper Sandstone and Lower Marls.

Economic Uses.—The pebble-beds of Uffculm and Burlescombe are quarried for gravel*. The conglomerates of Milverton, between Thorn St. Margaret and Alcombe, near Minehead, are quarried out for building-purposes, but more often for the sake of the contained limestone pebbles to burn for lime.

I have not found seams of clay in either the conglomerates† or the pebble-beds. In one instance (east of Whimble) at Straightway‡ Head, I was informed that they had worked out a bed of clay in excavating the gravel.

In mapping the conglomerates west of Milverton I noticed clay, but concluded it was merely a soil or beds in the conglomerate. Near Tiverton Junction, however, the extent of ground it occupied led me to a better understanding; but it was not till the summer of 1873, in making a rapid survey of the coast section, that I recognized the true nature of the loamy clays in

The Second Series of Marls.

Underlying the pebble-beds conformably, we find red marls, variegated greenish grey in bands, and slightly calcareous in the upper beds. They seem to continue only for $\frac{3}{4}$ mile from their outcrop, under the pebble-beds on the top of the cliffs, in unbroken succession,

* P. O. Hutchinson, Esq., of Sidmouth, informs me that manganese was worked in the pebble-beds at Yattington (or Yettington), a hamlet to the north of Budleigh. In sheet 22 of the Ordnance map.

† Except where the base of the overlying sandstones consists of intercalated beds of clay and sandstone, when the top beds of conglomerate may occur in or with clay.

‡ Straightway Farm is called by the inhabitants Straightgate Farm.

and for $1\frac{1}{4}$ mile along the beach, but long enough to expose all the homogeneous portion of the deposit in the coast section. South of Westdown Farm some grey sandy beds begin to emerge on the beach; but a fault throws them against coarse red and greyish sandstones, of which, with a capping of marl, Straight Point consists. Beds of clay occur in these sandstones, which may either be the beds under the grey bed on the beach before alluded to, faulted up (in which case they would probably be beds of sandstone in the marl), or lower sandstones. The Lower Marls contain many beds of sandstone frequently impersistent in their lower portion. These are only mappable as far as Woodbury, owing to a thick loamy clay soil which effectually conceals the marly structure as well as any changes the deposit may undergo. From Straight Point to Exmouth numerous faults obscure the relations of the beds affected by them*; I have noticed nine of these. The relations of the marls are still further obscured by the last fault at Exmouth, which brings up the lower divisions and not even the upper beds of that.

Between Straight Point and Exmouth the principal difficulty consists in the position to which we assign the faulted sandstones. Some of them are undoubtedly beds in the marls, and as such indicate a passage into the lower series; but the sandstones of Straight Point, near Littleham, Withecombe, and Lymptone might well be taken as belonging to the lower division of sandstones, underlying the Lower Marls, and overlying the breccias of Heavitree, east of Exeter, and the breccia at Dawlish.

The Lower Marls occupy a considerable area, with an average breadth of 2 miles between Exmouth and Burlescombe. They lie on the slopes and low ground below the pebble-bed feature; but, owing to the thick loamy clay soil concealing them, it is difficult either to obtain dips or to trace faults, except by inference, in them. This loamy soil may be in a measure due to washes of sand from the feature above, whilst the superficial portions of the marl were redeposited by the former streams that assisted in the excavation of the valley of the Culm.

Where the valleys are broad, as in the Vale of Taunton, and between Topsham and Exmouth, I have not found much difficulty in observing the structure of the Upper or Lower Marls. Between Burlescombe and Castle Hill, near Wiveliscombe, the Lower Marls are much cut up by faults throwing them against conglomerate and Lower Sandstone, and near Westford, west of Wellington against Upper Sandstones. Northey Farm, near Fitzhead, north of Wellington, is the only instance in which they are altogether absent between Stogumber and Exmouth. This had been mapped by my colleague Mr. H. B. Woodward before we recognized this division at all; and the faults drawn by him in that instance, and in a few square miles he had mapped in the vicinity, amply account for the absence of the marls at Northey Farm, and are not susceptible of correction. Between this farm and Bicknoller (near Williton) the Lower Marls

* Marls with beds of sandstone, and sandstones with beds of marl.

are faulted against breccia (lowest series), Conglomerates, Upper Sandstones, and Upper Marls.

Economic Uses.—The loamy clay soil affords material for brick-making. The continuity of this division might almost be proved by the numerous brick-pits in its soil between Burlescombe and the coast, as in Leonard Moor, north of Tiverton Junction, east of Collumpton, Clist Hydon, near Exmouth, north of Burlescombe, at Cutcomb Farm east of Wiveliscombe. South of Williton, a thick drift-gravel often conceals the second marls.

Thickness.—We have now to consider the slender evidence procurable to assist us in arriving at an approximate estimate of the thickness of this division. If we could take the bed of grey sandstone on the north side of the fault, south-east of Westdown Farm, as the top bed of the Lower Sandstones, the breadth of outcrop*, allowing a persistent dip of 5° , would give a thickness of 530 feet. 600 feet is the utmost I should be inclined to allow for the whole division inland.

If the sandstones of Straight Point are beds in the Marl, indicating a local passage into the Lower Sandstones, and do not represent the upper portion of the Lower Sandstones themselves, they can scarcely add more than 300 feet to the thickness of the Lower Marls in this part of the district, giving a total thickness of 830 feet.

Unfortunately, inland we have no better data to go upon, as, in the cases where the relation between the marls and their over- and underlying beds are observable, their own structure is concealed. Allowing the average breadth of area† they cover as the breadth of outcrop, with a dip of 2° persistent, their thickness would be about 360 to 400 feet.

The intercalations of sandstones with the marls on the east of Exmouth seem to indicate a passage into the upper member of the lowest division in South Devon.

Lowest Division.

In considering this division (so far as we know, the lowest, and certainly the most varied member) of the Devonshire Trias we must treat the constituent parts, locally and lithologically, according as they are represented by (lower) sandstones, hard breccias, breccio-conglomerates, brecciated sands, brecciated loamy clays, or clays. In so doing it must not be implied that beds in different localities, of the same lithological character and composition, are either contemporaneous or occupy the same position in the division.

Where present, in the area between Minehead and the south coast, these beds present many different phases, occurring as sandstones and sands, brecciated sands and sandstones, gravelly breccias (conglomeratic) clays, often brecciated with shale-fragments, sandstones, and sands which occur intercalated at any horizon. Gene-

* $1\frac{1}{4}$ mile.

† About 2 miles, *i. e.* varying from 1 to 3.

rally in the southern part of the area sandstone seems to be the upper variety, faulted out at Exmouth*, but appearing immediately north of it, and probably occupying the bed of the Exe as far as Topsham, where it is developed. Between Topsham and Silverton it covers a considerable area with an average breadth of about two miles. It probably conceals other varieties of the division at Poltimore. Between Heavitree and Honitons Clist (east of Exeter) these sandstones appear to dip with the ground, and to contain traces of clay. Owing to the sudden changes the members of this division present, it is almost impossible to say whether the absence of Lower Sandstones about Bradninch is due to replacement by breccia, or whether their development north of Collumpton is due to the concealment of lower beds of different character, or to change from breccias.

Due east of Burlescombe the whole division is either concealed by Lower Marls, faulted out, or represented by clay-beds. Traces of the sandstones (Lower) occur at Ford Place and near Whipcoats. West of Thorn St. Margaret the Lower Sandstones either conceal or represent all the lower varieties of the lower division; for their junction with the Lower Marls is a faulted one, as also north and east of Thorn St. Margaret, where they are let in by faults. Between Thorn St. Margaret and Wiveliscombe the visible part of the lower division is chiefly represented by sandstones, faulted against the Devonian at Horridge Down, south of Wiveliscombe (fault shown in the railway-cutting).

It is very likely that north of Burlescombe these sandstones represent the middle or lower beds of the division, and not the upper part, as at Honiton's Clist and Broadclist. A large east-and-west fault from Grant's Farm, north of Wiveliscombe, shifts the position of all the divisions on the north side of it eastwards; so that we find sandstones and breccias of the Lower Series faulted against Upper Sandstones, and Conglomerates and Upper Sandstones against Upper Marls. From this fault to Washford (near Williton) the lower division is well developed. It is much faulted north of Stogumber. In this district sandstones generally occur intercalated with breccias; but, where separable, are found to underlie them.

From a point between Bilbrook and Roadwater, to Dunster, marls generally conceal the sandstone, which is shown at Withycombe and Dunster Park. I am inclined to consider these last belonging to the Upper divisions, and the absence of the rest of the series due both to numerous faults and overlap; but this is only a supposition, based on lithological affinities which are not always trustworthy.

From Dunster to Minehead sandstones occur in the Lower division, where it is thrown up by faults. Between Bratton and Selworthy, west of Minehead, sandstones with intercalated beds of breccia, which Mr. H. B. Woodward concurs with me in referring to the Lower series, occur. South-west of Grabbist Hill a thin fringe of sandstones and intercalated breccias occurs, probably overlapped

* At Dawlish red sandstones overlie the breccia, and are apparently brought down by successive step-like faults between Langstone Point and Dawlish.

and to a great extent concealed by Lower Marls, as, between the western extremity of Grabbist Hill and Horner (south-east of Porlock) the Lower series is developed principally in the form of breccia. South and west of Luckham sandstones occur either resting on or faulted against the older rocks.

Character of Lower Sandstones.—These beds consist of red-rock sands and hard sandstones, and differ from the Upper division in being almost uniformly red. They are stained blackish at Lower Welshford, near Thorn St. Margaret, near Gaulden Farm, south of Tolland, and in the neighbourhood of Luckham; though sometimes slightly calcareous, the network of concretionary veins and the calcareous nodules, often locally distinctive of the Upper Sandstones, are generally wanting*. They are also found passing into, intercalated with, and containing seams and beds of breccia, and at Bradninch associated inseparably with a gravelly breccio-conglomerate. In distinguishing them from the Upper Sandstones by colour I should have made a notable local exception in the light-coloured and banded sands and sandstones of Torbay. The Lower Sandstones, where the Lower division is developed, are found over the area treated of to occur at almost any horizon with reference to the other varieties, and also inseparably associated with them.

Breccias.

In describing the different purely lithological varieties of breccia we will first consider the apparently uppermost form exhibited in the coast-section. In the Shrubbery at Exmouth we find red sandstones brecciated with numerous angular grit-fragments, generally of a uniform size; the same general character is displayed by the breccias of Langstone Point and Dawlish, and, in a less degree, by breccia at the Docks in Exeter†. North of Exeter in many places brecciated rock-sands and sandstones occur, differing from the Dawlish breccias either by the fragments contained being closer and the matrix more impure, as shown in some of the railway-cuttings north of Stogumber, by a difference in the material, as displayed in the breccias containing shale and grit-fragments resting on Culm-measures on the north of the Tiverton Valley, or by resemblance to a gravel in containing rounded as well as angular and subangular fragments close together and of various sizes, as in the neighbourhood of Bradninch and Roundham Head, near Paignton,

* I have hitherto failed to detect the presence of gypsum in the Lower Marls; though it is possible that marls containing veins of gypsum near Withycombe (Williton district) may belong to this division, I am inclined upon other grounds to ascribe them to the Upper-Marl division.

† Fragments of igneous rocks are numerous in the Teignmouth and Dawlish breccias; and in parts of the Crediton valley the breccia is almost wholly made up of them.

Murchisonite is most plentiful in the breccia south of Exeter and in the Crediton valley. The crystals when found singly, as is often the case in the last-named locality, exhibit signs of attrition on their edges.

So far as I am aware, few, if any, fragments of igneous origin are found in the conglomerate and pebble-bed division

on the coast. The gravelly breccias in the vicinity of Tiverton, Col-lumpton, and Cadbury, near Crediton exhibit a matrix of brown earthy sand in which the fragments are often loose.

Hard Breccias.—Between Clerk Rock, north of Teignmouth, and St. Mary's church the coast-section exhibits hard breccias, often very thickly bedded, readily distinguishable from the Dawlish variety by their presenting all the characteristics of a hard rock in which matrix and contents are weathered alike, and not like the Dawlish breccias, from the weathered surfaces of which the fragments stand out, being much more indestructible than the matrix. The stones contained in the Teignmouth breccias are of all sizes, from boulders as large as a man's head to pebbles the size of a pea, and exhibit a much greater variety of derivation than the rocks of Dawlish; they also show a various amount of attrition, from perfectly unworn fragments to rounded boulders. The contained fragments consist of Devonian grit, granite, trap, quartz, and limestone rocks, in varying proportions, Devonian-grit stones being in considerable majority, limestone fragments occurring locally. The matrix consists of hard reddish sandstone, often coarse-grained. Inland the breccias of Heavitree, east of Exeter, and of Sampford Peverell exhibit some resemblance to those of Teignmouth: the contained fragments are angular and subangular, smaller than the average of those on the coast; and limestone is absent in the former. At Halberton and Sampford Peverell, at the mouth of the Tiverton valley, hard-bedded breccias occur, containing fragments of culm grit, limestone, and quartz; north of Sampford Peverell these beds present the appearance of a conglomerate.

At Canon Leigh, near West Leigh, a few beds of hard breccia are visible, faulted against culm limestones; east of Bathealton, south of Wiveliscombe, they dip over Lower Sandstones, and are cut out by a fault bringing up Lower Marls. North and north-east of Wiveliscombe breccias occupy high ground, dipping over Lower Sandstones, and at Castle Hill faulted against Lower Marls; here they contain rounded fragments and are not thick-bedded.

Between the great fault north of Fitzhead (near Wiveliscombe) and Lydeard St. Lawrence the beds present more the appearance of a conglomerate than a breccia, containing pebbles of grit, quartz, and limestone. North of Lydeard St. Lawrence beds of breccio-conglomerate and hard breccias occur, intercalated in brecciated sands and Lower Sandstones; but the general character of the breccia in the neighbourhood of Luckham*, Williton, and Stogumber is more in accordance with the breccias of Dawlish (with many exceptional phases, all of which have their congeners between the Watchet district and the south coast of Devon) than those of Teignmouth.

We cannot here go into all these minor modifications which the breccias present. In numerous instances, on the older rocks, bordering the Tiverton and Crediton valleys, and on Spray Down,

* A band of gravelly breccio-conglomerate, first noticed and mapped by my colleague Mr. J. H. Blake, occurs in the breccia near Luckham, and somewhat resembles the gravelly breccia of Bradninch in character.

near Broadclist, the Trias assumes the character of a brown gravelly mass containing numerous large grit boulders, with an earthy matrix and very feeble evidence of stratification. In all the varieties of breccia previously alluded to, local beds and impersistent bands of sand and sandstone may occur at any horizon.

The next (and, so far as I am aware, the final) variation this division assumes is not present on the coast, and only very locally observable inland, viz. brecciated loam and clay and intercalated clays and coarse sand finely brecciated. Exeter and the Crediton valley, and between Silverton and Bradninch, are the only localities in which I can speak with certainty of its occurrence.

The railway-cutting near Queen's-street Station, Exeter, shows red loamy clay, brecciated with shale-fragments, and containing a few even red-sandstone beds intercalated. Culm-shales are observable cropping out in one place at the base of the cutting; so that either there is a fault between Queen's-street and the Docks, where breccias somewhat resembling those of Dawlish occur at a much lower level, or the floor of the older rocks on which the Triassic beds were deposited is exceedingly uneven. However, as the mapping of Exeter is not quite completed, the question is open to settlement.

In St. Sidwell's parish, Exeter, brecciated loamy clay (fragments of culm-shales), with beds of red clay and loamy clay, occasionally brecciated, are shown. In places north of Newton St. Cyres, near Whipton, and near Polestow, north-east of Exeter, dark-red clay, mottled grey in the latter place, and in parts thickly brecciated with shale-fragments, occurs.

South of Thorverton and east of Crediton the beds are very variable, showing dark-red loamy clay, bands of coarse reddish-brown brecciated sand with lines of grey sandy loam, coarse dark-red sand and sandy loam, reddish-brown and red laminated sand, breccia of shale, igneous and grit-fragments in sand and loam, and breccia of small grit, igneous and quartz-fragments.

No definite position can be assigned to these clay-beds in the lowest division, as they probably locally replace the other lithological constituents.

We have now glanced at the lowest division of the Devon and West Somerset Trias, in itself exhibiting affinities to each and every other member of the group,—the clay-beds to the Upper and Lower Marls, the sandstones to Upper Sandstones, and the breccio-conglomerates to the Conglomerates, whilst the gravelly breccias exhibit some points of similarity to the Pebble-beds. We find the greatest and most complete development of this division exhibited in the coast of Devon, from Exmouth to Torquay and Paignton, in the valleys of Crediton and Tiverton, and north of the great fault north of Milverton. In the intervening districts we have pointed out the probability of some of the unrepresented varieties being concealed by the one superficially developed, and, by mentioning the occurrence of sandstones at the top of the division about Exeter and Broadclist and at apparently the bottom, from Wiveliscombe and Bathalton northwards, shown the possibility of the absent breccias being

represented by replacing sandstones. In close proximity to those localities where the Lower Division seems entirely absent we have pointed out at least two* considerable faults affecting the junction of the Trias with the older rocks, and shown the numerous disturbances displacing the members of the Trias; so that, though there is a possibility of the Lower Division being absent altogether in one or two places, facts seem to point to its elimination by faults or concealment by the Lower Marls.

Economic Uses.—At Woodcock's Well, west of Collumpton, and Cowley Moor, north of Tiverton, bands or lenticular masses of clay occur in the Lower Sandstones, and afford material for brick-making in both those places.

At Langford (Langord on Ordnance Map), near Upton Pyne, brecciated sandstones have been worked for manganese. Breccias and sands at Luckham, stained blackish, have been worked for iron-ore. In two brick-pits near Montle Grand, in Exeter, clay and brecciated clay are used for brick-making, the shale-fragments being burnt in the brick, which is hard and rough.

The breccias of Heavitree, Luckham, and Sampford Peverell are quarried for building-purposes, and, in the last-mentioned place also for burning lime, owing to the contained limestone.

Thickness.—Here, again, we are at a loss in forming an estimate of the thickness of the division as exposed in the south coast. In the first place, there is a probability of at least a hundred feet of sandstone being cut out at Exmouth; in the next, though many high dips are to be seen in the beds between Exmouth and Torquay, my friend Mr. H. B. Woodward assures me that they are in many cases due to faults, and that the beds are in numerous instances comparatively horizontal; it is also evident that the coast-line cannot represent their thickness, as it crosses the line of dip diagonally, so that, instead of 10 miles from Exmouth to Torquay, we must take 7 miles between Exmouth and Chudleigh. Starting with a fault, and the probability of several more occurring, but not to be traced, owing to homogeneity of beds traversed or variability of the division, any attempt at estimating their thickness would be very untrustworthy.

South of Exeter the area occupied by this division has a breadth of from 6 to 8 miles; north-east of Exeter about 3 miles, two of which may be taken as occupied by tolerably horizontal Lower Sandstones, and the lower beds as concealed. The broadest part of the Crediton valley occupied by these beds is $3\frac{1}{2}$ miles; but, both on the north and south side of the valley, they appear to dip away from the older rocks, forming a synclinal trough, the sandstones at Upton Pyne, on the south side of the valley, apparently concealing breccias. The axis of depression is a little to the north of Bramford Speke †.

* At Horridge Down, south of Wiveliscombe, and at Canon Leigh, near Westleigh.

† This synclinal axis seems to pass into the Culm-measure area on the south-west of Newton St. Cyres. West of St. Cyres the Trias in the Crediton valley is almost exclusively composed of breccia containing numerous fragments of igneous rocks.

Assuming the rocks north of this axis to be unfaulted, the few dips I have taken in them, averaging 10° due south, must not be taken into account, as they are only local; and any estimate before the whole valley is resurveyed and a more minute examination made of the part already gone over, would be premature.

The Tiverton valley, with a breadth of 4 miles north and south through Halberton, seems also to present a synclinal in these beds.

If we allow a tolerably persistent thickness for the Lower Division over the whole area, which is very unlikely, the Watchet district might afford a clue. Assuming that their average width, about a mile (south of Stogumber), is a persistent outcrop where the whole thickness of the division is represented, a persistent dip of 8° would give a thickness of about 720 feet. Allowing the coast-section beds to represent a maximum development, Mr. Woodward agrees with me in considering 1000 feet as an outside estimate for them.

General Observations.

In the foregoing all the estimates made of the thickness of the divisions must be considered merely approximations based upon such material as the survey of most of the district has supplied me with. Tracts yet remain to be investigated which will probably throw more light upon the relations of two of the divisions—the Pebble-beds and the Lowest Division.

Mr. H. B. Woodward has subdivided the Triassic rocks in the immediate neighbourhood of Williton, and in that district fully corroborated the sequence of which it is the object of this paper to attempt a description. As previously stated, I do not insist that this sequence is present over the whole area covered by Triassic rocks in West Somerset and Devon, or even over a much greater space than where it is exposed.

In a slowly and unequally subsiding area beds of breccia may have been forming before the land under the area now covered by the Upper Marls had come within the influence of the destructive and accumulating agencies at work in other portions of the district; and, when it did, the sediment deposited may have been of a totally different character. I only desire to show that, from the outcrop of the Upper Sandstones to the older rock-margin, this sequence, considering the impersistent nature of the divisions, is, we might almost say, abnormally persistent.

At Exeter, about Silvertown and south of it, in the Crediton valley, and at the western extremity of the Tiverton valley, patches of basalt occur in connexion with the Lowest Division. Their mode of occurrence and composition will be treated of in the Geological-Survey memoir.

The frequent high dips exhibited by the lower beds of the Trias down the slopes of the older rocks, upon which they rest, decreasing in amount of inclination, though generally persistent in direction as we recede from their (the older rocks') superficial limits, the presence of patches of the lower beds of the Trias on the Palæozoic Highlands,

as at Stoodleigh Beacon and Spray Down, and the rough parallelism to the old rock-margin exhibited by the majority of the faults affecting the Trias seem to lead to the conclusion that a partial upheaval, at least, of the rocks on which the Lower Division of the Trias rests, in Post-Triassic times gave their easterly tilt to the Secondary Rocks, and probably aided in producing the folds observable in the Culm-limestones of West Leigh and its vicinity.

To what extent the Triassic beds may have suffered from denuding forces since that elevation, and how far the upheaval of the older rocks has been Post-Triassic, is a question upon which future investigations and careful survey will probably throw some light. The existence of gravel patches upon the older rocks, near the margin of the Triassic area, in some districts, the fact that material for the formation of such gravels would be readily furnished by the disintegration of certain varieties of breccia of the Lowest Triassic division*, the fact that this gravel actually overlies and is hardly separable from an outlying patch of brecciated sand near Stoodleigh Beacon, 6 miles north-west of Tiverton, and isolated by nearly 2 miles of Culm-measure shales and grits from the main mass of the Trias, and the careful indication of three minute patches of sandstone (probably of the lower series) on the top of Grabbist Hill near Minehead, by my friend and colleague Mr. Blake, all lead to the inference of a very much greater extension of the Devonshire and West Somerset Triassic rocks before the upheaval which (probably successively?) exposed them to denuding forces, and, leaving but very few traces as beacons of their former site, afforded by their destruction plentiful material for the formation of subaerial gravels and thick soils.

Thickness †.

Summing up the outside and very problematical estimates want of better compel me to offer, we have for—

Upper Marls	1350
Upper Sandstone	530
Conglomerates	100
Lower Marls	600
Lower Sandstone and Breccia	1000

3580 feet in all,

though 2500 feet appears a more likely estimate.

* Some of these outlying patches of High-Level Gravel have been visited since the above had gone to press; and I do not now entertain a doubt as to their Triassic age.

† The different amount of the dips allowed in forming estimates of the thickness of each division would at first sight appear anomalous in a conformable series of beds; but when the different localities from which the estimates have been made, and the local variations so commonly experienced in the occurrence of the divisions, are taken into account, the difficulty of obtaining results from one locality alone will be appreciated.

General Deductions.

We find in the area last treated of a tolerably persistent series of conformable strata of much greater thickness and more variable composition than that of the Bridgewater district and the other tracts covered by Triassic rocks south of the Mendips, whilst in the area north of the Mendips they seldom exceed 200 feet.

Hence we are justified in considering that the area east of the Quantocks and of Taunton, and south of the Mendips, was dry land during the deposition of the Breccias, Lower Marls, and Conglomerates in the West-Somerset and South-Devon areas, and did not come within the influence of the Triassic waters till after the commencement of the deposition of Upper Sandstones in the latter. The question as to the correlation of the Devon and Somerset Trias with that of Lancashire, Cheshire, Staffordshire, Leicestershire, and Warwickshire yet remains to be solved. Whilst the Upper Marls and Sandstones of the South-coast and Watchet areas, and their easterly extension to the Bridgewater area, and that of the former, at any rate, to the southern flanks of the Mendips, leave no room for doubt as to their Keuper age, and the dolomitic conglomerate and marls north of the Mendips are evidently the later deposits of the Keuper period, we are at a loss to account for the remaining members of the South-Devon Trias.

Taking an average of 2187 feet for the Keuper in the midland counties, and 924 feet as the average thickness of the Bunter, from Prof. Hull's table of thicknesses in his memoir on the Permian and Trias (p. 108), we have a total of 3111, or about 460 feet under the outside estimate allowed for the South-Devon Trias. Of that estimate of 3580 feet, the Upper Marls and Sandstones, which are evidently of Keuper age, constitute 1880 feet.

If the remaining 1700 feet be taken as Keuper, we have an abnormal development; but if, as appears most likely, the lower divisions are of Bunter age, the absence of unconformity throughout the series makes it evident that no break here took place during the Muschelkalk period, but that that hitherto unfound division must have its British representative in South Devon. Whether we consider the Pebble-bed division or the Lower series of marls as representing the Muschelkalk, it is evident that if we consider the Lower beds as Bunter, it must also be represented.

It would be puerile were I to infer that, because no lithological equivalent occurs, contemporaneous deposition did not take place, and would be in the face of the evidence I have endeavoured to bring forward as to the interchangeable nature of the constituents of single divisions within a limited area, as, for instance, the marlstones almost replacing the Upper Sandstones near Bishop's Lydeard and at Cothelstone, and the different positions occupied by the sandstones in the Breccia division in the north and south parts of the area.

As every one knows, the nature of accumulating sediments depends largely upon the materials whence they were derived, which is well instanced in the dolomitic conglomerates of the Mendip

country (where the old rocks were chiefly composed of Carboniferous Limestone), the prevalence of arenaceous deposits at the base of the Trias fringing the north-east and south slopes of the Devonian grits and shales of the Quantocks, the basement breccias and sands of the West Somerset and South Devon Trias (where the older rocks chiefly consist of Culmiferous and Devonian shales and grits), and the admixture of calcareous material in the form of derived fragments or in the matrix in places where neighbouring exposures of limestone were favourable for their production; so that we are not only unable to see any reason why the Muschelkalk should present similar characteristics in different areas, but fail to see why its representative should form a perfectly distinct division.

Whether the Budleigh pebbles travelled from Normandy or Cornwall, their advent seems to mark an epoch in the Triassic history of Devon, when either by the breaking of a barrier, allowing the incursion of foreign sediments into a salt lake or inland sea, or by a natural extension of the local sources of derivation, a supply of foreign material was swept into the area, furnishing the depositing agents with a different supply from that which had before been and was afterwards afforded by the local rocks.

In the Geological-Survey memoir on this area the bibliography of the subject will be gone into, and these few precursory notes will be modified and strengthened, when additional observations, greater latitude, and time allow us to enter into details and amplify many in our possession not alluded to here*.

DISCUSSION.

Mr. ETHERIDGE remarked that the Rhætics form a most important feature in Somersetshire. He thought that the ignorance of the Triassic rocks so common among geologists was to be ascribed to a great extent to the want of interest attaching to these non-fossiliferous red beds; and hence our thanks were due to those who, like Mr. Ussher, would work upon them.

Prof. RAMSAY said that Sir Henry De la Beche grouped the whole of the Triassic rocks together, but nevertheless there was no doubt that he fully understood their nature. In passing over part of the country, he had once fancied that some of the lower breccias might be Permian; but he had never been able to investigate the matter.

The AUTHOR remarked that if the Lower Breccias were Permian, the Bunter and Muschelkalk must be also represented, in the absence of unconformity.

* Should any of my observations tally with those of my predecessors in the field, I have only to state that the latter part of this epitome has in a still more abstracted form appeared in the 'Geological Magazine,' dec. 2, vol. ii. No. 4, April 1875, and has been strung together and condensed entirely from my own notes and observations.

41. *On the Discovery of Melonites in Britain.* By WALTER KEEPING, Esq., B.A., of the Woodwardian Museum, Scholar of Christ's College, Cambridge. (Read March 22, 1876.)

(Communicated by Professor Hughes.)

IN the appendix to a paper read before the Geological Society, June 9, 1875, I noticed the discovery of a large Urchin, nearly allied to the American genus *Melonites*, from the Carboniferous Limestone of Derbyshire, and preserved in the museum of the Geological Survey. I have since been permitted to examine the specimen more carefully, so as to determine it to be a new species of *Melonites*, a type of Echinoids characterized by its numerous ranges of ambulacral plates, which until now was unknown beyond the boundaries of the New World.

Another fragment, smaller, but well preserved and presenting all the characteristics of the species, may be seen in the British Museum.

Description of the specimens.—The larger specimen is a confused mass of stout plates covering an area of $7\frac{1}{2}$ inches by 7 inches. Among these may be seen some broad bands and broken masses of another set of plates, which are each perforated by a pair of pores. From the arrangement of this latter system of plates, converging, as they do, roughly to the centre of the specimen, we see that this is the remains of one large Echinoid broken up and much disarranged, the larger scattered plates having formed its interambulacral areas, the masses of smaller plates its ambulacral zones.

The interambulacral plates (figs. 3, 4) are very numerous, and are all about the same size, which shows that new series of plates were intercalated to form the increasing circumference towards the equator of the test, where there must have been as many as eight or nine* ranges of plates. The plates themselves are very thick, and are rather irregular in form, most of them being unequally six-sided; others are pentagonal, with one face rounded. These latter formed the marginal ranges of plates, and they are marked with indentations for the ambulacral plates, with which they articulated. The surfaces of all are ornamented with closely set minute tubercles.

The plates were articulated with each other in a very irregular manner, some of their edges being perpendicular to the surface, while others are inclined as much as 30° , every intermediate stage being seen. The marginal ranges share the irregularity so characteristic of this Urchin; for some of these plates are bevelled off from their upper edges, others from the lower, so that in some parts of the test the ambulacral areas overlapped the interambulacrals, in others *vice versá*.

The ambulacral areas are in better condition. When the test was crushed their plates still cohered, and the areas were broken up into

* Supposing, as the specimen seems to indicate, that the circumference of the test was that of a circle with $3\frac{1}{2}$ inches radius, then, the ambulacral areas being 36 millims. broad (see *infra*), the interambulacral areas were 72 millims. broad; and allowing each interambulacral plate 8 millims., there were nine ranges of such plates at the ambitus.

masses of various shapes, the larger ones remaining as broad bands converging to the centre. Their upper surface is distinctly convex both longitudinally and laterally; on one border they are festooned to receive the convex articulations of the adjoining interambulacral plates; but the opposite edge is a regular simply denticulated border (ω , fig. 1). I therefore believe that these masses are broken *halves* only of the ambulacral areas—the festooned edge being the outer border of the area and the denticulated edge its middle line. An examination of the constituent plates confirms this view; for the pores which they bear are *all situated towards that edge of the plate which is nearest the festooned border*.

We have seen that each half of an ambulacral area is convex laterally; they are in fact much more convex than the general surface of a test 7 inches in diameter could have been; and they must therefore have stood out as ten broad ribs on the test, set in pairs separated by a gentle valley in the median part of the ambulacral areas, and by the broader planes of the interambulacral areas.

The half ambulacral areas, as here preserved (see fig. 2), are composed of six or seven ranges of small irregular plates, which are broader than high, thicker than broad, and ornamented with minute tubercles like the interambulacral plates. The middle ranges are more regular. Each plate is perforated by a pair of pores, subtriangular where best preserved, and situated close to that edge of the plate which is nearest the festooned border. Although the plates are so irregular, yet the pores are most of them arranged in lines and set in shallow grooves running longitudinally upon the areas. On the internal surface of the test these grooves (or “poriferous furrows,” as they may be called) are represented by a corresponding set of ridges.

The tubercles form a very uniform granulation over the whole test, but are best marked on the ambulacral areas. They are imperforate, without boss, and are of two orders: the larger ones, which are most numerous, are surrounded by a smooth areola, bounded by an elevated ring (fig. 5); contiguous rings are almost in contact.

On the surface of one of the ambulacral masses and elsewhere on the block some minute acicular spines are abundantly scattered; the microscope shows them to be sulcated, with a prominent collar at the base (fig. 6).

The dimensions of the specimen are as follows, viz. :—

	in.	millim.
Greatest length of specimen	$7\frac{1}{2}$	
Greatest breadth ,,	7	
Average length of interambulacral plates		8
Average breadth ,, ,,		6
Average thickness ,, ,,		$3\frac{1}{2}$
Length of an ambulacral plate		4
Breadth ,, ,,		2
Thickness ,, ,,		$3\frac{1}{2}$
Breadth of half ambulacral area		19
Length of spine		3-6

Figs. 1-6.—*Melonites Etheridgii*, *sp. n.*, from the Carboniferous Limestone of Derbyshire.

Fig. 1.



Fig. 4.



Fig. 3.



Fig. 2.

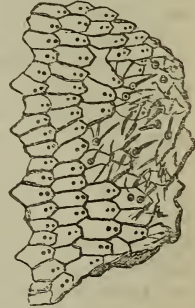
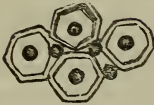


Fig. 5.



- Fig. 1. Crushed specimen of *Melonites Etheridgii*, *n. sp.*, half nat. size (Museum of Practical Geology).
 Fig. 2. The ambulacral mass marked χ in fig. 1. The outer festooned border and the spines are shown.
 Fig. 3. An interambulacral plate, showing the bevelled edge and the tubercles.
 Fig. 4. One of the marginal interambulacral plates, showing the grooves for the articulation of the ambulacral plates.
 Fig. 5. Tubercles, magnified. N.B. The rings around the tubercles are here made to look too angular and too prominent.
 Fig. 6. Spine, much magnified.

The British-Museum specimen is smaller (4 inches by 3 inches); but it is a fragment of probably quite as large an individual, as we see from the size of its plates.

On one side the test has been much disturbed, the whole surface being covered with a confused mass of interambulacral plates and a few ambulacrals; but on the other surface we have a well-preserved interambulacral area composed of five or six ranges of plates, an extra range being intercalated between the others as we approach the equator. The outer edges of the bordering ranges are bevelled off, showing that they were overlapped by the ambulacral plates; these latter are seen confusedly heaped together in two masses bordering the interambulacral area on either side.

The tubercles and spines are well preserved.

It is remarkable that whereas in the larger specimen the ambulacral areas are preserved with their plates in position amid the scattered plates of the interambulacral system, here it is the ambulacral ranges that have given way, while the interambulacrals still preserve their natural relations.

MELONITES ETHERIDGII, n. sp.

Specific Characters.—*Test* large (diameter of crushed specimen $7\frac{1}{2}$ inches), spheroidal (?), composed of very thick plates arranged in five ambulacral and five interambulacral areas. All the plates ornamented with minute tubercles for the support of the spines.

Interambulacral areas broader than (twice as broad as?) the ambulacrals, composed of numerous (nine?) ranges of plates, marginal ranges pentagonal, the rest hexagonal, articulating with each other by faces which vary from a right angle to one of thirty degrees with the exposed surface. *Ambulacral areas* large ($1\frac{1}{2}$ inch wide), each consisting of two broad ribs separated by a slight depression along its median line running from mouth to anus; composed of numerous (twelve to fourteen) ranges of irregular plates, each perforated by a pair of simple pores on its outer margin.

Tubercles minute, imperforate, without boss, of two orders, the larger kind surrounded by a smooth areola, bounded by an elevated ring.

Spines small (length 3–6 millims.), tapering, coarsely sulcate, with a prominent collar round the articular end.

Affinities and Differences.—The only forms which require a close comparison with our fossil belong to the genera *Melonites* and *Oligoporus* of the group Perischoechinidæ; with these it agrees in the thickness of its test, its numerous ambulacral and interambulacral plates, and in the absence of large tubercles; but *Oligoporus* has not more than four ranges of plates in its ambulacral areas.

As a species, this is well distinguished from *Melonites multiporus*, N. & O., by the characters of its ambulacral areas: these are composed of twelve or fourteen ranges of plates separated into two zones by a median depression, and the two middle ranges are not larger than the others; in *M. multiporus*, N. & O., they are composed of eight

ranges of plates, with a prominent median *ridge* formed by arched plates which are twice as large as the others.

M. Etheridgei is perhaps further distinguished by the size of its tubercles and spines, no trace of either of these being seen in the beautiful specimens of *M. multiporus* preserved in the British Museum*. Although some of the plates in this Urchin articulate with each other by inclined faces, yet I do not believe that its test was flexible, but rigid, as is proved by the thickness of the plates and the mode of preservation of the ambulacral areas; therefore it must be classed in the group of *Perischoëchinida tessellata*†.

I have named this species after Mr. R. Etheridge, F.R.S., and take this opportunity of thanking him for that assistance which he is ever ready to give.

Locality and Formation.—Both the specimens are from the Carboniferous Limestone of Derbyshire.

DISCUSSION.

Prof. MORRIS remarked that certainly *Melonites* was hitherto unknown in England. The American species has 8 ambulacral and 7 interambulacral ranges of plates. He thought the specimen was in too imperfect a state of preservation to show whether the valleys described by the author as dividing the ambulacral areas really existed.

The PRESIDENT remarked that the presence of the spines in these specimens was very interesting, as the spines of *Melonites* were previously unknown. He inquired as to the true relationships of this genus, and whether it approached the Crinoids, and stated that similar plates were to be met with in abundance in a separate state in the Lower Carboniferous shales near Glasgow.

Mr. KEEPING stated that Mr. J. Young had mentioned to him the existence of traces of *Melonites* in the Glasgow shales. He explained further the grounds on which he assumed that the ambulacral areas showed a double convexity; and, in reply to the President, stated that he regarded these Urchins as allied to the Cystoids, and mentioned that a Russian form of Caradoc age, described by Schmidt, is intermediate between the Echinoids and Cystoids, the part described by that author as the mouth being really the mark of a stalk.

* Prof. J. Hall kindly informs me that *Melonites multiporus* has no tubercles or spines on the test, the plates being simply pustulose over the entire surface.

† *Perischoëchinida tessellata*, as defined by me, Q. J. G. S. Feb. 1876.

42. *The GLACIAL CLIMATE and the POLAR ICE-CAP.* By JOSEPH JOHN MURPHY, Esq., F.G.S. (Read June 21, 1876.)

In a paper "On the Nature and Cause of the Glacial Climate," in the *Journal of the Society for 1869* (p. 350), I gave my reasons for thinking that the glacial climate was not one of intense cold, but of snowy winters and cold summers, with a small range of temperature—in four words, *not Siberian but Fuegian*. I agree with Mr. Croll that a glacial epoch is one of maximum eccentricity of the earth's orbit, and that the northern and southern hemispheres, during such an epoch, are glaciated alternately. Where I differ from him is, that while he thinks the glaciated hemisphere has its *winter* in aphelion, I maintain, on the contrary, that the glaciated hemisphere is that which has its *summer* in aphelion. Mr. Croll, in his work on 'Climate and Time,' has replied to me; and I propose in this paper to supplement my former one and give a fuller exposition of my views, showing also where I think he has fallen into error.

I quote the following from 'Climate and Time' (p. 54):—

"According to the calculations of Leverrier, the superior limit of the earth's eccentricity is 0.07075. Lagrange's determination makes the superior limit 0.07641. Recently the laborious task of reinvestigating the whole subject has been undertaken by Mr. Stockwell, of the United States. He has taken into account the disturbing influence of the planet Neptune, the existence of which was not known when Leverrier's computations were made; and he finds that the eccentricity of the earth's orbit will always be included within the limits of 0 and 0.0693888."

In order not to take too high a value, and for facility of calculation where minutely accurate results as to the effect on climate are unattainable, I take the maximum eccentricity at 0.069. The following tabular statement shows the sun's mean, perihelion, and aphelion distances, at present, and at maximum eccentricity, the ratios of the same, and the ratios of heat received by the earth at each distance:—

	At present.	At maximum eccentricity.
<i>Sun's distance in miles.</i>		
Mean	91,400,000	91,400,000
Perihelion	89,864,000	85,093,400
Aphelion	92,936,000	97,706,600
<i>Ratios of distance.</i>		
Mean	1.000	1.000
Perihelion	0.983	0.931
Aphelion	1.017	1.069
<i>Ratios of heat received.</i>		
Mean	1.000	1.000
Perihelion	1.035	1.154
Aphelion	0.967	0.875

The sun's aphelion distance occurs at present near the midsummer of the northern hemisphere; so that if, as I maintain, glaciation is the result of a cold summer due to the remoteness of the sun, the glaciation has to be accounted for by the heat received by the earth at the northern midsummer being less than at present in the ratio of 0·875 to 0·967, equal to 0·905 to 1·000, or nearly a tenth part less.

The following attempt to estimate the effect of this difference on terrestrial temperatures is by the method adopted by Mr. Croll from Sir John Herschel ('Climate and Time,' p. 37).

The temperature of space is estimated by Pouillet and Sir John Herschel at -239° Fahr. The mean temperature of the entire northern hemisphere for July is estimated by Dove ('British-Association Report, 1848) at 71° . The mean July temperature of the northern hemisphere is therefore 310° above that of space—in other words, 310° degrees warmer than it would be in the absence of the sun. If, then, the amount of solar heat received by the earth is diminished in the ratio of 0·905 to 1·000, the temperature due to the sun should be diminished in about the same ratio, or from 310° to 280° ·5, say by 30 degrees.

This estimate makes, of course, not the slightest pretension to accuracy; but it is probably nearly enough true to give an idea of the scale of the effect. In one way it is much too high. There would not be time to produce the result: the remoteness of the sun when at aphelion distance would not have so great an effect on climate as if his distance were permanently increased. But on the other hand, we have every reason to believe that Herschel's and Pouillet's estimate of the temperature of space is much too high; and the greater the difference between the temperature of the earth's surface and that of space, the greater will be the effect of any variation in the sun's distance.

The hemisphere which has its summer in aphelion has its winter in perihelion; and the winter temperature will be raised by the nearness of the sun about as much as the summer temperature is lowered by his remoteness; so that the annual range of temperature will be greatly diminished, without necessarily altering the mean temperature at all. The mean annual temperature will no doubt be lowered, from causes to be stated further on; but for the present we will suppose it unchanged. If, then, the midsummer temperature is lowered by 30° and that of midwinter raised by as much, the effect on the annual range will be 60° ; and this will be enough to destroy the present difference between summer and winter in all except the most extreme climates. According to Mr. Keith Johnston, jun. ('Proceedings of the Royal Society of Edinburgh,' 1868-69), there are only three regions of the earth where the range is more than 60° : these may be roughly defined as Siberia with Central Asia, part of North America with Baffin's Bay and part of Greenland, and Lapland.

In the following tabular statement I assume the eccentricity to be at its maximum, and the perihelion to occur at the midwinter of

the northern hemisphere, which under those circumstances I believe to be the glaciated one. The parallel columns describe the climates of the world at the two solstices :—

<i>When the Earth is in Perihelion.</i>	<i>When the Earth is in Aphelion.</i>
The northern hemisphere has a mild winter.	The northern hemisphere has a cool summer.
The equatorial region has its hot season.	The equatorial region has its cool season.
The southern hemisphere has a hot summer.	The southern hemisphere has a cold winter.

It is thus seen that the southern hemisphere will have an extreme annual range of temperature, while that of the northern is very small; and not only so, but the effect of the equatorial hot season will spread far into the northern hemisphere, making the winter of at least the lower latitudes of that hemisphere warmer than the summer. This reversal of the seasons will probably in no case extend to the pole; in the immediately circumpolar regions the summer will always be warmer than the winter; but the line of no annual range, where the temperatures of midsummer and of midwinter are the same, instead of being, as now, near the equator*, will be perhaps near the Arctic Circle. If this is the case, the eccentricity is a little too great for the maximum of glaciation. The condition most favourable to glaciation will probably be that where the line of no annual range is at or near the margin of the polar ice-cap. But if the maximum of eccentricity is too great for the maximum of glaciation, the degree of eccentricity which will produce the maximum of glaciation will be attained at some time while the eccentricity is approaching, and again while it is receding from, its maximum.

The statements in the above tabular form would probably be accepted by every one as self-evident, if they applied to a globe having its surface all land, so that the subject of climate was not complicated by the thermal effects due to evaporation, condensation, freezing, and melting; and Mr. Croll in that case would not have propounded his strange paradox, that the mean temperature of the whole earth at maximum eccentricity is higher when in aphelion than when in perihelion. The principles stated in the above table, however, are not physical, but purely astronomical; and we have now to trace their physical results.

Round the north pole there is a considerable area, including Greenland and great part of the Asiatic and American continents, where the mean temperature of the year is below the freezing-

* See the paper by Mr. Keith Johnston, jun., already referred to.

point, and where consequently the ground at some depth is always frozen. Yet so far is this frozen area from being covered with perpetual ice, that there is no continental ice on any part of Asia or America; and though the interior of Greenland is covered with a true continental ice-sheet, yet this descends to the sea only at particular places, forming glaciers resembling, in all but magnitude, those which descend into the Alpine valleys. In few if any parts of the northern hemisphere does the ordinary line of permanent snow descend to the level of the sea. The reason of this is, that the short summer is warm enough to melt away the winter's snow. So effectually is this done, that in Siberia trees grow and crops of rye are harvested over a permanently frozen subsoil.

But let us suppose, what has repeatedly occurred, that during a period of maximum eccentricity, the precession of the equinoxes gradually brings the midsummer of the northern hemisphere round until it coincides with the aphelion. The total amount of heat received from the sun at any given latitude will remain unchanged, but, as shown above, the range of temperature will be greatly lessened. Suppose that at the border of the frozen circumpolar area (that is to say, along the isothermal of 32°) the annual range of temperature is reduced to nothing, so that the temperature is always freezing, the result will be that over the frozen area the ice and snow will never melt, and a polar ice-cap will be formed.

In one way this is a little overstated; for in no region is the climate quite invariable, and even where the mean temperature of the warmest month does not rise above 32° , there will no doubt be some melting. This, however, will have no effect, except slightly to diminish the extent of the ice-cap at its margin; and it will probably be much more than counteracted by the spreading of the ice-cap, from the same causes that make a glacier descend. Moreover the ice-cap will tend to extend itself, in consequence of the effect of masses of ice in preventing the temperature in their neighbourhood from rising much above the freezing point. For this reason the accumulation of ice will depress the temperature, especially the summer temperature, along the margin of the ice-cap; and this chilling effect will be spread into lower latitudes by means of cold currents and icebergs.

The ice-cap, as Mr. Croll has elaborately shown, will, by displacing the earth's centre of gravity, draw a greater share of ocean-water to the glaciated hemisphere; and this will promote glaciation by diminishing the range of temperature; for the range is always least in oceanic climates. Meantime the non-glaciated hemisphere will have a climate of opposite character—a climate of extremes. This is partly because of the withdrawal of ocean water from it, which will increase the area of land and make the climate more continental; but chiefly because of the nearness of the sun in summer and his remoteness in winter. The instances of Siberia and North America show that such a climate may produce a vigorous forest vegetation, which appears to be injured by no severity of

winter cold ; and such was probably the climate of Greenland when it was clothed with forests.

It is true that a long and cold winter will be favourable to the formation of ice, by the freezing of water. But no great accumulation of ice, like that of the glacial period, can have been due to this cause, because the freezing of water is such a slow process that the thickest ice thus formed does not approach the thickness of a moderately thick glacier.

Thus the great heat of the perihelion summer will rapidly melt away the snow which has fallen during the aphelion winter. The question of the effect of summer heat on glaciation is, practically, to what height the temperature of the hottest month is able to clear the mountains of snow. This height is the height of the snow-line ; and I have shown in my former paper, by an appeal to the facts of physical geography, that this depends chiefly on the temperature of the hottest month.

Humboldt, in his 'Cosmos,' makes the interesting remark, that if the mountains of the world were high enough, we should see an upper as well as a lower limit to the region of perpetual snow. That is to say, at a very great height the snowfall would be so small that the snow would disappear by evaporation under the summer sun. It seems not unlikely that this actually took place during the perihelion summer at maximum eccentricity, when the amount of heat received by the earth in perihelion exceeded what it is now in the ratio of 1.154 to 1.035, equal to 1.115 to 1.000, or about 10 to 9.

There is one fact of physical geography, which seems at first sight to support Mr. Croll's theory that the glacial climate was due to an aphelion winter, and not, as I maintain, to an aphelion summer. In the Antarctic regions there is a glacial climate now ; the entire Antarctic continent is covered with perpetual snow down to the water's edge ; yet the Antarctic summer is in perihelion. Mr. Croll thinks this is the normal state of things, and in support of his theory he states (p. 77) that

"1. The mean temperature of the southern hemisphere is less than that of the northern.

"2. The winters of the southern hemisphere are colder than those of the northern.

"3. The summers, though occurring in perihelion, are also comparatively cold.

"4. The mean temperature of the whole earth is greater in June, when it is in aphelion, than in December, when it is in perihelion."

I believe it may be confidently asserted that the first two of these statements are erroneous. The mean temperatures of the two hemispheres appear to be very nearly the same : what makes the great difference in their climates is difference of range of temperature. As compared with the northern hemisphere, the range in the southern is less ; the summers are cooler, and the winters warmer. The following tabular statement of the climates of the two hemispheres is from Mr. Hopkins's paper on "Changes of Climate" in the 'Quarterly Journal' of this Society, vol. viii. (p. 72) :—

Lat. 20° N.		Lat. 20° S.	
Mean	75	Mean	74.5
Range	14	Range	9
Lat. 30° N.		Lat. 30° S.	
Mean	68	Mean	69
Range	20	Range	12
Lat. 40° N.		Lat. 40° S.	
Mean	54.5	Mean	53.5
Range	35	Range	9
Lat. 50° N.		Lat. 50° S. (Falkland Islands).	
Mean	39	Mean	43
Range	46	Range	18

We know nothing of the winter temperatures of the Antarctic continent; but it seems in no way improbable that there also the range is comparatively small, so that the mean temperatures are not lower than those of corresponding Arctic latitudes, though the summer temperatures no doubt are lower. From the fact that the southern summers are cooler than the northern, it follows that the mean temperature of the whole earth is lower in the southern than in the northern summer. All this is generally and satisfactorily referred to the law that maritime climates are less extreme than continental ones, in consequence of water taking longer than land to become heated and to become cooled; and the climate of the southern hemisphere is on the whole maritime, and that of the northern continental. But if the relative extent and distribution of land and sea were nearly the same in the two hemispheres, I cannot doubt that, contrary to Mr. Croll's opinion, the southern hemisphere, having a perihelion summer and an aphelion winter, would have a warmer summer and a colder winter than the northern.

If, however, it is hereafter shown that the mean temperature of the Arctic regions is much higher than that of the Antarctic, this will be amply accounted for by the influence of the warm currents of the Atlantic. Mr. Croll has shown what an enormous quantity of heat they carry northward; but there are no corresponding currents in the southern hemisphere. The currents that carry heat into the North Atlantic and the Arctic Ocean receive their direction, first from the coast of South America, which diverts the equatorial current to the north-west, and afterwards that of Europe, which diverts the Atlantic currents to the north-east*. Mr. Croll is probably right in supposing that the glaciation of the northern hemisphere would cause the north trade-wind to blow further south than at present, and that this would diminish the volume of the Gulf-stream, and so tend still further to lower the northern temperatures. But this cause would

* See 'Climate and Time,' map facing p. 212.

not act during the glaciation of the southern hemisphere, because, in consequence of the totally different disposition of the land, there are not in that hemisphere any great poleward currents.

My theory of the glacial climate, however, does not come into collision with Mr. Croll's on the subject of ocean currents, because the effect on climate of any change in the currents will be the same in kind, whether glaciation is caused by an aphelion winter or an aphelion summer. Such a change in the currents as Mr. Croll supposes cannot begin to act on climate until a change of climate has first begun to divert the currents. I think, however, that the cold of an aphelion summer at maximum eccentricity will amply account for the glacial climate by its direct effect, without any agency of ocean currents being needed.

43. *On the METAMORPHIC ROCKS surrounding the LAND'S-END Mass of GRANITE.* By S. ALLPORT, Esq., F.G.S. (Read June 21, 1876.)

[PLATE XXIII.]

IN the following notes I propose to lay before the Society the results of a microscopical examination of certain metamorphic rocks surrounding the Land's-End granite. In doing so my principal object will be to point out the structural and mineralogical changes produced in clay-slates and certain igneous rocks by the intrusion of a mass of granite, and also to compare the phenomena of contact-metamorphism with those produced by other agencies in rocks of similar character at a distance from the granite.

On referring to the map of the Geological Survey of Cornwall, it will be seen that in the vicinity of Penzance the granite is surrounded by a belt of altered Devonian slates extending from St. Ives Bay on the north coast to a point a little beyond Mount's Bay on the south; they also occur along the coast north-east of Cape Cornwall, and reappear in the same direction at Porthnear Cove and near Zennor. The so-called greenstones occur in four distinct groups, also round the outskirts of the same mass of granite, viz. around Penzance and in the other localities just mentioned. In all cases they are represented as occurring in the altered slates either at a short distance from the granite or in actual contact with it.

A microscopical examination of both these groups shows at once that they have all been highly metamorphosed, and that the alteration varies greatly in character and extent according to the nature of the rock and its distance from the granite. The change observable in the so-called greenstones, for example, differs essentially from that produced by the intrusion of the granite among the clay-slates. In specimens of the former, taken at some distance from the granite, the alteration consists principally in the formation of pseudomorphs quite similar to some described by me elsewhere in the Carboniferous dolerites of Scotland; while, nearer the granite, similar rocks have been completely decomposed, and hornblende has largely replaced the original constituents.

The action of the granite on the slates in immediate contact with it, however, has been far more direct and energetic, the result being the frequent introduction of new minerals, and the conversion of an ordinary clay-slate into a crystalline foliated rock.

On approaching either of the granite masses of Cornwall, one cannot fail to recognize the fact that the clay-slates gradually assume a different character: they become more and more indurated and are traversed in all directions by numerous quartz-veins; they frequently become more or less micaceous, schorl begins to make its appearance, and at the junction of the two rocks their slaty character has in many cases been completely obliterated. In the neighbourhood of Penzance the petrological relations of the granite to the adjacent sedimentary deposits may be readily observed in

many places. At Mousehole, St. Michael's Mount, and Cape Cornwall, where good junctions are exposed on the shore, there is not the slightest indication of a gradation from one to the other; the mass of granite cuts sharply through the slates, and has thrown out numerous veins, both large and small, which have penetrated them in various directions. In all such cases the slates have evidently been greatly altered along the line of junction; and fragments of them have not unfrequently been torn off, and are now enclosed in the granite. There can be no question, therefore, that the granite here presents all the characters of an intrusive igneous rock; and it will presently be seen that its action on the surrounding strata is chiefly characterized by the development in them of some of the minerals which constitute its own mass, and that occasionally the original lamination of the fine sedimentary matter has been replaced by a very distinct foliated texture. It should be stated, however, that a decided foliation is restricted to the immediate vicinity of the granite.

MICROSCOPICAL EXAMINATION.

I. *Metamorphic Rocks of Sedimentary Origin.*

Slates in contact with Granite.

Hand-specimens showing the junction of the two rocks may be obtained with a little trouble; and, as was observed in the case of the larger masses, the altered slates never pass gradually into granite, but present a distinct line of separation when examined by the naked eye or pocket-lens. This is well seen in Pl. XXIII. fig. 1, drawn half the natural size from a polished slab. The dark streaks on each side of the granite-vein represent folia composed of tourmaline with a little mica.

Tourmaline-Schist.—Under the microscope a thin slice exhibits, however, a kind of junction rather difficult to describe in words. Both rocks then appear to be so intimately associated together as to form one continuous siliceous mass; they are, in fact, so completely blended that the line of junction can only be recognized by the presence of innumerable grains and crystals of mica or tourmaline which have been developed in the slaty portion of the slice, while the opposite half presents the usual crystalline granular texture of granite. This is the appearance presented when the crystals of mica and tourmaline are moderately large and not too numerous; when, however, they occur in very small grains, and thickly crowded together, the line of junction becomes far more sharply defined. Pl. XXIII. fig. 2 represents a junction with slate from Mousehole, as seen in a thin slice cut from the same specimen as fig. 1. The granite has here cut through the slate obliquely to the plane of bedding; and this coincides in direction with certain lines of foliation, in which small grains of mica and tourmaline are arranged in irregular streaks alternating with narrow bands and lenticular patches of quartz. The folia containing the larger grains consist

almost exclusively of brown tourmaline (dark shade in figure), together with good examples of its micaceous or chloritic pseudomorphs; and the intervening layers are composed of finely granular quartz, sometimes clear and colourless, but more frequently stained by a brown colouring matter, also disposed in parallel bands. We have here, therefore, an example of the conversion of a clay-slate into a somewhat micaceous tourmaline-schist. Another specimen, also taken close to the granite, and within twenty yards from the one just described, is a still more characteristic example of a tourmaline-schist; it consists wholly of folia of crystalline granular tourmaline alternating with others of quartz, as seen in Pl. XXIII. fig. 3. The entire section is drawn twice the natural size, and represents accurately the relative proportions of the two minerals. The tourmaline does not occur in distinct crystals, but appears to have run in among the grains of quartz, and to be moulded on to them, as shown in fig. 4, which is a small portion of the same section magnified 50 times.

Mica-schist.—In the same locality, and at a distance of a few yards only, a different bed of slate has been converted into mica-schist.

The mica is a reddish-brown lepidolite, the crystals of which occasionally contain laminae of a pale green colour; a little schorl also occurs here and there along the line of junction; and in one slice there are three small veins of well-crystallized tourmaline showing the prisms arranged nearly at right angles to the sides.

In a very fine-grained compact schist, also in contact with the granite, the mass of the rock is crowded with innumerable minute scales of lepidolite arranged in undulating lines interspersed with narrow stripes of clear quartz.

The junction of the two rocks is here very sharp and well defined.

A section of the fine-grained schist, at about 15 feet from the granite, exhibits a most remarkable arrangement of both quartz and mica, as shown in Plate XXIII. fig. 5. The general appearance is that of an irregular foliation produced by the linear grouping of numerous red spots, each surrounded by a clear ring, and alternating with narrow bands of red mica and strings of quartz. In the figure, the clear spaces are quartz containing either extremely minute specks of mica, or none whatever; the granular parts consist of numerous larger flakes, thickly crowded together, with small grains of magnetite disseminated here and there among them. In this case the two constituents are not merely foliated in the usual way, but have also undergone a further process of segregation into spheroidal and elliptical nodules. This structure is well brought out in polarized light; for the clear crystalline quartz forming the oval rings then exhibits colours differing from that of the surrounding parts, and the nodules thus appear to be distinctly separated from them. Concurrently with this process of rearrangement and partial crystallization of the silica, some of the flakes of mica became crowded together in clusters towards the centre, while others were at the same time pressed outwards so as to occupy the angular spaces and lines between the numerous adjacent nodules. Moreover all the

nodules are elongated in the direction of the irregular planes of foliation,—a clear indication, I think, that in this instance metamorphism was effected under an amount of pressure sufficient to interfere with the process of crystallization; or possibly the nodules were originally spherical, and were forced into their present form while the mass was in a somewhat plastic condition.

A singularly interesting example of metamorphism is afforded by a specimen of altered slate from Botallack, collected close to the granite, and represented in Pl. XXIII. fig. 6. On examining a thin slice, the first thing that strikes one is the occurrence of innumerable minute black grains of magnetite arranged in rather wavy lines of foliation, which traverse the section from side to side, and occasionally bend round small patches of quartz. Then there are numerous long flat blades of nearly colourless tremolite, many of which are arranged in radiating groups, while others lie at all angles to each other; and thickly scattered through the quartzose matrix there are crowds of small flakes of lepidolite, none of which are to be found in the tremolite. The most remarkable and interesting point is, that the undulating parallel lines of black granules pass uninterruptedly from the base through and across the blades of tremolite, several of which are thus traversed by two or three rows of granules; and as the flakes of mica also contain them in considerable numbers, it is evident that the black grains must have been arranged in lines prior to the crystallization of either tremolite or mica. We have here, I think, the distinct record of two great changes in the structure of the rock—first its conversion into foliated schist, and subsequently the development in it of the tremolite. But, during the process of crystallization of this mineral, the structural character of the mass became greatly changed; and the final result has been the production of a highly crystalline rock in which the bands of black granules constitute the only vestige of its previous foliated texture.

There is no doubt as to the hornblendic character of the bladed prisms; for, by cutting slices at right angles to each other, there are seen several excellent transverse sections of the four-sided prism with opposite angles of $124^{\circ} 3'$.

Cape Cornwall.—Specimens containing junctions of granite and slate from Cape Cornwall present the same general characters as those from Mousehole, but also occasionally afford some interesting varieties of texture. In one thin slice the granite contains many small crystals of tourmaline irregularly scattered through it, while parallel with the line of junction, yet still well within the granite, they form a narrow band composed of numerous prisms, and associated with them are many plates of white mica; then there is a well-defined sharp junction with a fine-grained micaceous schist consisting of green, white, and red mica, together with quartz and tourmaline. Close to a large granite-vein seen on the shore, there is an imperfectly foliated schist of very similar character to the one previously described from Botallack: it contains similar lines of black granules and red mica; but instead of tremolite, there is a clear

mineral which may be andalusite ; it gives moderately bright colours in polarized light ; but as it only occurs in granular patches and irregular plates closely aggregated, I have not been able to make a satisfactory determination of it.

St. Michael's Mount.—At the well-known junction of the granite and slate on the south side of the Mount, a porphyritic granite occurs in contact with a fine-grained mica-schist of dark-purple colour, the junction being very sharp and well defined. The granite contains a few small prisms of tourmaline ; the mica is white, while that in the altered slate is deep red.

A thin slice showing both rocks contains a narrow vein extending from the granite through the slate at right angles to the line of junction ; it is filled with white mica and a little quartz, and along both sides numerous flakes of red mica are thickly crowded together, being of larger size than in other parts of the slice. Another specimen from the Mount is a fine-grained white granite in contact with a contorted mica-schist, the diminutive crumpled folds consisting of red mica and small grains of magnetite. The crumpling was probably not caused by the intrusion of the granite, as the pressure by which it was effected evidently acted at right angles to the line of junction. This is the best example I have hitherto observed among Cornish rocks of contortions on a microscopic scale. The structure, however, is far more fully developed in other localities ; and I will conclude this portion of the subject with a brief description of two specimens selected from several, for which I am indebted to Prof. Hull and Mr. Wylie ; they are from the granitic district of the south-east of Ireland, where the granite is intrusive in Lower Silurian slates.

Plate XXIII. fig. 11 represents the metamorphosed portion of a thin slice showing the junction of slate and granite near Ennis-corthy, county Wexford. The granite is of medium texture, with black mica disseminated through the mass. The altered slate is very fine-grained and of a dark colour ; but with a lens there may be seen numerous small specks of light colour, which impart to it an appearance of foliation.

The black mica of the granite is strongly dichroic, changing from deep reddish brown to yellow ; the plates are often broken, ragged at the ends, and the laminae partially separated from each other. The altered slate is an extremely interesting object. It is an imperfectly foliated gneiss containing numerous small well-formed crystals of orthoclase surrounded by innumerable minute flakes of brown mica which stream round them in flowing lines ; and these two constituents are enclosed in a quartzo-felspathic matrix. This specimen, and others in my possession, show that some of the Irish Lower Silurian slates are still more highly altered than those previously described. Fig. 12 is a highly contorted mica-schist, also close to the Wexford granite. The micaceous layers and alternating clear spaces frequently contain Belonites, which always lie with their long axes in the ever-varying planes of the contortions. I have omitted them in the figure, as it is quite sufficiently complicated.

In this instance, the lateral pressure has reduced the dimensions of the rock in one direction to about two thirds of its original volume.

As previously stated, the extreme metamorphism of the Cornish slates extends to a very short distance only from the granite; indurated slates traversed by quartz-veins then occupy a much wider zone; and the rocks at a still greater distance are ordinary "killas" or clay-slate, having a more or less distinct slaty cleavage, but differing greatly in texture and mineral constitution from those just described.

As is well known, nearly all the Cornish granite is schorlaceous; and it also very frequently contains two varieties of mica, the principal mass consisting as usual of quartz and felspar. Now, of these constituents, felspar is the only one absent from the altered slates; it is stated, however, by De la Beche that in other Cornish localities rocks of gneissic character are found in contact with granite.

The facts observed appear therefore to warrant the conclusion that the intrusion of the granite has not only altered the structure of the slates, but has also developed in them some of its own constituents. De la Beche was evidently inclined to adopt this view of the introduction of mineral matter from the adjoining granite; and he concludes his observations on the subject with the following remark:—"It is difficult to conceive that nothing should have escaped from the hot fluid granite in the shape of vapour into the pores and cracks of the adjoining disrupted beds, or that, when the mass was sufficiently cool to allow water to permeate among both rocks at a high temperature, some modifying combinations were not then produced"*.

Summary.

It appears from the preceding investigations that the alteration of the slates in contact with the granite has been of two kinds, mineralogical and structural. 1. The minute particles of an ordinary clay-slate have been replaced by crystalline quartz, tourmaline, and three distinct varieties of mica, to which tremolite, magnetite (and andalusite?) have occasionally been added, and in other localities felspar also occurs.

2. The texture produced by the grouping of these minerals is various, the two most remarkable being:—A, foliation more or less perfect, with every gradation from nearly straight parallel lines to the most complicated contortions; and B, concretionary, showing a decided tendency to segregation of both quartz and mica, the result being a spotted schist.

Minerals produced by Metamorphic action.

The minerals by which the foliated schists are characterized are quartz, tourmaline, and mica; each of them presents special points

* Report on the Geology of Cornwall, p. 270.

of interest, which it may be convenient to consider apart from the descriptions of the rocks themselves.

Quartz.—The strata near the granite are far more highly silicated than those at a distance from it; and there can be no doubt that much of the quartz has been derived directly from the intruded rock.

In thin sections, showing the junction of the two rocks, there are many microscopic quartz-veins extending from the granite across the slate; they are not fissures traversing both rocks, but commence at the sharp line of junction, and are seen in the slate only: they are continuous with the quartz of the granite, and sometimes contain small quantities of felspar or mica.

A great part of the quartz may nevertheless have been produced by a more or less complete decomposition of the constituents of the original sedimentary deposit; the aluminous and other portions would then be removed, leaving the silica free to rearrange itself and form the separate folia. That movements of this kind have taken place, and that the mass was at one time in a plastic state, is evident from the fact that the quartz was often injected into fine fissures, and very frequently has enclosed in it crystals of tourmaline and mica.

One of the most interesting points connected with this mineral is the number of minute fluid-cavities with which it is so frequently crowded.

Fluid-cavities.—Fluid-cavities are abundant in the quartz of the large masses of granite, in that forming the veins, in the schorl rock, and in the altered slates.

I have examined very many of these cavities with excellent objectives, and have satisfied myself beyond a doubt that there is very great irregularity in the relative sizes of the cavities and vacuities, not only in different parts of the same mass of rock, but even in single crystals or grains of quartz.

A remarkable example occurs in the granite in contact with altered slate at Mousehole; in a single grain of quartz there are several fluid-cavities containing active bubbles, three of which exhibit widely different proportions to the size of the cavities.

There are also not a few cavities which appear to be quite filled with a fluid of similar refractive power to that containing bubbles. There are also very many cavities containing cubic crystals in addition to liquid and vacuity; these are shown by Mr. Sorby to be either sodic or potassic chloride, and are no doubt preserved in a saturated solution; the fluid is probably therefore of a different density from that in which there are no such crystals. That the density of the liquid varies considerably in different cavities is quite evident, however, from direct observation; for on rotating the stage of the microscope in order to cause the bubble to move from one end of a cavity to another, the motion is comparatively rapid in some, while it is so sluggish in others as to be more like the rise of a bubble in oil than in water.

Considering these difficulties, and the impossibility of obtaining

accurate measurements, I find myself compelled to differ from the views maintained by Mr. Sorby in his well-known and valuable paper on the "Microscopic Structure of Crystals," and which have been adopted by Mr. Ward in his memoir on the granitic rocks of the Lake-district, recently communicated to this Society*.

A reference to Mr. Sorby's paper will show that his calculations are founded on the following assumptions:—

1. That the cavities were exactly filled with the fluid at the time the crystals were formed.

2. That the vacuity was produced solely by contraction on cooling; and

3. That the quartz of the various igneous rocks crystallized at about 360° C., a temperature assumed to be that at which the trachyte of Ponza might probably have been formed under a pressure of about 4000 feet of rock.

If the first two assumptions were true, it would of course follow that the relative size of the cavity and bubble ought to be the same in all quartz crystals found in any small portion of a rock, as, according to the hypothesis, they must necessarily have been formed at the same time and under the same conditions. This, however, is so far from being the case, that it is difficult to find any specimen in which such uniformity exists. This difficulty appears, in fact, to have presented itself to Mr. Sorby, who admits (p. 487) that "there is sometimes a passage from fluid- to vapour-cavities as if there had been an alternation of liquid and vapour or gases; both of which circumstances would be likely to occur;" and again, when describing certain vapour-cavities in the quartz of granite, he says (p. 488) that they "gradually interfere with and pass into fluid-cavities."

Now the extremely probable occurrence of an intermixture of fluid and gases ought surely to be regarded as sufficient to invalidate any argument founded on the presence of a fluid only. It may afford a satisfactory explanation of the great irregularity which certainly does exist in the relative dimensions of the bubble to the liquid; but, as it is quite impossible to decide in what particular cases vapour of some kind may have been enclosed together with the fluid, it is difficult to see the value of any calculations based on such data.

An escape from the difficulty, however, is suggested by Mr. Sorby who says (p. 473):—"In determining the relative size of the vacuities in fluid-cavities, of course care must be taken not to make use of such as have caught up bubbles of gas along with the fluid, which is more likely to have happened with large cavities than with small. There is also a greater risk of the large coming across flaws in the crystal, so as to lose fluid. The very minute should, however, be avoided. It is therefore better to select those of moderate size, *which have vacuities of very uniform relative magnitude* in parts where vapour or gas-cavities do not occur and the crystal is very solid." Now, as to the directions here given, I would observe that it certainly would be better to avoid such cavities as have caught

* Quart. Journ. Geol. Soc. vol. xxxi. p. 571.

up bubbles of gas, if one only knew how to recognize them; there appears, however, to be no reason why gases should not have been mingled with water in various proportions, and have become enclosed in the cavities, so that the latter were never exactly filled with fluid only; nor is it by any means clear why large cavities should be more likely to contain both than the small ones*. As regards flaws by which fluid may have been lost, it is not likely that an experienced observer would be misled by them or by a partial drainage caused by grinding down the sections, as suggested by Mr. Ward. Whatever may be the cause of the discrepancy, it is quite certain, from an examination of a great number of Cornish rocks, that the ratio of the bubble to the cavities is not constant in the same rock, or even in the same crystals, whether the cavities be large or small. This is a fact which may be readily ascertained without making a single measurement by any one moderately experienced in microscopic work, and is even apparent in the Tables given by Mr. Ward, and in the figures in his plate xxx.; it is moreover a fact of primary importance in these investigations, and appears to me absolutely fatal to even an approximate estimation of either temperature or pressure. In conclusion, it can scarcely be necessary to point out that if it be permitted to select such cavities as have a *very uniform relative magnitude*, and also to assume a standard temperature for the process of crystallization, there can be no difficulty in obtaining concordant results as to the amount of pressure under which the rocks were formed.

Moreover, a mean value obtained from a selected number of measurements or by rejecting others that appear to be extreme cases, can obviously be of no value whatever as a basis for exact calculation.

The supposed exceptions are, in fact, far too numerous to be ignored; and it will be admitted that no theory as to the origin of these cavities can be satisfactory unless it includes all the facts observed.

Tourmaline.—The black tourmaline (or schorl) is usually of a rich brown colour as seen in thin slices; but yellow, grey, and blue varieties are not uncommon, and in one specimen of a schorl rock from the Land's End blue crystals (indicolite) are far more abundant than the brown.

The phenomena of dichroism and absorption are strongly marked, except in the comparatively rare case when a prism happens to be cut at right angles to the principal axis. On rotating the polarizer (the analyzer being removed) the colour changes from a rich brown to pale yellow, and in the blue varieties from blue to a nearly colourless grey.

Many crystals exhibit a fine blue in one part and brown in another; and not unfrequently the arrangement of the two colours appears to be closely connected with the crystalline form and the mode of growth. This is well seen in Pl. XXIII. fig. 7, in which a

* It must be remembered that all these cavities are of microscopic dimensions.

transverse section of a polygonal prism exhibits alternating bands of blue and brown.

Of this arrangement I have observed several examples in "schorl rock" from Cape Cornwall; and there are excellent examples of blue and brown tourmaline in one of the schorlaceous granite-veins near Mousehole: the central portion consists of the usual schorl rock, gradually passing into fine-grained granite on each side, the width of the vein being about 14 inches.

The mode of occurrence and the various crystalline forms of this mineral present several points of interest. The well-known "schorl rock," which occurs so frequently in the Cornish granite, consists of a mass of crystalline granular quartz, in which distinct crystals of tourmaline are often enclosed; frequently, however, the latter has no definite crystalline form, and then occupies the interstices between the grains and crystals of quartz, presenting the appearance of having run in among them in the form of long straggling bands. In such cases the tourmaline is not always in a granular state; for some of the long branching arms prove to be portions of a single crystalline mass, the action of which on polarized light is uniform over the whole surface. Although the assumption of a regular crystalline form may thus be prevented by the presence of other rigid bodies in sufficient quantity, yet, on consolidation, the molecular grouping of the elements is precisely the same as though no such interference had taken place; for, as we have seen, an irregular shapeless mass may possess the same optical properties as a perfect crystal. In specimens like the one here mentioned the tourmaline occurs in comparatively small quantity, while in others it constitutes a very considerable proportion of the mass, and then forms more or less perfect crystals, in which quartz grains are enclosed. Between these extremes there is every possible gradation.

It is evident, therefore, that in some cases the quartz solidified before the tourmaline; for it has impressed its form on the latter; in other specimens, however, long prisms of schorl may be seen to traverse one, or even several grains of quartz, which had evidently not solidified when the prisms were enclosed. It appears, therefore, from these facts, that when the schorl rock separated from the granite the entire mass must have been in a plastic state, and that, in accordance with varying conditions, either of the two minerals might be the first to crystallize.

In the granite itself the tourmaline and quartz present precisely the same relations as in the schorl rock: sometimes both are interstitial and appear to have crystallized together; yet not unfrequently the schorl must have been the first to consolidate.

Small well-formed crystals frequently occur in the quartz of the granite, of the schorl rock, and of the altered slates, and in many cases are built up of minute acicular prisms, which project from one end of the crystal, while the other is perfectly terminated, as seen in Pl. XXIII. figs. 8, 9, & 10. The specimen in which they occur was broken off close to the granite, and consists of fragments of slate and granite intermingled with quartz containing tourmaline and

chlorite; the clear quartz is crowded with fine crystals of both minerals; and, in addition to individual crystals scattered through the mass, numbers of small tourmalines are collected together and form most beautiful microscopic groups of radiating prisms. Being set in clear colourless quartz, they are exquisite objects in polarized light.

Alteration.—Many of the rocks here described contain excellent examples of the alteration of tourmaline, and the process may be observed in various stages.

Chloritic pseudomorphs are formed by the gradual conversion of a crystal into a green substance which exhibits no bright colours, but shows the distinctive characters of aggregate polarization, and under a magnifying power of 200 is seen to consist of a mass of confused fibrous bundles. In other cases the fibrous structure is indistinct, and there are vermicular crystals in various stages of formation.

Other pseudomorphs appear to be micaceous; some of the plates exhibit distinct cleavage-lines, and they are slightly dichroic, changing from a light yellowish-green to a darker shade; the absorption of light, however, is considerable.

These pale green substances show very clearly how greatly the absorptive property of minerals depends on the dissemination through them of minute quantities of colouring-matter: many of them contain extremely minute black grains, which form the nuclei of indistinct spots of a barely perceptibly darker shade than the light yellow parts; the shade deepens, however, as the polarizer is rotated, and they gradually become dark opaque spots, devoid of any well-defined edge, but strikingly different from the surrounding parts.

Lithia Mica.—In the altered slates and granite there are three varieties of mica, which may be readily distinguished from each other under the microscope; they occur, however, in such small flakes that it is impossible to obtain sufficient for chemical analysis or optical examination in the usual way. 1. A dark brown mica, resembling biotite in its action on polarized light, changing from light yellowish-brown to very dark brown, and nearly opaque. 2. Red mica, which also exhibits dichroism and absorption, but to a far less degree than the preceding. 3. White mica, in minute scales, having a pearly lustre. I have examined the three varieties by the following method:—A few small flakes were carefully collected, moistened with fluoric acid, and placed on a platinum wire, then exposed to the flame of a Bunsen's burner and examined with the spectroscope. The red lithium-line was quite distinct in all three, but flashed out more brightly and remained longer in the case of the white mica than in the others, clearly showing a larger proportion of lithium. The white mica is probably a typical lepidolite; and I think that the difference in the absorptive power of the others is due merely to the presence of a little more ferric oxide in one of them.

II. *Metamorphic Rocks of Igneous Origin.*

ALTERED DOLERITES.

The rocks remaining to be described are the "*Greenstones*" of the Geological-Survey map; a few of them would doubtless be regarded as diabase or melaphyr by some authors, and since the publication of the geological map they have even been described as nothing but altered slates. They appear to have been correctly mapped, and for the most part rightly named, by the officers of the survey, according to their use of the term greenstone. These rocks vary in colour from a dark bluish green to dark brownish green, and afford several varieties of texture. Some specimens from Tolcarn, Penlee Point, and elsewhere are rather coarsely crystalline; they are not fissile in any direction, and yield with difficulty to repeated blows of the hammer; while other portions of the same masses are either fine-grained or compact, and possess an imperfect slaty cleavage. The coarsely crystalline rocks are, as I shall presently show, altered dolerites; while some, if not all of the more compact slaty varieties were originally fine-grained basaltic portions of the same rocks, but have been in most cases so highly metamorphosed as to be almost incapable of recognition. These dark-coloured rocks are locally known as blue or grey elvans, and differ greatly in appearance from the "*killas*" in which they occur; their stratigraphical relations are, however, not quite clear. All the rocks of the district have been greatly disturbed; and it would require more time than I had at my disposal to determine whether these masses of trap are contemporaneous and interbedded, or intrusive sheets. Probably both occur, as frequently happens in volcanic districts, and may thus, in either case, belong to the same period *as a whole*; but, however this may be, they are certainly older than the granite.

A good example of the coarsely crystalline variety occurs in an old quarry at Tolcarn, between Penzance and Newlyn, where it may be seen to overlie the slate; and on ascending the hill, slates are again found above it. On the opposite side of the road it forms a bold rock, and also appears in the bottom of the valley, close to the new church. Thin slices of the least altered portions of the rock exhibit under the microscope numerous plates and crystals of augite in various stages of alteration, many comparatively large crystals of felspar (for the most part highly metamorphosed), grains of magnetite, and many long hexagonal needles of apatite.

These original constituents are enclosed in a more or less clear felspathic matrix, thickly crowded with minute green and pale brown belonites, together with flakes of hornblende, which give the general colour to the mass.

The augite occurs in large grains of irregular shape, and also in distinct crystals. The central parts are frequently quite unaltered, but are usually surrounded by a border of fibrous green hornblende: sometimes there is merely a central grain of augite remaining; and there are numerous examples of the completion of the process by its

entire conversion into hornblende. Frequently, however, the product of alteration is a dull green substance, which is very slightly or not at all dichroic. In the first sections examined, the rather large irregular plates suggested the idea that the pyroxenic mineral might be diallage; but the absence of regular cleavage-lines and the occurrence of characteristic forms in some of the smaller crystals render it far more likely that it is common augite.

A comparison with the beautiful gabbro of Crousa Down ("diallage rock") on the one hand, and with several Cornish dolerites on the other, also tends to confirm this opinion; I would, however, by no means venture to assert that diallage is never present in the more coarsely crystalline parts of the rocks. Although the felspar has usually suffered an extreme amount of alteration, there is nevertheless unquestionable evidence of its presence in the form of rather large crystals.

As they occasionally penetrate the augite, their original form is perfectly preserved, and in two specimens of the Tolcarn rock there are several prisms so slightly altered that they still exhibit a beautiful striation; there can be no doubt, therefore, as to the true character of the rock.

Besides the minute green belonites and pseudomorphs after augite, there are numerous larger blades and flakes of dull green hornblende disseminated through the base, and also filling cavities and veins.

Like all hornblende it exhibits colours in polarized light, and is dichroic; but the crystals differ in character from those occurring in diorites and other igneous rocks, nor are they the same as those forming the true hornblende-schist of the Lizard district for example; they have often the character of actinolite, and are frequently aggregated in radiating groups composed of flat blades of a bluish-green colour, and not very translucent; occasionally, however, there are crystals quite similar to those in ordinary hornblende-schist.

In one specimen of the Tolcarn rock they fill small veins and spaces which were evidently cavities in the originally felspathic or, possibly, glassy matrix.

In many places the rock has been much fractured, and fine cracks have broken across the various constituents, and have been subsequently filled by actinolite, with here and there a little pyrites. One vein has been filled with clear quartz, in which actinolite has also been formed.

A careful examination of the mode of occurrence here described shows conclusively that all the hornblende of these rocks is a product of alteration; and it appears highly probable that a continuation or modification of the process would produce a typical hornblende-schist.

Certain portions of these metamorphosed dolerites are, in fact, half-formed hornblende-schists, which only require the addition of foliation to render the transformation complete.

In the Tolcarn rock and several others there are many patches of a brown colour, and only dimly translucent; they have a distinct

angular outline, and several of them present the characteristic forms of aggregations of magnetite. Many have the central parts occupied by granular patches of that substance, which appear to be corroded round the edges, and pass gradually into the brown matter in such a way as to indicate that the latter is the product of their alteration. They must, I think, be regarded as pseudomorphs after magnetite; but I have not been able to determine their composition.

Their mode of occurrence is precisely that of magnetite, being found in the crystalline constituents and in the matrix; in the latter they are surrounded by innumerable minute flakes of brown hornblende or mica, while that at a short distance is usually green—a fact clearly indicating the diffusion of ferric oxide.

In the rocks just described some of the original constituents are of considerable size, and have partially preserved their former character and structure; but in more compact varieties the minute constituents have been so completely decomposed and obliterated as to be quite unrecognizable in their present condition.

A specimen of this kind occurred in the mass of rock near Tolcarn, one part of a large block being coarsely crystalline, the other fine-grained—a circumstance of common occurrence in rocks of this character.

In a thin slice of the compact portion the most conspicuous constituent is actinolite, with its radiating blades and flakes either filling veins or thickly disseminated through the mass in small patches, many of which were evidently cavities. These are everywhere surrounded by an extremely fine granular matrix containing many comparatively clear spaces. Augite, in small grains, was abundant, and has been converted into a brown granular substance.

The metamorphism is here so complete that there are no distinct traces of any crystalline forms; it is, however, quite possible that such forms may never have existed; for there are compact basaltic rocks of various geological periods having a minute granular or crypto-crystalline texture; and as regards the feldspar, a rock from Clicker Tor (to be presently described) and other examples show clearly that the crystalline form is frequently quite obliterated.

An examination of this specimen only would not have enabled me to determine positively its igneous origin; I had seen, however, that it formed part of a crystalline mass of unquestionable character; and the following examples not only afford a striking illustration of the various degrees of metamorphism to which these rocks have been subjected, but also exhibit every gradation from an obscure specimen like the one just described, to others readily capable of recognition.

A specimen taken from an old quarry in Rose Hill, near Castle Horneck, is a highly altered dolerite intermediate in texture between the coarse and compact varieties just mentioned. The remains of the feldspar prisms are still traceable; and there is the same minutely granular texture; there are many grains of magnetite and of altered granular augite, together with much flocculent green matter, but very little clearly recognizable hornblende. The slice is traversed

by a vein partly filled with this green substance, chlorite, and a little imperfectly crystallized blue tourmaline.

This specimen was originally rather vesicular, as it contains many well-defined cavities filled with the green substance.

At a short distance from the place just mentioned there is a new quarry in the same mass; but the rock is in a different stage of alteration: the flocculent green substance is here replaced by the usual dull green hornblende; and the slice is traversed by a quartz-vein containing numerous blades of actinolite, with several blue and brown crystals of tourmaline.

Altered Dolerites from other localities.

It will now be interesting to compare these Penzance rocks with others having similar petrological relations; and a reference to the map will show that such may be found on the east and west sides of the Dartmoor granite.

Tavistock.—At Peter Tavy the rock forming Smear Ridge and its prolongation to Cock's Tor, near the granite, is an altered gabbro or dolerite, some specimens having a coarsely crystalline texture, while others are fine-grained; both varieties are rather less altered than the Penzance rocks, and are therefore important for comparison.

In the coarsely crystalline variety the alteration is of precisely the same character as that described in the Tolcarn rock: the diallage has been partially converted into hornblende, and this substance also fills veins and former cavities; the felspar, though highly altered, may be readily recognized; and there are the same pseudomorphs after magnetite.

In a fine-grained specimen of the same mass the pyroxene (apparently augite) is very well preserved, but the felspar is completely decomposed, being represented by pale green pseudomorphs; the same substance also fills cavities, several of which contain groups of radiating blades of tremolite.

Brentor, four miles north of Tavistock, presents many of the features of a volcanic mass, being chiefly composed of purple bedded ash, together with scoriaceous and compact trap of a greenish-grey colour.

The latter is an altered basalt, in which the augite occurs in small well-formed crystals; it has suffered little or no alteration, while the felspar is converted into pale green pseudomorphs.

The mass of "Greenstone," half a mile north-east of Brentor, is chiefly ash of the same character as that of Brentor itself. On the east side of the Dartmoor granite there are also several masses of the so-called greenstone, of which the following may suffice as an example.

Hennock, N.E. of Bovey Tracey.—This mass and the two adjacent bands of trap are altered dolerites. Near Hennock, at the end furthest from the granite, some specimens of the rock have a well-marked porphyritic texture, many rather large crystals of dull white felspar being scattered through the mass. Under the microscope

this mineral is seen to be much decomposed, although the original striation is here and there quite distinct; the augite is but slightly altered, and many of the crystals are well developed.

The Botter Rock, forming part of the same mass, but nearer the granite, is rather coarsely crystalline, dark greyish-black in colour, and without felspar porphyritically enclosed. A thin slice exhibits quite similar characters to the last, except that the augite is rather more altered, and there is much more flocculent green matter disseminated through the mass: there are also numerous rather large crystals of apatite, which appear either as long prisms or perfect hexagons.

St. Austell.—At a place called the “Sanctuaries” near this town, and just outside the band of altered slate surrounding the granite, the largest mass of “greenstone” is also an altered dolerite, some parts of which are highly instructive. Part of the augite is unaltered; some of the crystals have assumed a brown granular appearance, while others have been converted into the hornblende substance previously described. Apatite is abundant; felspar crystals are distinct, though much altered; and there is a considerable quantity of actinolite, filling cavities and the angular spaces between the larger crystals.

Helston.—The “greenstone” to the north of Helston occupies precisely the same relative position to the granite as the rock just mentioned. The specimens examined, however, are far more highly metamorphosed, and might almost be described as hornblende-schist; the original character of the rock is nevertheless apparent from the remains of felspar and other crystalline forms.

Having described several examples of dolerites occurring among the altered slates close to the granite, it will now be well to examine some of those found in the ordinary “killas,” or clay-slate, at a distance from the altered band.

Clicker Tor.—This hill is close to the Menheniot Railway Station, about three miles south-east of Liskeard; it forms the mass coloured serpentine on the map of the Geological Survey. It is an elongated ridge having a nearly east and west direction, and rising rather abruptly from the surrounding undulating country; its general aspect is quite that of an intrusive mass; and an examination of its relations to the adjacent deposits shows clearly that such is its true character. At the east end of the hill all the rocks are well exposed in the railway-cutting; and in the section exhibited close to the station Devonian slates are seen on both sides of the central mass. On the south side the line of junction is nearly vertical, and the ends of the highly inclined and contorted slates lie directly against the trap. Under the microscope, a thin slice of the intrusive rock exhibits a variegated mass of pale green serpentine and a nearly colourless substance intimately blended together; imbedded in this matrix there are numerous pseudomorphs after olivine, and irregular plates of unaltered augite together with minute grains of magnetite scattered here and there through the mass. The pseudomorphs after olivine are of two kinds, consisting either

of serpentine or the white substance just mentioned; both are highly characteristic; the crystalline forms are perfectly preserved, and they are traversed by veins representing the original cracks so generally formed in this mineral.

In one slice the augite is also greatly altered; and it is interesting to compare the two pseudomorphs side by side.

Although the ground-mass of the rock exhibits a confused amorphous appearance both in ordinary and polarized light, we are fortunately not left in doubt as to the nature of at least one of its original constituents. The augite frequently encloses highly characteristic pseudomorphs after felspar; some are completely enclosed, while others are only partially imbedded in it; the mode of occurrence is, in fact, precisely the same as that observed in the altered gabbro of Corstorphine Hill, near Edinburgh, and in several Scotch dolerites described by me on a previous occasion*. In many cases the unaltered augite has preserved in the most perfect manner the sharp edges and angles of the felspar prisms; and whenever the latter project from the augite, it may be readily seen that both the enclosed and outlying portions have been converted into precisely the same serpentinous substance as that forming the ground-mass. It should also be noted that, in the case of partially enclosed prisms, only those sides or ends which have impressed their shape on the augite exhibit a crystalline form, the outstanding portion being quite undistinguishable from the surrounding mass.

As it would evidently be absurd to suppose that originally there was no felspar save that enclosed in the augite, there can be no doubt that the original feldspathic matrix has been completely metamorphosed, and that we have in the Menheniot rock a highly interesting and instructive example of the conversion of an intrusive olivine-dolerite into a mass of imperfectly formed serpentine.

Near Torquay in Devonshire there are two masses of eruptive rock exposed on the shore—namely, in Babbacombe Bay, and on the south side of Anstis Cove; they are intrusive in Devonian slates and limestone, and like other rocks of the district are altered dolerites. The mass in Anstis Cove is in the best state of preservation; it is rather coarsely crystalline, of a dark green colour, and consists of augite, small prisms of triclinic felspar, apatite, and magnetite. Some of the augite is but slightly altered; there is a little pale-green serpentine disseminated through the mass, and a few crystals of epidote. One part of the rock is traversed by a vein which contains numerous small crystals of this mineral enclosed in quartz; the clear quartz crowded with minute perfectly formed crystals of yellow-green epidote is an exquisite microscopic object. Other portions of the rock are so highly altered that there is nothing left but a mass of pseudomorphs.

In Babbacombe Bay there is an excellent section of the rocks, where the intrusive character of the trap may be well seen. There are here two principal varieties of dolerite:—one rather fine-grained and of a uniform grey colour; the other of a lighter shade and por-

* Quart. Journ. Geol. Soc. vol. xxx. p. 557.

phyritic texture, having conspicuous crystals of felspar scattered through it. Both varieties are highly altered: the secondary products are serpentine and calcite; and in some specimens there is a little quartz; characteristic pseudomorphs after augite are abundant, and, as not unfrequently happens, the triclinic felspar has suffered less than either of the other constituents.

Summary and Conclusion.

Microscopical examination shows clearly that the pyroxenic mineral, whether augite or diallage, has frequently been converted into a hornblendic substance, and that the variety actinolite is found filling cavities and fissures precisely in the same manner as other products of alteration.

That the more compact varieties of these metamorphosed dolerites or basalts should exhibit an imperfect cleavage which is entirely absent from the coarsely crystalline portions, is quite in accordance with the facts observed in typical slates. In such rocks it is found that even a slight change of texture in the beds is frequently accompanied by an alteration in the direction of the cleavage-planes; and it is no unusual circumstance to meet with coarse uncleaved gritty bands lying between fine slates, and abruptly terminating a plane of cleavage, which is as suddenly resumed on the other side of the band.

All the metamorphosed dolerites which occur in the altered Devonian slates have been collected at a greater distance from the granite than the schists previously described; the metamorphism is of a different kind, and there is but little evidence of any direct action on the part of the intruded rock. The alteration that has taken place appears to be the result of internal rather than of external action; in other words, it must have been caused by a more or less complete decomposition and rearrangement of mineral substance *in situ*, and not to any great extent by the introduction of new material from without.

Some of the facts observed in the course of these investigations are singularly interesting and important from a petrological point of view.

By an examination of a sufficient number of specimens the process of alteration may be followed step by step from a slight external change in a single mineral to the production of a perfect pseudomorph, and ultimately to the complete transformation of the entire mass of constituents, the result being the formation of a metamorphic rock whose original composition and structure could only be detected by a study of a good series of the intermediate forms. In a previous communication to this Society*, I have described a number of pseudomorphs after augite and olivine, and the frequent diffusion throughout the surrounding mass of various chloritic, serpentinous, or other green-coloured products of their decomposition; but in the more highly altered rocks of Cornwall, it becomes easy to trace new

* Quart. Journ. Geol. Soc. vol. xxx. pp. 535-542.

combinations of these secondary products, and to follow the gradual assumption of definite crystalline forms. In the rock from Rose Hill, for example, one specimen contains a quantity of flocculent green matter destitute of any definite character, except in one or two places, where there is evidently an approach to crystallization, whereas in another piece nearly the whole of the green substance exhibits the well-marked characteristics of hornblende.

It appears, moreover, that two rocks of similar origin and composition may follow different lines of metamorphism, and thus become converted into two widely different substances, the ultimate result depending upon the nature of the active agent and the duration of its operation. The Clicker-Tor dolerite, for example, situated at a distance from the granite, has been converted by aqueous agencies into a serpentinous rock; while the Penzance dolerites, in closer proximity to the granite, have been transformed into hornblende rocks differing from each other in texture and state of alteration in accordance with the coarseness or fineness of their original crystallization.

There remains one important point to be noted. Many of the metamorphic rocks described in the first part of this paper have undergone a second series of changes, in which chemical forces have evidently played the principal part, this subsequent alteration being indicated by the occurrence of micaceous and chloritic pseudomorphs after tourmaline, and an alteration (probably hydration) of the mica.

The granite has also suffered similar changes.

The origin of the metamorphic crystalline schists has hitherto been involved in the greatest obscurity; and it is with the hope of gaining some insight into the nature of the processes concerned in their formation, that I have commenced the inquiry with an attempt to ascertain the nature and extent of metamorphism produced by at least one powerful agent which must necessarily have brought into play enormous chemical and mechanical forces.

The results already obtained from a very limited number of observations afford sufficient encouragement to continue the investigation; for it appears not only that clay-slate may be transformed into mica-schist, gneiss, and tourmaline-schist, but that, among the more basic rocks, hornblende-schists may be metamorphosed igneous rocks, some being derived from dolerites or gabbros, while others are very probably foliated diorites.

In concluding these notes I will refer very briefly to one other point of interest, namely the origin of the granite. In Cornwall, neither examination in the field, nor a microscopical study of the rocks, lends the slightest support to the notion that granite is a metamorphic rock in any proper sense of the term.

On the contrary, there is the clearest evidence of the former existence of deep-seated volcanic action; for not only have the slates been subjected to the violent disturbance and alteration previously pointed out, but the surrounding country is seamed for miles by vast numbers of granitic and felsitic dykes ("elvans"); and considering the enormous amount of denudation to which the entire district has

certainly been exposed, it must be admitted that we have a sufficient explanation of the absence of lavas or other superficial products, and that only the more deeply seated masses of igneous rocks could remain as evidences of former volcanic action.

As regards the principal masses of granite in other parts of these islands, it appears to me that the evidence is equally strong in favour of their eruptive origin. Mr. Judd has shown conclusively that the phenomena presented by the great granitic masses of the Grampian Mountains are the exact counterpart of those observed in the lower portions of the Tertiary volcanic masses of the Hebrides; and, lastly, with respect to the granites and syenites of the Lake-district, I cannot but think that all the facts so clearly described by Mr. Ward in his recent valuable memoir*, are quite consistent with the volcanic origin of these masses. There is evidence to show that the Cornish slates existed as metamorphic rocks (cleaved and sometimes contorted) long before the intrusion of the granite. The contact metamorphism produced thereby extends to a short distance only, and may generally be distinguished from the other by microscopical examination, although there will of course be a gradual transition from the one to the other. Whenever clear indications of this contact metamorphism occur among stratified rocks at a considerable distance from granitic masses on the surface, it becomes extremely probable that such masses exist at a very short distance below. This is known to be frequently the case in Cornwall; and I should be strongly inclined to infer the existence of similar relations between the granite and slates of Skiddaw Forest.

Although there is an absence of direct evidence in the Lake-district as to the geological period at which the granites and syenites were erupted, there is apparently nothing inconsistent with the idea that they may belong to the great series of volcanic outbursts which occurred during the newer Palæozoic epoch; and it seems to me highly probable that they may be approximately of the same age as the granitic masses of Cornwall, Devonshire, and the Highlands of Scotland.

EXPLANATION OF PLATE XXIII.

- Fig. 1. Polished slice showing granite-vein in altered slate, collected close to junction with the main mass near Mousehole. The slate has been converted into a tourmaline-schist. Drawn half natural size.
- Fig. 2. Portion of thin slice from same specimen as fig. 1, showing the junction of granite and slate. The clear spaces are quartz; and in the granitic part the light shade represents the felspar; the dark, tourmaline or mica. In the slate the two shades are tourmaline and mica. See p. 408. Magnified 10 times.
- Fig. 3. Foliated tourmaline-schist close to the granite, Mousehole. See p. 409. Magnified 2 diameters.
- Fig. 4. Small portion of fig. 3, showing the relation of the tourmaline to the quartz grains. Magnified 60 times.
- Fig. 5. Spotted and foliated mica-schist containing a band of granular quartz (a). See p. 409. Magnified 10 times.

* Quart. Journ. Geol. Soc. vol. xxxii.



Fig. 1 $\frac{1}{2}$ nat. size



Fig. 2 $\times 10$.

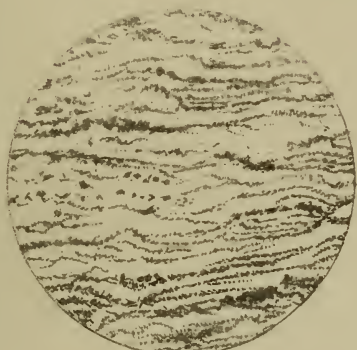


Fig. 3 $\times 2$.

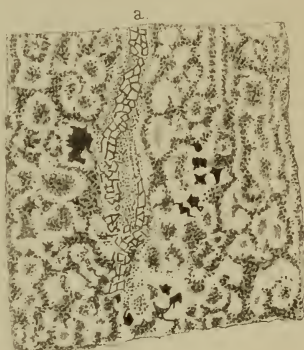


Fig. 5 $\times 10$.

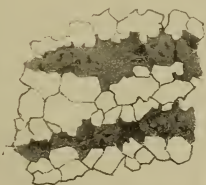


Fig. 4 $\times 60$.



Fig. 6 $\times 20$.



Fig. 7 $\times 60$.



Fig. 8 $\times 15$.



Fig. 9 $\times 15$.



Fig. 11 $\times 10$.

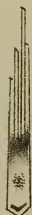


Fig. 10 $\times 30$.

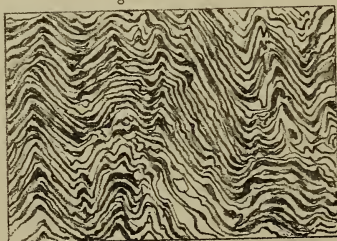


Fig. 12 $\times 6$.

- Fig. 6. Altered mica-schist containing radiating crystals of tremolite and bands of magnetite. See p. 410. Magnified 20 times.
- Fig. 7. Transverse section of polygonal prism of tourmaline composed of alternate bands of blue and brown colour. See p. 415. Magnified 60 times.
- Figs. 8, 9, & 10. Small crystals of tourmaline with one end regularly terminated, the other formed of slender prisms. See p. 416.
- Fig. 11. Gneiss (*altered Silurian slate*) in contact with granite, consisting of orthoclase, quartz, and mica, Ballynamuddagh, co. Wexford. See p. 411. Magnified 10 times.
- Fig. 12. Contorted mica-schist (*altered Silurian slate*), co. Wexford. See p. 411. The rock has been bent into numerous sharp contortions, and compressed in the direction of the pressure to about two thirds its original dimensions.

All the figures, with the exception of fig. 1, have been carefully drawn under the microscope by the author, with the aid of the camera lucida.

44. NOTICE of the OCCURRENCE of REMAINS of a BRITISH FOSSIL ZEUGLODON (*Z. Wanklyni*, Seeley) in the BARTON CLAY of the HAMPSHIRE COAST. By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., &c., Professor of Geography in King's College, London. (Read June 21, 1876.)

IN 1872 my late college friend Dr. Arthur Wanklyn, who had for a long time devoted himself to a study of the Barton Clay, was so fortunate as to obtain, from the Barton Cliff, nearly the whole of the skull of a zeuglodont of moderate size. The skull was extracted entire; but the local collectors, in carrying it up the cliff, had the misfortune to reduce it to fragments. The day before Dr. Wanklyn was leaving London for professional duties, he desired me to draw up some notice of the specimen for publication; but the time at my disposal was too brief for me to attempt a full description of the whole of the remains, and I contented myself with some memoranda on the maxillary bones, teeth, and roof of the brain-case. These I have hitherto kept for myself in the hope that Dr. Wanklyn would be able to bring the fossil to London, in a more perfectly restored condition, for fuller study. But the specimen never came; and since Dr. Wanklyn's death I have been unable to get any tidings concerning it. It has therefore seemed desirable to offer to the Society the notice which I made four years ago; and I do this the more gladly that it enables me to associate with the species the name of its discoverer, of whose enthusiasm for science this may serve as a slight memorial.

Maxillary Bones.

The maxillary bones are imperfectly preserved posteriorly. They show a length of about 8 inches of the bone on the left side, and less than 7 inches on the right side. The anterior termination of the bones is perfect and rounded convexly; and there they measure transversely across the palate $2\frac{1}{4}$ inches from side to side. Each bone in its alveolar surface is about $\frac{7}{8}$ inch thick; and the palatal space between the bones is at present filled with matrix. The external lateral surface of each bone is slightly convex from above downward; but in length the sides of the bones are concave, because they diverge posteriorly. The alveolar border of the bone preserves for some distance backward approximately the same thickness from side to side.

The fragment shows indications of five teeth on the left side. Between the second pair of tooth-sockets the jaw measures $2\frac{3}{5}$ inches from side to side; at the third pair of teeth it is $3\frac{1}{2}$ inches from side to side; and then it widens more rapidly behind. There is a strong oblique inner alveolar thickening of the jaw behind the posterior denticulated teeth. These processes are prolonged inward,

and meet in the mesial line so as to form a flattened slightly convex palate. On the superior surface these bones form a concave channel, which widens behind. The median suture [of the palate] is overlain, for 4 inches, by a fragment of a thin bone $\frac{1}{8}$ inch thick, which appears to have been $1\frac{3}{4}$ inch wide in the middle, and to have narrowed in front and behind. Posteriorly it extends beyond the maxillaries. This bone is presumably the vomer. External to it laterally are the impressions of the premaxillaries, which were about $\frac{5}{8}$ inch wide where they rested on the maxillaries; but behind the third tooth the impressions of these bones widen rapidly and converge towards the median line, as though they met posteriorly.

The Teeth.

The first two teeth in the maxillary bone were presumably simple and conical crowns, with a single fang; from the sockets for these the teeth are gone. The first socket extends to within less than $\frac{1}{4}$ inch of the anterior termination of the jaw; it is $\frac{7}{8}$ inch long and $\frac{5}{8}$ inch broad, is ovate in section, and placed evenly between the inner and outer sides of the jaw. Between this and the second socket is an interspace of $\frac{9}{16}$ inch. This interspace is hollowed out on each maxillary bone into a shallow hemispherical pit outwardly placed on the alveolar margin, caused apparently by absorption due to the pressure from a tooth in the lower jaw. The second socket is more than an inch long, and less than $\frac{5}{8}$ inch wide; so that it is more elongated than the other. On the internal alveolar margin, behind these teeth, runs a narrow elevated marginal ridge of bone.

The next interspace is about $\frac{9}{16}$ inch long; towards the third tooth it is excavated as though by pressure from a tooth in the lower jaw. The third tooth is $1\frac{3}{4}$ inch long, is compressed from side to side, less than half an inch thick in the middle, and attenuated to a sharp margin in such a way that the angle at which the inner and outer sides of the tooth meet is less than a right angle. The anterior and posterior parts of the crown are moderately serrated, so as to form four small denticles on each side of the larger median denticle which divides them. The denticles are much smaller in front than behind. The cutting-margin of the denticles of the tooth is faintly crenulated. Around the base of the crown runs a narrow elevated cinguloid ridge of enamel, which does not extend mesially above the fangs. The inner surface of the crown above these ridges is marked with vertical striæ on the enamel. The portion of the unenamelled fangs which projects from the sockets is less than $\frac{1}{4}$ inch deep. The height of the crown is less than an inch. The interspace between the third tooth and the fourth is $\frac{1}{4}$ inch. The fourth tooth is also $1\frac{3}{4}$ inch long. Its crown, though equally high, has a different aspect; for the denticles are larger, longer, thicker, and more deeply divided from each other than in the preceding tooth, so that the outline of the crests of the denticles of each side is convex from back to front. As in the third tooth, the posterior denticles are the larger; and the denticles are similarly crenulated. The cingular

ridge is much more developed; the anterior and posterior halves of it do not meet. Above this tooth the outer bone of the jaw thickens into a fold.

The fifth tooth is imperfectly preserved; it appears to be shorter than the others, somewhat thicker, with the denticles a little better marked.

The teeth were inclined towards each other from both sides of the snout, and locked between those of the lower jaw.

There was found with the specimen a remarkable single-fanged tooth, which may be one of those missing from the empty sockets. This tooth resembles the canine tooth of a Carnivore. It is longitudinally ovate in section, and in length recurved, with a tapering crown and a fang which continues to enlarge for some distance below the crown and then contracts somewhat towards the base. The extreme end of the fang is broken away, while its whole lower part has been greatly fractured and somewhat crushed. The extreme length of the portion of the tooth which is preserved is $2\frac{3}{4}$ inches, of which the crown covered with enamel constitutes 1 inch. The base of the crown from back to front, where the enamel terminates, measures $\frac{5}{8}$ inch, and from side to side in the same line it measures less than $\frac{1}{2}$ inch; the crown is more compressed from side to side in front than behind; and while the anterior margin, in common with the outline of the whole tooth, is convex, the posterior margin in the same way is concave, but with a curve which belongs to a much larger circle than that of the anterior margin. Along these anterior and posterior margins on the crown runs an elevated ridge of enamel. The ridges do not extend over the point of the crown, which is blunt, rounded, and unworn. On the sides of the crown and towards its base the enamel, which nowhere has a burnished smoothness, but an exceedingly fine subgranular shining texture, becomes wrinkled into sharp short vertical folds, which are more numerous on the back than on the front aspect, and may number about a dozen on each side of the tooth. They are fine, irregular, not straight; and sometimes two converge and unite into one in passing up the crown. The fang where widest measures $\frac{3}{4}$ inch from front to back. Like the crown, it is more compressed from side to side on its convex than on its concave side. It is marked throughout with exceedingly fine longitudinal striæ; and at intervals among these are faint ridges which are prolongations downward of the chief ridges on the crown. The pulp-cavity is large.

This form of tooth would yield one of the best distinctive characters for the species.

The Parietal Bone.

The parietal bone, which is single, has the form usual in Zeuglodonts, as far as can be judged from the fragment preserved, though various small pieces collected with it probably indicate that the parietal region was longer in this animal than in the American Zeuglodonts. The anterior suture, with the adjacent part of the

frontal bone, is well seen, and on the inferior margins are two small bones which are in the position of alisphenoids; posteriorly the bone is very imperfect; on the under side it is traversed by a groove which widens posteriorly and becomes part of the cerebral cavity. The parietal rests upon and encases the frontal bone, much in the way seen among Ichthyosaurs; so that while in the fragment measuring $6\frac{1}{2}$ inches in length $4\frac{1}{2}$ inches are occupied externally by the parietal, on the cerebral surface only $2\frac{1}{2}$ inches are occupied by that bone. The sides of the parietal bone are nearly vertical, and nearly parallel, measuring 2 inches from side to side in front, where they are about $1\frac{1}{4}$ inch high. Above this height the sides become rounded, and converge towards the middle line into an elevated mesial keel, which rises higher the further it is prolonged backward; so that while the bone as it stands on its sutural base is but little over 2 inches high in front, it becomes, where fractured behind, nearly $3\frac{1}{2}$ inches high. In front the ridge is rounded; but the last $1\frac{1}{2}$ inch of it preserved becomes flattened horizontally and widens posteriorly, being at the fracture $\frac{3}{8}$ inch wide. Concomitantly with the formation of this ridge the bone appears to widen out from side to side behind, and the lateral inclined halves of the upper surface exchange their rounded outlines for a sloping flattened surface. In front the ridge dies away just behind the suture. The suture is deep and well marked; it is somewhat irregular, and penetrates back into the parietal in the form of an inverted W with long outer arms, which on the shoulder of the side of the bone contribute to form a similar uninverted figure, the outer arm of which, in an irregular line, is prolonged downward and backward at an angle of about 45° with the basal outline of the bone; so that the parietal extends a less distance along the side than along the superior surface, where its termination is bifid.

The Frontal Bone.

The sutural end of the frontal necessarily corresponds closely with the parietal; but as the sides of the bone are similarly flat and vertical, and the superior surface is horizontal, it results that the section of the bone at the fracture is nearly quadrate, being rather higher than wide. The frontal bone is also notched on the under-side with a nearly quadrate olfactory canal about half an inch in section. The angles between the lateral surfaces and superior surface become elevated; and where it is fractured anteriorly the bone appears to be widening outward from side to side. The horizontal surface of the frontal continues forward the anterior depression in height of the parietal, and at its anterior termination the frontal is but $1\frac{1}{2}$ inch high.

Thus the portion of the frontal preserved has extremely thick walls. The walls of the skull scarcely become thinner in the parietal region; for the groove which traverses the bones only slowly widens and deepens. Its surfaces are nearly flat, and, except that it is relatively deeper, it corresponds closely in form with the external

ridge already described; and under the region where the ridge becomes flattened, the middle of the enlarging cerebral cavity becomes flattened, though there are concave excavations on each side. The suture between the parietal and frontal is deeply impressed on the cerebral surface. Behind its inferior termination is, on each side, another suture $1\frac{5}{8}$ inch long and about $\frac{3}{8}$ inch above the flat irregular basal surface of the specimen. The small bone thus indicated is not quite perfect behind, where it is shown by a fracture to be imbedded between the outer and inner walls of the parietal. These bones have none of the usual characteristics of the alisphenoids, and are probably to be regarded as orbito-sphenoids. They are about $\frac{1}{2}$ inch wide; and the film of parietal external to them is about $\frac{1}{8}$ inch thick. In front of these bones and internal to them are concave grooves, which widen in passing forward to more than $\frac{3}{4}$ inch, which is the width of the frontal bone on each side of the groove.

Almost the whole of the skull could be reconstructed from the materials preserved by Dr. Wanklyn. Among other parts I noticed the two egg-shaped tympanic bones, remarkable for their regular form.

In no respect does it approach *Squalodon*, which not only has the parietal region constructed on a different pattern, but also has the teeth of different form.

It differs from all known species of *Zeuglodon* in the shortness of the interspaces between the teeth, and apparently in the characters of the premolar teeth, as well as in the shorter form of the skull. But in the absence of the specimen any detailed comparison with other species must be deferred.

The parietal and frontal fragment is about the same size as in *Zeuglodon brachyspondylus* of Müller, which similarly has the frontal region flattened, with a sharp crest along the parietal region—which, however, does not become flattened posteriorly into a narrow table as in the species described; nor has the parietal in the foreign species the folded sutural junction with the frontal of our English specimen.

I would express my thanks to Mr. W. Davis for assistance in examining the Zeuglodons in the British Museum, and a hope that Dr. Wanklyn's *Zeuglodon* may eventually be deposited in one of our National collections.

45. *On an associated SERIES of CERVICAL and DORSAL VERTEBRÆ of POLYPTYCHODON, from the CAMBRIDGE UPPER GREENSAND, in the Woodwardian Museum of the University of Cambridge.* By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., &c., Professor of Geography in King's College, London. (Read June 21, 1876.)

THE rarity of vertebræ of *Polyptychodon* in the Cambridge Greensand is out of all proportion to the relative abundance of teeth. In the Woodwardian Museum alone more than a hundred teeth are arranged in illustration of the dentition of the genus, about half of which (probably the remains of one animal) were found at a Phosphatite washing on the Huntingdon Road. Many hundreds of teeth have probably been collected, all in a state of black mineralization; and these can only be referred to several individuals. The vertebræ collected do not appear to be the remains of more than two individuals; and these probably represent two species. They consist of the bones so admirably described by Professor Owen in the publications of the Palæontographical Society for 1860, which were found near Haslingfield, and the associated series of remains from the Huntingdon Road, belonging to a somewhat smaller animal, catalogued at p. 45 of my 'Index to Aves, Ornithosauria, and Reptilia,' which latter are the subject of the present notice. All the vertebræ are in a condition of somewhat pale mineralization. I mention this fact, because it is within my own knowledge that different parts of the same specimen are sometimes differently mineralized, and the condition has no importance as indicating a native or derivative origin of the fossils.

The Atlas and Axis.

Professor Owen's figure represents the atlas and axis as being more excellently preserved than they are, and as showing a clear separation between the atlas and axis, which is not very definitely marked in the fossil.

The atlas and axis are preserved in the associated series, and show no indication of consisting of separate bones—so perfectly are the osseous elements blended—either where the external unarticular surface is preserved or where the internal tissue is exposed by abrasion.

The extreme transverse width of the specimen is 5 inches; its depth from the middle of the neural canal is not more than $3\frac{1}{2}$ inches; so that it is rather broader than the first specimen, and not so deep. It shows no visible marks of compression, though it may perhaps have been a little depressed. There are no traces preserved of the neural arches.

The anterior surface of the specimen is concavely cupped for the hemispherical basioccipital; but the cup is considerably abraded, what remains of it being a circle of not more than 3 inches diameter.

The superior lateral angles of the atlantal cup show some indications of large flattened surfaces, which look obliquely forward and upward and somewhat outward, and encroach on the cup; from these the neural arch has come away. The inferior and outer corners of the cup are greatly abraded; but they show no indications of having been formed by distinct subvertebral ossifications.

The posterior articular face appears to be smaller. It is flattened, slightly concave from above downward, and more concave from side to side. As preserved, the axis-face measures $3\frac{1}{4}$ inches in depth and 4 inches in transverse diameter.

The base of the specimen is slightly convex in vertical outline, and less than 4 inches in length between the facets on the axis for the cervical ribs.

The side of the fossil is formed of two areas:—first, a superior surface $2\frac{1}{4}$ inches deep, on each side of the vertebræ; these converge somewhat upward towards the neural arch; and secondly, a smaller inferior impressed surface on each side, $1\frac{1}{4}$ inch in diameter, which looks backward and downward, and gave attachment to the first cervical rib. This area was defined and separated by ridges from the unarticular side of the centrum above, and from its base beneath.

The length of the specimen from front to back was greater at the base of the centrum than at the neural arch. Its greatest antero-posterior measurement is nearly $2\frac{3}{4}$ inches, which is more than in the species called by Professor Owen *Polyptychodon interruptus*.

The least antero-posterior measurement through the centres of the articular cups is $1\frac{3}{4}$ inch; the antero-posterior measurement below the neural canal as preserved is rather over 2 inches.

The basal or visceral surface of the atlas and axis is slightly convex in length, slightly concave from front to back, and shows rounded nutritive foramina at a distance of 2 inches from each other, and 1 inch from the postarticular border.

Other Cervical Vertebrae.

I have arranged the five succeeding vertebræ in natural sequence. They are remarkable for a Pliosauroid antero-posterior shortness, and a Pliosauroid flatness of the articular surfaces; but they differ from the cervical vertebræ of Pliosauroids hitherto described in having a single articular facet on the centrum for the cervical rib, instead of two facets; and this character is the only one so far as I am aware by which a short-necked member of the Plesiosaur family can be distinguished from a short-necked Pliosauroid when only centrams of vertebræ are available for comparison. The facets for the ribs on the side of the centrum gradually ascend the side of the centrum from the neck backwards, after the manner of Plesiosaurs, the ribs evidently becoming supported on the transverse processes of the neural arch in the dorsal region; so that *Polyptychodon* is essentially a big-headed Plesiosaur with no characters at present discovered to separate it from other Plesiosaurs, except the not very

easily defined ones of a big head and the short cervical centrams described.

It is probable that several cervical vertebræ are missing from the series; and although for convenience I shall number the vertebræ 3rd, 4th, 5th, 6th, and 7th, these numbers must not be taken to indicate the sequence of the vertebræ in the neck, for several may be missing between the axis and No. 3.

The third vertebra has its anterior face in the form of a pentagon, the median angle being in the middle of the base of the vertebra. It is nearly 4 inches deep, and $4\frac{1}{2}$ in transverse diameter in the middle of the vertebra. It is apparently much more cupped than the corresponding face of the axis. It measures rather more than $1\frac{1}{8}$ inch from back to front in the middle of the centrum; at the base, as preserved, it measures $2\frac{7}{8}$ inches from back to front, while at the neural canal the antero-posterior measurement is $1\frac{3}{4}$ inch. The neural canal, as in the axis, is somewhat impressed; it is not more than $\frac{3}{4}$ inch wide. On each side of the canal are the facets for the neural arch, each more than an inch wide. Below these facets are the unarticular sides of the centrum fully $1\frac{1}{2}$ inch deep. Then, below the middle of the vertebra succeed the impressed facets for the ribs; they have a diameter of $1\frac{3}{8}$ inch, are more deeply impressed behind than in front, and extend across nearly the whole antero-posterior length of the vertebra. Below these surfaces is the external unarticular base of the centrum; it is $3\frac{3}{4}$ inches long, terminates on each side in a sharp ridge, and is prolonged forward in the middle as though a subvertebral wedge-bone were blended with its anterior margin. The posterior surface presents a corresponding concavity on its basal border. These outlines are repeated in the succeeding neck-vertebræ. The posterior articular surface is more elliptical, smaller, and flatter, rather more than 4 inches wide, and rather more than $3\frac{1}{2}$ inches deep.

The fourth vertebra is badly preserved, but appears to have resembled the third.

The fifth vertebra increases a little in antero-posterior measurement; and the facet for the cervical rib becomes larger, and ascends a little up the side of the centrum. The articular faces remain flattened; but there is now on each a low, flattened, broad, central elevation, between which and the margin is a concave area. The back-to-front measurement is everywhere about 2 inches, though at the base it is a trifle less. The facets for the neurapophyses are placed a little further forward, so as not to reach within $\frac{1}{4}$ inch of the posterior articulation; each is an inch in diameter. The sides of the centrum are worn. The articular facets for cervical ribs, $1\frac{3}{8}$ inch in diameter, are so placed that their superior margin is above the middle of the centrum. The base measures 4 inches in transverse diameter, in which direction it has become a little more convex, while from front to back it has become rather less concave.

In the sixth vertebra the larger articulation for the rib is so placed that half is above and half below the middle of the centrum. The width of the vertebra across these facets is 5 inches; and though

the width of the anterior articular face is $4\frac{1}{2}$ inches, its depth is $3\frac{3}{4}$ inches. The articular faces become a trifle flatter, and the central elevation rises a trifle higher. The posterior articular face is 7-sided. The articulations for the ribs are now on very slightly elevated pedicles, separated by a narrow margin from the anterior face of the centrum. The facets appear to be flat, nearly circular, and $1\frac{1}{4}$ inch in diameter. The transverse convexity of the base of the centrum increases, while the antero-posterior concavity becomes flatter.

The antero-posterior measurement of the seventh vertebra is $2\frac{3}{8}$ inches. The facets for the ribs ascend so high on the sides of the centrum that they must touch the neurapophyses; hence this would be the last cervical. It is $3\frac{3}{4}$ inches deep, and as preserved measures $4\frac{5}{8}$ inches from side to side over the facets for the ribs.

The remainder of the 16 vertebræ are dorsal; but they are not well preserved. In these vertebræ the centrum steadily increases in length. Several have an antero-posterior measurement of $2\frac{1}{8}$ inches; and one, probably from the middle of the back, is 3 inches long and 4 inches deep. The articular faces, though $3\frac{5}{8}$ inches wide and $3\frac{1}{2}$ inches deep, look vertically elongated, owing to the centrum being a little compressed from side to side below the neural arch. The margins of the articulations are sharp, and the central boss still remains. The upper part of the centrum leans a little forward as in *Pliosaurus*.

I entertain little doubt of the specific distinctness of this fossil; but since the teeth of animals of this kind rarely furnish specific characters, it will be difficult to prove the separation of the species from *Polyptychodon interruptus* till better materials of that species are discovered; and the remains described from the Cambridge Greensand by Professor Owen were not so satisfactory as to yield good characters for comparison.

The British Museum contains a tooth of *Polyptychodon* from the Gault. The remains in the British Museum from the Lower Greensand named *Polyptychodon* present no characters by which I can recognize their claim to a place in that genus.

46. On CROCODYLUS ICENICUS (Seeley), a second and larger SPECIES of CROCODYLUS from the CAMBRIDGE UPPER GREENSAND, contained in the Woodwardian Museum of the University of Cambridge. By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., &c., Professor of Geography in King's College, London. (Read June 21, 1876.)

It is a curious coincidence that the evidence of the fossil now described, like that of *Crocodylus cantabrigiensis*, consists of one cervical and one dorsal vertebra. The vertebræ in this species, however, are associated; and their striking resemblance to existing Crocodiles had, I believe, already been recognized by Mr. Walter Keeping.

The centrum of the cervical vertebra is $2\frac{1}{4}$ inches long, and is divided from the neural arch by a rather deep suture, more than usually well marked by the neural arch projecting laterally a little beyond the centrum. In front the procelous articulation is as deeply cupped as in any recent species. The cup is circular, about $1\frac{1}{8}$ inch in diameter; it was surrounded by a narrow border, now somewhat worn, so that the transverse diameter of the centrum, which was about $1\frac{5}{8}$ inch, cannot be exactly determined. Its depth appears to have been as great—though, as the small anterior hypapophysis is broken away, the depth as preserved is only $1\frac{1}{2}$ inch.

The neurapophyses are very strong. As they rise from the centrum they are directed outward and upward, constricted and rounded anteriorly above the centrum for the passage of the cervical nerve. The neurapophyses are constricted between the parapophyses and diapophyses, as well as between the diapophyses and zygapophyses. The least measurement of the neural arch from front to back is rather more than one inch.

The anterior zygapophysial facets are inclined at an angle of about 45° looking upward and inward; they measure about $\frac{3}{4}$ inch from front to back, and about 1 inch from below upward. Only that on the left side is preserved: it is smooth, its anterior margin hardly projects in front of the anterior face of the centrum, and its posterior margin is hardly behind the anterior margin of the diapophysis. The width between the anterior zygapophyses was about $2\frac{1}{2}$ inches. The inner margin of the facets of the zygapophyses descends below the top of the neural canal, which in front is subtriangular. As usual, there is an interspace between the facets, due to the neural spine being placed further backward; and from the middle of this area the vertical slightly elevated anterior margin of the neural spine arises. On the side of the neural arch the zygapophyses laterally curve downward and backward to the diapophyses, which project prominently. Above the diapophyses and behind the anterior zygapophyses the sides of the neural arch are considerably compressed, measuring $1\frac{3}{8}$ inch transversely at the shoulders of the

sides, where a concave area is terminated posteriorly by a ridge arising from the diapophysis; which runs upward and backward, presumably to the faces of the posterior zygapophyses, which are broken away.

The neural canal somewhat excavates the middle of the neural surface of the centrum. The posterior outlet of the neural canal appears formed of two pairs of sides—a short pair below, converging to the middle of the centrum, and a long pair, $1\frac{1}{8}$ inch in length, converging upward and prolonged in the notch between the zygapophyses. The posterior aspect of the neural arch below the zygapophyses is flattened. The flattened surfaces are $\frac{1}{2}$ inch broad, and look obliquely outward and backward; they converge somewhat upward, and terminate inward in the rounded margin of the neural canal, upward in the posterior zygapophysial ridge, and outward and forward in the diapophyses. The length of the neural suture is $1\frac{3}{8}$ inch.

The neural spine appears to have been compressed, but is entirely broken away.

The diapophyses are obliquely ovate, $\frac{1}{2}$ inch long and $\frac{3}{8}$ inch deep; they are situate rather nearer the front than the middle of the side of the centrum. The transverse measurement through the diapophyses, as preserved, would be about 3 inches.

The lateral unarticular part of the centrum is about $1\frac{1}{2}$ inch long. Posterior to this region the centrum terminates in a large rounded articular ball, $1\frac{3}{8}$ inch wide, not quite so deep, and extending backward for fully $\frac{3}{4}$ inch. The greatest width of the centrum behind the posterior articulation is $1\frac{3}{8}$ inch.

The side of the centrum carries on its upper half, at less than half an inch behind the anterior articular margin and extending upward to the neural arch, the vertically ovate parapophysis, which as preserved is $\frac{9}{16}$ inch high and $\frac{6}{16}$ inch broad. Its lateral projection is probably but slightly worn. The width of the vertebra through the parapophyses is $1\frac{7}{8}$ inch.

The sides of the centrum below the parapophyses are slightly concave in length, somewhat flattened; and towards the middle of the base of the centrum they form a well rounded median surface, concave in length, which in the anterior half inch is prolonged downward into a small hypapophysis, now broken away.

The measurement from the rounded base of the centrum to the upper margin of the anterior zygapophyses is nearly 3 inches.

This vertebra is probably the last cervical. It differs from that of existing Crocodiles in the large size of the parapophyses, in the distinct anterior notch in the neural arch for the vertebral nerve, and the perfect convexity of the articular ball.

The dorsal vertebra has the centrum elongated, compressed from side to side, and well rounded on the under surface. It is $2\frac{1}{2}$ inches long, the lateral unarticular part being $1\frac{7}{8}$ inch, while the remainder is occupied by the well rounded, convex, posterior articular ball. The anterior cup is apparently circular, and measures $1\frac{1}{2}$ inch from side to side. The ball is $1\frac{1}{4}$ inch from side to side, and

has an aspect as though placed slightly below its proper position on the centrum; its external surface is rather concave behind the ball. The transverse diameter of the centrum at one inch from the posterior extremity is $1\frac{1}{8}$ inch. The neural suture is straight, $1\frac{1}{8}$ inch in length. The neural arch is remarkable for its length and for the small extent to which it is notched in front and behind for the vertebral nerves, its least length being fully $1\frac{5}{8}$ inch. It rises vertically and continuously with the side of the centrum; and at a height of about $1\frac{7}{8}$ inch from the base of the centrum gives off the compressed transverse processes, which are almost entirely broken away. This process is continuous in front with the anterior zygapophysis, the articular facet of which is not horizontal, but looks a little inward as well as upward; the facets appear scarcely to project forward in front of the anterior articular margin. The transverse processes at the base, as preserved, have an antero-posterior measurement of $1\frac{5}{8}$ inch. Behind the process is a concave notch, posterior to which the postzygapophysis is produced; across the notches the measurement is $1\frac{1}{4}$ inch. There is a slight depression below the notch, bounded in front by a ridge directed outward and forward. As preserved, the transverse processes, which were horizontal, measure $2\frac{1}{4}$ inches from side to side. The neural arch was greatly compressed above the transverse platform. The neural spine is fractured at a height of less than 3 inches from the base of the centrum; it measures $1\frac{1}{4}$ inch from front to back. The neural canal (which is obscured in front) appears to have been remarkably small; from side to side behind, the neural arch measured 1 inch.

This vertebra is the 6th or 7th dorsal. The depression of the posterior articular ball, and its perfect convexity, are the chief points in which it differs from existing species.

The remains indicate an animal about 16 feet long.

I have seen no other vertebrate fossil from a secondary stratum in which the bones preserved so closely resemble those of an existing type.

47. On *MACRUROSAURUS SEMNUS* (Seeley), a LONG TAILED ANIMAL with PROCELLOUS VERTEBRÆ from the CAMBRIDGE UPPER GREENSAND, preserved in the Woodwardian Museum of the University of Cambridge. By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., &c., Professor of Geography in King's College, London. (Read June 21, 1876.)

ABOUT twelve years ago the Woodwardian Museum acquired from Mr. W. Farren a series of some 25 associated and successive caudal vertebræ, found at one of the deeper phosphatite washings on Coldham Common, Barnwell. At the same date, the Rev. W. Stokes Shaw, M.A., Caius College, obtained from a similar working at Barton, a locality a few miles westward, another associated series of 15 smaller vertebræ showing identical characters, and of such size as to exactly join on to the first series and complete the tail. These latter vertebræ, not improbably part of the same individual, being presented to the Museum, I arranged both sets in a continuous series. Very few appear to be missing in any part of the sequence, though the extremity of the tail is probably not preserved, and there are no means of estimating how many vertebræ may have intervened between the last of the sacral region and the earliest caudal which is preserved. The tail probably included 50 vertebræ, and may have reached a length of 15 feet, which would have amounted to one half the length of the animal if the proportions of modern crocodiles obtained. A few isolated vertebræ have also been collected; but no distinctive portions of the skeleton have come under my notice. The affinities of the animal are at present somewhat obscure; for the only available data from which a determination could be made are the following facts:—The articulation of the earlier vertebræ is procœlous; this character gradually changes till the articulations of the centrums are nearly flat; then they become biconcave, and towards the end of the tail are irregular. There are no chevron bones; and the centrum becomes elongated and rounded like a dice-box, after the pattern of *Cetiosaurus* and *Lalaps*. The neural arch in the greater and earlier part of the tail was supported on pedicles rising from the centrum; it was depressed, and devoid of neural spine.

The procœlous character in the caudal region has never before been recorded, so far as I remember, in combination with an absence of chevron bones in an animal of this size; and though the tail as a whole is more in harmony with the Lacertian type than with any other order of true Reptiles, yet we must look to future discoveries for evidence of the systematic position of the animal to which it belonged. In my 'Index to the Secondary Reptiles,' &c. *, I classed the animal doubtfully with the Dinosauria. If it is allowed

* Pp. xvii, 45.

to remain there, I do not see my way to placing it in any one of the subdivisions of that group.

The vertebræ are in different states of mineralization—some showing no indications of phosphatic infiltration, while in others this process has gone on to a considerable extent.

The preservation of the specimens is occasionally such that I cannot feel certain that all are arranged in exactly their true order of succession. The first vertebra preserved is an early caudal much decomposed on one side, and considerably abraded, with only the base of the neural arch preserved, and an indication of the antero-posterior extent of the fractured transverse process. Its imperfect preservation is due to the fact that the bone is open and cellular, and but slightly mineralized with phosphate of lime.

The articular surface of the centrum is deeply cupped anteriorly, and is more expanded in front than behind, where it forms a large hemispherical ball. The sides of the centrum are compressed, and converge towards the ventral surface, where they form a median rounded ridge. The length of the centrum is 8 inches, and of this the unarticular side of the centrum measures $5\frac{1}{2}$ inches; the depth from the neural canal to the base of the hinder part of the centrum, as preserved, is fully $5\frac{1}{2}$ inches, and in front was probably more. The side is smooth, with some longitudinal vascular impressions, gently concave from front to back. The basal keel is well rounded from side to side, and gently concave from front to back.

The transverse process appears to have been $3\frac{1}{4}$ inches in antero-posterior extent at its base, where fractured. It was strong.

The neural canal was smooth and narrow.

What are probably pedicles for the neural arch extend to the anterior border of the cup. This process on the right side is compressed, less than half an inch thick, with an antero-posterior extent of $2\frac{1}{2}$ inches.

The worn fragment of the next vertebra is $7\frac{1}{2}$ inches long. On the third the transverse processes have disappeared. The anterior cup of this vertebra, as preserved, is $5\frac{1}{4}$ inches wide; and the centrum does not exceed that length; but the ball and the margin of the cup are both broken. The neural canal is more than an inch wide. On each side of it the centrum gives off strong compressed pedicles 2 inches in antero-posterior length, half an inch thick, inclined a little towards each other, and approaching to within half an inch of the anterior border, as preserved. These pedicles are not much more than half an inch high, and were probably separated from the neural arch by a horizontal suture.

The centrams now become rapidly smaller in diameter and flattened on the visceral surface. The articular cup remains as deeply marked; but the ball appears to have a depressed, flattened margin an inch wide around the elevated central boss, as in existing crocodiles. That numbered 8 is $6\frac{1}{2}$ inches long and has the cup $4\frac{1}{2}$ inches deep. No. 11 is $5\frac{1}{4}$ inches long, has the cup much less deep, but the ball is not at all preserved. The centrum has now acquired a dice-box form. No. 12 is as long, but the centrum is smaller, the cup

is flatter; and there is scarcely any trace of a ball. The greatest diameter of the constricted part of the centrum is $2\frac{1}{2}$ inches; the neural pedicles become more elongated, measuring $2\frac{1}{2}$ inches. After the 13th the centrans get rapidly smaller. The 15th is distinctly biconcave; the centrum is somewhat compressed laterally; the neural canal is narrower, with a concave channel in the centrum, margined by shorter pedicles. The 16th is $4\frac{3}{4}$ inches long. The 20th is 4 inches long, has the centrum $2\frac{3}{4}$ inches wide posteriorly, and, as preserved, is $2\frac{1}{4}$ inches deep. The least diameter of the centrum where most constricted is $1\frac{3}{4}$ inch. The articular ends are greatly flattened, but slightly concave, as in many Plesiosaurs. The pedicles for the neural arch remain at one inch from the anterior margin; the extreme external width across the pedicles is $1\frac{1}{2}$ inch; the width of the neural canal is $\frac{1}{2}$ inch; the antero-posterior extent of the pedicles is $1\frac{1}{2}$ inch. Between No. 23, the last of the Barnwell series, and 24, the first of the Barton series, a few are probably lost. The Barton portion of the animal is in rather better preservation, though a few of the vertebræ, which have been washed with the phosphatic nodules in the mill, show curiously how the circumstances under which fossils are collected may modify their appearance. In No. 24 the centrum is $3\frac{1}{2}$ inches long, and 2 inches deep in front; the anterior articulation is deeply cupped; and the posterior articulation somewhat approximates to a ball. The least diameter of the middle of the centrum is less than $1\frac{1}{2}$ inch. The pedicles are now placed nearly in the middle of the length of the centrum. No. 25 is $3\frac{5}{8}$ inches long, with the articular ends $2\frac{1}{8}$ inches in diameter; they are deeply cupped with a central deeper depression. The next vertebra has the articular ends much flatter, with a transverse depression which does not appear to result from pressure. No. 28 is $3\frac{1}{4}$ inches long, and has pits in the neural canal like foramina for blood-vessels. No. 30 has the centrum anteriorly deeply concave; posteriorly it is subconvex with a transverse groove. No. 35 is $2\frac{3}{4}$ inches long. The posterior articulation is convex with a slight central depression; as preserved it is $1\frac{1}{8}$ inch wide. The centrum is compressed from side to side, measuring $\frac{5}{8}$ inch in least diameter; the anterior articulation is very irregular. The neural canal is about $\frac{3}{8}$ inch wide. The pedicles are compressed, $\frac{1}{3}$ inch wide and 1 inch long.

A few neural arches are preserved. They are remarkable for great antero-posterior extent, compression from side to side, and absence of a neural spine, the superior margin being concave from front to back, and only rising two inches above the top of the neural canal in the deepest specimen. In that example the posterior zygapophysial facets are preserved. They are $\frac{1}{4}$ inch in diameter, and are raised like wafers on the inferior margin of the specimen so as to look outward and downward. The median posterior portion of the arch is prolonged for some distance behind the facets; anteriorly the arch is forked. Further back in the tail, where the arch is more depressed, the articular facets are lost; but the posterior process, ovate in section, is still directed for some distance upward

and backward, and terminates in a rounded end. The length of the neural surface on a large neural arch is $2\frac{7}{8}$ inches.

The irregularity of the articulation of the centrums seems characteristic; for in a second series of three large vertebræ, two are procelous and the third is biconcave.

Fig. 1.—*Side view of caudal vertebra of Macrurosaurus semnus, probably about the 35th. (Natural size.)*

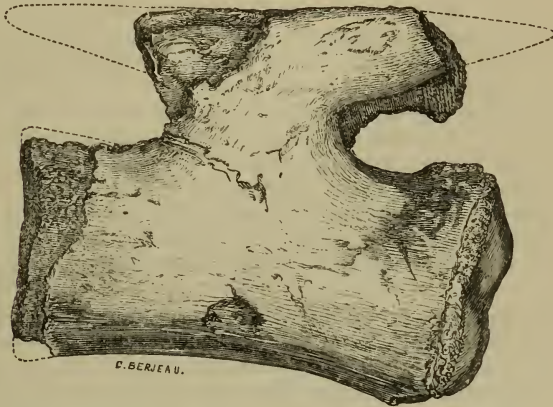


Fig. 2.—*Anterior view of caudal vertebra of Macrurosaurus semnus. (Natural size.)*



Two or three small vertebræ were also found about 1859 at Barnwell. One of these (figs. 1 & 2) retains the neural arch, and shows an indication of the separation between the neural arch and centrum. It is $2\frac{5}{8}$ inches long at the superior part of the centrum, and a little less at the base. The anterior articulation (fig. 2) is subconcave and

irregular; the posterior is subconvex, with a transverse impressed groove (fig. 1). The articular margin is somewhat worn; but on the base the centrum is somewhat flattened, and on one side posteriorly there is a faint slight ridge such as might indicate a chevron bone, had there been any other reason for suspecting such a structure. The neural arch seen from above (where it is worn) is wedge-shaped, 1 inch wide in front, with the straight sides converging posteriorly in a distance of $1\frac{1}{2}$ inch to $\frac{1}{2}$ an inch. The superior surface of the arch is flattened, and rounds into the sides; it is straight and inclined forward; but the extremities of the processes are broken both before and behind. In front the height from the base of the centrum is $1\frac{7}{8}$ inch; $1\frac{1}{2}$ inch further back the height is $2\frac{1}{8}$ inches. The antero-posterior extent of the pedicles of the neural arch between the concave notches in front and behind it is 1 inch. The centrum is $1\frac{1}{4}$ inch deep at the posterior articulation, while in the middle of the neuro-central suture it is 1 inch deep.

In the 'Annals of Natural History' for November 1871, I described and figured under the name of *Acanthopholis platypus* the metapodium of a large animal. As the middle bone is 6 inches long, and the bones measure 9 inches over their proximal ends from side to side, and there is no other evidence of bones of *Acanthopholis* reaching a corresponding size, I am inclined to speculate on the probability of those bones being a part of the foot of *Macrurosaurus*, probably the metacarpal bones. If the remains both belong to the same genus, then *Macrurosaurus* would probably indicate a gigantic modification of the Crocodilian type of Dinosaurs.

48. *On REMAINS of EYMS HORDWELLENSIS (Seeley) from the LOWER HORDWELL BEDS in the HORDWELL CLIFF, contained in the Woodwardian Museum of the University of Cambridge.* By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., &c., Professor of Geography in King's College, London. (Read June 21, 1876.)

By the intervention of Mr. Henry Keeping the Woodwardian Museum acquired in 1868 some fine Chelonian fragments mineralized nearly black (now arranged on shelf *d* of case 109)—which after a little effort I found to reunite themselves into a plastron from which the xiphoid bones are lost, and a large connected part of the carapace which comprises the nuchal plate and the two adjacent marginal plates, the first six neural plates, and portions more or less perfect of the first five pairs of costal plates. The marginal plates are all or nearly all lost, having probably been washed away by the sea while the specimen was lying on the shore. Two disconnected marginal bones were collected with the other remains.

Mr. Keeping tells me that the horizon of the fossil is about 20 feet below the bed which yields the chief remains of *Crocodilus Hastingsæ*, and about 10 feet above the brackish-water Upper Bagshot beds, which are seen in the cliff rising westward at an angle of 3° at Mead End; so that the position of the specimen is low down in the Lower Hordwell series.

The fragment of carapace as preserved is 9 inches long and 6 inches broad; so that when perfect it probably measured about 12 inches in length and nearly 10 inches in breadth. In length it is gently inflated, so that in the portion preserved (nine inches) the highest part of the curve rises more than an inch above a base-line drawn from the ends of the specimen. As is usual, the transverse section is more inflated; and in the width of 6 inches the highest part of the curve rises $1\frac{1}{4}$ inch above a base-line drawn from the two sides. The carapace is impressed with a small subtriangular nuchal scute, the first and part of the second marginal scute on each side, the first, second, third, and part of the fourth vertebral scutes, and parts of the first, second, and third pairs of costal scutes. I will first give the characters of the scutes, and then describe the forms of the skeletal osseous plates.

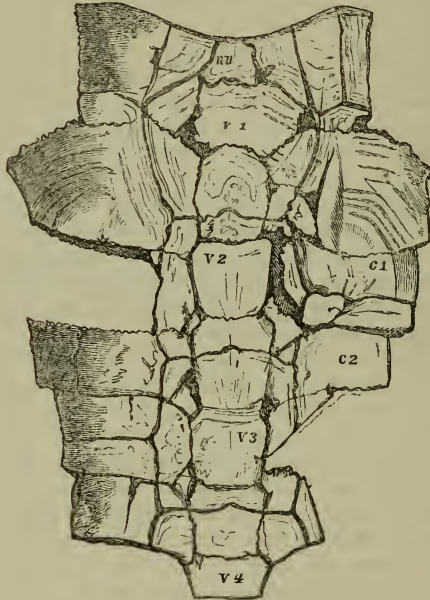
The Scutes of the Carapace.

The nuchal scute (fig. 1, *nu*) is small, has its margins sinuous, is $\frac{3}{4}$ inch in length, measures $\frac{7}{8}$ inch in breadth behind, and is $\frac{1}{4}$ inch wide on the anterior margin of the carapace. The first vertebral scute (*v* 1) is six-sided and subpentagonal, three of the sides being in front of the scute, there being a median side behind the nuchal scute, and two lateral margins in which it joins the first marginal

scute on each side of the nuchal scute. It is $2\frac{1}{3}$ inches long in the median line, $2\frac{7}{8}$ inches broad at the anterior lateral angle (where it meets the first marginal and first costal scutes), and $1\frac{7}{8}$ inch broad along the sinuous transverse posterior line (in which it meets the second neural scute). Like all the other scutal areas, both of the carapace and plastron, it is marked with subparallel impressed concentric lines indicative of the intermittent growths of the scutes. These lines are least distinct on the posterior border.

The first vertebral scute extends transversely beyond the nuchal plate (which is $2\frac{3}{4}$ inches broad) so as to impress the angles of the

Fig. 1.—*Carapace of Emys hordwellensis*. (One third natural size.)



nu. Nuchal scute. *v 1, v 2, v 3, v 4.* First, second, third, and fourth vertebral scutes. *c 1, c 2.* First and second costal scutes.

marginal plates. The scutal area is convex in length as well as in width; its posterior border impresses the first neural plate at less than half an inch in advance of its posterior sutural border.

The second vertebral scute (*v 2*) is nearly square, being about $2\frac{1}{4}$ inches long and nearly $2\frac{1}{4}$ inches broad. The two pairs of sides, which are somewhat sinuous, are subparallel; and the area is convex in length as well as in width. Its anterior and posterior borders cross the first and third neural plates, while its lateral borders cross the first, second, and third pairs of costal plates.

The third vertebral scute (*v* 3) has subparallel sides, but is longer than broad, measuring fully 2 inches in breadth and $2\frac{1}{2}$ inches in length. Its anterior and posterior outlines cross the third and fifth neural plates, behind the middle of the plate in both cases; and the lateral outlines cross the third, fourth, and fifth pairs of costal plates at about half an inch from the neural plate adjacent to each.

The fourth vertebral scute (*v* 4) is imperfectly indicated by the bones preserved, but was rather broader than the third.

The first costal scute (*c* 1) in antero-posterior length measures 3 inches; it stretches from the first marginal plate to behind the middle of the second costal plate. Its breadth is uncertain, as is that of all the other costal scutes, for every costal plate is imperfect; but it appears to have been subtriangular and as broad as long. The second costal scute (*c* 2) measures $2\frac{1}{2}$ inches from front to back. The third pair of costal scutes is imperfectly indicated. The boundaries between these scutes are all sharply incised rather than deeply impressed.

The Osseous Elements of the Carapace.

The nuchal plate is six-sided, concave along its front margin, which is about $1\frac{5}{8}$ inch wide. It is similarly concave behind, where it receives the convex anterior margin of the first neural plate, and is one inch wide. Of the two lateral sutural surfaces on each side, those which join the marginal plates converge in front, and are each $1\frac{1}{2}$ inch long; those which join the first costal plates converge behind more rapidly, and are each about $1\frac{1}{4}$ inch long. The length of the plate in the median line is $1\frac{7}{8}$ inch; its greatest width from side to side is about $2\frac{7}{8}$ inches.

The first neural plate is subovate in outline, being convex in front and behind and convex at the two sides. Its greatest width is $1\frac{1}{8}$ inch, and its greatest length $1\frac{5}{16}$ inch. It articulates with the nuchal plate in front, with the first pair of costal plates at the sides, and with the second neural plate behind. It is depressed in its hinder third, as well as impressed by the transverse scutal margin.

The second neural plate, which is short and broad and gently convex, has the usual shape. It is concave in front, and an inch wide where it meets the first neural plate. Here there are lateral shoulders a quarter of an inch long, which meet the first pair of costal plates, and widen the bone to $1\frac{1}{4}$ inch. The posteriorly converging lateral surfaces which meet the second pair of costal plates, measure $\frac{1}{16}$ inch in length. The bone in the median line is $1\frac{1}{8}$ inch long, and is $\frac{1}{16}$ inch wide posteriorly, where it joins the third neural plate.

The third neural plate has the same general form as the second, but is longer; and it is depressed behind the middle, but not so deeply as the first neural plate. It is $1\frac{3}{8}$ inch long in the median

line; it is $1\frac{1}{4}$ inch broad across the shoulders for the second pair of costal plates, measures nearly $1\frac{1}{4}$ inch along the posteriorly converging lateral surfaces for the third pair of costal plates, and is $1\frac{3}{8}$ inch wide behind.

The fourth neural plate is more like the second, but is relatively wider behind. It is smooth and convex, and measures $1\frac{3}{16}$ inch in length, is $1\frac{3}{16}$ inch broad over the shoulders for the third pair of costal plates, and measures $1\frac{5}{8}$ inch along the posterior sides for the fourth pair of costal plates. These sides do not converge so rapidly as those of the plates in front; the bone measures $\frac{7}{8}$ inch from side to side behind.

The fifth neural plate is subquadrate; it is crossed transversely behind the middle by the scutal impression. It measures $1\frac{1}{4}$ inch long, $1\frac{1}{4}$ inch broad over the shoulders in front, $1\frac{5}{8}$ inch along the lateral border, and $1\frac{5}{8}$ inch wide from side to side behind.

The sixth neural plate is transversely oblong, $\frac{3}{4}$ inch long, $1\frac{3}{8}$ inch broad, and fully an inch broad behind.

These neural plates are less than $\frac{1}{4}$ inch thick; and to each of them is ankylosed the neural arch of a vertebra. The neural arches are greatly compressed from side to side, and are expanded a little in the middle, where two centrums met and gave attachment to the rib. The neural arches become successively wider from before backward: this character was probably also seen in the centrums. The fifth neural arch has the anterior half of the corresponding centrum preserved. It is remarkable for compression from above downwards, expansion opposite the rib, and constriction in the middle of the centrum. The rib articulates both with the centrum and with the neural arch.

The nuchal plate is greatly thickened on the visceral surface, in a line which corresponds to the transverse scutal impression. In front of this line the marginal scutes are prolonged on the under-side of the carapace; behind it the plate is smoothly excavated as if to form a recess for the animal's head. The first epipleural plates are greatly thickened where they join the marginal plates anteriorly, and have blended with them a pair of strong greatly elevated ribs which curve forward. But the second, third, and fourth epipleural plates show no sign of the confluent rib, except where it rises near the centrum at a sharp angle as a narrow pedicle compressed from above downward. The transverse space between the bases of the first pair of ribs is $1\frac{5}{8}$ inch; but the distance lessens from before backward; between the fifth pair it has diminished to $1\frac{1}{4}$ inch. This pair of epipleural elements has the rib slightly elevated.

The costal or epipleural plates are all imperfect. The first pair is by far the largest. Each is of irregular form; and, owing to the fact that it meets the nuchal plate and three marginal plates, its outlines converge towards both ends. It is 2 inches long in a line with the suture between the nuchal plate and the first marginal.

The second costal plate widens outward from $1\frac{1}{8}$ inch near the neural plate to $1\frac{1}{2}$ inch where fractured. It is marked with a Y-shaped scutal impression.

Third pair of costal plates hammer-headed at their junction with the neural plates, where they measure $1\frac{1}{2}$ inch in length; but they become narrower, and where fractured measure only an inch in length.

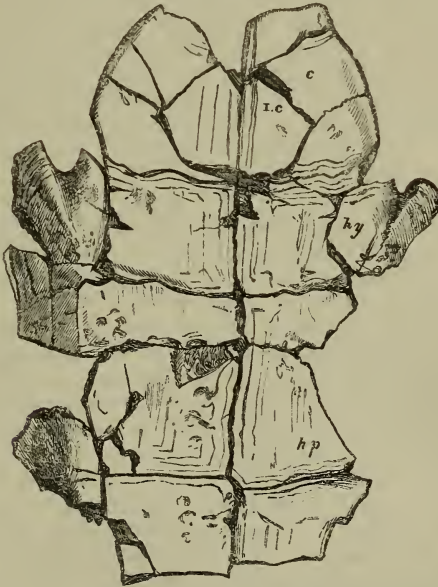
The fourth costal plate where it joins the neural plate is curved backward; it is about $1\frac{1}{4}$ inch long, and gets narrower from within outward.

The fifth costal plate has the same form, and is an inch long.

The Plastron.

The plastron (fig. 2) is made up of the usual bones. A somewhat heart-shaped five-sided interclavicle (or sternum, fig. 2, *i.c*) is enclosed in front by two clavicles (*c*), and behind by two hyosternal bones (*hy*), which are followed by two hyposternal elements (*hp*). The plastron is more than usually convex from front to back.

Fig. 2.—*Plastron of Emys hordwellensis.* (One third natural size.)



c. Clavicle. *i.c.* Interclavicle. *hy.* Hyosternal. *hp.* Hyposternal.

The gular scutes are small, and become narrower from the median line outward; each measures $1\frac{1}{4}$ inch from the median line transversely, and $\frac{3}{4}$ inch from before backward. The postgular or humeral scutes are large, and have the posterior margin convex, though the

border is sinuous; they are entirely in the hyosternal bones. They measure $1\frac{3}{4}$ inch in length in the median line; and each scute is $2\frac{1}{2}$ inches broad; in the entosternal or interclavicular region the plates are concave.

The pectoral scutes have subparallel borders; they are $1\frac{3}{4}$ inch long; and each is $3\frac{3}{4}$ inches broad. Their posterior border is entirely in the hyosternal bones.

The abdominal scutes are 3 inches in length; and each is nearly square. Their posterior border is $1\frac{1}{4}$ inch from the hinder border of the hyosternal bones. The femoral plates are imperfectly indicated.

The hyosternal plates are $3\frac{1}{2}$ inches long; and each is $2\frac{3}{8}$ inches broad to the femoral notch, and $\frac{1}{2}$ an inch thick where it joins the xiphisternal bones behind.

The hyosternal plates measure 4 inches in extreme length from the margins where they join the clavicles to the hyosternal suture; but they measure only $1\frac{3}{4}$ inch in the median line. Each is $2\frac{3}{4}$ inches broad at the humeral notch, and $3\frac{3}{4}$ inches broad at the lateral suture.

The interclavicle is $2\frac{1}{8}$ inches broad and $1\frac{1}{2}$ inch in length. It is rounded in front, and has two straight anterior surfaces for union with the clavicles; posteriorly the bone is convex; and this margin is received into a concavity formed by the hyosternal bones.

In front the clavicles form a concave border $2\frac{1}{4}$ inches long; this border terminates laterally in a sharp angle, behind which the bone extends laterally on each side for $1\frac{3}{4}$ inch. Every scutal area is marked with concentric lines of growth.

The only Emydian remains from Hordwell hitherto noticed are a few isolated plates figured by Prof. Owen in 1849, in the Palæontographical Society's Monograph of the fossil Tertiary Reptilia (pl. xxiv.), and the hyosternal and the hyposternal bones of a large Chelonian plastron (pl. xxvii.), named *Emys crassus*. These latter remains are briefly noticed on the last page of the monograph, and are said to be remarkable for their large size and great thickness. The hyosternal bone is in the British Museum. And the hyposternal bone in the species now described differs from it not only in these points, but in the form of the plate, which is more rounded anteriorly, and in the positions of the scutal impressions.

The most distinctive characters by which this species is separated from all others, recent or fossil, are:—the broad, short, gular scutes with sinuous sutures; the subtriangular nuchal scute; the sub-pentagonal first vertebral scute, broader than the succeeding quadrate vertebral scutes; and the concentric ornamentation left on the carapace and plastron by all the scutes.

49. *On the Mode of Occurrence and Derivation of Beds of Drifted Coal near Corwen, North Wales.* By D. MACKINTOSH, Esq., F.G.S.* (Read June 21st, 1876.)

ABOUT four years ago the late Mr. Jones, of Angharad, directed my attention to the remarkable fact that beds of drifted coal are to be found in sand and gravel around Corwen, at a great distance from any *known coal in situ*. The belief that this coal was of *local* derivation had led to unsuccessful mining operations in the Wenlock rocks of the neighbourhood.

Positions occupied by the Drifted Coal.—Around Corwen the lowest drift consists of yellowish (occasionally bluish) clay, irregularly alternating with beds of coarse gravel. Many large boulders are to be found at or near its base; and still larger boulders occur at or near its summit. The former are often rounded and local; the latter subangular, or angular, and erratic (chiefly from the Arenig hills to the west). Above this drift there is a deposit of clean sand and fine gravel, which, in other parts of the Dee valley, often graduates into very coarse gravel with boulders. In many places around Corwen this deposit is covered by an irregular kind of brick clay. The coal is generally found in the sand and fine gravel. Immediately to the east of the mountain-limestone quarry (about a mile and a half to the west of Corwen), a roadside section shows fine gravel and sand with streaks of decomposed coal. In the Dee valley, some distance east of Corwen, and not far from Carrog station, considerable quantities of coal may be seen imbedded in sand in the railway-cutting. I was assured that coal may be found in *many* other places around Corwen; but the principal instance occurs to the north of the town, and near to where the Denbigh railway crosses the river Dee. In the deep railway-cutting on the north side of the river there are several beds of coal in forms varying from large lumps to fine dust. At the time when the cutting was made the coal kept a temporary smithy going for about a month. The outcrop of the coal-beds may still be seen after removing a facing of sand. The fine gravel associated with these beds, so far as I could see, is almost entirely made up of local micaceous Silurian grit; and none of the small stones show any decided traces of glacial action, in this respect differing from the boulders in the underlying drift, which are often intensely striated. Northward from this cutting, in the direction of Denbigh, I could find no indications of coal in the sand and gravel; and this seemed to suggest that the coal could not have been transported from the Vale of Clwyd.

* This paper is intended as a supplement to one entitled "Additional Remarks on Boulders, &c." which appeared in 'Quart. Journ. Geol. Soc.' for December 1874, vol. xxx. p. 711. Since that paper was written, I have traced the dispersion of felspathic boulders from the Great Arenig, in a south-easterly direction, across Bala Lake, and have likewise found Arenig boulders around Denbigh; so that they must have *radiated* over the fourth of a circle.

Derivation of the Drifted Coal.—In order to arrive at a satisfactory conclusion on this subject, it may be necessary to take into account the direction of the glaciation in the neighbourhood of Corwen. On the north slope of the hill to the south of the town, after carefully eliminating a number of structural furrows on rock-surfaces, which could be traced to where they ran *under* overlying strata, I found true glacial striæ coinciding with the rounded sides of rocky projections pointing to about W.S.W., or approximately in the direction from which the boulders of the district were transported. This at first led me to suppose that the coal had been drifted *from* W.S.W.; but this involved the supposition that a portion of the coal formation *in situ* must have been faulted down * on the top of the remarkable outlier of Mountain Limestone which occurs about a mile and a half west of Corwen, and that, as the limestone strata dip between E.N.E. and N.E. at an angle of about 45°, the coal *in situ* must have remained in a depression (now covered with drift) on the east or dip side of the limestone until the glacial period, if not until the present time. After corresponding with Mr. Aveline (who formerly surveyed this part of Wales, and who informed me that he regarded the above theory as very improbable), and after reconsidering the subject, I became convinced that the drifted coal around Corwen must have come from the Cefn and Ruabon district, about 12 miles east of Corwen in a straight line, but at least 20 miles following the sinuosities of the valley of the Dee. The height above the sea of the drifted coal in the cutting north of Corwen is about 550 feet, which is not high enough to preclude the idea of its having found its way from the above district; and this idea is corroborated by the similarity of the Corwen to the Ruabon coal †.

Mode of Transportation of the Corwen Coal.—As no boulders, striated stones, or other traces of glacial action are to be found immediately associated with the drifted coal under consideration, it would seem that it must have been transported during a comparatively temperate interglacial period when very little ice floated on the surface of the sea, but still sufficient ice to carry lumps of coal (though not large fragments of rock) as far as Corwen. The limitation of the Corwen coal to a low level suggests the idea that at the time of its transportation the land was not submerged beyond a few hundred feet, and that the coal was floated along the sinuosities of the valley of the Dee, until, arriving at shallow water in the Corwen area, it stranded, and became imbedded in sand by sea-currents or waves. It is not necessary to suppose that there was any thing more than a tidal current flowing up the Dee valley at the time when the coal was floated.

Principal Bearing of the subject on Glacial Geology.—If the foregoing be a correct explanation of the derivation of the Corwen coal, it follows that during the glacial (including interglacial) period, *the*

* The great Bala fault, which divides the whole of North Wales into two parts, runs through the Vale of Conwy.

† In the drift around Ruabon and Wrexham there is a considerable quantity of coal débris, showing that at least a local drifting of coal must have occurred.

transportation of débris may at times have taken place in a direction almost diametrically opposite to that of the glaciation of a district. But it would not be difficult to bring forward many instances in the north-west of England and Wales, of the interweaving of drifts from points of the compass ranging from 90° to even 180° . This interweaving, however, is generally of very limited extent.

Postscript.—Since this paper was written I have unexpectedly had occasion to visit the Corwen district a second time. I reexamined the coal-beds in the railway north of Corwen, and in the fine gravelly matrix of one of them found a considerable variety of rock-specimens, in this respect differing from the coarser gravel I had previously observed. The gravel, in all probability, was partly worked up out of the underlying or adjacent Boulder-drift: but such could not have been the case with the angular lumps of coal; for, while the waves would have rounded them or reduced them to powder, no trace of coal (so far as I am aware) has yet been found in the Boulder-drift. A little north of this spot, Mr. Jones, toll-house keeper, has lately found coal in still greater abundance.

50. *On an ADHERENT FORM of PRODUCTUS and a SMALL SPIRIFERINA from the LOWER CARBONIFEROUS LIMESTONE GROUP of the EAST of SCOTLAND* *. By R. ETHERIDGE, Esq., Jun., F.G.S. (Read June 21, 1876.)

[PLATES XXIV. & XXV.]

I. ON AN ADHERENT FORM OF PRODUCTUS.

1. *Introduction.*—The habits and mode of life of the *Producti* have been a fruitful source of speculation to the various authors who have written on the genus. Some writers contended that the various species lived a free and independent life; others, on the contrary, conceived that they were attached by muscular fibres passing from the interior of the shell, and in fact acting the part of a byssus, whilst yet others believed that their position during life was at least aided by the long tubes or spines which usually ornament their surface.

I have now much pleasure in announcing the discovery (by Mr. James Bennie, of the Geological Survey of Scotland) of an adherent form of *Productus*, which, although not an entirely new fact in connexion with this genus and its allies, has not, so far as I am aware, been observed in so complete a manner before. Notwithstanding that the facts now brought to light will not warrant us in applying the principle to the whole of the *Producti*, they yet conclusively prove that at least one form spent a very considerable portion if not the whole of its existence adhering firmly by its spines to extraneous bodies.

The specimens were met with by Mr. Bennie in the Lower Carboniferous Limestone group at two localities in East Lothian, at one of which the form occurs rather abundantly, as the collections of the Geological Survey of Scotland and Museum of Practical Geology now collectively contain at least one hundred and forty individuals.

2. *Bibliography.*—Before proceeding to describe the specimens, it will be as well to give a brief digest of the principal views held by previous writers on the mode of life of *Productus* and the use of the spines scattered over the valves of many of its species.

1828. The Rev. Dr. Fleming considered it “probable that all the *Producti* and *Pentameri* were free shells” †.

1831. Baron von Buch, under the generic name of *Leptaena*, described a shell resembling a *Productus*, with annulated tubes along the hinge-line on each side of the umbo, and communicating by holes placed under the hinge-line with the interior of the shell, and

* Communicated with the permission of the Director-General of the Geological Survey of the United Kingdom.

† British Animals, p. 380.

through which, he considered, passed small tendons of attachment*.

1831. M. G. P. Deshayes, in giving the characters which separate the genera *Terebratula* and *Productus*, drew attention to the absence of any foramen in the beak of the latter, the resulting want of a peduncle, and probable free condition of the shell †.

1832. The same author, in his continuation of Bruguière's 'Encyclopédie Méthodique,' stated that *Productus* showed no trace of attachment, and lived a free life after the manner of a large number of the Acephalous Mollusca ‡.

1835. The Rev. A. Sedgwick and Sir R. I. (then Mr.) Murchison, in their paper "On the Geological Relations of the Secondary Strata in the Island of Arran" §, describe *Producta scotica*, Sow. (= *P. semireticulatus*, Mart.) as occurring in the Carboniferous Limestone of the Corry Caverns so abundantly "as entirely to form the lower layer of many of the beds, being arranged very symmetrically in the exact position of the living shell [misprinted shale] with their convex valves downwards."

1836. M. G. P. Deshayes, in the second edition of Lamarck's famous work ||, states that from the absence of spines in some *Producti* he was disposed to abandon his opinion regarding the use of the tubes or spines as a passage for tendinous appendages (*appendices tendineux*) of attachment, replacing the peduncle of *Terebratula* ¶.

1838. M. von Buch, in his 'Essai d'une Classification et d'une Description des Térébratules' **, divides the Brachiopoda into two groups. In the non-perforate division of the second section of the first group, or those with the point of attachment from the edge of the upper valve below the hinge-margin, M. von Buch placed the genera *Calceola* and *Leptæna*, including in the latter *Productus* and *Strophomena*.

The views previously enunciated by M. von Buch as to the nature of the tubes in *Productus*, appear to have been abandoned by that eminent naturalist in his memoir "Ueber *Productus* oder *Leptæna*" ††. He there considers it very doubtful if the tubes or spines were used for fastening the shell; for he found that in some species, instead of being confined to the hinge-line, they were scattered over the shell, as in *Productus aculeatus*.

* Abh. d. k. Akad. Wiss. z. Berlin, aus dem Jahre 1828 (pub. 1831), pp. 53-56.

† Descr. des Coq. caractéristiques des Terr. p. 112.

‡ Encyclopédie Méthodique: Hist. Nat. des Vers, par Bruguière et de Lamarck, continuée par M. G. P. Deshayes, iii. p. 846.

§ Trans. Geol. Soc. 2nd ser. iii. p. 30.

|| Hist. Nat. des Anim. sans Vertèb., par J. B. P. A. de Lamarck. Deuxième édition, par MM. G. P. Deshayes et Milne-Edwards, vii. pp. 378, 379.

¶ According to Prof. de Koninck, the division by M. Deshayes of the Terebratuliform shells into two genera, *Terebratula* and *Productus*, on the presence or absence of any opening in the beak, was an erroneous one. Deshayes placed in *Productus* all those with an articulated hinge in which the opening is quite obliterated, and completely neglected the presence and form of the area &c. (Anim. Foss. Terr. Carb. Belg. p. 150, and Mon. *Productus* et *Chonetes*, p. 8).

** Mém. Soc. Géol. de France, iii. p. 126.

†† Abh. d. k. Akad. Wiss. z. Berlin, aus dem Jahre 1841 (pub. 1843), pp. 53-56.

1842. M. Bouchard-Chantreaux described a Devonian *Productus* from the neighbourhood of Boulogne possessing a rudimentary area and a median triangular cleft under the beak, through which the author supposed a peduncle for its attachment passed*.

1844 (1842-). Prof. L. de Koninck. It is impossible to reconcile, says this eminent author, the presence of the long and delicate tubes of the *Producti* with the idea that they could withstand the tossing waves of the sea and the buffeting with a large number of rough bodies, which evidently would have destroyed them. It is improbable, he adds, that attachment took place by means of ligaments issuing from these tubes or spines, according to the view formerly held by M. von Buch; neither does he think that there is sufficient evidence to admit that the *Producti* were fixed by fibres issuing along the hinge-margin of the valves. Prof. de Koninck supposes that muscular fibres issued from between the free edges of the valves, and so gave attachment to the shell, and in support of his view cites the case of *P. proboscideus*, De Vern., in which he thinks the tubular prolongation served to protect the fibres of attachment †.

1845. M. de Verneuil supported the later opinion of M. von Buch, that the cardinal spines did not serve to attach the shells to submarine bodies, but, he added, were probably used as channels for the introduction of water into the interior of the shell, necessary for its life and respiration ‡. M. de Verneuil considers that the *Producti*, with the exception of those species possessing a rudimentary area and a median triangular cleft (*P. horrescens*, *P. subaculeatus*, and *P. productoides*), have the cardinal margins so tightly pressed and united along the whole length of the hinge that there is neither room for an area nor for a triangular cleft. With regard to those species in which the latter did exist he had considerable difficulty in conceiving that it gave exit to a muscle of attachment §. Of the opinions expressed by M. Deshayes and Prof. de Koninck, on the one hand that the *Producti* were free and non-adherent, and on the other that they held fast by muscular fibres passing from between the free edges of the valves, De Verneuil conceived the former to be the more probable of the two. Notwithstanding the peculiar prolongation of the shell in *P. proboscideus*, which lends colour to the latter theory, the valves are so united and tightly pressed along their margins that it is difficult to imagine how they could have been separated by fibres during the life of the mollusk ||. If the *Producti* were, as a rule, free shells, adds M. de Verneuil, some, however, were attached by the apex of the beak of the convex valve, as for instance *P. horrescens*, De Vern. In this species the part in question is obliquely truncated; and it is probable that it adhered by the apex of the beak or by very short fibres which issued from the base of the median aperture or cleft ¶. Finally, in a note** to the general description of *Productus*, De

* Ann. d. Sc. Nat. 2^e sér., Zoologie, xviii. p. 160.

† Anim. Foss. Terr. Carb. Belg. pp. 153 & 204.

‡ Géol. de la Russie d'Europe, &c., par R. I. Murchison E. de Verneuil, et le Comte A. de Keyserling, ii. p. 249.

§ Ibid. pp. 249, 250. || Ibid. p. 250. ¶ Ibid. p. 286. ** Ibid. p. 249.

Verneuil adds that the tubes or spines could not in the least have served to attach the shell.

1846. Count A. von Keyserling appears to have believed that the *Producti* lived with their convex or ventral valves downwards, a position which would be assumed by an example if thrown into water, divested of matrix, and filled with a material having the same specific weight as water*.

1847. Prof. L. de Koninck, in criticising M. de Verneuil's theory as to the admission of water through the tubes or spines, thinks that, had they been intended for so important an office, it is probable that their distribution over the valves of the shell would not have been left so much to chance—in other words, that the distribution would have been on a more defined plan †. The views expressed by M. de Verneuil on the theory of M. Bouchard-Chantereaux are acquiesced in; and Prof. de Koninck further believes that the latter writer included in his *Productus* certain forms which should have been placed in *Leptaena*. The learned author is unable to reconcile a free and unattached habit (as supposed by M. Deshayes and others) with the possession of long and delicate tubes by the majority of the species. He believes that in the *Producti*, with the exception of *P. proboscideus* and its allies *P. Nystianus* and *P. genuinus*, the fibres of attachment issued from between the free margins of the valves. The truncated apex of the beak in *P. horrescens* is regarded, not as caused by the attachment of the shell directly to submarine bodies by the beak, but by friction of the same part against the rock to which the animal was attached by its fibres ‡.

1848. Prof. H. B. Geinitz figures an example of *Orthotrix Goldfussi*, Münster (= *Strophalosia*, King), from the Lower Zechstein of Milbitz near Gera, which is distinctly represented with some of its hinge-spines encircling and clinging to a spine of *Productus horridus* §. On the succeeding plate he gives a restoration of *P. horridus*, Sow., suspended by its fibres of attachment passing from between the valves ¶.

1850. M. A. d'Orbigny supposed that the *Producti* rested on sea-bottoms of fine sediment with their convex or ventral valves downwards, held in that position by the long spines, which he compared to those of *Spondylus striatus* and other shells. The mode of attachment of *P. horridus* he regarded as exceptional, and the proboscis-like prolongation of *P. proboscideus* as a deformity due to an accidentally constrained position of the shell in holes or crevices of rock during life, the edges of the mantle being prolonged upwards so as to reach the surface of the ground ¶¶.

* Reise in das Petschora-Land im Jahre 1843, pp. 198, 199.

† Monographie du genre *Productus*, Mém. Soc. Royale des Sc. de Liège, iv. pp. 104, 112–114; Rech. sur les Anim. Foss., Mon. des Genres *Productus* et *Chonetes*, p. 15.

‡ Ibid. pp. 21, 22.

§ Die Versteinerungen des deutschen Zechsteingebirges, pl. 2. fig. 27, b, c.

¶ T. 6. f. 1.

¶¶ Ann. des Sc. Nat. sér. 3, xiii. (Zoologie) p. 314.

1850. Prof. W. King figured and described a specimen of *Strophalosia parva* (King)* adhering to the interior of the shell of *Productus horridus* by means of its umbone and the spines of that part of the shell. Prof. King considered this to be the mode of attachment of all the species of *Strophalosia*, at least in the young state †.

1851. Dr. H. G. Bronn ‡ doubts if the spines were used for the conveyance of water into the shell at all; for had they done so their distribution over the shell would have been regular and strictly determined.

1853. Mr. T. Davidson, in his magnificent 'Monograph of the British Fossil Brachiopoda,' passed in review the various speculations which had been advanced on the habits of *Productus*, and adopted D'Orbigny's view of the function of the proboscis of *P. proboscideus* §.

1854. The late Dr. S. P. Woodward considered that the *Producti* may have been attached when young, and that a few species were perhaps permanently fixed. The large spines on the ears of the ventral valve may have served to moor the shell ||.

1857. Mr. T. Davidson, in a note appended to the description of *Strophalosia Goldfussi*, Münster (= *S. parva*, King?), quotes a remark of Prof. de Koninck's that "sometimes the spines while interlacing each other surround foreign objects which may lie within their reach, and that those situated on the beak appear to have possessed that faculty in particular." Specimens, says Mr. Davidson, are in the possession of Prof. de Koninck in which the spines envelop a fragment of the spine of *P. horridus* ¶.

1860. Chevalier d'Eichwald considers that the use of the spines or tubes is unknown; they are probably simply ornamental. According to his view *P. proboscideus* was fixed to rocks by its long tube; and from this he argues that probably the other species of *Productus* were similarly provided with a tube, which was membranous and easily detached from the shell. It is extremely probable that the numerous species of this genus were in general fixed by muscular fibres which issued from the interior of the shell at the lower margin **.

1862. Dr. J. C. Chenu describes *Productus* as a free shell ††.

1868. In the second edition of Dr. S. P. Woodward's valuable work on the Mollusca, by Mr. R. Tate, similar views are expressed to those previously noticed as given in the first edition of the work.

The evidence contained in the foregoing quotations regarding the

* Considered by Mr. Davidson to be a synonym of *S. Goldfussi*, Münster.

† Mon. Permian Foss. England, p. 95, t. 12. f. 33.

‡ Lethæa Geogn. 2nd ed. i. p. 376.

§ Mon. Brit. Foss. Brach., Introduction, p. 119.

|| Manual of the Mollusca, 1st ed. pt. 2, p. 234.

¶ Mon. Brit. Permian & Carb. Brach. p. 40, note 1.

** Lethæa Rossica, i. pp. 885, 886.

†† Manuel de Conchyliologie et de Pal. Conchyl. ii. p. 226.

habits of the *Producti*, and use of their spines, briefly summed up under those two headings, is as follows:—

A. Habits.

That the *Producti* were regarded as:—

1. Free shells, by Fleming, Deshayes, De Verneuil (partly), and Chenu.
2. Living with the ventral or convex valve downwards, by Sedgwick and Murchison, Keyserling and D'Orbigny.
3. Attached by tendons passing through tubes arranged along the hinge-line, under the general name of *Leptaena*, by Von Buch (an opinion afterwards abandoned).
4. Attached by means of a peduncle passing through a central triangular foramen, by Bouchard-Chantreaux.
5. Attached by fibres passing between the free edges of the shell, by De Koninck, Geinitz, and Eichwald.
6. Probably attached when young, but a few permanently attached, by S. P. Woodward.
7. Attached by spines (in the case of the allied genus *Strophalosia*), by King and De Koninck (*vide* Davidson).

B. Spines.

That the spines were considered—

1. To be for the passage of tendons of attachment, by Von Buch.
2. To be for the introduction of water into the interior of the shell, by De Verneuil.
3. To be for simply retaining the shell in position in fine sediments, by D'Orbigny.
4. To be without essential function, by Bronn.
5. To be of unknown function, by Eichwald.
6. Not to serve as a means of attachment to the shell, by De Koninck and De Verneuil.
7. Not to act as a conduit to the interior of the shell, by De Koninck and Bronn.

3. *Description of the Specimens.*—With the foregoing brief outline of the views of some of the more eminent authorities, I pass on to a description of the specimens.

We possess specimens of this adherent *Productus* in four conditions:—1st, attached by the spines of the ventral valve to foreign bodies (figs. 1–5, & 11); 2nd, a few detached conjoined ventral and dorsal valves; 3rd, detached dorsal valves (figs. 18–22); and, 4th, fragments of detached ventral valves with the remains of spines (figs. 16, 17). The first and fourth conditions are by far the most common, and with regard to one another in about equal proportions. In size the individuals vary from less than a line in diameter (fig. 13) up to a little more than two lines (fig. 24), and are attached to small Encrinite stems and fragments of Polyzoa, but generally to

the former. The spines of the ventral valve are wound round the bodies of attachment in the most complete manner (fig. 1 &c.), one individual holding on by as few as two spines and a portion of a third (fig. 11), another by six spines, and again another by seven, and so on, sometimes singly (figs. 1, 2, 3, 5, &c), at other times in clusters (fig. 4). When the organism to which the *Productus* is attached is of larger size than the latter, the whole of the ventral valve is applied to it, the spines spreading out and round on each side (figs. 2, 4, 5); but when the foreign body is of less diameter than the *Productus*, as is usually the case with fragments of Polyzoa, several of the spines are wound tightly round, especially near the beak, and the remainder of the valve remains free (figs. 1, 3, 11). Attachment took place during the life of the Crinoid; for, in nearly every case where the *Productus* remains adhering, we find that its rate of growth was less than that of the Crinoid, the result being that the substance of the latter surrounded or enclosed its parasite, first the encircling spines disappearing and gradually the shell (figs. 6-10). We have specimens showing this remarkably well in all stages of the process, from the mere absorption of the spines by the substance of the Crinoid, up to the total disappearance of the *Productus* itself, when the Crinoid stem assumes a swollen or distorted appearance (fig. 10). From a consideration of this gradual absorption by the Crinoid stem there arise two questions:—Did the *Productus* when once attached lose the power to free itself? or, Did the absorption by the Crinoid, contrary to the view indicated previously, commence only after the death of the *Productus*? To show how closely these little shells congregated I have given a figure of an Encrinite stem on which may be seen the grooves caused by the removal of a number of the encircling spines (fig. 12).

In the young state the characters of this hugging *Productus* are obscure; but in the mature (or what I take to be the mature) form they become well marked and constant. In marginal outline the shell somewhat resembles the *P. aculeatus* group, with the hinge-line scarcely as long as the shell. The auricular expansions are well marked but flattened (figs. 13, 14, 19), and the cardinal angles sharp (figs. 13, 14). The ventral valve is slightly convex when the individuals are partially free, and without sinus (figs. 13-15). The dorsal is flat or a little concave (figs. 18, 19, 22, 24), and granular on the interior surface. The cardinal process is bifid and broadly V-shaped (figs. 18, 21, 24), with strong lateral ridges proceeding from it to the cardinal angles (*a*, figs. 21, 23). The mesial ridge in the interior of the dorsal valve, immediately under the cardinal process, is divided into two portions (*b*, figs. 21, 23), which unite at about one third from the hinge-line, enclosing between them a rather deep pit or space (*c*, figs. 21, 23), which partially represents the convex visceral region of the shell externally. The mesial ridge becomes stronger and more pronounced towards the front, and divides the shell symmetrically. Both valves are covered with a variable number of sharp, undulating, concentric wrinkles or corrugations, coarse for the size of the shell, and occasionally irregular

(figs. 13-20, 22, 24), sometimes almost becoming geniculate. In the dorsal valve they are perhaps finer and more numerous than in the ventral valve; and in the visceral region of the shell the circular concentric character gives place to an almost square concentric form of wrinkle or corrugation (figs. 18, 24). As the shells increased in age the corrugations became broken up in a roughly reticulate manner (figs. 22, 24). In the young state the ventral valve only is partially covered with spines (figs. 13, 14), the dorsal being devoid of them (fig. 19); but as growth went on they also appeared on the latter, but apparently without attaining to the same size. The spines are irregularly scattered over the surface of the valves; those of the ventral valve long, thin, tapering (figs. 16, 17), and encircling (fig. 11), and when broken leaving the shell covered with a series of small warts (figs. 13-17). A row of prominent strong spines occurs along and immediately below the hinge-line of the ventral valve (*a*, figs. 16, 17), but in the two figured examples broken off. In a few instances one or more of the spines may be seen pressed down against the surface of the ventral valve, as if it had so grown between the shell and the object to which it was attached, without encircling the latter. The umbo of the ventral valve is small, sharp, plain, and slightly incurved over the hinge-line. The visceral region of the same valve is often grooved vertically or indented, the impression of the body to which the individual was attached, such grooving elevating the beak (figs. 13, 14) and obliterating the corrugations on other portions of the valve more than would otherwise be the case. The adductor muscular scars are only preserved distinctly in one specimen. They appear to be elongated vertically, and are apparently lobed transversely.

4. *Considerations as to Specific Identity.* The question which most prominently presents itself is:—Is this adherent *Productus* the young of some well-known species, or is it to be regarded as a minute and undescribed form? Let us examine the evidence that we possess to settle this question. Of the unattached examples fully two thirds are dorsal valves. The predominance of these over the ventral valves would appear to indicate that it was at least an attached species up to that point of its existence represented by the largest of our specimens, which are dorsal valves, and which may, I think, be taken as representing maturity, unless very strong evidence to the contrary can be produced. It is only reasonable to suppose that had the *Productus* at a certain point of its life disunited itself from the Crinoid stems, upon which it had hitherto lived, we should be in possession of relatively as many large, and what I take to be mature, ventral as dorsal valves. But we are not; for out of a large number of specimens now in the possession of the Geological Survey of Scotland and Museum of Practical Geology nearly all the largest examples are dorsal valves.

When Mr. Bennie was fortunate enough to light upon these interesting fossils, I at once submitted characteristic examples to Mr. T. Davidson, F.R.S., who, in his usually kind manner, gave me the benefit of his valued opinion. He pointed out that the

present fossils might either be the young of *P. longispinus*, Sow., or *P. Wrightii*, Dav., and recommended careful observation as to the other species of *Productus* found in company with the present form. Mr. Bennie, when collecting the disintegrated shale from which the specimens were obtained, observed that the only other *Productus* present in any thing like appreciable quantity was *P. longispinus*, Sow., with this peculiarity, however, that at one of the localities (East Barns) *P. longispinus* was very plentiful and the adherent form correspondingly rare, whilst at another locality (Skateraw) the proportions were just reversed. The characters in which the adherent form differs from *P. longispinus*, Sow., are the following:—The ornamentation of the shell is concentric and not longitudinal; there is no trace of a sinus in the ventral valve, but a strong mesial ridge in the interior of the dorsal valve extending to the front, which does not appear to be so well marked in *P. longispinus*; the upper portion of this mesial ridge splits into two, leaving a space between, which is not the case in *P. longispinus*. The adductor impressions of the latter are situated much higher up under the cardinal process than in the present instance (fig. 23). Lastly, there is a good deal of difference in the distribution of the spines, and in the relative convexity of the valves.

The division which takes place in the mesial ridge of the dorsal valve (*b*, fig. 21) appears to resemble that figured by Mr. Davidson in *Productus scabriculus*, Martin*; but I think it is unnecessary in this case to carry the comparison further.

The concentric wrinkles or corrugations are sharper and more widely separated than those of *Productus undatus*, Defrance; and there is no trace in the adherent form of the fine longitudinal striæ of that species.

The affinities with *P. Wrightii*, Dav., are much closer than in any of the foregoing cases. In both shells the ornamentation is concentric, although apparently more regular in *P. Wrightii*. The size of the two forms is much more approximate, especially one of Mr. Davidson's figures †; and the spines in the enlarged figure of the same author have much the appearance of those of the adherent form, although fewer in number. At the same time there do not appear to be any along the hinge-line of *P. Wrightii*; and, so far as my own observation has gone, there is no trace of the marginal frill of the latter in the present instance.

I do not feel justified in immediately publishing this form as a distinct and undescribed species, but would rather await the opinion of those more intimately acquainted with the structure and variations of the genus *Productus* than I can pretend to be. At the same time, should further researches prove these little shells to be worthy of separate specific recognition, I do not think any name could be more appropriate than one which would express the peculiar habit for which they are remarkable—such for instance as *Productus complectens*, the embracing or encircling *Productus*.

* Mon. Perm. & Carb. Brach. pl. 42. f. 8 a.

† Ibid. pl. 33. f. 6.

In concluding this part of my communication, it may be well to shortly recapitulate the chief peculiarities of this remarkable form of *Productus*. First, its parasitic habit, the indication of which can be seen in some form or other throughout nearly the whole suite of specimens, either as a groove in the ventral valve from the beak forwards, or as a distortion, or by a curving and twisting of the spines. Secondly, the characteristic and well-defined nature of the concentric ornamentation, and, when preserved, the elongated clasping spines. Thirdly, the well-marked mesial ridge in the interior of the dorsal valve, and its separation into two portions, as in *P. scabriculus*, Martin. Fourthly, the absence of a sinus in the ventral valve. Fifthly, the well-marked peculiarities of character continuously traceable from the smallest to the largest specimen, and no apparent gradation onwards to some well-known species.

5. *Locality and Horizon*.—Skateraw Harbour, near Dunbar, plentiful; East Barns Quarry, near Dunbar, not common; Carlops Quarry, near Carlops, Peeblesshire, very rare; shale over the No. 2 Limestone (=Hosie Limestone) of the Lower Carboniferous Limestone group of the Midlothian series.

Collected by Mr. James Bennie.

When collecting fossils from the Calderwood series in the East Kilbride district, Lanarkshire, a year or so since, Mr. Bennie noticed bodies with radiating processes adhering to Encrinite stems, which he thinks may be this *Productus*.

II. ON A SMALL SPIRIFERINA.

I take this opportunity of figuring and briefly describing a small shell which may be new, in the hope that the attention of collectors may be called to it. As we at present only possess one specimen, I shall content myself with merely placing it on record, and await the discovery of other specimens, when we may be better able to judge of its specific value.

SPIRIFERINA, sp.

Specific Characters.—Small, transversely oval, wider than long; ventral valve the more convex of the two. Hinge-line less than the width of the shell; cardinal angles rounded; beak incurved and moderately produced above the area, which is concave and triangular; fissure wide. Ventral valve with a simple shallow sinus, and three rounded ribs on each side, the outer ones indistinctly marked. In the dorsal valve the mesial fold is composed of a single rib, larger than either of the others, two on each side. No laminae of growth. Shell-structure perforated by minute tubuli giving to the surface a dotted appearance.

Obs.—This little shell differs from *Spiriferina cristata*, Schl., var. *octoplicata*, Sow., by the hinge-line being less than the width, by its very rounded cardinal angles, perfect simplicity of the mesial fold

and sinus, much less number of ribs, total absence of any laminae of growth, spinous asperities, or granules on the surface.

From *Spiriferina insculpta*, Phill., it is distinguished by the same character of the hinge-line as in the former instance, greater convexity of the ventral as compared with the dorsal valve, absence of concentric laminae of growth, and smaller area. On the other hand, it agrees with *S. insculpta* in the number of the ribs when that species is found in its simplest form; but these again are decidedly obtuse and not angular. These points of difference can only be regarded as provisional, as the discovery of further specimens may bring to light varieties intermediate between the shell as here figured and the typical *S. insculpta*, to which, of the two species mentioned, it appears to be most nearly allied. In outline, simple mesial fold, and sinus it is not unlike some forms of *Spirifera triradialis*, Phill.; but the beak in the ventral valve is much less elevated, and the shell-substance punctate.

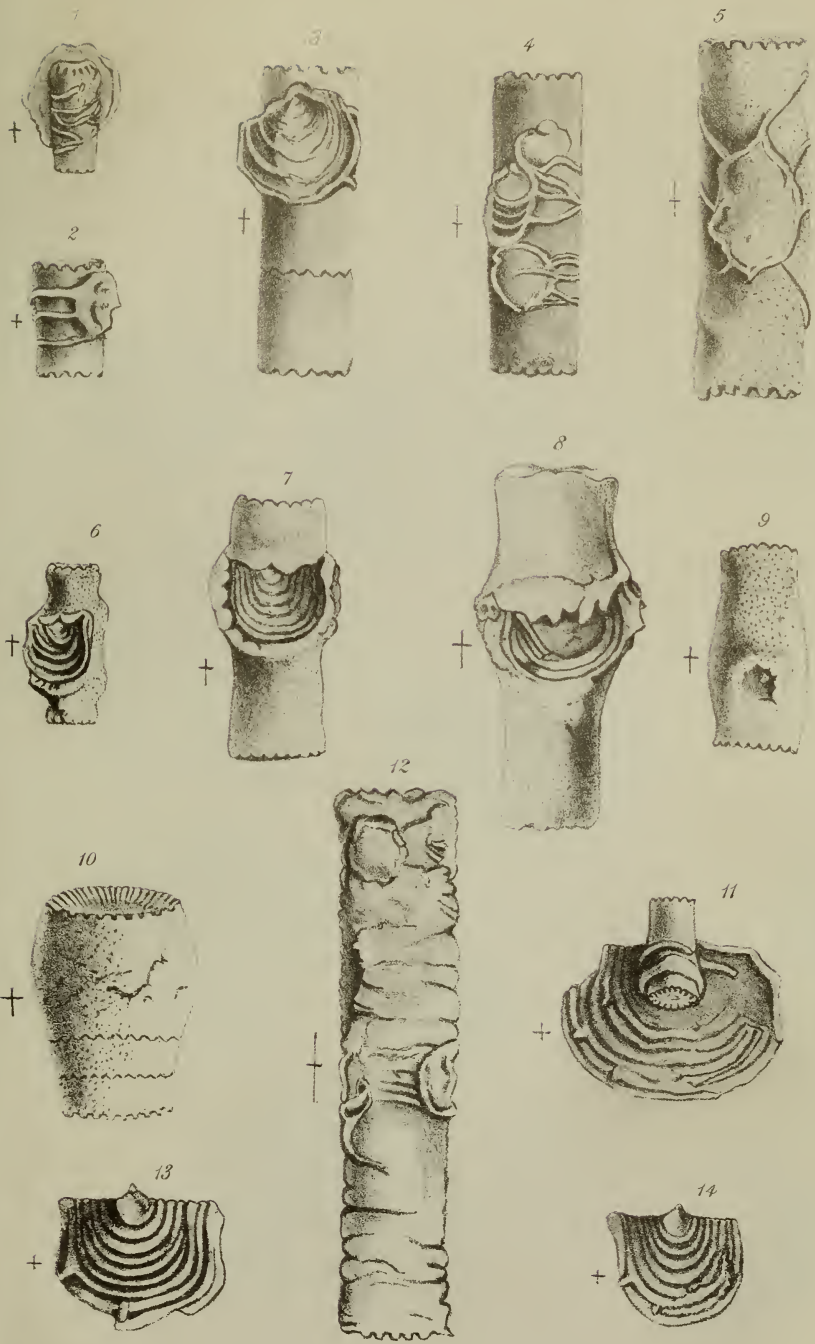
Locality and Position.—Fullarton Quarry, near Temple, Edinburghshire; in shale between bands of the No. 2 Limestone (= Hose Limestone) of the Lower Carboniferous Limestone group of the Midlothian series.

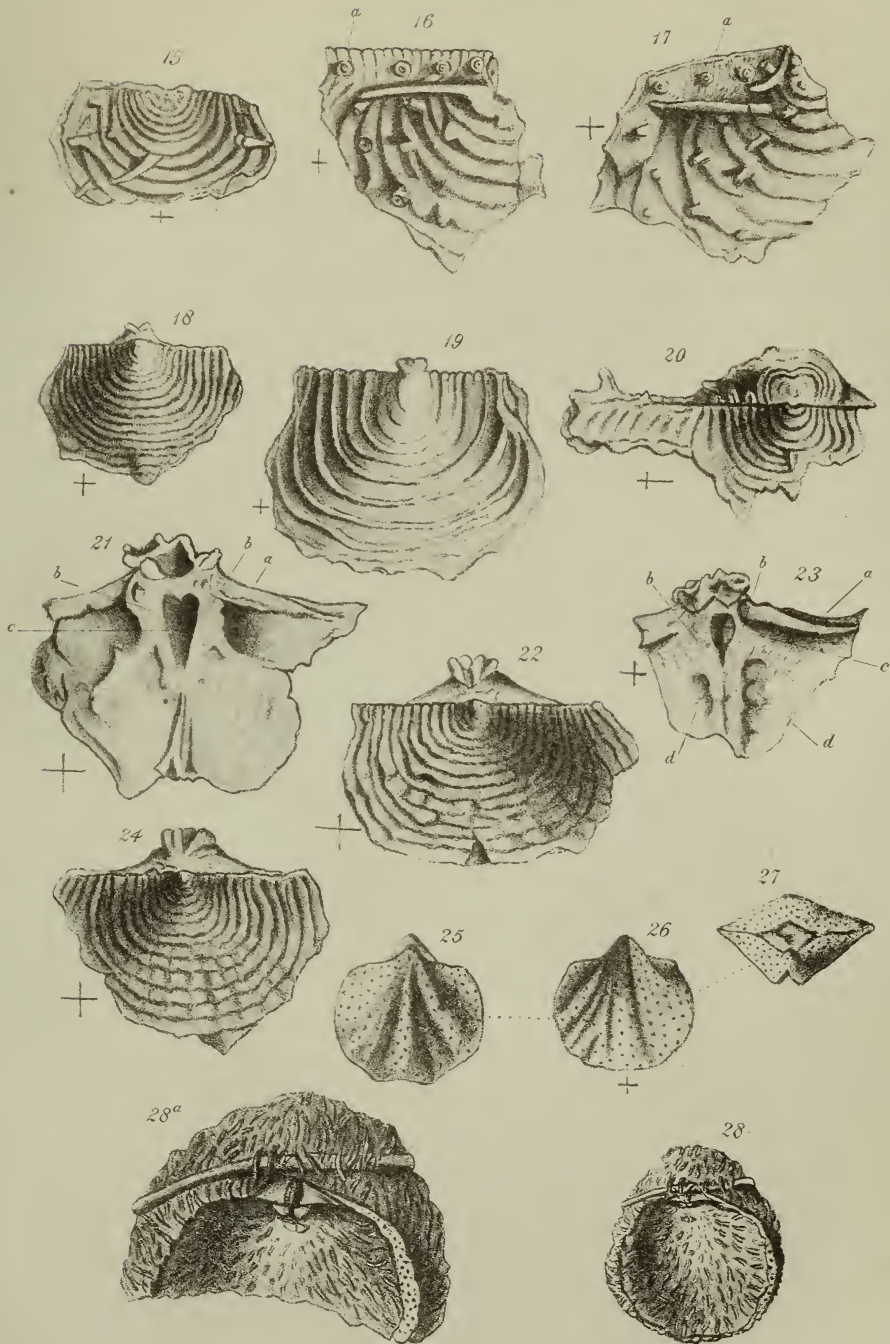
In conclusion I have to acknowledge the obligations I am under to my colleagues Messrs. G. Sharman and R. L. Jack, the former for supplying me with a series of beautifully executed drawings, and the latter for assistance in translating certain foreign memoirs, &c.

DESCRIPTION OF PLATES XXIV. & XXV.

PRODUCTUS, sp. (Figs. 1-24.)

- Fig. 1. Portion of Encrinite stem with adherent *Productus*, showing the spines tightly clasping it. Back view, ventral valves.
2. A similar specimen, side view; three spines shown.
 3. A larger and more mature specimen, front view.
 4. Three individuals clustered together; front view, ventral valves.
 5. A larger specimen, adhering by seven spines, front view.
 6. Interior of the ventral valve, showing the margins gradually enclosed by the substance of the Encrinite stem.
 7. The same process carried a little further.
 8. The same process carried still further.
 9. Almost total disappearance of the *Productus* within the substance of the Encrinite stem.
 10. Total absorption of the *Productus*, and distortion of the Encrinite stem.
 11. Exterior of a ventral valve adhering by two and a half spines to the end of a segment of an Encrinite stem. Broken spines are shown round the margins of the valves.
 12. Encrinite stems with the remains of three young individuals and the markings of numerous encircling spines.
 13. Exterior of the ventral valve, with the elevated umbo and groove caused by the object to which it was attached. Two broken spines are seen.
 14. A similar specimen. Both these figures show the concentric wrinkles in a marked manner.





- Fig. 15. A more transversely elongated ventral valve, with spines, exterior view.
- 16, 17. Portions of the exterior of two ventral valves, showing the hinge-spines, *b*.
- 18, 19. Exterior of two dorsal valves, showing the cardinal process and concentric wrinkles.
20. Hinge-line, and portions of both dorsal and ventral valves united, with one of the large hinge-spines in position.
21. Interior of the dorsal valve: *aa*, ridges from the cardinal process to the cardinal angles; *b, b*, divisions of the mesial ridge; *c*, enclosed space.
22. Exterior of the dorsal valve, with the cardinal process, concentric wrinkles, and traces of the reticulate character assumed by the latter.
23. Interior of a portion of the dorsal valve: *a & c* similar to fig. 21; *d, d*, adductor impressions.
24. Similar to fig. 22.

SPIRIFERINA, sp.

- Fig. 25. Dorsal valve, showing the mesial fold.
26. Ventral valve, showing the sinus.
27. Hinge and fissure &c.

STROPHALOSIA (ORTHOTRIX) GOLDFUSSI, Münster.

- Fig. 28. After Geinitz, showing the form clinging by its umbonal spines to one of the large spines of a *Productus horridus*. (Die Verstein. d. deuts. Zechst. pl. 2. f. 27.)
- 28 *a*. The same, enlarged.

(N.B. The natural size of the fossils is shown, as nearly as possible, by the indicators placed near the figures.)

51. *The SECTION at the HIGH FORCE, TEESDALE.* By C. T. CLOUGH, Esq., B.A., F.G.S., Scholar of St. John's College, Cambridge, of the Geol. Survey of England and Wales. (Read June 21, 1876.)

(Communicated by permission of the Director-General of the Geological Survey of Great Britain.)

It has been my duty, in the course of Survey work, to examine the ground near the High Force. In doing this, several facts have come to light which will, perhaps, be not uninteresting, as they refer to a somewhat classical district, and correct ideas which have been hitherto erroneously held on the authority of Phillips's section at the High Force. These ideas have lately acquired a special importance from their bearing on the subject of "selective metamorphism;" and in correcting them I may be helping, in some small degree, to clear the way for the formation of a theory to satisfactorily account for those instances of selective metamorphism which stand undoubted.

In Phillips's 'Geology of Yorkshire' (1836), part ii. pp. 78, 79, the following passage occurs in connexion with the section at the High Force:—"Shale or plate is so much altered at the High Force in the relation of the joints that most persons mistake a part of the prismatic masses, really composed of metamorphic shale, for trap, and suppose the latter to rest on limestone. The true series is as follows, proceeding downwards:—

- a.* Basalt, rudely prismatic, grey with lichen.
- b.* Thin plate, not very much indurated.
- c.* Bed of plate, subprismatic.
- d.* Beds of plate, laminated.
- e.* Thin limestone bed, with a superficial layer of pyrites.
- f.* Bed of hard pyritous limestone.
- g.* Several beds of common dark limestone, with white shells and corals."

(Among the Dalesmen the word "plate" is equivalent to "shale;" and the basalt referred to is part of the great "whin sill" of Teesdale, &c.)

On reading over this section it naturally strikes one at once as a very odd thing that there should be a subprismatic bed of plate, *c*, below the thin plate not very much indurated, *b*—in other words, that the plate which lies nearest to the altering cause should be less altered than the plate which is further from it. Here, indeed, if the beds *b* and *c* had really been of the character described above, we should have a most striking instance of selective metamorphism. I think I shall be able to show, however, that the above description is not correct—that the bed *c* is not altered plate, but basalt, that an examination of the general rock-structure of the beds *a* and *c* proves conclusively that the only differences between them are such as should naturally be looked for in beds of such different thicknesses, and that this conclusion is fully borne

out by what can be seen of the physical disposition of these beds in the grounds immediately adjoining the High Force.

What a very great difference there is between *b* and *c* and between *c* and *d* is evident at once from a first look at the Force—*b* and *d* being conspicuously crossed by lines of lamination rudely parallel to their upper surfaces, while *c* is completely without any such lines, and is rudely prismatic, like the basalt at the top of the Force. But these differences are seen to be, if possible, still greater when we come to examine the Force, and the minuter structure of the beds: *b* and *d* have no trace of crystalline structure whatever, while *a* and *c* both have, and the structure of *c* appears to agree exactly with that of the lower part of *a*. Both *c* and the lower part of *a* are much more finely crystalline than the more centrally situated parts of *a*; but this is only what one would expect on considering the different conditions under which their cooling would probably take place. The outside of the mass would naturally cool much more quickly than the inside; and the underflow, *c*, is only about 6 feet thick, and therefore the whole of this would probably cool down comparatively quickly.

I think, then, that there can be no doubt that the bed *c* is really basalt (microscopic examination would prove this), here a sort of underflow to the main mass. For Phillips's section I would substitute the following:

Fig. 1.—Section at the High Force.



a. Basalt, 24 feet.

b. Shale, altered, $1\frac{1}{2}$ foot (average).

c. Basalt, 6 feet (average).

d. Shale, altered, 12 feet.

e, f, g. Limestone, 32 feet.

The thicknesses given are only approximate.

It must be understood that the above section refers to the Force itself, the actual place where the water comes over. The sections on either bank of the Tees a few dozen yards below the Force differ from that at the Force itself, and at the same time differ *inter se*.

On the north bank, at about 20 yards below the Force, it can be distinctly seen that there is no separate bed *c*, and that the space between the top of *a* and the bottom of *c* is one uniform mass of basalt. We have, then, the following as the section:—

Basalt, 32 feet (+ any that may be above the level of the top of the basalt at the Force).
Shale, 12 feet.
Limestone, 32 feet.

We will call this section the section at X.

On the south bank the section, at a point about 30 yards below the Force, is:—

Basalt, 24 feet (+ any that may be above the level of the top of the basalt at the Force).
Shale, 20 feet.
Limestone, 32 feet.

We will call this section the section at Y.

Owing to the banks being, in places, inconveniently steep, and bearing a thick covering of hanging trees &c., the entire passage between the above three sections cannot be quite so well seen as one would wish; enough, however, is shown to enable one to come to a safe conclusion as to the true state of the case. On looking at the section at the Force more carefully, it is distinctly seen that the bed of shale, *b*, is thicker on the south side than on the north side of the Force—that from $1\frac{1}{2}$ foot it dwindles down to one foot, and from one foot it dwindles more and more as we go towards the section at X, until it is only doubtfully represented by a thin line marked by ferns and grass, and that this thin line then ceases, and we get the state of things at X—that, on the other hand, as we go from the Force towards the section at Y, the bed of shale, *b*, gets thicker and thicker (from $1\frac{1}{2}$ foot it gets to 2 feet, and so on), until, at a point about 20 yards below the Force, it is 3 feet thick, and in 10 or 12 yards more it has thickened out and formed one mass with the bed of shale, *d*; and now there is no underflow of basalt.

It appears, then, quite safe to conclude that the underflow of basalt, which has its origin from the main mass at X, gradually thins out as we go south-west and south from this point, until at Y it has ceased altogether.

If we examine the bank a few yards beyond X, we find the section change again, and again we have an underflow of basalt separated from the main mass by a thin bed of altered shale, thus:—

Basalt.
Sandy shale, about 2 feet.
Basalt.

The top of the underflow of basalt here is roughly on the same

level as that of the underflow at the Force, and the shale parting, which at first makes its appearance somewhat abruptly, can be seen for a dozen yards or so gradually thickening as we follow the bank of the river in a north-easterly direction. The section then becomes lost, owing to the covering of tumbled whin, &c., and we have to go on for some 70 yards before the beds are well shown again. Here the section is much the same as that at Y, viz.:—

Basalt.
Shale, about 20 feet.
Limestone.

We have, then, good evidence that the section at X changes towards the north-east in the same way as it does towards the south-west and south.

And so, finally, we see that near X a small part of the lower portion of basalt becomes separated off from the main mass, and that this lower portion rapidly thins out towards both the south-west and south, and the north-east.

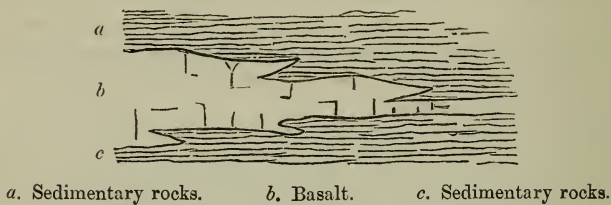
There are other places, both in the immediate neighbourhood of the High Force and elsewhere, where similar undoubted underflows exist. Sometimes these underflows can be seen distinctly in the act of being gradually separated off from the main basalt mass, altered beds coming in between; and sometimes these altered beds consist of altered sandstone, or of altered limestone, instead of altered shale. And, as there are underflows, so also there are overflows; parts of the top of the basalt gradually get separated off from the main mass, and then thin out.

In some cases we can see beds of altered shale and sandstone apparently surrounded by basalt on every side: there is basalt above; and there is basalt below; and the altered beds can be seen to end in basalt as you follow the section along on either hand. There is a very good instance of this in the Slate Scar, a little more than half a mile above the High Force. The greatest dimensions of these beds are seen to be generally in the direction of their planes of original deposition; their thicknesses are, in fact, generally strikingly less than their length. For instance, with an average thickness of 2 feet, we may get a length of 60 yards. This is, I think, strongly suggestive of some stable connexion between these and the other beds among which the basalt has been intruded; they appear to have kept something of their original position very much better than one would suppose at all likely if they had been completely isolated in the great basalt mass. I would suppose, then, that, certainly in most cases, these beds are not surrounded by basalt on every side—have not, in fact, been simply “caught up” in it—but that, if they could be traced in directions both away from the observer and towards him, they would, in one of these directions, be found to join on with the great mass of the sedimentary rocks of the country. It is evident that, in any ordinary section, we have only four sides visible out of the six wherewith any geographical point may be supposed

to be bounded; and in either of the two unseen the state of things may be very different from that seen in the others.

These subordinate beds of basalt have been spoken of as underflows and overflows; in every case observed, however, they thin out so very rapidly that it might be better to call them simply wedges. They appear to belong in every way to the main mass of basalt; and probably one of the ordinary methods of the thinning out &c. of the basalt is the giving off of these separation masses, and their then dying out. Thus the thinning out &c. of the basalt as a whole might probably be best represented, diagrammatically, somewhat as below:—

Fig 2.—*Thinning-out of the Basalt at the High Force.*



I do not wish to imply by the above diagram that there is one point from which the basalt can be made out to be thinning away in every direction, but simply that, where the basalt is thinning out, the thinning-out probably takes place in some such way as represented.

Prof. Sedgwick, in his paper on the Geology of High Teesdale (Cambr. Phil. Trans. 1824), brought forward evidence which was quite conclusive as to the truly intrusive character of the whin sill. Prof. Phillips, at the time he wrote his 'Geology of Yorkshire,' does not seem to have loyally accepted this conclusion, but to have been more impressed with its supposed "general conformity over a vast area to the beds above and below." It is this partial conformity which still causes it to be an article in the miner's creed that the great whin mass is a "sill," a bed regularly interbedded with the other beds or "sills." On close examination of the ground, however, it is seen that this conformity is not nearly so general as is supposed, and that even in cases where the whin, as a whole, does keep on the same geological horizon, there are numerous instances of small subordinate beds separating off from the main mass in the manner already described, and conclusively proving its intrusive character. The High Force is one of the four localities specially mentioned by Phillips ('Geology of Yorkshire,' part ii. p. 77) as showing the conformity between the surfaces of the whin sill and the surrounding beds. We have seen that, instead of showing this, it affords striking evidence to the contrary. The bed of the Tees near Winch Bridge is another of the localities mentioned. This, too, shows good evi-

dence to the contrary; and I have very little doubt that the more the country is worked over the more and more evident will the intrusive character of the whin sill become.

P.S. Since the above was written, Mr. F. Rutley has kindly cut, and microscopically examined, sections of the rocks *a*, *b*, and *c* of the High-Force section (*vide supra*); and the results obtained entirely confirm my statements: *a* and *c* are basalts; and *b* is evidently an altered sedimentary rock. The examination of the rocks in the field really left no doubt on this head.

52. *On the MECHANISM of PRODUCTION of VOLCANIC DYKES, and on those of MONTE SOMMA.* By R. MALLET, Esq., C.E., F.R.S., F.G.S. (Read June 21, 1876.)

IN the year 1864 I was enabled to employ some time in the study of some of the chief volcanic phenomena presented by the cone of Etna, devoting my attention principally to the laws which govern the flow of lava currents, the formation of the parasitic cones which abound upon certain portions of the surface of the great mountain, of which Monte Rosso and Monte Peleri in the neighbourhood of Nicolosi are amongst the largest examples, and in examining the Val del Bove and the many so-called dykes which intersect its surrounding escarpment in so many places. These last objects were examined by me with the able memoir of Sir Charles Lyell, published in the Philosophical Transaction for 1858, in hand, the title of which is "on Lavas of Mount Etna," &c.

In the second part of that memoir the author rests part of the evidence upon which he concludes that an ancient great vent existed in the Val del Bove at Trifoglietto, upon the convergence at about that point of the prolonged lines of direction of thirteen dykes existing in the surrounding escarpment, in accordance with the views previously promulgated by Von Waltershausen (Phil. Trans., Part ii. 1858, page 703). I have no intention of casting any doubt here upon any part of the above able memoir of Sir Charles Lyell, in all the main conclusions of which, indeed, I concur, my present object being limited to remarking upon some of the conditions which affect the formation of volcanic so-called dykes of injection, such as those existing in the escarpment of the Val del Bove, and of that of Monte Somma, and to pointing out the extent to which the orientation or direction of such dykes can be safely employed as a means for determining, with any thing approaching to certainty, the existence or position of a central chimney or crater, from which such dykes may be supposed to have emanated, by means of the intersection of lines or planes prolonged in the direction of such dykes. On going round nearly the entire escarpment of the Val del Bove, with Von Waltershausen's map in hand, the dykes, which are almost innumerable, when examined at many points both from above and below the escarpment, presented phenomena in many other respects as well as in direction, so perplexing as to raise in my mind much doubt as to whether they could be at all accounted for upon the commonly accepted theory of their production, and suggested the inquiry whether that theory which assigns their production to the injection of fissures in crater walls by the liquid lava within the crater might not need considerable modification, and if so, whether, in its imperfect state, the orientation of dykes could, by intersection, be safely employed at all for determining the position of craters which have disappeared, as in the case of that of Monte Somma

and of those supposed to have existed in the Val del Bove. In the latter region the orientations or lines of horizontal direction of the numberless dykes are so various and discordant as to resemble in very many places nothing more than the chance directions which might be assumed by a number of short straws or sticks cast at random upon the ground. Lines drawn through them might be made to create great numbers of points of intersection; and yet great uncertainty would attend attempts to infer from any of them the former existence of a crater there. These perplexed phenomena in the Val del Bove are upon too large a scale for easy disentanglement, and are far less suitable for the study of the laws of production of injected dykes than are those found so abundantly in the escarpment of Monte Somma, where the whole scale is smaller, the dykes generally closer together round the amphitheatre, the phenomena less perplexed than in the Val del Bove by the circumstances which produced that immense depression, and where there exists the main chimney or axis of the cone of Vesuvius, the position of which is not presumed to have materially changed from that before occupied by the crater while Somma was in existence, and to which therefore it might be presumed that the directions of all the existing dykes of Somma should show a general convergence. Reserving therefore the formation of any conclusion as to the facts I had observed upon Etna, I resolved upon my return to Naples to make a careful study of the dykes of Somma, and to endeavour to decipher therefrom the laws of production of these and other similar volcanic dykes. For though these dykes of Somma have been again and again described in their general aspects, and though almost all writers on volcanoes have assumed without question that their directions do really converge at the axis of the existing cone of Vesuvius, I could not find that any careful determination by actual survey had ever been made of the directions of these dykes; nor had sufficiently exact observations been made as to many points in the dykes themselves tending to elucidate the exact nature of their origination. Accordingly, in November 1864 I made arrangements for determining with instrumental accuracy the positions and directions, both horizontal and vertical, of a considerable number of these dykes of Somma. Having, through the kind assistance of Professor Palmieri, been permitted to lodge at the Observatory above the Hermitage upon Vesuvius, I ran a line of trigonometric triangles from the south-east corner of the Observatory, passed the wooden cross existing at that time, and known as La Croce del Salvatore, and into about the centre of the Atrio del Cavallo, whence I was enabled to fix the position of a point chosen for that of observations upon one of the slight elevations at the northern base of the cone of Vesuvius, which commanded an uninterrupted view of a very large portion of the entire escarpment of Somma, extending from the Canale del Inferno, or thereabouts, on the eastward, and passing round the amphitheatre westward to a point nearly opposite La Croce, and a little to the west of north with respect to the same. I was obliged to choose the quoin of the Observatory as an initial station-mark, although the building cannot be

seen from the floor of the Atrio, nor the latter from it, because no station-mark of a permanent character, or offering a reasonable chance of not disappearing in perhaps the very next eruption, could be found in or nearer the Atrio del Cavallo. At this point, very near the head of the Fossa di Vetrano, the first prominent dyke of the escarpment of Somma occurs, which I called No. 1; and having perambulated the entire base of the escarpment, thence going eastward and choosing out for geodetic determination, from the innumerable dykes of every size which intersect it in almost every direction, twenty-seven of those which seemed largest, highest, and generally most characteristic, I numbered the whole of these with red oil paint in figures five or six feet long upon the projecting edge or face of each near the base or level at which these dykes generally disappear below the floor of the Atrio del Cavallo, taking care that all these figures should be discernible by the telescope of my theodolite from the point of observation chosen at the base of Vesuvius as already mentioned. I however examined carefully as to their lithological circumstances a number of other dykes intercalated at various points between those numbered, amounting with the preceding to thirty-four in all.

Having in connexion with the line of triangles by which the observing-point was fixed, measured a short base of 374 feet (English) upon a level part of the Atrio del Cavallo extending in a S.E. direction, the N.W. extremity being nearly in a line between the Punta del Naso and the centre of the Vesuvian cone, I then extended my triangulation so as to fix, in reference to my observing-point, and to the then existing cone and crater of Vesuvius, the general line of the escarpment of Somma from west to east, extending along the curve of the escarpment to a distance of rather more than $2\frac{1}{4}$ English miles. This line has in reality much less of the form of a regular circular curved amphitheatre than it appears to the eye as viewed from the northern side of the cone of Vesuvius; and I found it was by no means exactly laid down upon the engraved sheets which contain Vesuvius and Somma, issued from the topographical office at Naples by the former Government of the King of the Two Sicilies. I was thus in a position to fix trigonometrically the orientation of the twenty-seven numbered dykes in reference to my observing-point, and to the axis of the cone of Vesuvius; and then, again perambulating the whole line of dykes from west to east, I observed and noted the characteristics of each, the lithological character of its mass, the horizontal direction in which the plane of the dyke penetrated the bank of the escarpment, the "hade," or dip, or departure in a vertical direction from perpendicularity in the plate of rock, its curvature, if any, and other particulars to be hereafter noticed. These operations and observations occupied me, along with a staff of men hired at Naples and Resina, for about a fortnight in November, during several days of which there was continuous rain and so boisterous a wind as rendered work with a theodolite difficult. My chief assistant was Antonio d'Antonini, who had been my faithful and intelligent attendant in exploring

the results of the Neapolitan earthquake of 1857, and who is, I believe, still in Naples.

After my return to England my survey was to a great extent plotted; and the results showed themselves as concordant as could have been expected from geodetic work carried on upon excessively uneven and elevated ground, and under the disadvantages of weather described. The necessities of professional engagements and other circumstances, however, obliged my laying aside for a considerable time the completion of my work, until ultimately failure of sight and the impossibility of my note-books and sketches being deciphered by another have compelled me to lay it aside altogether. Unwilling, however, that the results of so much labour and care should be wholly lost, especially as some of the facts ascertained are new and appear not devoid of importance, I have thought it best to note down some of the more salient results, which others more fortunate than myself may perhaps accept as a basis for further research. My inability to produce the whole of my work, together with the triangulation, in a fit state for publication is now the more regretted by me since most of the features, the surface-levels &c. of the Atrio del Cavallo, as they existed in 1864 have been to an immense extent altered by the great eruptions of lava that poured into it during the great eruption of 1872, so well described by Signor Palmieri. It is also probable that the scorching heat then produced in the Atrio del Cavallo, and extending westward far beyond the Observatory, may have partially, if not wholly, obliterated most of the red numbers painted by me upon the dykes, and perhaps even consumed by fire the wooden cross of the Salvatore, which was one of my marks.

On examining with care, and aided by the telescope, the entire surface of the escarpment of Somma, it is seen to consist of a precipitous but nowhere actually vertical bank, with a highly irregular or serrated sky-line rising at some points 800 or more feet above the floor of the Atrio. Its exposed face consists to a preponderant extent of beds of volcanic conglomerate, composed of fragments, subangular or more or less perfectly rounded, of various sizes, from masses occasionally of a cubic yard or more in volume to nodules of the size of a human head, or of an orange, mixed with pebbles of various smaller sizes and with gravel or lapilli. Of the latter there are also great beds. Intercalated with all these are many beds of lava, which, though now for the most part cross-fractured and twisted, had flowed in a state of fusion from the ancient crater of Somma and consolidated upon its slopes. All these beds, though wildly confused in many places, yet preserve a general horizontality round the amphitheatre. Crossing all these in very various directions, forming different angles with the horizon, and scattered at very irregular distances from each other, existing sometimes singly but often several in close proximity, and sometimes inosculating with each other, and with their edges highly irregular and broken, projecting more or less from the abrupt face of

the escarpment, whose slope they very nearly follow, are the dykes so often referred to by authors. These sometimes run up the entire height of the escarpment, sometimes stop far short of this, sometimes give the observer the idea that they are the edges of straight planes, but often show themselves twisted or curved at the first glance. Many are broken across into separate fragments, which are separated more or less from each other by conglomerate or lapilli. (The general appearance of a large portion of the escarpment, as seen from the north flank of the Vesuvian cone, is shown in the panoramic photograph exhibited, for which I am indebted to the photographer who executed it shortly before my survey.) On examining in detail the face of the escarpment, it is observable that the beds of conglomerate or of lapilli present in many places evidences of severe compression in both lateral and vertical directions, and are, over considerable areas, more or less perfectly glued or cemented together by the percolation of water having acted upon the partially soluble silicates of which the disintegrated material consists, and which have subsequently indurated and formed the cementing material. This mode of forming a compact mass, which is not an uncommon volcanic phenomenon, has been observed by myself as taking place in large beds of broken-up slags deposited in the neighbourhood of the Barron Iron Works in Cumberland. The large quantity of lime employed as flux for smelting the hæmatite ores operated upon in these vast works produces slags the silicates in which are sufficiently soluble to form a compact mass, requiring the pick to break it up at a depth of only 8 or 10 feet from the surface, and within a period of about as many years from the time when the slags were in liquid fusion, the water acting upon them being derived from rain only. The bank of the escarpment of Somma thus composed of masses of very variable or of no coherence, is acted upon by rain falling upon its abruptly sloping face; and in several places deep recesses or *barrancos* are cut back into it, some of which are of great size, and have their floors at the level of the Atrio covered more or less with a steep sloping talus of detritus swept down by rain torrents from the lofty bank above.

On ascending at the western extremity to the crest and following along more or less nearly the edge of the escarpment upon the outer slope of Somma, which falls towards the plain at angles generally of from 25° to 32° , we find it intersected by numberless rain-channels generally tending down the slope; these in many instances attain the magnitude of large "nullahs," or even of gorges, and, from the loose nature of many of their materials, are not crossed even in dry weather without some danger and difficulty; indeed the walk along the edge from west to east is extremely laborious and difficult. It is, however, instructive in several ways, and especially as showing that not very many of the superior or northern terminations of these dykes reached as far as even the existing surface, and were far from ever reaching the surface of the northern slope of Somma, while that mountain still existed as a vol-

cano; for a great depth of the loose material which mainly constituted the original cone of Somma, a depth which may in some places have reached perhaps 200 or 300 feet, has been removed and swept down towards the plain by the action through long ages of rain and of pluvial torrents. In passing, it may be remarked that the rapidity with which the incoherent matter deposited upon the flanks of volcanic mountains is thus swept away by rain is well exemplified upon the flank of Etna by the condition of the old oak trees which constitute the Bosco della Casa, which is crossed, three or four miles above Nicolosi, by the usual mule-path towards the summit. The slope of the mountain here, the inclination of which generally is very moderate, not exceeding perhaps 10° , is composed almost wholly of loose black pyroxenic sand, in which and probably in old tufaceous beds beneath the oak trees grow.

On examining the trunks of these, it is at once apparent that the level of the surface during their earlier life was from two or three to (in several places and over large areas) five feet above what it is at present, the lowermost part of the bole proper, or trunk, of the tree, with its rough bark and spreading-out base, marking the original ground-line, while the tree now stands, as it were, upon its toes, the great tap-roots, one or several, forming its only connexion with the present ground (1864), which they penetrate so as to support the tree. None of these oaks are probably more than one hundred or one hundred and fifty years old; within that time therefore a depth of from three to five feet of material has been denuded from from this part of the mountain over a very large area, and this notwithstanding that relays of like detritus have during the interval been brought down by rain from still higher parts of the slope.

The results of my survey may be classed into:—1st, Observations on the directions in space and in reference to the material of the escarpment of the dykes. 2nd. The lithological and other circumstances of the dykes themselves and of the matrix adjacent to them, which throw some light upon the nature of their production. 3rd. Conclusions to which these data appear to point.

The apparent horizontal direction in which a dyke observed at the level of the floor of the Atrio plunged into the bank of the escarpment, I have called the *strike*. This direction, when referred to the axis of the cone of Vesuvius, I have called the *orientation* of the dyke. The divergence, if any, from verticality of the plane of the dyke I have called its *dip* or *hade*. *Curvature* refers to bending round some imaginary line other than vertical, while *twisting* means torsion round some imaginary line exterior to the dyke and not far from vertical. The dykes, at their exposed edges, rise to very various heights, some to the top of the escarpment, generally thinning out as they ascend; others only rise sixty or seventy feet above the floor of the Atrio, and taper rapidly, coming to an edge from a thickness of perhaps five or six feet at the visible base, and without any observable fissure extending beyond the summit into the matrix. Some are so curved, twisted, and often dislocated into fragments of greater or less length that no deduction as to orientation is possible; but many others,

though not free from twist or curvature or even from cross fractures, still admit, within moderate limits, of the deduction of their orientation as well as of their general dip. One source of possible error which may affect some of my observations I must not omit to mention. From the smallness of the exposed surface and the necessity of observing each dyke at but a few feet from its base, the only practicable method of determining the strike was by means of the compass. But as many of these dykes are, like most volcanic products, magnetic, and sometimes with polarity, the indications as to horizontal direction afforded by compass are somewhat uncertain; and the amount of deviation from this cause, if it exist, is not easily determinable. I do not think, however, that any very large error due to these causes exists in my observations; for on comparing the directions shown by two different compasses, one carrying a heavy and powerful pivoted bar-magnet, the other a very light needle, both successively placed in the same position and within a few feet of the base of some of the largest of these dykes, and on also comparing the direction of both compasses when removed a hundred yards or more from the base of the same dykes and still in the direction of the plane of the dyke, I did not find a notable difference of indication, though sometimes reaching a degree or two. The observations of strike thus made, when combined with the position at the escarpment and level of the floor of the Atrio, of the terminal edge of each dyke, completed the elements necessary for the determination of its orientation or line passing horizontally through its general plane when produced through the axis of the existing Vesuvian cone.

The orientation of five or six of the dykes thus obtained is such as to pass, though only approximately, through the axis of the cone—all the others observed presenting wide disparities in direction of orientation, which in most cases passed outside the confines of the cone itself at the level of the Atrio. Indeed in some cases two dykes of different ages cross one another; and while the orientation of one roughly approximates to the Vesuvian cone, that of the other passes wide away from it. The divergence from axial orientation increases much as we approach nearer to the eastern end of the escarpment; and as we begin to descend from the level of the floor of the Atrio along the prolongation of the escarpment towards where it is lost in the eastern slope of the mountain, we find a large number of dykes whose orientation is seen at a glance to be wide away from any part of the existing cone of Vesuvius, and whose dip, or hade, is towards the west and north, and rapidly increases as we descend, so that several of the most easterly of these dykes present to the eye the character of old beds of lava inclined at angles steeper than the slope of the mountain, and dipping into the latter, in which they are partially buried, rather than of dykes at all. I did not determine the exact strike of any of these dykes or beds eastward of my number 27, partly by reason of the facts just given, but mainly because their bases could not be seen from my observing-station at the base of the cone and could only be approached over a bed of hugely scoriaceous lava which had overflowed from the Atrio at this

eastern outlet, and descended by the Canale del Inferno. Of the whole of the numbered dykes, ten present as their main feature an approximately vertical plane, all the rest having a very sensible dip or hade. This dip, from No. 1 to No. 13, is towards the west and north at various angles, none exceeding 38 degrees with the vertical. Between Nos. 13 and 27 the dip trends towards the east and north, never exceeding from 30 to 40 degrees, and the average being not more than about 20°.

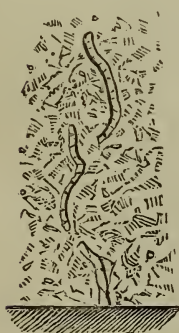
I did not observe any case in which a dyke was intersected by a coherent bed of lava; but in one instance the highest part of one dyke (No. 1) is stopped at its upper extremity by the underside of an overlying and nearly horizontal bed of lava. Not only do many dykes bifurcate or send off branch dykes at different heights, but two dykes frequently intersect each other and often at considerable angles, so that in one instance (No. 10) the general plane of one is nearly orthogonal to that of the other.

These and many other circumstances prove these dykes to have been produced at very different and successive ages. Many of the curved, twisted, or broken dykes present proofs of having been subjected to severe and long-continued pressures in both vertical and horizontal directions, which have resulted in great displacements from their original positions. Thus the third dyke examined, between No. 13 and No. 14, has been crushed by descending movements of the surrounding matrix, as roughly indicated in fig. 1. In others lateral displacement has attended also upon vertical movement, as in the dyke No. 9, which has been cross-fractured with lateral displacement and descent of one segment of the dyke, as indicated in fig. 2. An ideal figure of this form of displacement has been given by

Fig. 1.—*Dyke crushed by descending movement of matrix.*

Fig. 2.—*Dyke fractured with lateral displacement.*

Fig. 3.—*Curved Dyke.*



Phillips, 'Vesuvius,' page 132, whose very slight notice of these dykes in that work leaves much to be desired. A third form of displacement is seen in the first dykes examined, between No. 22 and

No. 23, which have been abruptly curved in contrary directions and broken into numerous voussoir-like fragments with but little displacement from each other by pressure while gripped by the matrix, as indicated by fig. 3.

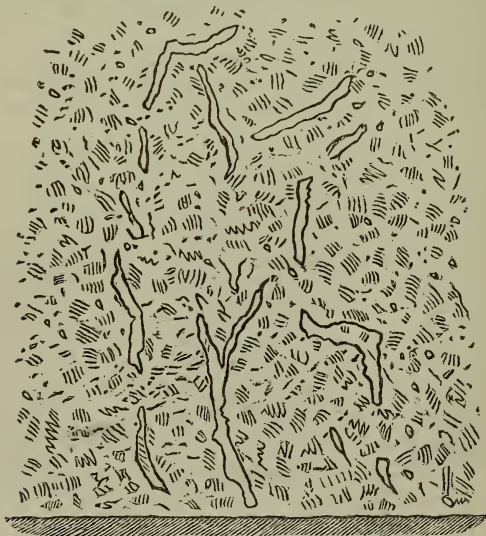
In the dyke No. 7 there is intersection of one dyke with another, the surfaces at the intersection being so altered and dislocated that it is impossible to say which of the two is the intruder; both dykes are here violently distorted and broken, as roughly shown in fig. 4. In many instances, as in the dyke No. 5, one or more adjacent dykes have been broken across into short fragments, twisted, curved, or straight, which have been forced away from each other for distances of many feet or yards, and now occupy the most irregular positions in the matrix, as remarkably evidenced in the dyke No. 16, of which the annexed figure 5 is a rough representation. These transpositions and dislocations are of much interest and importance.

They indicate the vast extent as well as the force of the internal movements, due principally to gravity, which are constantly taking

Fig. 4.—*Intersecting Dykes.*



Fig. 5.—*Dykes fractured and displaced.*



place in the mass of volcanic cones. Material in active volca noes

being constantly ejected about the upper parts of the cone, and with a weight in reference to surface increasing with proximity to the crater, the tendency would be to increase the angular slope of every volcano as we approach nearer the top. But as the great mass of ejected material is fragmentary and incoherent, and can therefore only repose permanently within a certain slope (or angle of repose), so the tendency to increase the angle of the cone by the deposit of new material is more or less met by irregular creeping downwards, and sometimes by slipping of parts of the mass downwards as in landslips, the discontinuous materials, when thus forced downwards, often carrying along with them and dislocating or distorting such connected beds of lava or dykes as may be involved in the mass. An inspection of the general surface of the escarpment of Somma for its entire length and height at once shows the observer how small, proportionally, is the mass of lava-beds or dykes included in the enormous surrounding mass of volcanic conglomerate, lapilli, and sand, and appears to the writer fully to sustain the estimate made by him in his paper "On the Nature and Origin of Volcanic Heat and Energy" (Phil. Trans. 1873), that the incoherent material, heated but not fused, ejected during volcanic eruptions, exceeds by twenty-fold the mass of the material which is poured forth in fusion.

The relatively attenuated ribs or plates of consolidated lava, present extremely small resistance to the pressures produced by the enormous weight of the discontinuous material around them, and which, by reason of its discontinuity, acts somewhat as if it were an imperfect liquid or a mere heap of dry sand, in transmitting the internal movements which are continually taking place within it under the joint influence of slope and gravitation.

Although the rounding, more or less complete, of the fragments which constitute beds of volcanic pebbles, large or small, and of the constituents of conglomerates compacted together after deposition, is, as has been stated by several authors, produced by mutual attrition prior to their ejection, there can be little doubt that further comminution and rounding is produced by these powerful though little-noticed movements of descent after their deposit in the mass of volcanic mountains. The same phenomena, though upon a minuter scale, are to be seen in the rounding which is known to take place to considerable depths in the macadamized stratum of roads which have been long traversed. In these the originally angular fragments of broken road-metal are found rounded when the mass is broken up and exposed to view, to far greater depths than the impacts or pressures upon the surface would seem to have been transmitted, intestine movements, extending deep into the mass though not noticeable at the surface, being sufficient to rub together and round the once angular fragments to an extent less as their position is deeper from the surface.

It is obvious, from what has been stated as to the movements of dykes at periods subsequent to their production, that the present positions in which they may be found do not necessarily infer any thing as to the position, whether in orientation or in dip, in which

they may have been originally deposited. Any such inference as to a particular case might be grossly in error, and would probably be so in the case of curved or twisted though more or less continuous dykes. The error may be greatly less, or perhaps no error may exist, where the inference is drawn from nearly flat dykes, whose planes present neither considerable twist, curvature, nor fracture. But as we never can be certain that any dyke may not have had its position, especially its orientation, more or less changed or shifted subsequently to its production by injection, and as we also never can be certain that any two dykes, whether distant or adjacent, and of which we can only see some one section of a *part* of the dyke, which may be chiefly a vertical section as in Somma, or may be more commonly horizontal sections as well as vertical ones, such as are found surrounding the Val del Bove, so we never can be certain that any two, though now apparently converging, must have emanated from a common volcanic axis or crater. The evidence as to such common origin can never be more than probable, though the probability may certainly be strengthened in some ratio to the number of dyke-planes, or planes of orientation, which we may observe (after sufficiently exact geodetic operation) all to appear to converge to a single axis. The divergences from even approximation to any such single axis, found by me in the dykes of Somma, at one time raised doubts in my mind as to whether they were injected dykes at all, or might not be ancient lava-beds which had flowed down the slope of the mountain at various epochs, and had, by some unexplained causes, been broken up, more or less turned on edge in planes in a line with, or transverse to, the slope, or even occasionally inverted altogether. This view I was subsequently compelled to abandon, though some facts observed during the careful lithological survey which I made of these beds seemed for a time to support it; and I should add that one class of facts observed and about to be referred to, which seemed to support this hypothesis strongly, are to me still without an explanation and remain for the more complete investigations of others. I may remark here that the descent of large surfaces of lava-beds, along with the sand and detritus which, from the causes already referred to, and aided by rains, are in many instances observed to have descended more or less upon volcanic flanks, and the turning up of such beds more or less on edge, either in a direction transverse or approaching to their line of descent, are by no means uncommon phenomena in volcanic countries. If the large plate of lava thus descend upon the detrital slope of an uninterrupted volcanic cone, the lower or forward end of the huge slab, like a flat coultter, tends constantly to increase the volume of a ridge of detritus heaped up before its foremost edge; and a time may arrive when, from this cause and the slowly digging deeper into the detrital bed of the advancing edge, the whole huge plate is brought to rest. If sufficiently large, the detrital matter of the bed is interrupted in its descent by the upper or higher edge of the plate, while it is washed out more or less from the lower edge by the percolation of rain, which makes its exit

in rain-channels towards the lower edge. The angular tilt of the plate therefore continues to increase slowly with time, and to exceed that of the slope, until at last the lava-plate stands on edge, its lower part being buried in the detritus, and the upper part in free air, the plane of the plate in this position being more or less nearly transverse to the line of slope; and this process, if continued, may even cause the inversion of the bed, so that what was its upper surface as it flowed from the crater over the upper part of the slope, and consolidated there or further down, becomes the lower surface, upon which it now reposes, and what was the bottom surface would then face the sky. But the surface of no volcanic mountain is a simple cone; its sides, at least so far as they are deeply covered with detrital material, are deeply furrowed and broken into small valleys and torrent-beds, having banks of increasing steepness at either side as they get nearer the bottom, and the general direction being often with but little sinuosity up and down the slope, as frequently seen on the flanks of Monte Vulture. Now, if a plate of lava descending under the mechanism just described should reach the brow of one of these rain-gullies, its course of descent directly down the mountain-slope may be gradually changed, and it may begin to descend by quite the same mechanism along the banks of the gully in a direction diagonally transverse thereto, and may finish its course by being turned up on edge as before described, but now with its plane in a direction more or less nearly orthogonal to that just described, and in an approximately vertical direction, its plane being directed more or less nearly towards the axis of the mountain. If such a plate be subsequently buried in detrital matter, it will present very much the characters of a dyke of injection, with this difference, that the two sides of the plate will present those marked differences always seen in the top and bottom surfaces of consolidated plates of lava. I have observed several instances of these remarkable changes of position; thus, for example, in Auvergne, on the left and within a short distance of the carriage-road from Clermont Ferrand and about five miles from that city, passing over the great volcanic plateau on the direct road to Pont Gibaud, on the slope of a hill of volcanic detritus, there exists a thick bed of lava with many included boulders tilted thus and standing several feet in the air. I observed also several such instances in 1858 upon the flanks of Monte Vulture, upon the side towards Melfi; and I have been informed by a friend who resided in Mexico that like facts are not unknown there.

In making my lithological survey of these dykes I was prepared to notice particularly whether the two opposite surfaces of the same dyke were alike or different, whether the parts more or less adjacent to each surface were the same as those of the interior of the dyke, or differed in character or mineral composition, compactness, fracture, &c., from the material of the latter, or whether any pyromorphic changes were observable at or near the surfaces of contact where a dyke intersected another dyke or a lava bed, whether the mass of the dyke was amorphous, and if jointed, in what direction

the joints lay, and whether the structure differed at different parts, being amorphous and jointed into great blocks or having a more or less slaty or shivered structure conferred upon it.

I gave particular attention to the prevalent directions in which elongated air-bubbles were found imbedded in each dyke.

It is a fact now familiar to most geologists that the longest axis of air-bubbles occurring in lava or other igneous rocks is turned more or less exactly in the direction in which movement or flow has taken place in the mass while in fusion, just as in most igneous granites which contain large crystals of felspar or others of a flattened form, the larger dimensions of these crystals indicate the line of flow of the granite while in fusion. This is prominently seen in the granite of Dartmoor in those quarries from which a large portion of the pavements of the city of Exeter have been obtained. It is obvious, therefore, that in a dyke the longest axes of these air-bubbles should indicate the direction in which its molten material has been forced into the cleft. If the injection had been from below the lowest point of the dyke, and the flow into the cleft had been therefore approximately vertical, as was perhaps the case in many of the subaerial dykes of geologists, and, so far as I can comprehend the not very clearly expressed views of Mr. Scrope, also in volcanic dykes (Volcanoes, 1862), then it is obvious that in these dykes of Somma the prevalent direction of the longest axes of these bubbles should be approximately vertical. If, on the other hand, the injection of these dykes has been lateral, and though perhaps inclined upwards, still, on the whole, horizontal, as being derived from the molten matter, more or less filling a crater, from which the dykes diverged, then the longest axes of the air-bubbles should be found nearly coincident with the plane of the dyke, and if not horizontal, not very divergent by inclination slightly upwards, or, with much less probability, still more slightly downwards. Should the prevalent direction of the longest axes prove transverse to the plane of the dyke, it would cast considerable doubt upon the fact of the dyke having been filled by injected matter at all—just as in lava streams which have flowed and consolidated on gentle slopes, although, owing to intestine movements of the still viscous mass, bubbles with their longest axes vertical are occasionally found, the greatest preponderance of these axes is in the direction of the flow, and were we to find the preponderant direction to be vertical, it would cast much doubt upon whether there had been an approximately horizontal flow at all.

I also observed the characteristics of each dyke as indicated by its included minerals. On this last point I may at once remark that although it is generally and correctly stated by authors that the distinguishing characteristic between the ancient lavas of Somma, and the modern ones of Vesuvius is the great prevalence of leucite in the former, the statement that the dykes of Somma are all of leucitic lava is by no means correct. Leucite is, no doubt, the characteristic mineral included in the larger number of these dykes; but pyroxene is also found in most of them, and in some is very preva-

lent, though I am not aware that any one dyke is to be found quite free from leucite in large or small crystals. One dyke of those examined by me (namely, 11 *b*) contains crystals of idocrase in notable proportion. As respects the lithological character of the entire mass of each dyke, the whole may be divided into three classes:—1. those of dark-coloured compact and generally subcrystalline lava, which constitute a large proportion of the whole; 2. those of a much lighter-coloured, softer, and very imperfectly subcrystalline lava of that sort which Lyell has denominated “Graystone,” of which material immense dykes also occur in the escarpment of the Val del Bove (a few of the larger of these dykes in Somma show, though obscurely, a tendency to a cross columnar structure, one which, in the case of some of the very largest of these dykes of the Val del Bove, is magnificently developed, the hexagonal prisms being, in the case of one very thick dyke examined by me upon the west side, nearly horizontal and perfectly square to the sides of the dyke, and in prisms perfectly detachable from each other, and from ten to fifteen inches in diameter); 3. the third class on Somma consists of thin dykes of highly compact material, dark-coloured, and either gray or green, very hard, and with but little appearance of even minute crystalline structure.

The substance of these may be called phonolite in the grey, and greenstone in the other dykes. In one of the triple dykes examined by me, viz. no. 11, *a*, *b*, and *c*, *a* and *b* are in absolute contact with a mere joint of separation, and are nearly vertical, while *c* appears to meet the others at a point a few feet below the Atrio, diverging from them at an angle of about 45°, the intervening wedge being filled in with volcanic conglomerate and pebbles. All these three adjacent dykes are of different sorts of lava: *a* is largely leucitic, and contains very small crystals of olivine, or perhaps of sphene; *b* is leucitic with crystals of pyroxene, and containing also idocrase; while *c* is an extremely hard and absolutely compact pyroxenic lava, like a greenstone, with a well-marked cross sub-columnar structure.

These three dykes would therefore appear to be either of different ages, or derived from different sources of crater-contained lava, differing in composition and perhaps injected from very different depths. While the jointing in all these dykes is generally more or less transverse to their plane, evidences of a distinct laminated or slaty cleavage, sometimes with complete separation of the flakes, are perceptible in some of the dykes which have been subjected to severe lateral pressures, producing curvatures and twisting. The planes of lamination are very generally inclined to the general plane of the dyke, the strike of both more or less coinciding; and this structure usually becomes evanescent at a few yards in length of the dyke, which then returns to the normal transverse jointing. The dykes numbered 5, 6, 7, 10, 12, 13, 15 *bis*, 16, 22, and 25, all present more or less distinct evidences of this structure, the crushing forces producing which do not seem to have been always in a direction normal to the lamination, but to have shattered the mass by a

diagonal or "wiping" local thrust. These facts present striking evidence of the immense power of the internal movements which take place within the mass of volcanic cones at periods long subsequent to original deposition.

Referring now to the disposition of the air-bubbles, these are comparatively rare in the thin and more compact dykes. They are not uniformly diffused, generally existing in greater numbers near the sides of the dyke, although more or less *parsemés* throughout; in some instances they thickly congregate in zones towards the centre of the mass, running nearly parallel with its sides. Some large and generally longish irregular cavities of considerable size, with very rough internal surfaces, and often a foot or more in length, occasionally occur, the direction of their longest axes being very indeterminate. But these must not be confounded with the air-bubbles, as they are obviously rents produced in the viscous lava as it was forced onwards. The long axes of the air-bubbles are found on the whole to be nearly horizontal, or pointing at moderate angles upwards, and in directions very nearly parallel with the plane of the dyke at the place where they occur. This is well observable in the dykes Nos. 1, 5, 6, 9, 11, 17, 22, and 27. In Nos. 11, 17, and 27 the rents or cavities above spoken of are also to be found.

From this great preponderant horizontality or slight slope upwards and coincidence with the planes of the dykes of the long axes of these air-bubbles, I consider the conclusion is fully warranted that these dykes have been filled by injection, not from below, in a nearly vertical and upright direction, but horizontally, as from some source or sources of liquid lava exercising statical pressure upon the containing walls, as in the case of volcanic craters filled more or less with liquid lava. It does not seem possible to assign any physical reasons why the two surfaces of a dyke thus injected should present any characteristic differences, in the material of the dyke differing near one or other of its surfaces from the interior of its mass, but not so differing at the other surface, nor any reason why the two opposite surfaces of the same dyke should present any obvious differences, both being derived alike from the impress given to the viscous and cooling mass by the opposite surfaces of the cleft or fissure into which that was injected. That the parts adjacent to *both* surfaces of the dyke should present certain differences in texture may be expected; for if the walls of the fissure be at a considerably lower temperature than the viscous mass forced into it, the surfaces of the latter will become, when cold, more or less vitreous, while the interior of the mass remains stony or subcrystalline, this being in accordance with all the well-observed facts as to the rapid or gradual cooling of molten stony masses; but that *one* surface of a dyke should present this vitreous character and the other present none, is not easily explained; and equally difficult is it to explain why one surface should have its irregularities mainly concave to the general surface and contain imbedded pebbles picked up and partially involved, and being of the same sort as those pebbles contained in the matrix

adjacent, while the opposite side of the dyke has its irregularities mainly convex to the general surface, and sometimes running into wrinklings such as do not occur on the first-mentioned side.

This difference always characterizes and distinguishes the bottom from the top surface of lava beds which have flowed over slight slopes, and which have not become superficially broken up into lumps of scoria: the lower surface takes concave markings from protuberant or irregular portions of the surface over which it has run, and contains stones and pebbles imbedded in the mass which have been picked up from that same surface; the upper surface of the lava presents, on the contrary, irregularities which are in the main convex, protuberant, or *bombées*.

This diverse character at opposite sides of the same dyke, however, is obscurely presented by some of the dykes examined by me, in which pebbles are found imbedded in one side and none in the other, although the matrix at both sides appeared the same. In others one side only shows the superficial change into vitreous matter, while the other shows no such change,—the more general fact, however, being that both surfaces of the dyke show a vitreous crust, which is often but a fraction of an inch in thickness. The following dykes show in a marked manner these disparities of the two opposite surfaces:—In No. 6 A, $3\frac{1}{2}$ feet thick, a thin vitreous crust at the south-west side, at the opposite side a thick vitreous crust, with pebbles imbedded in the surface. In dyke No. 8, 8 feet thick, there are large imbedded but not adherent pebbles on the east face, none on the other, which is covered with a wrinkled crust. In dyke No. 9, thickness $3\frac{1}{2}$ feet, large and small imbedded pebbles on the north-east side, with adherent blackish scoriæ; opposite side no imbedded or adherent matter, and irregularities of the surface convex or *bombées*. Dyke No. 20, 6 to 7 feet thick, many imbedded pebbles, some as large as a man's head in east face; opposite sides wrinkly and scoriaceous without pebbles. Dyke No. 22, 3 to $3\frac{1}{2}$ feet thick, east side hollow, with some pebbles and cavities, and wrinkled; west side *bombé*, and contains many air-bubbles. Dyke No. 24, 8 to 9 feet thick, north side *bombé* irregularly, no crust, pebbles, or cavities; south side with deep large and small pits or cavities, and with adherent crust and pebbles. It will be noticed that these differences in opposite surfaces are most observable where the dykes themselves are thick, indeed are not seen at all in the thin dykes. The vitreous external crusts generally present the mineral characters of obsidian passing into a less vitreous material, having the external character of basanite or Lydian stone, and always very dark-coloured, the fracture vitreous and subconchoidal. I can only vouch for the above particulars as affecting such a height in each dyke above the floor of the Atrio as I was enabled to climb to and examine. It is remarkable that no pyromorphic change or action is noticeable in the material lying in contact with or adjacent to any of these dykes. The disparity in the characters of opposite faces here described appears to be very difficult of explanation, and presents a proper subject for further observation here and in other

localities ; I venture to commend it to the attention of volcanic explorers. Some light may be thrown on the subject by the remarks about to be made on the mode of production and of injection of the fissures of these dykes, a subject which has engaged but very slight and insufficient attention hitherto.

So far as my reading extends, I do not find that any writer on geology or volcanoes has attempted to frame a physical theory professing to account for the mode of production of the fissures which, when filled, form volcanic dykes, nor for the positions they are found to occupy, *i. e.* their apparent general fan-like arrangement when viewed horizontally. Nearly all that Dr. Daubeny has to say upon the subject is comprised in the following sentence :—“ Whatever theory we may adopt with respect to the formation of the beds in which these dykes occur, it is probable that we shall all concur in considering them produced by the injection of a leucitic lava into cracks which previously existed in the containing rock ” (Daubeny, ‘ Volcanoes,’ 2nd edit. 1843, p. 232).

The phrase “ previously existed ” is indistinct ; no crack can be filled until after it has been previously opened ; but how opened, or how long previously to filling, we are afforded no light by this passage.

Most English and several foreign text-books make reference to volcanic dykes in so casual and incomplete a manner that the reader can gather little more than the general notion that they appear to radiate from some central axis or axes ; even this is very often not stated, but left to be inferred from the description of the dykes given. In the late Professor Phillips’s generally admirable little book upon Vesuvius, an ideal diagram is given at page 132 of the aspect of a part, at least, of the dykes of Somma ; but throughout the work, where a most complete description and discussion of these dykes and of the mode of their production might have been looked for, we do not find a single paragraph which treats of them.

De la Beche, generally so exact as to questions of physical geology, is little more explicit (Geol. Observer, 2nd edit. 1853, p. 378), except that he distinctly affirms that fissures formed in the mass of volcanic cones are filled by the liquid lava, which exercises hydrostatic pressure upon the interior walls of the crater.

Sir Charles Lyell, in his paper already referred to, “ On Lavas of Mount Etna ” (Phil. Trans. 1858), following Von Waltershausen, by employing the apparent convergence of thirteen of the dykes of the Val del Bove as the means of fixing the position of the second axis or ancient crater which he assigns to Etna at Trifoglietto within the Val del Bove, tacitly assumes that the clefts in which these dykes were produced were so formed as all to emanate radially from Trifoglietto as an axis. He however assigns no reason why this should be so ; and from the words (page 760) “ near the principal crater, where earthquakes rend the mountain, and where lava is ever ready to flow into rents,” he appears to be of opinion that the clefts of these dykes were rent open by earthquakes—admitting which, it is difficult to conceive why they should pass outwards from the

volcanic axis radially, or indeed why they should show any determinate directions at all in reference to that axis. It seems, therefore, that while all authors have tacitly or expressly supposed the radial arrangement of volcanic dykes, none have made the attempt to explain the mechanism by which the fissures occupied by these dykes have been produced, or appear to have discerned that the production of a fissure and its filling with molten matter had been simultaneous and due to the same cause, viz. the hydrostatic pressure of the liquid lava more or less filling the crater. A right understanding of the physical conditions of this mechanism leads to some not unimportant conclusions.

A volcanic cone may be considered simply as an embankment surrounding a central cavity or crater, approaching usually in plan more or less to a circular form, an irregular cone whose base is the brim of the crater. The embankment being formed, as Lyell rightly insisted, merely by the continued projection of materials from the crater, some poured forth as liquid lava, but by far the larger proportion projected as dust, lapilli, and stones, must be regarded as formed by loose material having little or no coherence. It therefore resists the tendency to being burst open by hydrostatic pressure of lava filling up the crater, merely by the weight or mass of incoherent matter forming the embankment, the general vertical section of which anywhere round the axis is rudely triangular, the slope of the interior side being comparatively steep and constantly changing, while that of the exterior at the upper part of the cone depends in a great degree upon the angle of repose of the loose material composing it, while further down, by the degrading action of rain and other erosive causes, the angle constantly decreases to the base, where the mountain rises from the plain.

A straight embankment, like one of those constructed of earth and clay across a natural valley basin for the purpose of impounding water, and having usually a triangular section, very much like that which we have just assigned, the inner or water-slope being usually in the ratio of 3 horizontal to 1 vertical, while the outer slope is generally rather steeper (exactly the reverse of the case of the volcanic embankment, in which the inner slope is small and may even be evanescent, while the outer slope varies from perhaps 25° near the top through an average of about 18° for the whole slope, becoming evanescent at the bottom or plane), resists the hydrostatic pressure of the water which it impounds simply by its mass, which is too great to permit its being caused to slide upon its base by the horizontal component of the fluid pressure; and so long as the mass of earth and clay is kept free from the percolation or leakage of water through it, its resistance is almost wholly independent of cohesion in the material of the bank, and wholly so as regards cohesion in the direction of its length. The sides of a volcanic mountain are not straight, but form an embankment approximately circular in plan about the cavity of the crater, which it surrounds; and hence another condition of its resistance to fluid pressure within the crater comes into play. The radial and horizontal pressure of the fluid

within a ring-formed embankment whose plan is a closed curve, is normal to the embankment at any point, and is resolved into tangential forces tending to pull asunder or rupture the mass transversely to its circumference, as well as to push every part of it outwards upon its base. The degree of cohesion which the material of a circular embankment possesses is thus an important element of its resistance to fluid pressure within it; and such resistance in any circular embankment of given section, material, and depth of cavity, or of fluid pressure within, decreases with the increase of the diameter or surface of the cavity within. There is, in fact, a close analogy between the mechanical conditions of resistance of a circular embankment and those which resist bursting in a water-pipe, the cylinder of an hydraulic press, or the chase of a cannon. The resistance in these depends almost wholly on cohesion of the material; and it has been shown by mechanical authors that in a thick tube, such as a cast-iron smooth-bore gun, the exterior portions of the metal are greatly less strained by any expansive force from within than are the interior portions next the cavity; and as soon as the pressure within that, whether liquid or gaseous pressure, reaches the rupturing-point, *i. e.* exceeds the cohesion per unit of section of the material at the interior surface, the thick hollow cylinder begins to burst by fissures passing outwards from the interior surface, extending in planes radial to and passing through the axis of the gun or tube. After this point has been reached, no increase of thickness can add to its strength or prevent the formation of such fissures, because, as is obvious, the circumferential strains at any distance from the inner surface are everywhere proportional to the normal pressures transmitted to the same distance; and as these pressures are only transmitted to any exterior couche by the compression already sustained by those interior to it, and as, in accordance with Hook's law, the resistance in all cohesive bodies is proportional to the rupturing force acting upon them, so the exterior portions of the gun or pipe are exposed to a much smaller strain than are those within, and the strain is greatest at the interior surface, where, as has been said, the tube first commences to burst.

The construction of modern ordnance in ringed structure, or in two or more separate tubes, each grasping and therefore compressing those within it with a certain amount of initial tension, is based upon the conditions just stated. Were the cavity of a volcanic crater an exact form of revolution, either a cylinder or a cone, and were the materials composing the embankment around it perfectly uniform, and the mass and slope such that the resistance was everywhere proportional to the depth of liquid lava filling it, fissures, if formed by the liquid pressure, would be in true radial and vertical planes, like those in which burst cannon are found to divide; and this would be so whether the cohesive resistance of the material of the cone were great or small. Like fissures would take place if the material of the cone or circular embankment were absolutely devoid of cohesion, as if it consisted of an incoherent mass of sand or earth;

for all such material is more or less compressible, the resistance to compression depending upon the size, form, closeness, and mutual friction of the particles composing it, whether small or great. A circular embankment composed of such compressible but incoherent material, when exposed to liquid pressure from within, suffers a radial compression or approximation of its particles, which is greatest at the interior surface and becomes less and less as we approach the exterior. But the radial or normal pressures which produce this compression or packing up of the particles, also tend by resolution of force, as has been already explained, to separate or draw off the particles one from another in the circumferential direction; and this drawing asunder of particles, like the compression radially, will be greatest the nearer we are to the interior surface. In other words a circular embankment such as we have imagined that of a perfectly regular volcanic cone composed of compressible though perfectly incoherent or loose material, must under sufficient liquid pressure from within begin to give way by the formation of fissures (unless, indeed, the interior material were viscous or plastic for a considerable thickness, the exterior still being compressible, in which case the interior circumference of the cone would enlarge by mere change of dimensions without any fissures being formed) commencing at the interior surface and passing outwards into the mass in planes whose directions would be perfectly radial and vertical if the material were perfectly uniform or homogeneous; and if the thickness of the embankment be sufficient in relation to the pressure and the time of its continuance, the fissures may never reach the outer surface.

The hydrostatic pressure of the liquid originates the fissure into which the pressing liquid at the same time enters and fills it as fast and as far as it is formed. The fissure is in fact the inceptive of bursting; and if the liquid pressure and its continuance be sufficient the fissure might be prolonged throughout the entire thickness. As in nature, however, the thickness is generally enormous in proportion to the cavity of the crater, fissures commenced from within are seldom found to reach the exterior surface of a volcanic cone, but generally stop short within its mass, partly by reason of the cooling and solidifying of the molten matter forced into the fissure.

A fissure thus produced and at the same time filled with molten matter will always be widest where nearest the crater; and were the material of the cone which it divides perfectly uniform, the general form of the dyke produced would tend towards that of a wedge whose outer edge would be bounded by a curve, the nature of which would depend upon the vertical extent of the fissure, and the liquid pressure at increasing depths, and, in nature, of course upon many other conditions.

The material composing the cone of a volcano, however, is far from uniform. Besides the material of various sorts and various degrees of coherence, usually small, there are intercalated beds of lava of various ages, thicknesses, and qualities, all sloping more or less outwards and at different depths dividing like shelves the mass

of little-coherent material lying between them. These lava beds probably seldom if ever traverse the entire circumference of the crater, but merely such portion of it as represented the width of the overflow or lava stream at its brim. Were such plates or shelves of intercalated lava free from joints and unbroken, they would, by their cohesion, offer great resistance to the opening of any fissure through them; but from the effects of their cooling after outflow, and from the immense and unequal pressures to which they have been subjected by the superincumbent mass of the cone, they are all, we must suppose (as, indeed, observation indicates), greatly broken. Still, however, such intercalated plates of lava must greatly increase the resistance of that portion of the crater-walls in which they occur to becoming fissured in the way described.

From all these causes, and the concurrence of many other circumstances which will readily occur to those familiar with the features of volcanic mountains, it will be obvious that fissures commenced at the interior and propagated into the mass of volcanic cones can seldom be uniformly distributed round the crater, being chiefly formed at the weakest places, and can be but rarely produced in perfectly regular vertical planes having a truly radial direction from the crater; and the disparity from such normal form or direction, which must always exist more or less, will become greater with the increased length of the fissure (that is, with the distance from the crater), having at every point of its course been forced through heterogeneous material and such as may have its directions of easiest division in very different directions at different points of the path. Thus, for example, the position assigned by Lyell in the Val del Bove to the ancient crater of Trifoglietto is in a right line more than a mile from the nearest points of the escarpment in which the orientation of the dykes is observable, and by the convergence of which the position of Trifoglietto was fixed. Again, assuming, as is commonly done, that the axis of the ancient Somma was the same in position as that of the present Vesuvius, the distance of that point from which the dykes of Somma are supposed to have emanated is more than a mile.

In traversing such a distance through material highly irregular as regards hardness, cohesion, and direction of easiest fracture, and remembering that all these may vary in any one dyke at every few fathoms of its depth, we are forced to conclude that, even supposing the fissures to have commenced perfectly normally at the respective craters of Somma and Etna, they can scarcely but have diverged largely in many cases, both in dip and strike, and in different degrees at different parts of their height, from the directions in which they were first started.

A fissure, for example, commencing vertically and, let us suppose, in a direction due north in the interior of the ancient crater of Somma, and being caused by the diversity as to material through which it is opened to diverge gradually, so as to take a curved direction towards the east or west, must have its orientation changed to an extent proportionate to the distance it has traversed outwards;

so that at a distance of a mile from its crater origin, the orientation of the fragments, as well as the dip of the dyke now observable in the escarpment, may be wide away from those at the point whence it is supposed to have started. Further, this change of direction may be repeated in opposite directions, producing planes of double curvature such as were actually observed by Lyell and Hartung in a dyke in Madeira, and as observed by me in some of the twisted dykes of Somma.

Without disputing the fact that the horizontal coincidence at or near a single point of the apparent orientation of a considerable number of the fragments of dykes observed only at considerable distances, may afford a presumptive probability, greater or less, in proportion to the greater number of the coincidences and to the generally straight and unshattered character of the fragments of the dykes observable, I must yet come to the conclusion from what has preceded that the concurrence or intersection at a single point of the apparent orientation of dykes is too unsafe a guide to warrant our fixing the position of an ancient crater upon such a basis alone, and that such a mode of determining crater-position, though it may attain to probability, can never amount to certainty.

In stating this conclusion I wish not to be misunderstood as casting any doubt upon Sir C. Lyell's views expressed in his paper to which I have already referred, as to the ancient existence and position of a second crater to Etna. The evidence which he has adduced as to such a crater at Trifoglietto does not rest alone upon the convergence there of the greenstone dykes observed by Von Waltershausen and himself, but is also sustained by the synclinal position, as adduced by him, of the lava and conglomerate beds towards some line between the existing crater of Etna and that concluded to have existed at Trifoglietto; and to this evidence as supporting the former existence of a second crater there is no objection to offer. At the same time I must remark that the position of the lowermost beds of any volcano upon the vast scale of Etna must have greatly changed in the course of ages by the depression beneath the central parts produced by the enormous superincumbent weight, which is constantly being added to, of the cone itself, and from the erosion constantly proceeding irregularly under the base of the mountain.

If Etna, after having broken through the Tertiary strata, deposited its materials on a nearly level surface, that, as the mass of the mountain has been heaped up through long ages, must from the causes mentioned have become depressed towards the central parts into a shallow saucer-shaped dish; so that the lowermost beds with the non-volcanic strata upon them, could we now see them, might be found to dip more or less from the circumference of the mountain downwards towards its axis, the same phenomena here occurring upon a colossal scale that are well known to happen when heavy earthen embankments are formed over even very firm soil, which is depressed beneath the weight, and sometimes more or less raised at considerable distances from that, but often not sensibly

raised at all. These views, however, tend rather to strengthen Lyell's inferences from the contrary dip of the Etnean beds observed by him.

Lyell, desirous of doing full justice to the views of M. Élie de Beaumont, admits that the intrusion of volcanic dykes may increase the slope of volcanic mountains. It appears to me, however, that the possible increase of slope thus conceived to be producible has been much overestimated, the following conditions being taken into account :—

1. The united or total thickness of all the dykes in the escarpment of Somma, as examined by me, was a little under 150 feet; and that is the thickness of the intruded matter in the amphitheatre of 2 miles round the curve, which, regarded as circular, has a mean radius from the axis of Vesuvius of about a mile. If we even double this thickness of intrusive matter in order to allow for that of unobserved broken up or obliterated dykes, intermixed with those surveyed, and bear in mind that the north slope of Somma at the level of the Atrio averages about 25° , it can be easily seen that the increase of inclination, taking the entire original slope of Somma from the summit to the plain at about three miles, would prove very insignificant and might be estimated as still less in reference to the much larger features of Etna.

2. Although intrusive dykes may occur at all altitudes, they preponderate in numbers and in thickness about a zone extending hypsometrically to a height very far short of that of the entire mountain, few or none probably reaching any considerable depth below the base, where the horizontal resistance to the fissuring pressure is enormous, and but seldom reaching a height greater than about two thirds the entire height of the mountain, because the filling of the crater with liquid lava high above this level is probably not very common. Hence the effect of such intruded dykes must rather be to produce gibbosity or some local increase of slope about the middle zone of volcanic mountains than any general increase in the inclination of the sides.

3. As these dykes are not produced at one time or radially all round the circumference, but singly or a few at a time, and sporadically distributed where the weakest parts at different times permit, so it seems difficult to assume any noticeable increase of general slope or of inclination of the internal beds as arising from this cause.

The length of this paper forbids my entering at all upon the mechanism by which so many of the parasitic dust cones existing upon Etna, of which Monte Rosso may be regarded as a type, and found also in the numerous "Puis" of Auvergne, have been opened at one side and become horseshoe-shaped. This has been commonly attributed by authors to their having been burst by the hydrostatic pressure of lava, filling more or less completely these steep cones of almost completely incoherent material; and the streams of lava still observable in some of them at the opened side have been appealed to in proof of this, though the greater

number of these opened cones show no trace of ever having contained lava. The true nature of the mechanism by which they have been opened may, I believe, be inferred from the preceding pages. The opening has been effected not by bursting but by the undermining of one part of the base of the crater-wall, either by a small outburst of lava beneath or, in the case of those opened cones which present no trace of lava, by the erosive leakage of rainwater filling to some depth the cavity of the crater. Although these hollow dust heaps are porous, the bottoms are more or less stanch'd to rain by a sort of natural puddling with very fine material washed down from their inner sides, in the same way as certain portions of the Atrio del Cavallo have been made watertight and contain ponds of water in the winter time.

53. *On the BRITISH FOSSIL CRETACEOUS BIRDS.* By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., Professor of Geography in King's College, London. (Read June 7, 1876.)

[PLATES XXVI., XXVII.]

History.

THE oldest remains of British fossil birds are recorded by Sir Charles Lyell as having been first found in 1858, in the Cambridge Upper Greensand*. This stratum still continues the only member of the British Secondary deposits in which the bones of birds have been identified by morphological characters; for though the Rev. Mr. Dennis had previously asserted the occurrence of birds in the Stonesfield Slate †, on the evidence of the microscopic structure of osseous tissue, it is safer, in the absence of recognizable bones, to believe that the ornithic structure he detected was found in an ornithosaurian rather than in a true bird. The discovery of bird-bones in the Cambridge Greensand was made by Mr. Lucas Barrett, F.G.S., then Assistant Naturalist to the late Professor Sedgwick in the Woodwardian Museum of the University of Cambridge; but I am not aware that Mr. Barrett ever published any account of his discovery. The bones are mentioned by Lyell as "the remains of a bird which was rather larger than the common Pigeon, and probably of the order Natatores, and which, like most of the Gull tribe, had well-developed wings. Portions of the metacarpus, metatarsus, tibia, and femur have been detected; and the determinations of Mr. Barrett have been confirmed by Professor Owen." What became of Mr. Barrett's specimens I was never able to find out. They were not in the Woodwardian Museum when I succeeded to Mr. Barrett's duties in 1859; and the whole of the remains to which I shall have to refer were collected subsequent to that date. Professor Owen, in his 'Palæontology,' remarks ‡:—"One of the evidences of birds from the Cambridge Greensand, transmitted to the writer by their discoverer, Mr. Barrett, is the lower half of the trifold metatarsal, showing the outer toe-joint much higher than the other two, and projecting backwards above the middle joint; it indicates a bird about the size of a Woodcock."

In the 'Annals Nat. Hist.' for August 1866 I mentioned, in a Note on new Genera of fossil Birds, that I had collected or seen from the Cambridge Greensand cervical, caudal, and dorsal vertebræ, proximal and distal ends of the tarsometatarsus, proximal ends of tibiæ, proximal and distal ends of femora, humeri, metacarpal bones, &c., and suggested that the typical species should be called *Pelagornis Barretti*. In my 'Index to Aves, Ornithosauria, and Reptilia,'

* Supplement, Elements of Geology, 1859, p. 40.

† Quart. Journ. Micr. Sci. vol. v. (1857) p. 63.

‡ Second edition, 1861, p. 327.

&c., 1869, I abandoned the generic name *Pelagornis* (which had been preoccupied by Lartet) for *Enaliornis*, and recognized a second species. In that catalogue forty-seven fragments of bird-bones are enumerated and briefly described. In 1870, in "Remarks on *Dimorphodon*"*, I drew attention to the fact (afterwards confirmed in American specimens by Prof. Marsh) that some dorsal vertebræ of Cretaceous birds have flat or slightly concave articular ends; and in other writings† I considered the affinities of the birds to be with *Colymbus*‡ and the Penguins. Most of the Upper-Greensand bones were found in the neighbourhood of Coldham Common near Cambridge, or at Granchester. When I was residing at Cambridge, and endeavoured to add to the University collection every portion of the bird's skeleton which came under my notice, I was never so fortunate as to secure a perfect long bone; and the only specimen which I have seen with the shaft unbroken is a femur in the collection of Mr. Jesson, F.G.S. Many of the fragments are worn; but most are broken without being much abraded. And it is quite possible that the specimens may have been more perfect in the deposit than the state in which they are collected would imply; but allowance, in judging of this, must be made for the accidents of fossilization, and the carelessness and ignorance of the phosphatite diggers, whose interest in these remains is usually too small to ensure the preservation of inconspicuous bones which are only met with at long intervals of time; and thus portions of one skeleton, or even of one bone, sometimes get distributed to several collectors. In the remains of other animals I have seen several cases in which the fragments of fractured shafts of bones have lain in juxtaposition in the deposit, and oysters have grown on the fractured surfaces—showing, I think, that though the nodules may have been formed and mineralized in shallow water, they were rolled, with such of the bones as are unassociated, into a somewhat tranquil depth of sea before they were covered up by the Upper Greensand sediment.

There is no evidence of more than one bird-bone being found at a time; so that every fragment of bone may have belonged to a separate individual bird.

The Skull. (Pl. XXVI. figs. 1-4.)

A suspicion often occurred to me that the hinder part of the cranium (drawn in pl. 11. figs. 3-6 of my book on the Ornithosauria) might perhaps be the skull of a bird. In describing it seven years ago as Ornithosaurian I was influenced chiefly by probabilities and considerations such as these:—The specimen closely resembles the back part of the cranium in several Pterodactyles from Solenhofen; its Avian characters are in harmony with the characters of other

* *Annals Nat. Hist.*, Aug. 1870, p. 129.

† *Ibid.* Nov. 1871, p. 305.

‡ May 2, 1864, I communicated a note to the Cambridge Philosophical Society "On the Fossil Birds of the Upper Greensand (*Palæocolymbus Barretti* and *Pelagornis Sedgwicki*);" but nothing beyond the title of the paper was printed.

parts of the skeleton of *Ornithocheirus* from the Cambridge Greensand, and it closely resembles the specimen figured on pl. 11. figs. 1 & 2, the Ornithosaurian nature of which I see no reason to doubt; while it seemed improbable that so many specimens (as were known to me) of birds' skulls should have been found, and so few of Pterodactyles—the bones of birds being so rare, and those of Ornithosaurs, especially jaws, being relatively abundant. Confessedly it is extremely difficult, if not impossible, to distinguish the hinder part of the cranium in some Natatorial birds from the corresponding region in some Ornithosaurs merely by the form of the head, the arrangement of its regions, or the proportions of its several osseous elements. When first describing the specimen referred to, I pointed out* the difficulties in the way of distinguishing the fossil from the cranium of a bird. The withdrawal of the specimen from the Ornithosaurian list would leave the question of the Avian nature of Ornithosaurs unaffected, as in most respects some of the admitted crania of Pterodactyles are almost as bird-like as this specimen.

I propose now to regard the skull as that of a true bird:—first, because, on careful reconsideration, I find no characters by which it can claim more than a generic distinction from living birds; secondly, it is more like a bird's skull than is the skull of any British Pterodactyle; thirdly, the cranial bones are comparatively thin and dense, instead of having the cellular structure characteristic of Ornithosaurs from the Cambridge Greensand, and in this character the skull agrees with the other portions of the bird's skeleton. It is about the size of the Red-throated Diver's cranium, and, in common with all the other bird-bones found, presents a marked resemblance to that Avian type.

I have already described elsewhere† the essential features of this specimen, and now offer a few measurements of its several regions, which were then omitted.

Transverse measurement over the lateral processes which form the articulation for the quadrate bones, $1\frac{1}{8}$ inch.

Transverse measurement of the constricted squamosal region of the skull just in advance of the preceding measurement, $\frac{3}{4}$ inch.

Transverse measurement of anterior termination of the squamosal region $1\frac{5}{8}$ inch.

The parietal region rapidly rises as it extends forward from the occiput.

The parietal bones, which met in the median line in a slight ridge, are oblong, $\frac{5}{16}$ inch long, though, owing to the anterior margin being concave, each becomes much wider ($\frac{7}{16}$ inch) where the parietal joins the squamosal bone in a nearly straight suture, $\frac{9}{16}$ inch below the median cranial crest. There is a bend in the upper third of the parietal bone; the superior portion looks upward and outward; the lower portion is more inflated than in the Diver, but is similarly directed outward a little to meet the expanded frontal. The parietal bone ($\frac{1}{16}$ inch thick) had a smooth union with the

* Ornithosauria, pp. 80–83.

† Ornithosauria, p. 80, pl. 11. figs. 3–6.

frontal, which it obliquely overlapped. The parietal appears to have been prolonged further forward in the line of the median crest than is evidenced by the preservation of the bones. The bones are transversely arched.

The squamosal bone differs from that element in the Divers, Cormorants, and Grebes (which in general form of cranium approximate to the fossil) in being folded so as to form a narrow inferior surface more than $\frac{1}{8}$ inch wide and about $\frac{3}{8}$ inch long, and a superior triangular, somewhat V-shaped area fully $\frac{1}{4}$ inch deep and as wide. In this folded character there is some approximation to the condition of the squamosal bone in the Goose tribe.

The occipital crest seems to have been well elevated. It is sinuous and curves forward laterally, as in the Diver, but is more elevated inferiorly than in that type, and has the articulation for the quadrate bone placed entirely behind it, which is not the case in the Diver. The occipital aspect of the fossil is wonderfully like that of *Colymbus*, and differs chiefly in the fossil being somewhat broader, owing to the two sides of the occipital crest making a greater angle with each other. The basioccipital articular condyle in the fossil is probably removed by fracture. The Diver has the bone in front of the condyle vertically compressed; but in the fossil the basioccipital was compressed even more, since the fracture has left but a narrow rim to the base of the foramen magnum. The foramen magnum is vertically ovate, and relatively rather larger than in the Diver; it is $\frac{3}{8}$ inch high, and $\frac{5}{16}$ inch broad; its upper border considerably overhangs the base.

The tympanic area is large, internal to the articulation for the quadrate bone, and is best exposed in lateral view. It is limited by four irregular sides, and has an irregular surface in which are several perforations. The basitemporal bones, which are missing, were shaped as in birds. The remarkable short-triangular form of the base of the sphenoid may result from abrasion. It is broader than in water-birds, but is essentially a modification of the sphenoid of the Diver. As preserved, it is $\frac{1}{4}$ inch long and $\frac{5}{16}$ inch wide at the base. This specimen I regard as the skull of *Enaliornis Barretti*.

Another specimen, in the collection of Mr. Reed, at York, probably belongs to another species.

A fragment which I regarded in 1871 as a premaxillary of a Toothless Pterodactyle has perhaps an equally good claim to be considered a portion of a premaxillary bone of a bird. It has already been figured by Prof. Owen as the proximal end of the metacarpal of the wing-finger of an Ornithosaur*. I have suggested for it (Ann. Nat. Hist. January 1871, p. 35) the name *Ornithostoma*; for, if a bird-bone, it has nothing in common with *Enaliornis*; and if an Ornithosaur, the name will be appropriate. It has the base flattened, concave from side to side, marked with blood-vessels, and terminating laterally in well-defined ridges gently rounded, which are concave in outline from front to back, so as to make the back wider than the front. If the specimen should hereafter prove to be a jaw, this

* Pal. Soc. 1859, pl. 4. figs. 4 5.

would be the palatal surface. It is $2\frac{1}{4}$ inches long, $\frac{3}{4}$ inch wide in front, and $1\frac{1}{8}$ inch wide behind. The sides are smooth, finely wrinkled, concave in length, convex from above downward, with small oblique vascular foramina near the border, which may be alveolar; there are also foramina on the middle of the side. Superiorly the sides converge in a rounded ridge. It is $\frac{1\frac{3}{8}}$ inch deep in front, and $1\frac{1}{4}$ inch deep behind. The great difficulty in the way of regarding it as an Avian premaxillary is that, although it widens behind somewhat rapidly, it shows no indication of a nasal groove or cavity, though the Diver has no lateral groove on the beak. And the recent discovery of Toothless Pterodactyles by Prof. Marsh in the Cretaceous beds of America lends some support to my original determination of the bone as Ornithosaurian.

I would suggest that since the birds from the American Greensand having teeth in their jaws show affinities with *Colymbus*, it is probable that *Enaliornis*, which has vertebræ resembling those of *Ichthyornis* in biconcave character, may also have had teeth in its jaws.

The Vertebral Column.

Cervical vertebræ have rarely been found. Some twelve years ago I detected what seemed to be a lower cervical in the collection of W. Reed, Esq., F.G.S., but have not noticed any other specimens. The vertebræ most commonly found, and best known, are dorsal. One in Mr. Reed's collection has the visceral surface of the centrum terminated by a sharp ridge, while all the other specimens (including four in the Woodwardian Museum) have this surface convex. Mr. Reed's two vertebræ probably belong to the two species of birds to which I refer the bulk of the remains, though this could only be definitely determined by a careful study of the somewhat abraded fossils. Of the sacrum, the Woodwardian Museum has three important specimens demonstrating the essential points of structure; another fragment of the postfemoral part of a sacrum has been obtained by James Carter, Esq., of Cambridge. These specimens are all from the anterior and middle regions of the sacrum, and are such as might all belong to one genus. The Woodwardian Museum also contains two other vertebræ, apparently procelous, which I am disposed to regard as bird-bones, and refer to the tail. As they have no transverse processes, they are probably elements which, in existing birds, are united in the ploughshare bone.

Lower Cervical Vertebra. (Pl. XXVI. figs. 5, 6.)

The centrum measures $\frac{5}{8}$ inch in width over the anterior zygapophyses; the length of the centrum is $\frac{7}{16}$ of an inch; the width of the centrum in front is nearly $\frac{5}{16}$ inch, where the anterior articulation is concave from side to side, convex from above downward; it is more than $\frac{4}{16}$ inch deep; and at its base a short tubercle is developed. The base is concave, long, narrow, flattened, and concave from side to side. It is margined by sharp concave borders.

The lateral areas are concave; the posterior articulation is slightly concave in depth, and more convex in breadth: it is nearly square, but broader above than below. The neuropophyses rise obliquely from above the upper part of the centrum behind, widening superiorly to above the neural canal in front. The depth in front of the centrum and neural arch is more than $\frac{2}{3}$ inch. The upper surface is obscured, and the neural spine is not preserved; it does not rise from quite the front of the arch, which is nearly horizontal above. The facets for the zygapophyses look upward and inward.

This specimen, in the collection of W. Reed, Esq., is not unlikely to belong to *Enaliornis Barretti*.

Dorsal Vertebrae. (Pl. XXVI. figs. 7-13.)

The four dorsal vertebræ in the Woodwardian Museum, like all the other specimens which have come under my notice, except Mr. Reed's, agree in their characters, though they differ a little in size. They are small in proportion to the size of the head, and show no resemblance to any vertebræ of the Diver. Two of the centrams of *Enaliornis Sedgwicki* (fig. 12a) display to some extent indications of the peculiar Ichthyoid biconcave articular condition already referred to; but, as it is wanting from the largest specimen, it is possible that the smaller specimens though adult are imperfectly ossified; many natatorial birds have the lower dorsal centrams nearly flat, while very young birds have a small central notochordal depression on the articular face. The centrams are much less compressed from side to side than is usual in the dorsal vertebræ of water-birds.

The largest specimen, *Enaliornis Barretti*, has the centrum rather more than $\frac{2}{3}$ inch long, expanded at both articular ends, somewhat flattened at the base and at the sides, which round into each other (fig. 9), and are each concave from back to front. The anterior articulation (fig. 11a) is $\frac{2}{3}$ inch broad and $\frac{1}{4}$ inch deep. It is remarkable for having the sides of the centrum prolonged forward for a considerable distance, so that the surface is markedly concave from side to side, while vertically the convexity, if it exists, is so slight as to be scarcely detected. Posteriorly the articulation (fig. 10b) is necessarily narrower; it is more than $\frac{1}{4}$ inch wide and less than $\frac{1}{4}$ inch deep. It is convex from side to side, flat from above downward, with a central concavity, is subquadrate, emarginate in the upper part of the side, with a slight impression dividing the basal margin. Laterally (fig. 7c), at the side of the anterior border of the neural arch is an oblique oval facet slightly elevated, $\frac{1}{8}$ inch long and concave, which has exactly the form and position of the diapophysis in the vertebræ of existing birds like the Gannet. The whole centrum closely resembles that of the Solan Goose, differing chiefly in being much more depressed, and not much more than half the size. The form of the neural arch, however, much more closely resembles that of *Colymbus*. A narrow, compressed, horizontal, transverse platform is given off (fig. 8d). It is emarginate anteriorly and posteriorly, and directed outward and somewhat back-

ward; it is imperfectly preserved. Small zygapophysial facets (fig. 8g) are preserved or indicated both in front and behind. The neural spine (fig. 8e), as preserved, is thicker posteriorly than in front, does not extend quite to the anterior border of the neural canal, and posteriorly is cleft vertically. Specimens of *Enaliornis Sedgwicki* (fig. 13) show the centrum to be considerably impressed laterally below the transverse process*, and that the neural canal is much wider than high; the neural spine is directed somewhat backward. The shortest centrum is more than $\frac{1}{4}$ inch long. The amount of the concavity of the centrum varies.

The Sacrum. (Pl. XXVI. figs. 14-19.)

There are three fragments of the sacrum in the Woodwardian Museum, and a fourth (from the posterior part of the sacrum) in the collection of James Carter, Esq., M.R.C.S. The Woodwardian specimens appear all to belong to the same genus, are in sequence to each other, and show the sacrum to have been constructed exactly after the water-bird pattern. The vertebræ, however, are more elongated, so that the sacrum is much longer in its several regions than are the corresponding parts of the sacrum of the Diver. The first fragment (fig. 14) comprises the first, second, and part of the third sacral vertebræ ankylosed, with the elevated margins of the confluent centrans unusually well marked on the basal border. The first centrum is depressed, with the articular surface flattened in front, as in the Gulls and the Gannet, and somewhat concave centrally. The anterior articulation is nearly $\frac{3}{8}$ inch broad. The centrans increase a little in length from before backwards; the first is about $\frac{5}{16}$ inch long, with a depressed form of centrum, broad and convex from side to side, and slightly concave from back to front. I am unable to detect any indication of the diapophysial articulation on the anterior border of this centrum usually to be seen in existing birds. A narrow transverse process, $\frac{1}{8}$ inch wide, is given off from the anterior part of the side of the centrum and directed outward and somewhat upward; its outline is emarginate both anteriorly and posteriorly. In the succeeding vertebræ the centrans become a little deeper, and rapidly more compressed from side to side, the third having the sides flattened, and base forming a narrow rounded ridge. The third vertebra shows the transverse processes, which, thick and strong, appear to have formed horizontal neural tables, the bases of which, as preserved, have a transverse measurement of $\frac{3}{4}$ inch. From the neural platform to the base of the centrum is more than $\frac{3}{8}$ inch. No indication of the neural spine is preserved.

The second specimen (figs. 15, 16), from the middle of the sacrum, is in a pale state of mineralization, and more free from matrix. It was collected by M. R. Pryor, Esq., late Fellow of Trinity College. It

* The impression is never as deep as in Gulls, or even as in the Wealden fossil *Ornithopsis*, a genus so named from the resemblance of its centrum to that of certain Gulls.

comprises portions of three vertebræ—one entire in the middle, and a fractured vertebra at each end. In general form the vertebræ rather recall the middle sacral region of Penguins. The centrum is rather more than $\frac{2}{3}$ inch long, while the least width at the intervertebral foramen is $\frac{5}{16}$ inch. The sides, concave in length, are compressed so as to converge inferiorly in a rounded median keel. The vertebral foramina are large, rounded, and placed behind the transverse process just at the hindermost part of the centrum (fig. 16). The neural platform is wide, horizontal, and imperfectly preserved; it is traversed in the median line by a low neural spine about $\frac{1}{16}$ inch high and as wide. The depth from the neural spine to the base of the centrum is fully $\frac{7}{16}$ inch. The substance of the centrum is largely excavated for the neural canal, which is cylindrical and $\frac{1}{4}$ inch in diameter. The position of the transverse processes is above the middle of the neural canal. Both the specimens described are from the part of the sacrum anterior to the femoral articulation in the pelvis.

The third specimen (figs. 17, 18, 19) is postfemoral; it has almost exactly the form of the region immediately postfemoral in the Diver. It comprises portions of four vertebræ perfectly ankylosed together. In transverse section the mass is triangular (fig. 17), having the base flattened; and the flattened sides converge dorsally to a sharp ridge, with which the iliac bones were in contact. The specimen is $1\frac{1}{8}$ inch long, $\frac{7}{16}$ inch high as preserved anteriorly, and about $\frac{1}{2}$ inch high posteriorly. The base (fig. 18), which is channelled in length as in the Diver, is margined on each side by a subangular ridge, external to which is a narrow flattened lateral area which looks downward and outward. The width of a centrum in front, where narrowest between the transverse processes, is less than $\frac{2}{3}$ inch; posteriorly the sacrum becomes steadily narrower. On the lower portion of the lateral aspect (fig. 19) is a row of four large rounded intervertebral foramina, less than $\frac{1}{8}$ inch in diameter, between which are the eminences forming the bases of the short transverse processes. The flat side above these foramina and processes, $\frac{5}{16}$ inch deep, is divided into rhomboid areas by impressed lines running upward and backward at unequal distances from each other. Posteriorly at the fracture the sacrum is becoming greatly compressed; but there is no means of estimating the number of vertebræ in the posterior missing portion. In the Diver there are six vertebræ posterior to the corresponding sacral region; but if *Enaliornis* had a long tail, the sacrum may have included fewer postfemoral elements.

Caudal Vertebræ. (Pl. XXVI. figs. 20, 21, 22.)

Two small vertebræ, apparently caudal and procelous, I am inclined to assign to the caudal region of *Enaliornis*; if so, they are separate elements of the ploughshare bone, and would indicate a peculiar condition of the termination of the tail. The centrum is compressed from side to side; and the neural arch, which hangs forward a good deal (fig. 20), shares in the compression. The centrum is about $\frac{1}{4}$ inch deep, and $\frac{3}{16}$ inch in width superiorly, where it is widest;

and the base is rounded, with a narrow median furrow. The articulations of the centrum are oblique, looking downward and forward; the anterior one (fig. 22) is concave from above downwards, and shows a less concavity from side to side. The posterior articulation (fig. 21) is evenly convex, somewhat compressed from side to side, broader above than below; it is $\frac{1}{4}$ inch deep, and $\frac{3}{16}$ inch wide superiorly. On the middle of the side of the neural arch, on a line with the base of the neural canal, is a slight eminence indicative of a rudimentary transverse process. The zygapophyses are broken away, but extended far forward, and were elevated to the upper border of the neural canal. The neural arch in front is wider than the centrum; posteriorly it is compressed and narrower than the centrum. There appears to have been a slight neural spine; but it is broken away. As preserved the vertebra is $\frac{7}{16}$ inch high. The neural canal is small, but is larger in front than behind.

The vertebral column, as a whole, is unlike that of any existing bird; but its affinities with members of the natatorial tribe admit of no question.

The Pelvis. (Pl. XXVI. fig. 23.)

Only one fragment has come under my notice; it is in the Museum of the Geological Survey, and had already been identified by Mr. E. T. Newton, F.G.S. I am indebted to Professor Huxley for the opportunity of studying this and other bird-bones in the Geological-Survey Museum. The ilium is large and deep, the acetabulum is perforated, and the small, but distinct, public and ischial bones are directed backward.

The specimen is a fragment of the left ilium (fig. 23 *a*) with the ischium broken short, and an indication of the pubis. The acetabulum is $\frac{9}{16}$ inch wide; it is subcircular, and is perforated as in living birds, the perforation being apparently nearly $\frac{3}{8}$ inch wide. The external surface of the ilium is smooth; but the posterior margin of the acetabulum is elevated considerably, as in existing birds, the anterior margin being similarly depressed. The pubis (fig. 23 *b*) is seen on the internal side of the fragment not to be blended with the ilium, but to be separated by a short straight suture directed upward and backward. The pubis is directed backward, but forms the inferior anterior margin of the acetabulum; it is slender, $\frac{3}{16}$ inch wide, subquadrate in section, with the external and internal anterior sides converging in a sharp anterior marginal ridge; consequently there are also posterior, external and internal ridges. As preserved, the pubis is $\frac{9}{16}$ inch long; it has a large medullary cavity. The ischium (fig. 23 *c*) is more slender and more circular in section; it forms the inferior posterior part of the margin of the acetabulum; is flattened anteriorly, and directed backward at the same angle as the pubis, from which it appears to be entirely separated: as preserved, it is $\frac{1}{2}$ inch long. The ilium is remarkably thin; it is compressed above and behind the posterior acetabular thickening, above which (as preserved) it extends for $\frac{7}{16}$ inch. The length of the specimen is about 1 inch.

The Femur. (Pl. XXVII. figs. 1-12.)

More specimens of femur have been found than of any other bone. The Woodwardian Museum contains twenty-four, of which eight are proximal ends. This is nearly half the total number of specimens of bird-bones in the Museum. In the collection of Mr. T. Jesson, F.G.S., in which there are seventeen bird-bones, six are fragments of femora—five of them distal ends, and one proximal. On the lowest computation these remains alone must have pertained to at least thirteen birds. The femora differ in size, form, and slenderness, but not to a marked degree; so that if the bones belonged to three different species, as is probable, they all may have been closely allied. The smallest femur is rather longer than that of the Red-throated Diver, but has the articular ends less expanded. One specimen in Mr. Jesson's collection (figs. 1, 2, 3) is $1\frac{1}{2}$ inch long, but has both articular ends worn and short of their true length. It is bowed superiorly, much as in the Diver, being concave in length inferiorly and convex superiorly. The shaft measures $\frac{1}{4}$ inch from within outward in the middle, and widens proximally to $\frac{3}{8}$ inch as preserved, and distally to $\frac{7}{16}$ inch as preserved.

The external surface is flattened, somewhat pitted with muscular attachments, rounded into the anterior and posterior surfaces, and is concave from the proximal to the distal end. The antero-posterior diameter of the shaft in the middle is more than $\frac{1}{4}$ inch, but becomes somewhat less towards both ends. The internal surface is somewhat compressed on the posterior margin, but is well rounded in the shaft from back to front, though towards the extremities it becomes more compressed. The proximal end is subtriangular when seen from above, the superior antero-posterior external measurement being much more than in *Colymbus*, while the articular head of the bone is smaller; and the shaft is slightly compressed superiorly external to the articular head, the impression being greatest in front. The distal end is marked in front with a shallow broad channel, nearly the width of the anterior surface, margined on the inner side by a sharp ridge, which is the edge of a flattened, narrow, short inner surface that looks inward and backward. As usual in birds, the proximal and distal articulations are both in the same plane, and the outer distal articular surface is the larger of the two.

Another femur, imperfect proximally (fig. 8) (presented to the Woodwardian Museum by Rev. T. G. Bonney, F.G.S.), appears to have been shorter and stouter, approaching nearer to that of the Diver, and the muscular attachments very like those of the Diver. As preserved, the fragment is $1\frac{1}{4}$ inch long and $\frac{5}{16}$ inch wide in the middle of the shaft; distally it is about $\frac{1}{2}$ inch wide. At the distal end there is wide pit rather than a groove, resembling that in the Red-throated Diver, only not so deep.

A third femur, badly preserved distally, and showing no trace proximally of the articular end, is $1\frac{3}{4}$ inch long; distally it is $\frac{5}{8}$ inch wide, while the larger condyle measures $\frac{3}{8}$ inch from front to back. This indicates an animal somewhat larger; but it is difficult, with

such worn fragments, to estimate aright the differences of size and stoutness.

The isolated ends exhibit corresponding differences of size. The smallest measures $\frac{7}{16}$ inch from within outwards over the proximal articulation, while the largest specimens are $\frac{9}{16}$ inch in that measurement, and have a corresponding thickness in the shaft. In all, the external proximal surface terminates in a sharp margin on each side, is flattened and wide— $\frac{7}{16}$ inch wide in the larger specimens, and less than $\frac{5}{16}$ inch wide in the small bones. Usually this area is somewhat concave below the articulation. The articular surface itself extends over the whole of the proximal end.

A medium-sized distal end of a left femur (Pl. XXVII. figs. 9, 10, 11) I refer to *Enaliornis Sedgwicki*. The fragment is about an inch long, subovate where fractured proximally, being $\frac{5}{16}$ inch in the greatest oblique measurement from before backward, and less from side to side. The shaft becomes compressed on the inner and posterior side towards the distal articulation, above which its section would be subtriangular; for the inner margin of the anterior aspect is a somewhat sharp ridge more marked than in the Diver, which is prolonged into the inner distal condyle. The outer condyle is much the larger, and extends about $\frac{3}{16}$ inch further distally than the other. The intercondylar space in the fossil has not so great an antero-posterior compression as in the Diver; and the inner condyle is rather deeper than in that type. The width over the condyles is $\frac{9}{16}$ inch; the depth of the outer condyle is nearly $\frac{7}{16}$ inch.

A larger distal end of a right femur (Pl. XXVII. fig. 12), which I regard as that of *Enaliornis Barretti*, more than an inch long, is nearly $\frac{3}{4}$ inch wide over the articulation; and the whole bone is proportionately larger. The condyle is relatively larger and deeper than in the other species, and the anterior channel between the condyles is relatively deeper. Another specimen, in better preservation, I noticed in the collection of W. Reed, Esq. I shall be quite prepared to find that the femora which have passed through my hands belong to more species than I have indicated; but, in the absence of other evidence, I do not see my way to giving them any useful definition.

The Tibia. (Pl. XXVII. figs. 13–21; Pl. XXVI. figs. 24, 25.)

The remains of tibiæ comprise two proximal ends of right tibiæ in the Woodwardian Museum, and one in that of Mr. Reed, and a left one in the collection of Mr. Jesson, all of which have a moderate patelloid process, which is more developed than in the Gannet, but makes no approximation in length to that of the Diver. There are also in Mr. Jesson's collection two specimens of right and left proximal ends of the smaller of the two forms of tibiæ, which are imperfectly ossified and have no trace of a patella, but terminate in rough cartilaginous surfaces. These bones seem to be young specimens of *Enaliornis Sedgwicki*, though the remains are not inferior in size to

those in which ossification is complete. In the Woodwardian Museum is a similar larger proximal end of a tibia without a patella, which I take to be that of *Enaliornis Barretti* (figs. 20, 21). There are also distal ends of tibiæ: the Woodwardian Museum is fortunate in possessing an example of each species.

The large proximal ends of the bone in *Enaliornis Barretti* are four in number. Mr. Reed's specimen is the finest. Twelve years since I noticed that it was $1\frac{1}{4}$ inch long, with a subquadrate shaft and strong compressed semiovate patelloid process fully $\frac{3}{8}$ inch high, with flattened subparallel surfaces. Both lateral margins of the patella develop ridges which are directed outwards. The ridge on the fibular side of the bone is the stronger. The shaft terminates upward internal to the patella in a flattened horizontal slightly convex surface wider than deep, though the depth is increased by projecting backward over the posterior face of the shaft. This articulation for the femur is nearly $\frac{1}{2}$ inch wide, but is not so deep on the inner side and is rather narrower towards the fibula; the surface is slightly oblique, sloping from the front backward. In front the shaft is channelled; and posteriorly it is somewhat concave from side to side. It is compressed externally and develops a fibular ridge on the posterior external margin at $\frac{5}{8}$ inch below the femoral articulation. The internal surface of the shaft is flat. The proximal end figured Pl. XXVII. fig. 20 is in the collection of T. Jesson, Esq., F.G.S.

The distal articular end of the right tibia of *Enaliornis Barretti* in the Woodwardian Museum (Pl. XXVI. figs. 24, 25) has the shaft much compressed from back to front, and sharp along the fibular margin. The articulation is $\frac{5}{8}$ inch broad. The (?) tarsal element is as completely ankylosed to the tibia as in most Ornithosaurs and existing birds. The condyles are broad and rounded, the internal one being the larger of the two. The depression between the condyles appears to be less deep than usual. There is a deep channel in front on the fibular side; but it does not appear to have been arched over by a bridge, but was defended by a strong process directed outward from above the inner condyle. This is one of the most distinctive parts of the skeleton of *Enaliornis*.

The tibia of *Enaliornis Sedgwicki*, like all the other bones, is smaller than the tibia of the species just described. The Woodwardian fragment of a right proximal end (figs. 13, 14, 15) is about $1\frac{1}{8}$ inch long. The shaft, where fractured at the commencement of the fibular ridge, is triangular in section, less than $\frac{3}{8}$ inch wide, and more than $\frac{1}{4}$ inch deep on the slightly convex internal aspect. The other surfaces of the shaft appear to be more flattened than in *E. Barretti*, the vertical channel on the anterior surface being conspicuously shallower. The proximal articulation for the femur is subquadrate, more than $\frac{3}{8}$ inch wide, and not quite so deep. The articular surface consists of a flattened internal surface for the condyle, and a mamillate process rising above that level, which extends to the outer margin of the bone, showing that the external condyle of the femur was supported entirely on the fibula. The patelloid process is shaped much as in the other

species, and is $\frac{1}{2}$ inch wide. It is ovately rounded proximally, strong, compressed from front to back, and extends a little outward and forward beyond the shaft, where it terminates in a sharp ridge, which is directed forward and continued a short distance distally down the shaft. On the inner side there is no ridge on the patella; but a sharp angle extends from its base down the shaft.

The distal end of a right tibia of this species in the Woodwardian Museum is well preserved (figs. 16, 17, 18). The shaft is much compressed from front to back, and set on to the small distal articulation so as to be flush with it behind. The shaft measures $\frac{5}{16}$ inch from side to side at about $\frac{5}{8}$ inch from the distal end, and is nearly $\frac{3}{16}$ thick. The distal articulation widens to $\frac{7}{16}$ inch; posteriorly it extends up the shaft for $\frac{3}{8}$ inch, forming a broad shallow channel margined laterally by two strong ridges which are continued round into the condyles (fig. 18), forming their external margins, and defining the lateral regions of the lower part of the shaft. The convex base of the inner side of the shaft is more than $\frac{1}{4}$ inch wide, while the base of the inner side, which is rounded superiorly, is $\frac{3}{16}$ inch wide. The anterior surface (fig. 16) of the shaft consists of an external half, which is deeply excavated, and an internal part which is somewhat thickened, and at its base, just above the middle of the articulation, gave off a slight process which appears to have been directed over the channel. The margins of the articulation are elevated; but the space between them is concave from side to side. The internal condyle is rather the larger of the two.

Fibula. (Pl. XXVI. figs. 26, 27.)

This identification is less evident than are the others. But as no bone of the fore limb, or scapular arch, or sternum, has hitherto been recognized among the bird-remains from the Cambridge Greensand, the only bone left to be identified which could unite to a slender shaft a moderately expanded proximal end, is the fibula. The bone is, relatively to the tibia, much larger than in existing birds; but since Professor Marsh finds this to be a characteristic of the fibula in fossil birds from the American Cretaceous deposits, it is probable that *Enaliornis* had a community of structure with the transatlantic genera in this particular as well as in general affinities. Two specimens have been preserved in the Woodwardian Museum, both probably from the left side. The longest is more than an inch long, is compressed from side to side so as to be four-sided at the distal fracture, where it is $\frac{1}{4}$ inch wide and less than $\frac{3}{16}$ inch thick. Proximally the shaft becomes wider on one of the narrow sides, and compressed on the opposite side, so that in section it is triangular, and wider in both dimensions than lower down. On what I take to be the inner posterior margin is a slight sharp ridge, which may be an indication of the ridge by which, lower down, the fibula united with the tibia. The proximal end is expanded and articular, subtriangular, inclined a little inward, and somewhat rounded superiorly from side to side. It measures $\frac{7}{16}$ inch from back to front, and

$\frac{3}{8}$ inch from within outward on the posterior side, and less on the anterior side.

Proximal end of Metatarsus. (Pl. XXVII. figs. 22, 23.)

Although many examples of the distal end of this bone have been found, I have seen but one specimen of the proximal end. It has been for many years in the Museum of Practical Geology; and I would express my thanks to Professor Huxley for permission to study its characters.

The bone is trifold, having lost the proximal ossifications which are at present usually reckoned as the distal tarsal row. The fragment is $\frac{1}{2}$ inch long, and measures $\frac{1}{2}$ inch in width over the articulation, but is only two thirds as deep. At the fracture distally the diameter of the almond-shaped section is $\frac{3}{8}$ inch.

The middle bone is entirely ankylosed with the other two. All are of equal length. In front the grooves between the bones are not very deep, and seem at the fracture to be disappearing. The bone which is probably external has the outer side flattened and the proximal end twice as long as wide. The middle bone is flattened in front; its proximal end is rather shorter. The third is half a cylinder, compressed a little behind. Its proximal end is put a little behind the other bones; and it extends a little above them.

Distal end of Metatarsus. (Pl. XXVII. figs. 24, 25.)

The distal ends are usually much broken, and rarely show the articulations perfect. Occasionally the want of definition on their articular surfaces may be the result of imperfect ossification. The specimens show some variation in size, probably a specific character; the large one figured is from the collection of T. Jesson, Esq., F.G.S., and may be referred to *Enaliornis Barretti*; while the smaller and less perfect examples at Cambridge seem to have belonged chiefly to *Enaliornis Sedgwicki*. The bone presents a very close resemblance to the metatarsus of the Red-throated Diver, but is larger. The several metatarsal elements in both types occupy the same positions and terminate in similarly grooved pulley-like ends, rounded from front to back.

The fragment is $\frac{1}{16}$ inch long, and is deeply channelled in front between the middle and outer metacarpal elements, as in *Colymbus*; but I have not been able to determine whether the groove in *Enaliornis* is similarly prolonged so as to perforate the metatarsus, or whether a deep cleft renders the perforation unnecessary. The external lateral surface is rather more inflated than in *Colymbus*, rather more enlarged at the distal articular end, and is thrown a little further backward. The two outer bones measure from side to side $\frac{3}{8}$ inch; they are nearly of the same length; but the outer one is slightly the longer: at the fracture proximally the diameter of these elements is less than $\frac{1}{4}$ inch. The middle articulation mea-

tures $\frac{5}{16}$ inch from front to back; and the outer one is nearly as long. The inner articulation is placed about this height above the middle one, and is more compressed from side to side than the others, but measures as much from front to back; it terminates posteriorly in a sharp ridge, which is prolonged up the bone. The inner element of the metatarsus is thrown behind the middle bone, so as to be very imperfectly seen from the front.

So far as I have seen, no digital bones have been collected.

These remains offer evidence of many parts of the skeleton in at least two species of birds, distinguished from each other by size and minor osteological characters: the larger, here named *Enaliornis Barretti*, is indicated by skull, vertebral column, pelvis, and all the larger bones of the hind limb; the smaller species, *Enaliornis Sedgwicki*, is at present only known by its dorsal vertebræ, femur, tibia, and metatarsus.

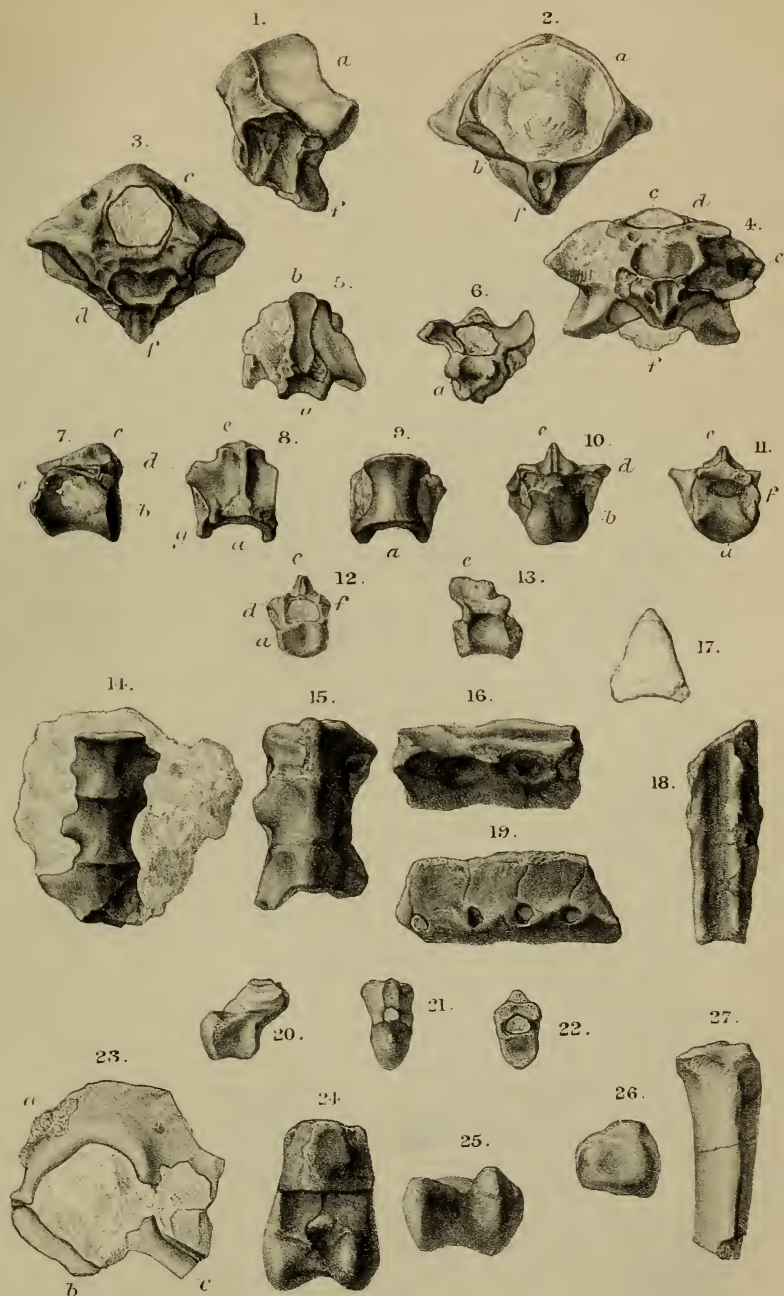
Although some of the bones and parts of the vertebral column in both these species sometimes show evidence of remarkable persistence of cartilaginous conditions of the articulations, especially in the region of the dorsal vertebræ, I do not find this character to suggest that the animals should not, in classification, be placed along with existing Natatorial birds, with which all their other osteological characters closely associate them. Even if these Greensand fossil birds should hereafter prove to have had teeth like *Ichthyornis* and *Hesperornis*, I should be inclined to remember the variableness of dental and other characters in the existing orders of Mammals and Reptiles as a reason for more than hesitation before contemplating the removal of these Cretaceous fossils from the Natatorial section of the class Aves. When the affinities of the fossil type to *Colymbus* are so persistent, both in the English and American genera, the biconcave condition of certain vertebræ seems to be of no more value than the opisthocœlous condition of dorsal vertebræ in the Penguins; and the toothed condition of jaws I should estimate in classification by our knowledge of dental variation observed in the jaws of *Monotremata* and *Edentata*, and conclude that the character is only generic.

Besides thanking the gentlemen whose assistance has been already mentioned, I would express my thanks to Professor T. M'Kenny Hughes, F.G.S., for the kindness with which he has permitted me to make use of the resources of the Woodwardian Museum, and figure the specimens referred to in this and other papers.

EXPLANATION OF THE PLATES.

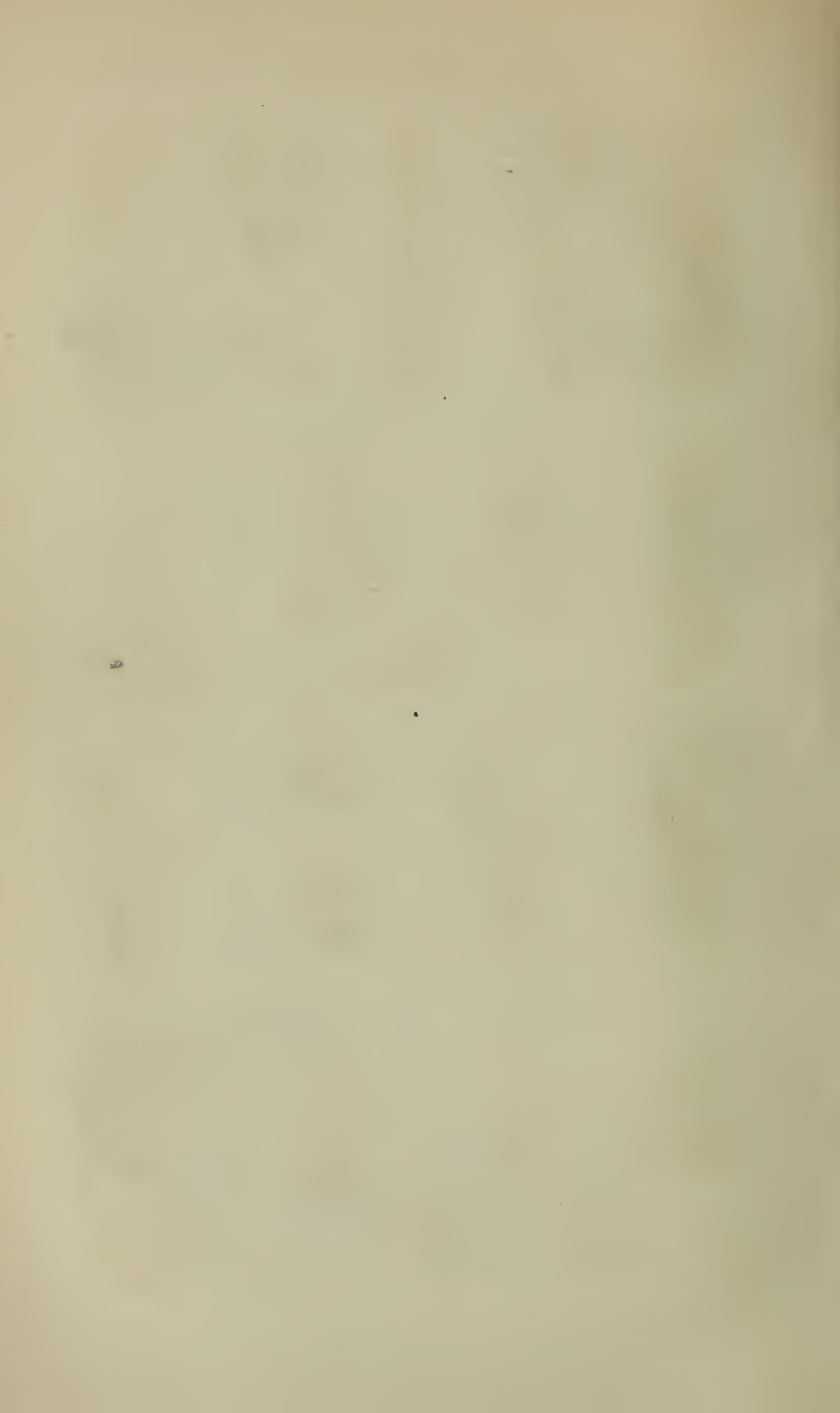
PLATE XXVI.

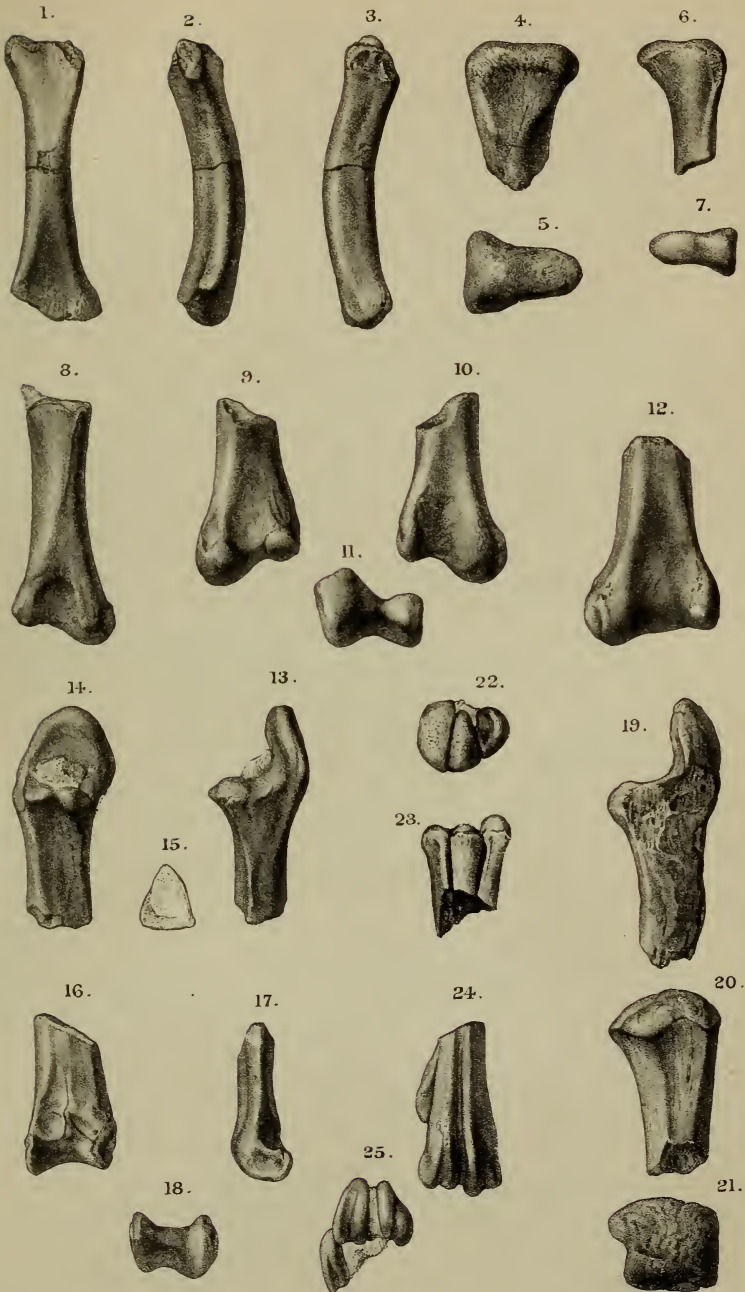
- Fig. 1. Right side of occipital and parietal regions of the cranium of *Enaliornis Barretti* in the Woodwardian Museum.
 2. Anterior view of the same specimen, showing a section of the cerebral cavity.
 3. Posterior view, showing the foramen magnum and occipital bones.



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C.L. Griesbach.

Monaco. P. de S. G.

- Fig. 4. Inferior aspect of occipital and sphenoid bones, showing the anterior divergence of the squamosal bones: *a*, suture between parietal and frontal bones; *b*, brain-cavity; *c*, foramen magnum; *d*, area from which the basitemporal bones have come away; *e*, articulation for the quadrate bone; *f*, basisphenoid.
5. Basal aspect of a cervical vertebra of *Enaliornis Barretti* in the collection of W. Reed, Esq., F.G.S.
 6. Anterior aspect of the same specimen: *a*, anterior articulation; *b*, posterior articulation.
 7. Left side of dorsal vertebra of *Enaliornis Barretti* in the Woodwardian Museum.
 8. Neural aspect of the same specimen.
 9. Visceral aspect.
 10. Posterior aspect.
 11. Anterior aspect: *a*, anterior articular surface; *b*, posterior articular surface; *c*, tubercle for rib; *d*, transverse process; *e*, neural spine; *f*, neural canal; *g*, anterior zygapophysis.
 12. Anterior aspect of dorsal vertebra of *Enaliornis Sedgwicki* in the Woodwardian Museum.
 13. Lateral aspect of the same specimen. Lettering as in previous figure. *a*, the concave anterior face of the centrum.
 14. Visceral aspect of anterior portion of the sacrum of *Enaliornis Barretti* in the Woodwardian Museum, showing the nearly flat anterior articulation of the first vertebra.
 15. Visceral aspect of middle portion of sacrum of *Enaliornis Barretti* in the Woodwardian Museum.
 16. Lateral aspect of the same specimen.
 17. Anterior end of postfemoral portion of sacrum of *Enaliornis Barretti* in the Woodwardian Museum.
 18. Visceral aspect of the same specimen.
 19. Lateral aspect of the same specimen.
 20. ? Caudal vertebra of *Enaliornis Barretti* in the Woodwardian Museum.
 21. Posterior aspect of same specimen.
 22. Anterior aspect of same specimen.
 23. Portion of pelvis around the acetabulum of *Enaliornis Barretti* in the Museum of Practical Geology: *a*, ilium; *b*, pubis; *c*, ischium.
 24. Distal end of right tibia of *Enaliornis Barretti* in the Woodwardian Museum.
 25. Distal view of the articulation of the same specimen.
 26. Proximal view of the articulation of a fibula of *Enaliornis Barretti* in the Woodwardian Museum.
 27. Lateral view of proximal portion of another specimen of the same species in the Woodwardian Museum.

PLATE XXVII.

- Fig. 1. Anterior aspect of a left femur in the collection of T. Jesson, Esq., F.G.S.
2. Inner view of the same specimen.
 3. Outer view of the same specimen.
 4. Proximal end of a femur, probably of *Enaliornis Barretti*, in the Woodwardian Museum.
 5. Proximal articulation of the same specimen.
 6. Proximal end of a small femur, possibly *Enaliornis Sedgwicki*, in the Woodwardian Museum.
 7. Proximal articulation of same specimen.
 8. Anterior view of distal end of left femur of another species of bird in the Woodwardian Museum.
 9. Posterior aspect of distal end of left femur of *Enaliornis Sedgwicki* in the Woodwardian Museum.
 10. Anterior aspect of same specimen.

- Fig. 11. Distal articulation of same specimen.
12. Distal end of right femur of *Enaliornis Barretti* in the Woodwardian Museum.
 13. External view of proximal end of right tibia of *Enaliornis Sedgwicki* in the Woodwardian Museum.
 14. Posterior aspect of same specimen.
 15. Fractured distal end of same specimen.
 16. Distal end of right tibia of *Enaliornis Sedgwicki* in the Woodwardian Museum.
 17. Fibular aspect of same specimen.
 18. Distal articulation of same specimen.
 19. Internal aspect of proximal end of left tibia of *Enaliornis Barretti*. (Distal end, figs. 24 & 25 in previous Plate.)
 20. Proximal end of right tibia of *Enaliornis Barretti*, in which the articular surface has remained cartilaginous, and has not been ankylosed to the patella.
 21. Proximal cartilaginous surface of same specimen.
 22. Proximal end of metatarsus of *Enaliornis Barretti*, seen from above, showing imperfect ossification. In the Museum of Practical Geology.
 23. Anterior aspect of same specimen.
 24. Anterior aspect of distal end of left metatarsus of *Enaliornis Barretti* in the collection of T. Jesson, Esq.
 25. Distal articulation of same specimen, showing the backward position of the articulation for the inner digit.

54. *Some RECENT SECTIONS near NOTTINGHAM.* By the Rev. A. IRVING, B.Sc., B.A., F.G.S. (Read June 21, 1876.)

[Abridged.]

THE author refers to papers on this district previously published*. In his previous paper on the district, reasons had been given for considering the Permian and the Triassic strata to be much more closely related to one another than is generally stated in the text-books, and for questioning the propriety of attempting to draw any hard and fast line of demarcation between the two formations, at least so far as they are represented in the north-eastern area. For further proof of the reasonableness of the position taken by him then, the author of the present paper refers to the careful and accurate paper of Mr. E. Wilson, F.G.S., of Nottingham, whose whole life has been passed in the district, and whose observations may be thoroughly relied upon. The description of the sections described by Mr. Wilson were included in the present paper, but are omitted in this abstract; and the reader is simply referred to the paper at p. 533 of the present Quarterly Journal for an account of a section which must strike every one who examines it as one of the most valuable pieces of evidence yet obtained of the relation that subsists between the Permian and the underlying Coal Measures.

There is an interesting point, however, in connexion with this particular geological horizon, which has not been touched upon by the author of the paper last referred to, and which illustrates the extreme difficulty which must have presented itself to the minds of the Geological-Survey officers in the earlier days of their work, when the extension of railways and coal-mining had not supplied such an ample store of data as we possess at present. Reference is here made to the uppermost strata of the Coal Measures, and particularly to a portion of them consisting of red sandstones and grits, with interbedded shales, known locally to mining-engineers as the "Rotherham Rock." This rock has not been penetrated near Nottingham, as it lies too high in the series to reach so far south as that place, which is probably not far from the southern limits of the synclinal basin in which the Coal Measures lie; but it was pierced in the Shire-Oak Pit, near Worksop. It crops out some miles to the west of that place. Prof. Hull, in the 1873 edition of his work on the Coal-Fields of Great Britain, has included the strata in question among the Upper Coal Measures, thus confirming the judgment of local observers; and on referring to the earliest edition (1852) of the map of the district issued by the Geological Survey, we find it represented there also as a part of the Coal

* 1. Memoirs of the Geological Survey, by Prof. Hull, F.R.S., and Mr. T. Aveling, F.G.S.

2. "Notes on the Geology of the Nottingham District," by A. Irving, F.G.S., Proceedings of the Geologists' Association, January, 1874.

Measures. Yet, strange to say, in a later edition of the same map (1867), the Rotherham Rock is coloured as *Lower Permian*. Of course, if this were rightly so named, there would be no great difficulty in pointing to an instance of close stratigraphical relationship between the Permians and the Coal Measures. But will it hold? Meanwhile, the anomaly which has been referred to is puzzling to students, and tends to destroy their confidence in those whom they ought to be able to look upon as authoritative guides in these matters; and it is to be hoped that another edition of the map may soon appear, by which the doubt may be removed. There will be much good work to be done in the district in the next few years, on account of the rapid development of the coal-field and the local extension of railways. As the railway on which the section above referred to is found proceeds eastward it exposes good sections of the Bunter and Keuper. Between the river Leen and the turnpike road which leads from Nottingham to Mansfield, the cuttings are not deep, and, for a great part of the way, the rock exposed consists of the usual red and mottled soft sandstones of the Lower Bunter. East of the road just mentioned the Pebble-beds of the Middle Bunter are well shown. They partake very much of the nature of those which compose the scarped rock on which Nottingham Castle stands, being massively bedded, of varying hardness (though throughout much harder than the Lower Bunter), whitish, distinctly jointed, the more compact beds forming a true conglomerate with sparsely scattered pebbles, and occasionally loose layers of pebbles between them. Frequent alternations in the force of the currents in the shallow arm of the sea in which these materials were deposited are recorded by the above facts, and by the general prevalence of false-bedding. The last-named character is even more prevalent in the higher strata of the Bunter which are exposed to the east. The characteristic pebble-beds of the Middle Bunter disappear; and in their place one finds a series of thinly laminated, micaceous, whitish, false-bedded sandstones, destitute of pebbles, which may perhaps be regarded as representatives of the "Upper Mottled Sandstones" of the Cheshire area, described by Prof. Hull*.

The junction of the Bunter with the Keuper is not exposed, as it lies in one of the numerous minor valleys of erosion so common in this district. The exposures of the Keuper strata are extensive and interesting, and include almost the whole range (with the exception of a few feet at the base) of the "Waterstones," together with some twenty or thirty feet of red marls above them, which may mark the passage into the Upper Keuper; but the greater part of the latter has, at any rate, been long ago removed by denudation from above. For more than two miles, in the direction of the village of Gedling (which lies in a lateral valley opening into the main valley of the Trent) the Waterstones are exposed, with a gentle easterly dip. There are no indications of faulting, nor contortions of the strata. The beds are a series of alternating red shaly marls and sandstones,

* Hull: 'Permian and Triassic Rocks of the Midland Counties,' one of the Memoirs of the Geological Survey.

the latter varying in thickness from one to four and five feet. One of these, with a colour approximating nearly to white, is characterized by numerous cavities, without any definite form or arrangement, which are probably to be accounted for by the dissolving away of calcareous concretions previously existing in the sandstone, by infiltrations of water charged with carbonic acid. About the middle of the Waterstone Series, the sandstones and shales are replaced by a kind of sandstone, in which the fine siliceous and argillaceous materials are intimately intermingled. At an horizon somewhat lower the sandstones are more purely siliceous, with numerous interstratified bands and thin marl-partings. The surfaces of these have received numerous ripple-marks, rain-pittings, and sun-cracks—many hundreds of truck-loads of such marked slabs having been brought up from the tunnel which penetrates underneath the Mapperley “Plains” to the north-east of Nottingham, at a depth below their highest point of 180 feet.

Though no fault is intersected by the railways, there are nevertheless some rather large ones in the Keuper strata of the district, the result, as I take it, of increased dislocation of the subjacent palæozoic strata in post-Triassic times. One such fault is exposed in the face of the cliff which overhangs the railways at Colwich, and has a throw of not less than 100 feet. On the east side of it are the upper marls of the Upper Keuper, with many bands of gypsum; on the other side of the fault are the sandstones of the Lower Keuper, which exactly correspond with the lower portion of those pierced by the Mapperley Tunnel. As this fault runs north-west, but not precisely in the direction indicated on the Survey-map (the effect of its throw being reversed by a second fault between it and the railway above described), it is exposed in several places. At two points, (1) at Blue-bell Hill, (2) at the top of Red Lane, where this joins the Mapperley Road, the fault forms what must have once been an open gaping fissure: at the first-named place, its width is 11 yards; at the latter, 15 yards. In both instances the fissures are filled with débris of Keuper strata broken up into a confused rubbly mass by drift action.

55. *On the MIOCENE FOSSILS of HAITI.* By R. J. LECHMERE GUPPY, Esq., F.L.S., F.G.S., C.M.Z.S., President of the Scientific Association of Trinidad. (Read May 10, 1876.)

[PLATES XXVIII. & XXIX.]

A VERY important memoir "On the Topography and Geology of Santo Domingo" has recently been published by Professor Gabb*. Whatever tends to elucidate the geology of the island of Haiti must of course contribute to our knowledge of West-Indian and American geology generally, and may also throw further light upon some of the problems connected therewith which have not as yet been solved.

Santo Domingo is a republic occupying two thirds of the Island of Haiti. A very large portion of the territory comprised within its boundaries has been geologically surveyed and mapped out by Prof. Gabb and his assistants. The formations examined by them are classified as Postpliocene, Miocene, and Cretaceous. Eruptive rocks are also developed to a large extent.

It is not my intention to speak of the geological part of Prof. Gabb's labours. That could only be done usefully by those acquainted with the country and conversant with its structure. My present business is with the palæontological portion of the work.

The Geological Society possesses the first regular collection of fossil Tertiary shells and corals made in Haiti, and, indeed, I might almost say, in the West Indies. This collection contains the types of the species described by Sowerby for Mr. Carrick Moore, and by Prof. Duncan. I have from time to time, when treating of the West-Indian Tertiary rocks and fossils, alluded to the fact that several of the species contained in that collection were unnamed.

Most of those species have now been described by Prof. Gabb; but it is to be regretted that his work is not accompanied by figures, so that our determinations may sometimes be open to doubts which the aid of pictorial illustration would enable us to dispel.

In the Proceedings of the Scientific Association of Trinidad for December 1873, I described several new fossils from Jamaica; and deeming it desirable that those fossils should be more widely known than they could be by means of that publication, whose circulation is very limited, I republished the descriptions and figures in the 'Geological Magazine' for September and October 1874, together with a revised list of the organic remains (exclusive of the corals and other fossils) which had been found in the Tertiary deposits of the Caribbean region. This list was a revision of one previously published by me in the Proceedings of the Scientific Association of Trinidad for 1867. The first knowledge I had of Prof. Gabb's work

* Trans. Amer. Phil. Soc. vol. xv. p. 49, with a geological map of Santo Domingo. See also, for the new genera described, Proc. Acad. Nat. Sci. Phil. 1872, p. 270.

was from the January (1875) number of the 'Journal de Conchyliologie,' which, however, I did not receive until some time after the date of its publication. In August last Prof. Gabb did me the kindness to send me a copy of his publications relating to the geology and palæontology of Haiti. I deemed the opportunity a favourable one for reexamining the Haitian fossil mollusca, which had been untouched since 1853. The present communication, which embodies the results of my reexamination, is confined for the most part to such species as I have identified in the collection of the Geological Society, or have noticed in other collections of West-Indian Tertiary fossils.

We have not escaped the tendency, almost inevitable in the case of little-known forms, to describe mere varieties, some more or less permanent, some merely individual, under distinct specific names. Prof. Gabb has done good service by uniting together some of these artificially separated forms; and in this labour he has had the advantage of large suites of specimens collected by himself in Haiti. While contributing my quota towards a reduction of our superfluous nomenclature, I may observe that it is not always a disadvantage in the beginning (particularly when the descriptions are accompanied by good figures) to distinguish the various forms which are mistaken for distinct species. Owing apparently to the great exuberance of Molluscan life in the West-Indian Miocene, much variation occurred, especially in certain genera.

In all the corrections I have ventured on in respect of Prof. Gabb's determinations, I have not acted in any spirit of derogation of his work, which I consider very valuable; and I could congratulate myself if my own had been at all times as well done.

One of the results stated by Mr. Carrick Moore has been brought out more strongly by Prof. Gabb's examination of the Haitian fossils. It is the alliance of the West-Indian Miocene fauna to that of the west coast of South America; and I think now that the conviction can hardly be resisted that during some portion of the Miocene period there was a free communication between the Pacific and the Atlantic. But other alliances point to the west coast of Africa; and there remain other alliances still more close with the Eastern and Indian Seas.

In a letter to me, dated 18th September, 1871, the late Prof. William Stimpson informed me that in the deep-sea explorations off Florida he had discovered shells either identical with or very closely allied to some species of the West-Indian Miocene. Among them he cited *Conus planiliratus*, *Pleurotoma Barretti* (= *Pl. haitensis*), *Phos elegans*, and *Corbula viminea*.

For the sake of conciseness I have, in the following remarks, used the abbreviation G. J. for the Quarterly Journal of the Geological Society.

1. DENTALIUM DISSIMILE, Guppy, G. J. vol. xxii. p. 292, pl. xvii. fig. 4.

I am inclined to believe that Gabb's *D. ponderosum* is a form of

this species having thick walls. Three other species are named by Prof. Gabb; but I cannot refer the specimens in the Geological Society's collection to more than two species, one of which is named below.

2. *DENTALIUM MISSISSIPENSE*, Conrad.

This is very like, if not identical with, *D. Kickxii* of the Belgian Miocene.

3. *BULLA PAUPERCULA*, Sow. G. J. vol. vi. p. 32.

This, and *B. Vendryesiana*, may be regarded as probably marked forms of *B. striata*, Brug.

4. *BULLA GRANOSA*, Sow. G. J. vol. vi. p. 51, pl. x. fig. 10.

5. *VOLVULA CYLINDRICA*, Gabb, Trans. Amer. Phil. Soc. vol. xv. p. 246.

6. *TORNATINA COIX-LACRYMA*, Guppy, Geol. Mag. 1867, p. 500, fig. 3.

T. recta, Gabb, l. c. p. 246 (as of D'Orb.).

The same species occurs in the Miocene of Trinidad and Jamaica. *T. canaliculata*, *T. olivula* and *T. recta*, D'Orb., which may all be synonymous, are nearly related to our fossil.

7. *CYLICHA BIDENTATA*, D'Orb. Moll. Cuba, pl. iv. figs. 13-16.

This is erected into a new genus, *Cylichnella*, by Gabb; but I do not concur in the necessity of that proceeding. An allied but larger species (*C. ovum-lacerti*, Guppy) is found in the Eocene of Trinidad.

8. *TORNATELLA (ACTÆON) CUBENSIS*, Gabb.

This may be identical with the shell I have described as *T. textilis* (Geol. Mag. 1874, p. 407, pl. xvi. fig. 4); but if so, it is distinct from *T. punctata*, D'Orb., as respects the surface ornamentation, which in *T. textilis* has more of a cancellate than a punctate character.

9. *RINGICULA TRIDENTATA*, Guppy, Geol. Mag. 1874, p. 406.

The specimens identified by Gabb as *R. semistriata*, D'Orb., may belong to this species.

10. *TURBONILLA TURRIS*, D'Orb. Moll. Cuba, vol. i. p. 219, pl. xvi. figs. 10-13.

A very variable species, found also in the Miocene of Jamaica and Pliocene of Trinidad. Other forms of the same have been described by D'Orbigny as *modesta*, *ornata*, and *pulchella*; and I believe that *T. dominicensis*, *angusta*, and *pertenuis* of Gabb may be placed in the same category.

11. *NATICA CANRENA*, Linn.

12. *NATICA SULCATA*, Born.

13. *NATICA MAMMILLARIS*, Lam.

Gabb considers *N. subclausa*, Sow., to belong to this species.

14. *NATICA PHASIANELLOIDES*, D'Orb.

Gabb redescribes this species under the name of *Amawa Guppyi*, but does not give his reason for disagreeing with my identification.

15. *SIGARETUS EXCENTRICUS*, n. sp. (Pl. XXIX. fig. 11.)

Shell globose-depressed, adorned with many regular rounded spiral ribs with much narrower threadlike interstices: spire depressed; whorls convex, the last much the largest; aperture oval, somewhat angulated posteriorly.

A more globose shell with much more convex whorls than *S. depressus*, Phil. (= *S. haliotideus*, D'Orb., = *S. Leachii*, Sow., but not the *S. haliotideus* of Linné. See Hanley, Ips. Linn. Conch. p. 390).

16. *TURRITELLA TORNATA*, Guppy, G. J. vol. xxii. p. 580, pl. xxvi. fig. 12.17. *TURRITELLA PLANIGYRATA*, Guppy, Proc. Scient. Assoc. Trinidad, 1867, p. 169; Geol. Mag. 1874, p. 408, pl. xviii. fig. 5.

Gabb has recognized this species among the Haitian fossils; and his remarks upon it are appropriate. The figure in Geol. Mag. shows only the general shape.

18. *VERMETUS PAPULOSUS*, Guppy, G. J. vol. xxii. p. 292, pl. xvii. fig. 3.

Gabb regards this as the end of the tubes of *Petalococonchus*; and in this he may be right, though I do not feel completely satisfied on the point.

19. *PETALOCOCHUS SCULPTURATUS*, Lea; P. DOMINGENSIS, Sow. G. J. vol. vi. p. 51, pl. x. fig. 9.20. *CERITHIUM UNISERIALE*, Sow. G. J. vol. vi. p. 51. (Pl. XXIX. fig. 4.)

This is a remarkable species; and Sowerby's description applies strictly to only one specimen. The species may be distinguished generally by its peculiar ovate shape, also by the ascension of the last whorl, near the aperture, halfway up to the suture, forming a canal upon the body-whorl, between the angle of the aperture and the callus of the inner lip, which terminates in a broad and blunt tooth.

21. *CERITHIUM OBESUM*, Gabb, Trans. Amer. Phil. Soc. vol. xv. p. 237. (Pl. XXIX. fig. 9.)22. *CERITHIUM PLEBEIUM*, Sow. G. J. vol. vi. p. 51; Guppy, G. J. vol. xxii. p. 290, pl. xvi. fig. 9.

Near to *C. (Vertagus) gemmata*, Hinds, Voy. Sulph. pl. x. fig. 56.

23. SOLARIUM QUADRISERIATUM, Sow. G. J. vol. vi. p. 81, pl. x. fig. 8.

The *Torinia rotundata* of Gabb can scarcely be other than a form of this species, differing, it would seem, in the greater elevation of the spire and convexity of the whorls.

24. CANCELLARIA BARRETTI, Guppy, G. J. vol. xxii. p. 289, pl. xvii. fig. 11.

Gabb considers this identical with the recent *C. reticulata*. I am not sure whether it is distinct from the species next named, which Gabb has allowed to stand; but it is a pronounced form whose proportions are more elongate than those of *C. laevescens*.

25. CANCELLARIA LÆVESCENS, Guppy, G. J. vol. xxii. p. 289, pl. xvii. fig. 12.

26. CANCELLARIA MOOREI, Guppy, G. J. vol. xxii. p. 289, pl. xvii. fig. 7.

Gabb includes in his list the names of *C. brevis* and *C. tessellata*, Sow. I am inclined to think that the forms so named by him are young specimens of *C. Moorei* and *C. laevescens* respectively.

The following species appears to me quite distinct. It does not appear to have been mentioned by Gabb.

27. CANCELLARIA EPISTOMIFERA, n. sp. (Pl. XXVIII. fig. 9.)

Shell pyriform, scarcely rimate, adorned with stout spiral ridges having longitudinal ones crossing them and rising into points on the intersections.

Spire acuminate, having seven or eight whorls (of which the nuclear ones are smooth). Aperture oblong, canal short, outer lip sinuous, carrying a spout-like protuberance.

Judging from the sculpture alone, this might be taken for a form of *C. Barrettii* or *C. laevescens*. It is, however, rather more coarsely sculptured than either of those species, in the latter of which the last whorl is smooth, or nearly so. The sinus of the outer lip is carried in a sort of spout, instead of forming a depression as in the outer lip of *C. laevescens*.

Cancellaria scalatella, Guppy (Miocene, Jamaica), does not seem to have been found in Haiti (see Geol. Mag. 1874, p. 408, pl. xvii. fig. 4).

28. ORTHAULAX INORNATA, Gabb. (Pl. XXVIII. fig. 8.)

O. inornatus, Gabb, Proc. Acad. N. S. Phil. 1872, p. 272, pl. ix. f. 3, 4; Trans. Amer. Phil. Soc. vol. xv. p. 234.

To whatever genus this shell may be assigned, I have little doubt of its near alliance to *Rostellaria macroptera*, Lam. (*Strombus amplus*, Brander), of the European Eocene (Sow. Min. Conch. vol. v. p. 177, tab. cxcviii., cxcix., and ccc.). The description of that shell by Sowerby might, with a few alterations, be taken for that of our species, even to the remarks as to the state of preservation of the fossil. The differences appear principally to be that in *O. inornatus* the

spire is usually more concealed, while the wing is not so much extended; the young shells of this species are also much less elongate in their proportions. There may be other differences; but the specimens in the Geological Society's collection do not enable me to speak with certainty of them, as no example is perfect. One (in fragments) attained the dimensions of at least six inches long and four wide.

29. *STROMBUS HAITENSIS*, Sow. G. J. vol. vi. p. 48, pl. ix. fig. 7.

Gabb regards this as being *S. bituberculatus*, Sow.

30. *STROMBUS PROXIMUS*, Sow. G. J. vol. vi. p. 48, pl. ix. fig. 8.

Strombus pugilis, C. Moore.

— *pugiloides*, Guppy.

— *ambiguus*, Sow.

In his synonymy of *S. pugilis*, Gabb includes the following:—*ambiguus*, Sow.; *bifrons*, Sow.; and *pugilis* (= *pugiloides*, Guppy).

Whilst admitting much truth in Gabb's rectification, I cannot go so far as to regard *S. bifrons* as a synonym of either *S. pugilis* or *S. proximus*.

In Geol. Mag. 1874, p. 433, I have given what I consider good reasons for separating the fossils formerly regarded by Mr. Carrick Moore and myself as *S. pugilis* under a distinct name, and I proposed that of *pugiloides*. I am, however, after an examination of the types in the Geological Society's collection, prepared to agree that *S. proximus* and *S. ambiguus* are not separable from the *Strombus pugilis* of Carrick Moore and myself. One of Sowerby's names (being prior) must therefore take the place of my name *pugiloides*; and the name *proximus* may be allowed, to indicate the position of the species so near to the recent *S. pugilis*.

31. *STROMBUS BIFRONS*, Sow. G. J. vol. vi. p. 48, pl. ix. fig. 9.

I prefer to retain this name for the specimens which resemble *Strombus dilatatus* and *columba* more than *pugilis*.

32. *MUREX DOMINGENSIS*, Sow. G. J. vol. vi. p. 49, pl. x. fig. 5.

Gabb notes the relationship of the species to *M. haustellum*. To my eye its nearest kindred is *M. messorius*, Sow., a West-Indian recent species by no means very close to *M. haustellum*.

I cannot decide if *M. antillarum*, Gabb, is distinct from *M. domingensis*, Sow.

33. *MUREX CORNURECTUS*, n. sp. (Pl. XXVIII. fig. 4.)

Ovate-turreted, with three varices, which are nearly continuous, and stout revolving ridges accompanied by finer lines; two or occasionally three variciform tubercles between each varix; varices fringed by subtubular spines, of which the one corresponding to the keel on the angle of the whorls is much the longest. Aperture oval, the inner margin callous, the outer margin dentate, the dentations running in pairs. Canal moderately long and slightly curved.

Nearly related to *M. cornucervi*, Mart. (= *brevifrons* = *M. cal-citrapa* of some authors).

34. MUREX TEXTILIS, Gabb. (Pl. XXIX. fig. 1.)

Murex textilis, Gabb, Trans. Amer. Phil. Soc. vol. xv. p. 202.

This species is a member of the group *Pteronotus*, and is allied to the following species, and more closely to the first named than either of the others:—

M. festivus, Hinds, Voy. Sulph. pl. iii. figs. 13, 14.

M. pinniger, Brod. ; Wood, I. T. Suppl. *Murex* 4.

M. tripterus, Born ; Reeve, C. I. *Murex* 55.

M. macropteron, Desh. ; Reeve, C. I. *Murex* 123.

M. gambiensis, Reeve.

M. cyclopterus, Millet, J. Conch. 1875, p. 147.

Under *M. textilis*, Gabb, I include *M. compactus*, Gabb.

35. TROPHON DOMINICENSIS, Gabb, *l. c.* p. 202.

The description of this species seems not to be inapplicable to *Murex collatus*, Guppy (Geol. Mag. 1874, p. 433, pl. xvi. fig. 8), and may refer to the same species. There is a specimen of *Trophon* in the Society's collection upon which I cannot venture to decide, as it seems different.

36. TYPHIS ALATUS, Sow. G. J. vol. vi. p. 48, pl. x. fig. 4.

I have recorded this species from the Miocene of Jamaica and the Pliocene of Trinidad.

The form described by Gabb as *T. obesus* is represented in the Society's collection ; and I have it also from Jamaica ; it is not specifically distinct from *T. alatus*.

37. RANELLA CRASSA, Dillw. G. J. vol. xxii. pl. xviii. fig. 9.

38. TRITON DOMINGENSIS, Gabb, pl. B. fig. 2.

Triton domingensis, Trans. Amer. Phil. Soc. vol. xv. p. 212.

39. TRITON VARIEGATUS, Lam.

40. TRITON FEMORALIS, Linn.

41. TRITON GEMMATUS, Reeve.

42. PERSONA SIMILLIMA, Sow. G. J. vol. vi. p. 48.

Persona simillima, Guppy, G. J. vol. xxii. pl. xvii. fig. 13.

Gabb remarks on the alliance of this species with *P. constricta* of the west coast of America. It is, however, as near to the recent *Persona reticularis*, Linn., found somewhat rarely in the West Indies, and to *P. clathrata*, a closely related form from the east coast of Africa (Madagascar) and Ceylon.

43. TURBINELLUS (LATIRUS) INFUNDIBULUM, Gmel.

Gabb describes as new species four forms. I entertain doubt whether they are distinct from the above; but want of material prevents me from speaking with certainty.

44. TURBINELLUS ÆDIFICATUS, n. sp. (Pl. XXVIII. fig. 5.)

Shell solid, rimate, very shortly fusiform, spire high, composed of seven or eight whorls adorned with strong longitudinal ribs each terminating on the angle in a subtubular spine, and with numerous close spiral ridges, which are crossed by fine squamose lines of growth. Aperture narrow; inner lip covered with a thick callus bearing about four plaits.

Nearest to *T. capitellum*, Lam. (Kien. Coq. Viv. *Turbinella*, pl. 12). Indian Seas.

This species seems very different from any noticed hitherto. I have endeavoured to identify it with one of Gabb's descriptions, but without success, and therefore assign it provisionally a new name. I am not, however, without a suspicion that the specimens called *Vasum haitense* by Gabb belong to this species, while his *V. tuberculatum* is really the *T. haitensis* of Sowerby.

45. TURBINELLUS VALIDUS, Sow. G. J. vol. vi. p. 50.

Allied to *T. scolymus*.

46. TURBINELLUS OVOIDEUS, Kicher.

47. TURBINELLUS HAITENSIS, Sow. (Pl. XXIX. fig. 3.)

Turbinellus haitensis, Sow. G. J. vol. vi. p. 50.

I think *Vasum tuberculatum*, Gabb, may be referable to this species.

48. FASCIOLARIA SEMISTRIATA, Sow. G. J. vol. vi. p. 49.

Fasciolaria semistriata, Guppy, G. J. vol. xxii. pl. xvi. fig. 12.

I can detect no difference between *F. intermedia* and *F. semistriata*. The papillary apex noticed by Sowerby as a character of the former is, as Gabb remarks, simply the single nuclear whorl. It may have originally existed in the specimens assigned to *F. semistriata*. This species (including *F. intermedia*) is allied to *F. tulipa*. *F. textilis*, Guppy (Geol. Mag. 1874, p. 410, pl. xvi. fig. 5) is nearer to *F. filamentosa*, but is more ovoid in shape, and is, indeed, almost intermediate between the groups designated as *Turbinellus* and *Fasciolaria*, which, together with *Pyrula* (= *Cassidulus* of some authors, but excluding *Ficula*), may in a large sense be considered as subgenera of *Fusus*. Another species of *Fasciolaria* found in the West-Indian Miocene, but not yet recorded from Haiti, is *F. Tarebelliana*, Grat.

49. PYRULA MELONGENA, Linn.

P. consors, Sow. G. J. vol. vi. p. 49.

Gabb considers that *P. patula* is conspecific. I have doubts

whether they ought to be so regarded, though unquestionably nearly allied. A reexamination of the Haitian fossil revealed to me some difference in the surface characters of the Miocene and recent shells.

50. *FUSUS HENEKENI*, Sow. (Pl. XXVIII. figs. 2 & 6.)

Fusus henekeni, Sow. G. J. vol. vi. p. 49.

An examination of Sowerby's *F. haitensis* proves that it is only an individual form of *F. henekeni*. Similar variations occur in the recent analogue of the species, *F. distans*, Lam.

51. *CUMA TECTUM*, Kiener.

This shell is well represented in the Geological Society's collection.

52. *PHOS GUPPYI*, Gabb, *l. c.* p. 212.

Phos erectus, Guppy, Geol. Mag. 1874, p. 410, pl. xvi. fig. 1.

53. *PHOS ELEGANS*, Guppy, G. J. vol. xxii. p. 290, pl. xvi. fig. 13.

Gabb makes this a synonym of *P. veraguensis*, Hinds, which I am not prepared at present to indorse; but I concur with him in regarding *P. Moorei* as a form of *P. elegans*. I should go a step further and unite, under the name of *P. elegans*, the forms described by Gabb as *P. costatus* and *P. semicostatus*. The *Nassa solidula* of the West-Indian Miocene appears to be distinct; but it is not recorded from Haiti.

54. *NASSA INCRASSATA*, Müll.

55. *CLEA TRUNCATA*, Gabb. (Pl. XXIX. fig. 6.)

Etracheliza truncata, Gabb, Proc. Acad. N. S. Phil. 1872, p. 271, pl. ix. fig. 2; Trans. Amer. Phil. Soc. vol. xv. p. 213.

The new genus *Etracheliza*, described by Gabb, appears to me identical with *Clea*, Adams, of which the type *Clea nigricans*, Adams, was figured in Gen. Moll. vol. ii. p. 625, pl. cxxxvii. fig. 8. The two species agree in general form, in the truncation of the apex, and even in the presence of an impressed more or less double spiral line below the suture. The fossil *C. truncata* appears to differ from the recent *C. nigricans* chiefly in the following respects:—The latter has a more vertical aperture, the outer lip not being so prominent anteriorly; and its columella is rather more strongly twisted.

The genus is with little doubt closely related to *Planaxis*, forming one of the links of connexion between *Oliva* and the other members of the Buccinidæ. Another species which may be compared with *Clea truncata* is the *Quoyia decollata* of Gray (Reeve, El. Conch. vol. i. p. 63, pl. iii. fig. 18), which, besides other differences, has a considerably higher spire.

56. *CREPITACELLA CEPULA*, Guppy.

Melanopsis cepula, Guppy, G. J. vol. xxii. p. 580, pl. xxvi. fig. 14.

Crepidacella cepula, Guppy, Geol. Mag. 1867, p. 500.

Dolophanes melanooides, Gabb, Proc. Acad. N. S. Phil. 1872, p. 273, pl. xi. fig. 7; Trans. Amer. Phil. Soc. vol. xv. p. 234.

After a careful examination no doubt remains on my mind of the correctness of the above synonymy, which is suggested by Prof. Gabb himself. The points of difference which he notices are not constant, as I have ascertained by the inspection of a series of specimens from Jamaica.

57. TEREBRA SULCIFERA, Sow. G. J. vol. vi. p. 47. (Pl. XXIX. fig. 8.)

T. bipartita, Sow.

T. inequalis, Sow.

Gabb considers *T. sulcifera* to be identical with *T. robusta*, Hinds. After an examination of the numerous specimens in the Society's collection, I can establish no constant differences between the individuals described under the three above-quoted names by Sowerby.

T. flammea is included by error in our list of West-Indian Miocene fossils.

58. CASSIS SULCIFERA, Sow. G. J. vol. vi. p. 47, pl. x. fig. 1.

59. CASSIS MONILIFERA, Guppy, G. J. vol. xxii. p. 287, pl. xvii. fig. 8.

C. reclusa, Guppy, Geol. Mag. 1874, p. 434.

Gabb identifies this species with *C. granulosa*; and I find a very close resemblance between them. But *C. monilifera* is distinguished by its varices, which, however, are wanting in the form I have called *C. reclusa*; and the latter is moreover devoid of the row of tubercles on the angle. The species is as near to *C. subulosa* (Miocene of Europe) as to *C. granulosa*.

60. CASSIDARIA LÆVIGATA, Sow. G. J. vol. vi. p. 47, pl. x. fig. 2.

Cassidaria sublævigata, Guppy, G. J. vol. xxii. p. 287, pl. xvii. fig. 10.

While agreeing with Gabb that *C. sublævigata*, Guppy, is only a variety, I may mention that it is a distinguishable form. Examples of it were separated in the Geological Society's collection by Mr. Carrick Moore as *C. lævigata*, var.

61. ONISCIA DOMINGENSIS, Sow. G. J. vol. vi. p. 47, pl. x. fig. 3.

62. MALEA CAMURA, Guppy, G. J. vol. xxii. p. 287, pl. xvii. fig. 9.

Gabb regards this as identical with *M. ringens*, Swains. (*latilabris*, Val.).

63. FICULA MISSISSIPIENSIS, Conr. Journ. Phil. Acad. 2nd ser. vol. i. p. 117.

F. carbacea, Guppy, G. J. vol. xxii. p. 580, pl. xxvi. fig. 7.

Found also in the Miocene of Jamaica and Trinidad.

64. COLUMBELLA VENUSTA, Sow. G. J. vol. vi. p. 46, pl. ix. f. 6.

For this species Gabb creates a new genus *Metulella*, in which he includes another shell found by him in the Haitian Miocene and described as *Metulella fusiformis*, Gabb, a figure of which is given by him in Journ. Acad. N. S. Phil. 1872, pl. xi. f. 3.

65. COLUMBELLA GRADATA, Guppy, G. J. vol. xxii. p. 288, pl. xvi. f. 10.

I am inclined, upon a reexamination of the fossils, to consider *C. ambigua*, Guppy, as only a marked variety of *C. gradata*; and I should include under the same name the *Strombina caribæa* of Gabb. The Cumana specimens of *C. gradata* exhibit all the characters ascribed by Gabb to his *S. caribæa*, including the *Ranella*-like flattening, which is less pronounced in the Jamaican examples, and not found at all in the form called *C. ambigua*. I further doubt if *C. inflata*, Gabb, is separable from *C. gradata*.

66. COLUMBELLA HAITENSIS, Sow. G. J. vol. vi. p. 46.

From the description I should suppose that *C. exilis*, Gabb, may be comprised under this name.

67. OLIVA CYLINDRICA, Sow. G. J. vol. vi. p. 45.

I cannot find any sufficient characters upon which to base a separation into distinct species of the Olives found in the West-Indian Miocene. Some of them approach more or less closely to *O. reticularis*; but I am not sure of their specific identity. One of my specimens of *O. cylindrica* from Jamaica is more than $3\frac{1}{2}$ inches long, and has lost about $\frac{1}{2}$ inch of its spire. Gabb names five other species; but I can give no certain opinion as to their validity.

Gabb describes under the name of *Plochelæa crassilabrum* (Proc. Acad. N. S. Phil. 1872, p. 971, pl. xi. f. 5) a form of Olive which I have not met with.

68. ANCILLARIA GLANDIFORMIS, Lam.

I am not certain of the distinctness of my *A. pinguis* (Jamaica) from this species.

69. PLEUROTOMA HAITENSIS, Sow. G. J. vol. vi. p. 50.

P. Barretti, Guppy, G. J. vol. xxii. p. 290, pl. xvii. f. 6.

Gabb considers *P. haitensis* to be the same as *P. virgo*, and includes in the synonymy (besides *P. Barretti*) *P. Jelskii*, Crosse, and *P. antillarum*, Crosse.

70. PLEUROTOMA HENEKENI, Sow. G. J. vol. vi. p. 50, pl. x. f. 6.

P. jaquense, Sow. l. c. p. 51.

I concur with Gabb in the fusion of the above two specific names; and I would add his *P. longicaudata* and *P. humerosa* to the synonymy.

71. *PLEUROTOMA VENUSTA*, Sow. G. J. vol. vi. p. 50, pl. x. f. 7.

My *P. jamaicensis* may possibly be referred to this species as a small and marked variety. The living analogue of this species appears to be *P. gibbosa*, Chemn.

72. *PLEUROTOMA CONSORS*, Sow. G. J. vol. vi. p. 50. (Pl. XXVIII. fig. 7.)

I cannot undertake to say that this is identical with *P. militaris*, Hinds, though Gabb considers it so. The likeness was remarked by Sowerby.

73. *PLEUROTOMA SQUAMOSA*, Gabb, Trans. Amer. Phil. Soc. vol. xv. p. 208. (Pl. XXIX. fig. 7.)

There is one example of this species in the Geological Society's collection. The sculpture is very remarkable. Several other forms of *Pleurotoma* are named by Gabb; but I have seen none which may not be referred to one or other of the above five species, which are well marked and decidedly distinct.

74. *CLAVATULA LABIATA*, Gabb, Trans. Amer. Phil. Soc. vol. xv. p. 209. (Pl. XXVIII. fig. 3.)

Near to *C. imperialis*, Lam. West Africa.

75. *CONUS RECOGNITUS*, Guppy.

C. solidus, Sow. G. J. vol. vi. p. 45; Guppy, G. J. vol. xxii. pl. xvi. fig. 1.

Gabb identifies this with *C. pyriformis*, Reeve. The *C. solidus* of Sowerby (Thes. Conch. 580, = *C. retifer*, Menke) is a different species, very unlike the Haitian shell.

76. *CONUS CONSOBRINUS*, Sow. G. J. vol. vi. p. 45; Guppy, Geol. Mag. 1874, pl. xvii. f. 3.

C. granozonatus, Guppy, G. J. vol. xxii. p. 287, pl. xvi. f. 5.

Prof. Gabb has so conscientiously worked out the Haitian Cones that I accept this rectification, which otherwise would have appeared to me difficult. The figure given by me in the Geological Magazine is fairly representative of the usual form.

77. *CONUS CATENATUS*, Sow. G. J. vol. vi. p. 45, pl. ix. f. 2.

C. interstinctus, Guppy, G. J. vol. xxii. p. 288, pl. xvi. f. 3.

C. stenostoma, Sow. G. J. vol. vi. p. 44; Guppy, G. J. vol. xxii. p. 287, pl. xvi. f. 2.

Gabb records *C. stenostomus* as distinct from *C. catenatus*; but I find great difficulty, on comparison of many specimens, in drawing the line of demarcation.

78. *CONUS GRACILISSIMUS*, Guppy, Geol. Journ. vol. xxii. p. 288, pl. xvi. f. 4.

Gabb refers this to *C. Orbigny*, Audouin (*C. planicostatus*, Sow.). Q. J. G. S. No. 128.

It bears much likeness to a shell recently described by Sowerby as *C. gracilis* (Zool. Proc. 1875, p. 125, pl. xxiv. f. 6).

79. *CONUS MARGINATUS*, Sow. G. J. vol. vi. p. 44. (Pl. XXIX. fig. 5.)

I believe the specimens from Cumana, which I formerly attributed to *C. haitensis*, really belong to *C. marginatus*—a mistake due to want of figures.

80. *CONUS PLANILIRATUS*, Sow. G. J. vol. vi. p. 44.

C. planiliratus, Guppy, G. J. vol. xxii. p. 287, pl. xvi. f. 7.
Gabb identifies this with *C. Stearnsi*, Conrad, Florida.

81. *CONUS HAITENSIS*, Sow. G. J. vol. vi. p. 44.

C. symmetricus, Sow. l. c. p. 44, pl. ix. f. 1.
C. domingensis, Sow. l. c. p. 45.

I adopt the above synonymy from Prof. Gabb. The shell described by me as *C. prototypus* may possibly be the same as *C. strombiformis*, Gabb.

Of the other species of *Conus* enumerated by Prof. Gabb I have no knowledge. All the West-Indian Miocene forms I have seen may be assigned to one or other of the species named above—though, owing to the great range of variation, some difficulty is sure to be felt until the student has obtained a closer acquaintance with these fossils.

82. *MITRA HENEKENI*, Sow. G. J. vol. vi. p. 46, pl. ix. f. 5.

I have recognized no other Mitre than this in the West-Indian Miocene; and I should be inclined to place under it most, if not all, of the forms described by Gabb under different specific names—the only exception being *M. tortuosa*, which Prof. Gabb states to belong to the group *Costellaria*, Swains., and to be akin to *M. semifasciata*, Lam. The *M. varicosa* of Sowerby has not been identified either by Prof. Gabb or myself. It is possible that *M. titan*, Gabb, may be a valid species.

83. *VOLUTA PULCHELLA*, Sow. G. J. vol. vi. p. 46, pl. 9. f. 4.

Gabb is right in considering *V. soror*, Sow., to belong to this species. It has no characters by which even to separate it as a variety. I have not met with *Scapha striata*, Gabb.

84. *MARGINELLA CONIFORMIS*, Sow. G. J. vol. vi. p. 45; Guppy, G. J. vol. xxii. p. 288, pl. xvii. f. 2.

85. *MARGINELLA SOWERBYI*, Gabb, Trans. Amer. Phil. Soc. vol. xv. p. 221. (Pl. XXVIII. fig. 1.)

86. *CYPRÆA HENEKENI*, Sow. G. J. vol. vi. p. 45, pl. ix. fig. 3.

87. *CYPRÆA GABBIANA*, n. sp. (Plate XXIX. fig. 10.)

The cowry for which I propose the above name has hitherto been considered by me to be *C. pustulata*, and has been identified by

Gabb as *C. nucleus*. I think it may be regarded as intermediate between those two species; and it presents, I think, some characters which, combined with its distance in time and space from its nearest congeners, may warrant a provisional specific name:—

Oval-elongate, rostrated at both ends, superiorly covered with large shining tubercles, which are almost circular upon the back, but become elongate and have a tendency to run into ribs near the thickened and regularly grooved lip, whose dentations are continuous with the ribs on the outside. A dorsal groove separates the back into two nearly equal halves.

The tubercles are larger than those of *C. nucleus*.

88. *CALLIOSTOMA CONICUM*, Gabb, *l. c.* p. 243.⁵

I possess a shell from the Miocene of Jamaica which may belong to this species. It differs from Gabb's description in having beaded ribs, of which the one on the angle of the whorls is largest. The shells described by me from the Pliocene of Trinidad under the names *Trochus decipiens* and *plicomphalus* are nearly allied.

A critical examination of the species of this section of *Trochus* found in the West-Indian area is much needed. They are very rare; but a few are occasionally found. The present shell resembles some of the European Miocene forms, e. g. *T. laureatus*, Mayer, and *T. Paulucciæ*, Mayer.

I do not recognize the *Margarita tricarinata* nor the *Adeorbis carinata* among the Haitian fossils. It has occurred to me that one or both of them belong to the species described by me as *Cyclostrema bicarinatum*; but I can speak with no certainty on this point.

89. *PHORUS DELECTUS*, n. sp. (Plate XXVIII. fig. 10.)

Shell conical, umbilicate, whorls sharply angulated below, forming a very concave base, and bearing on the periphery a keel carrying obtuse tubercles. Upper surface covered with close undulated ridges, occasionally dichotomous or anastomosing, and running in a more or less spiral direction, but directed rather towards the outer margin. Base concave, covered with spiral rows of small grains.

I do not feel sure that this is the shell indicated by Prof. Gabb under the name of *Phorus agglutinans*, Lam. It is certainly very different from the Eocene *P. agglutinans*, and it is apparently sufficiently distinct from the living *Phorus* of the West Indies (whose name is properly *P. conchyliophorus*) to deserve a specific appellation.

90. *TEREDO FISTULA*, Lea, ?=*KUPHUS INCRASSATUS*, Gabb.

91. *CORBULA VIMINEA*, Guppy, G. J. vol. xxii. p. 293, pl. xviii. fig. 11.

Bothrocorbula viminea, Gabb, Proc. Acad. N. S. Phil. 1872, p. 274, pl. x. fig. 3.

The new genus *Bothrocorbula* of Gabb is founded upon this species, and may possibly pass as a subgenus or section.

92. CORBULA VIETA, Guppy, G. J. vol. xxii. p. 580, pl. xxvi. fig. 8.

According to Gabb this is *C. disparilis* of D'Orbigny. I am not prepared to assert the specific identity of the recent with the fossil shell, although the latter is found in the Eocene, Miocene, and Pliocene of the West Indies.

Gabb records three other species of *Corbula*, of which one is described as new.

93. NEREA ORNATISSIMA, D'Orb.

It is possible that to this species may be referred the shell formerly regarded by me as *N. costellata*, Desh. Gabb (I think, rightly) regards as synonymous the *N. alternata* of D'Orbigny.

94. TELLINA BIPLICATA, Conrad, Tertiary Fossils, p. 36, pl. xix. fig. 4.

T. Sagre, D'Orb. Pal. Cuba.

Allied to *T. interstitialis*, *T. sobralensis*, and *T. ephippium*.

I have not identified with certainty any of the other *Tellinæ* recorded by Gabb. This one is not mentioned by him.

95. TELLIDORA CRYSTALLINA, Chemn.

This is recorded by Gabb, who identifies a Haitian fossil with the west-coast species of the above name. I mention it only to observe that I have found a shell in the West Indies which is nearly allied, if not identical, presenting some slight though constant differences.

96. LUCINA TIGRINA, Linn.

97. LUCINA PENNSYLVANICA, Linn.

98. CRASSINELLA MARTINICENSIS, D'Orb.

Crassatella martinicensis, D'Orb. Moll. Cuba, vol. ii. p. 288, pl. xxvii. figs. 21-23.

C. guadelupensis, D'Orb., ib. p. 289, pl. xxvii. figs. 24-26.

This species occurs throughout the Miocene and Pliocene beds of the West Indies. I have no doubt of the two forms named by D'Orbigny being referable to one species, which belongs to the genus *Gouldia* of C. B. Adams. The name *Gouldia* having been used for a genus of birds, I proposed in 1874 the name *Crassinella* to replace it for these shells.

99. VENUS PAPHIA, Linn.

100. VENUS BLANDIANA, Guppy, Geol. Mag. 1874, p. 436, pl. xvii. fig. 8.

Allied to *V. rugosa*.

101. VENUS WOODWARDI, Guppy, G. J. vol. xxii. p. 292, pl. xviii. fig. 1.

I think it not improbable that *Chione Guppyana*, Gabb, belongs to this species.

Gabb also records *V. magnifica*, Hanley, the recent analogue of which is an inhabitant of the Philippine Islands.

102. *CYTHEREA JUNCEA*, Guppy, G. J. vol. xxii. p. 582, pl. xxvi. fig. 13.

Closely related to *C. circinata*, with which Gabb considers it identical—a view which I am not prepared to controvert. But should we not add *C. acuticostata* and *Tryoniana* of Gabb, although placed in a different section?

103. *CYTHEREA CARBASEA*, Guppy, G. J. vol. xxii. p. 292, pl. xviii. fig. 13.

104. *CYTHEREA PLANIVIETA*, Guppy, G. J. vol. xxii. p. 292, pl. xviii. fig. 3.

The figure cited is taken from a slightly distorted specimen.

105. *CARDIUM HAITENSE*, Sow. G. J. vol. vi. p. 52, pl. x. fig. 11.

106. *CARDIUM LINGUALEONIS*, Guppy, G. J. vol. xxii. p. 292, pl. xviii. fig. 7.

Gabb regards this as identical with *C. subelongatum*, Sow.

107. *CARDIUM INCONSPICUUM*, Guppy, G. J. vol. xxii. p. 293, pl. xviii. fig. 12.

Gabb describes another species under the name *C. dominicense*; but although he gives it nearly 60 ribs, I am not sure that it is different from *C. inconspicuum*.

108. *ERYCINA TENSA*, Guppy, G. J. vol. xxii. p. 582, pl. xxvi. fig. 6.

This shell was described by me from beds which are now regarded as Eocene. Gabb records it from Haiti.

109. *CARDITA SCABRICOSTATA*, Guppy, G. J. vol. xxii. p. 293, pl. xviii. fig. 10.

110. *CHAMA ARCINELLA*, Lam.

111. *CHAMA INVOLUTA*, Guppy, Geol. Mag. 1874, p. 436, pl. xvii. figs. 5 a, b, c.

Some enormously thickened and heavy examples of *Chama* in the collection appear to me to be very old specimens of this species.

112. *ARCA PATRICIA*, Sow. G. J. vol. vi. p. 52.

Undoubtedly near to *A. grandis*, with which Gabb identifies it.

113. *ARCA CONSOBRINA*, Sow. G. J. vol. vi. p. 52, pl. x. fig. 12.

Gabb states that *A. floridana*, Conr., is a synonym.

114. *ARCA OCCIDENTALIS*, Phil.

A. noæ, Guppy, G. J. vol. xxii. p. 293.

I am not sure that I have the right name of this shell, which is determined by Gabb to be *A. imbricata*, Brug.

Gabb describes three other Arks; and we have also *A. pexata* recorded from the Haitian Miocene.

115. PECTUNCULUS DECUSSATUS, Linn.

This appears to be the prior name of the species formerly recorded by me as *P. pennaceus*, Lam. (Hanley, Ips. Linn. Conch. p. 96).

116. PECTUNCULUS ACUTICOSTATUS, Sow. G. J. vol. vi. p. 53, pl. x. fig. 3.

Of *Leda* and *Nucula* we have several species recorded from the West-Indian Miocene; but I have not recognized any of them among the Haitian fossils.

117. PECTEN THETIDIS, Sow. G. J. vol. vi. p. 52.

118. PECTEN OXYGONUS, Sow. G. J. vol. vi. p. 52.

P. exasperatus, Guppy, G. J. vol. xxii. p. 294.

I agree with Gabb in the above rectification.

119. PECTEN INÆQUALIS, Sow. G. J. vol. vi. p. 52.

Pecten inæqualis, Guppy, G. J. vol. xxii. p. 294, pl. xviii. fig. 6.

120. OSTREA VIRGINICA, Gmel.

121. OSTREA HAITENSIS, Sow. G. J. vol. vi. p. 53.

Gabb has corrected the error into which I fell in regarding this as identical with the preceding.

122. DITRUPA DENTALINUM, Guppy, Geol. Mag. 1874, pl. xvi. fig. 11, and 1875, p. 41.

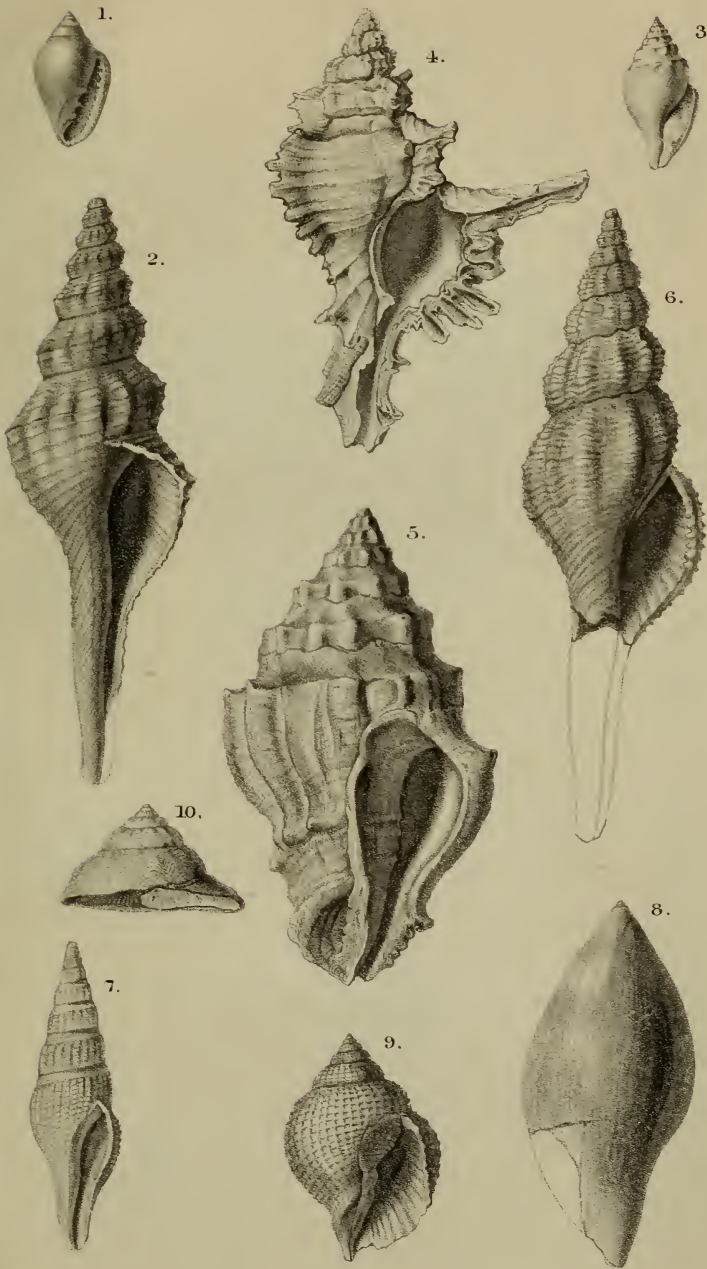
EXPLANATION OF THE PLATES.

PLATE XXVIII.

- | | |
|------------------------------------|-------------------------------|
| Fig. 1. Marginella Sowerbyi. | Fig. 6. Fusus Henekeni, type. |
| 2. Fusus Henekeni, var. haitensis. | 7. Pleurotoma consors. |
| 3. Clavatula labiata. | 8. Orthaulax inornata. |
| 4. Murex cornurectus. | 9. Cancellaria epistomifera. |
| 5. Turbinellus edificatus. | 10. Phorus delectus. |

PLATE XXIX.

- | | |
|---------------------------|------------------------------|
| Fig. 1. Murex textilis. | Fig. 7. Pleurotoma squamosa. |
| 2. Triton domingensis. | 8. Terebra sulcifera. |
| 3. Turbinellus haitensis. | 9. Cerithium obesum. |
| 4. Cerithium uniseriale. | 10. Cypræa Gabbiana. |
| 5. Conus marginatus. | 11. Sigaretus excentricus. |
| 6. Clea truncata. | |

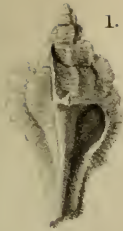


C.L. Griesbach.

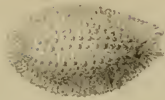
HAITIAN MIOCENE FOSSILS.

Mintern Bros. imp.

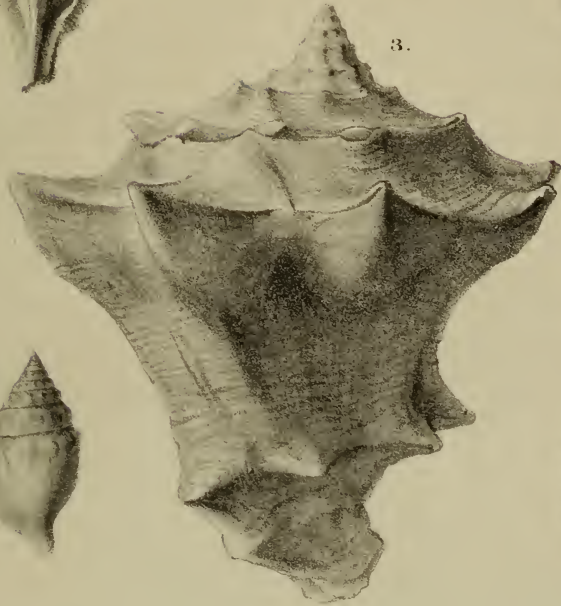
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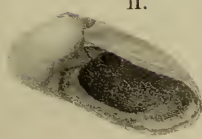
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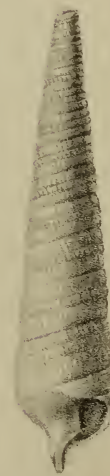
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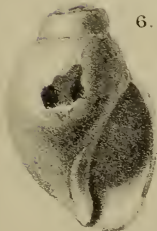
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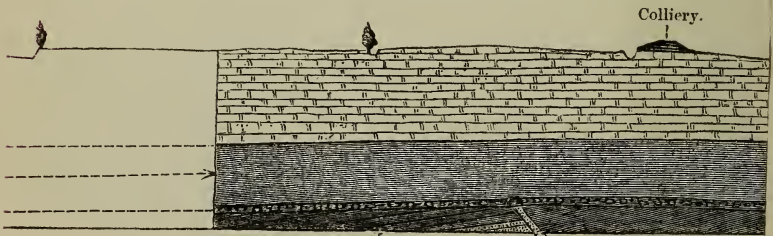
C.L. Griesbach.

Geological Section along the Great Northern R

Hempshill, near Cinderhill.



Hucknall Lane.



Fault,
Pre-Permian.

- d*⁵. Coal-measure
- e*. Permian Bre
- e*¹. Lower Permian
- e*². Magnesian Li

56. *On the PERMIANS of the NORTH-EAST of ENGLAND (at their SOUTHERN MARGIN) and their RELATIONS to the UNDER- and OVERLYING FORMATIONS.* By E. WILSON, Esq., F.G.S. (Read June 21, 1876.)

THE main object of the present communication is to bring under the notice of the Society a capital section (see figure), exposed by the Great Northern Company's Derbyshire Extension line, the peculiar interest of which is that it exhibits the whole series of the Permians of this district, and their relations to the under- and over-lying formations.

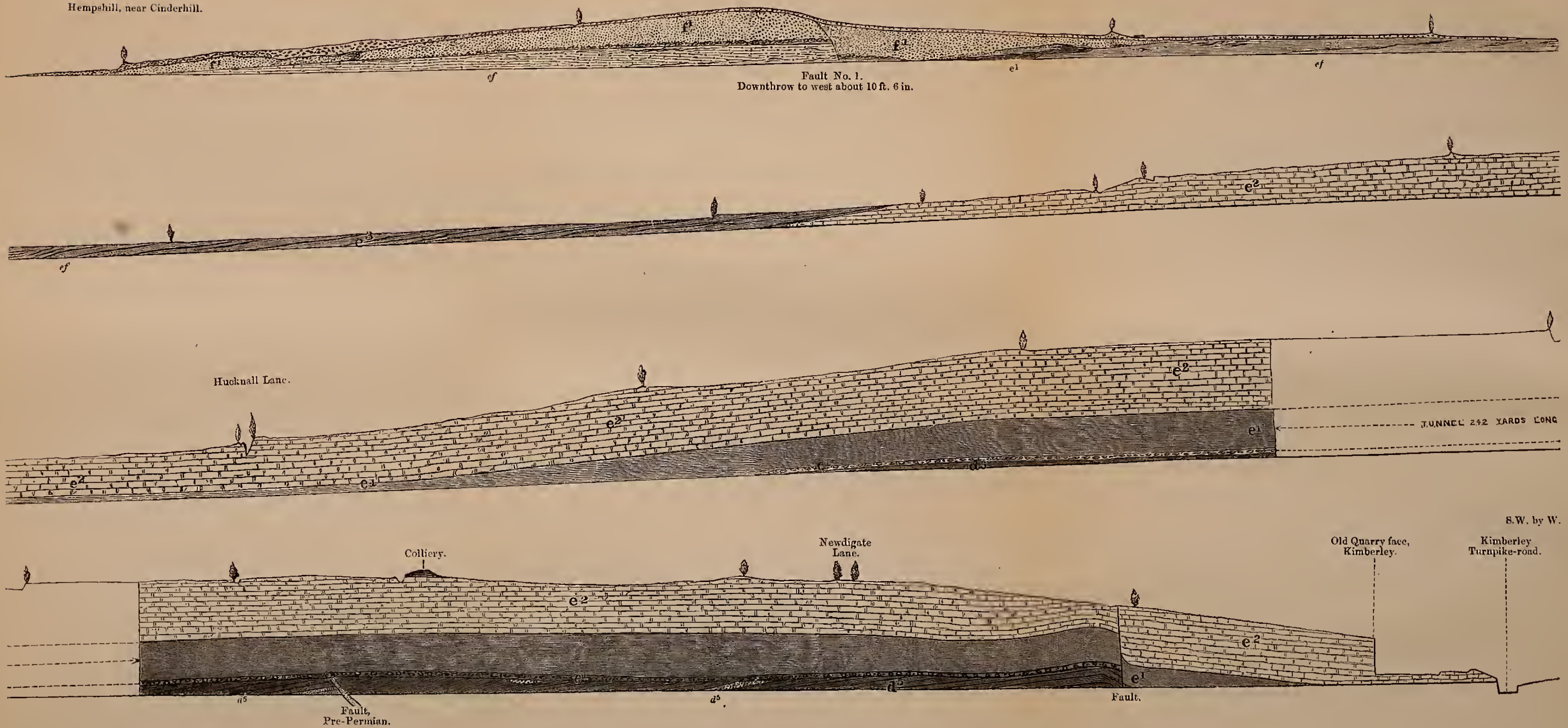
The section begins at the Hempshill cutting near Cinderhill, and ends at Kimberley West station. It bears, roughly speaking, north-west for a mile, and then gradually curves round and bears south-west, and throughout corresponds approximately in direction with the dip of the red rocks exposed.

Going west we get the following succession of strata:—

Characteristic mottled and obliquely laminated *Lower Bunter* sandstone (f^1), about 30 feet exposed, including its lower brecciated portion. The breccia, which is alternately sandy, marly, and calcareous, expands near fault No. 1, to 5 feet, including sandy interstratifications, but locally disappears on the east, where it becomes very difficult to separate the Lower Bunter from the next underlying deposit.

The breccia contains semiangular green, blue, and purple slates, more or less rounded grits, quartzites, quartz-breccia, and numerous white and discoloured slabs and nodular balls of fossiliferous Carboniferous-Limestone chert. Seeing that the yellow chert-balls are the chief centres of cementation, and are deeply indented by the adhering pebbles, it appears probable that their conversion into chert took place after being deposited in the breccia. Beneath the breccia comes a series of *comparatively* hard red-and-yellow-mottled and soft grey sandstones, becoming, after exposure, chocolate-coloured, in beds 1 inch to 1 foot thick, obliquely bedded, and containing lenticular purple *marls*, especially in their lower portions. The Hempshill upcast shaft passed through 39 feet of *strong* red sandstone, nearly all of which must represent these beds. Similar strata were first noticed by myself, several years ago, in Cinderhill brickyard close by, as something different from typical Lower Bunter.

The question arises, what are these beds? Are they Permian? are they Bunter? or are they passage-beds between the two? Little importance need, I think, be attached to the breccia as a line of demarcation, seeing that at Kimberley Knoll, Annesley, and elsewhere precisely similar deposits are met with at higher levels in the Lower Bunter. I would suggest that they form a connecting link between the Permian and Bunter formations of *this district*, and are the lateral equivalents of the lower portion of the Lower Bunter.



*d*⁵. Coal-measure Shales, Sandstones, Ironstones, &c.
e. Permian Breccia.
*e*¹. Lower Permian Sandstones, Sbales, Lignite, Limestones.
*e*². Magnesian Limestone.

*e*³. Upper Permian Marls and Calcareous Sandstones.
ef. Sandstone, hard, dull, laminated, with lenticular marls (passage-beds from Permian to Bunter).
*f*¹. Lower Bunter mottled Sandstone, with breccia at base.

(NB. The base-line is that of the Railway.)

At Bestwood, for instance, they replace all but 8 or 10 feet of that rock.

Then follow ordinary *Upper Permian marls* (e^3) with dolomitic sandstones, &c.; thickness in Hempshill upcast 21 feet. One of these sandstones is literally covered with annelid-tracks.

These are succeeded by *Magnesian Limestone* (e^2), rising west at a small angle, and forming a dip slope; when these beds fall west, near Kimberley, their dip also governs that of the ground: 33 feet are exposed in the vertical, at the east end of the tunnel; and this must be near their maximum hereabouts. I call particular attention to the indications this deposit gives of the proximity of land on the south. It is here (*i. e.* on the Great Northern Railway line) a coarse-grained thin-bedded yellowish and red arenaceous dolomite. At various levels, and sometimes through several feet, it is more or less gritty, and even becomes finely brecciated and conglomeratic. (Similar gritty bands are met with in the new Midland line west of Bulwell, but disappear going north.) There are also partings of highly micaceous laminated soft sand, running to 3 or 4 inches thick, and often at small intervals apart. Oblique lamination on a small scale often occurs. Generally in connexion with the gritty bands, the rock shows numerous cavities and casts of bivalves (*Schizodus* and *Mytilus*) difficult to determine with accuracy.

Further south at Strelley and at Radford Old Engine Houses the dying-out Magnesian Limestone consists of red flagstones, with odd pebbles and red shales. At Wollaton Old Park Farm and at Bobbers Mill (south of Basford) it reposes on the Lower Permian breccia; and at Bobbers Mill I noticed, while the Leen sewerage works were in progress, that in the course of a couple of hundred yards south from the turnpike gate the thinning-out Magnesian Limestone passes from an ordinary granular dolomite through a fine to a coarse brecciated rock, which seems to show that here, at any rate, we have reached a definite point on the original south margin of the Magnesian-Limestone sea.

Succeeding with perfect conformity the Magnesian Limestone, comes a series of *thin-bedded slate-coloured sandstones and shales* (e^1). Inclusive of a breccia at their base, they maintain along the Great-Northern-Railway section a uniform thickness of 19 to 20 feet, which (as shown at a point on the section) comprise no less than 75 different beds $\frac{1}{4}$ " to 8" thick. Several of the sandstones contain a large amount of imperfect plant-remains, woody stems and lignite permeated with iron pyrites; other bands are covered by annelid markings; and at least one sandstone shows casts of *Schizodus*. This series represents the Marl Slate of Durham &c.

These beds, which with the overlying limestone are traversed by numerous vertical joints, become along these, as also along some of the beds, rusted or discoloured light yellow. Supposing the blue colour to be due to finely disseminated carbonaceous matter intermixed with the bisulphide of iron, the discoloration is most probably due to the production of the sulphate and its decomposition into the hydrous peroxide, though the same result may have been

brought about by the peroxidation of the carbonate by carbonic anhydride, or by the conversion of the protoxide into the hydrated peroxide by access of oxygen introduced in water finding its way from above along the joints. In the three lowest feet of these beds are (locally) incorporated three minor brecciated seams. At the base of all comes a breccia varying in texture from a fine siliceous sandstone or grit a few inches thick to a coarse and massive brecciated rock 4 feet thick. Its upper surface frequently exhibits beautiful gently swelling ripple-marks. Its contained fragments are plainly seen to be largely derived from the fine ferruginous red and yellow coal-shales, the sandstones, and ironstones of the neighbourhood; there are also angular or subangular fragments of slate, quartz, quartzite, &c. The fragments are stuck-in confusedly at all angles. The breccia, as also the overlying sandstones and lowest Magnesian Limestones, contain many geodes lined with calc-spar and iron pyrites.

It will be seen that these sandstones, which have a marl-slate facies and horizon, have but locally this character. Going south, in a couple of miles they thin out altogether, and the breccia comes up against the base of the degraded and dying-out Magnesian Limestone; while, on the other hand, as we go north and north-east to Watnall, Bestwood, Linby, Annesley, Kirkby, Skegby, &c., they pass into a series of shales increasing in thickness, with subordinate bands of fine-grained sandstone and compact limestone. These beds, from their close resemblance in colour and texture, have in many instances been taken for coal-measures, and mapped accordingly.

Returning to our main section, we find that the breccia rests in a series of very gentle undulations on a planed-off surface of *coal-measure* shales, sandstones, &c. (*d*³). These latter beds dip in a north-easterly direction, at an angle of fully 15° (but, as the railway section is there running about N.E. by E., the full dip is not exhibited in the face of the cuttings). At one point a fault of unascertained throw crosses the line, affecting coal-measures, but not Permians.

Hence it will be observed that the unconformability between the Coal-measures and the Permian is most pronounced.

This is, I am aware, nothing new: it was a long while ago pointed out by Sedgwick; and colliery observations have rendered it a matter of notoriety in the Derby-Notts-Yorkshire coal-field: but never before has there been in this district such a splendid above-ground verification of the view that an enormous lapse of time intervened between the close of the Coal-Measure and advent of the Permian epoch in England, accompanied by the elevation and folding of the strata, not only along east and west (*e. g.* Pendle and Cheshire anticlinals), but also north and south (*e. g.* Pennine) axes, and by the sketching-out of the great coal-basins by denudation.

The general tendency of the breccia (at base of Permian) to expand westwards, and the occasional presence, according to Sedgwick, of Mountain-Limestone pebbles therein, seem to indicate the existence of a barrier of high ground, and perhaps also the exposure of the

Carboniferous Limestone in that direction during its accumulation* ; but surely the pre-Permian elevation and denudation of the Pennine axis is satisfactorily demonstrated by the above-mentioned overlap of Coal-measures, dipping east at so high an angle, by Permians practically horizontal. The total absence of that very durable rock the Magnesian Limestone at any distance from its escarpment (*e. g.* west of the Erewash) indicates, to my mind, that we have there passed beyond its original margin in that direction, a margin that would probably have been found as on the south, had it not happened to lie in the course of a powerful denudation. The great dissimilarity in mineral character and sequence of the Permian deposits on the west from those on the east of the Pennine axis points to the same general conclusion. It is not without considerable diffidence and reluctance that I venture to differ in any way from so high an authority as Professor Hull ; but, with all due deference, I must say that I cannot help considering the evidence afforded by the Red-Rock and Anticlinal faults near Stockport, and advanced by him in proof of the pre-Permian age of the Pennine axis, to be at best equivocal. For, as I apprehend the matter, we have there two contiguous and parallel faults. One of these, the Red-Rock fault (A), Professor Hull supposes has had two movements, the earlier of which was synchronous with the *only* (local) movement of the other or Anticlinal fault (B); but if so the later throw of A was the greater throw of A ; and yet *that* movement did not affect B in the slightest degree—though, being presumably at that time dislocated, it might be expected that if they ever acted in unison they would do so then. But as they did *not* do so then, their parallelism does not prove that they did so before ; and the old objection still remains that A faults Bunter &c. and B passes under without affecting it. Hence there is no particular reason for believing that the Anticlinal fault, or by consequence the Pennine system to which it belongs, was post-Permian. That there was an old east-and-west barrier, as enunciated by Jukes, and that this barrier divided the Lancastrian and Salopian Permian hydrographical areas, as so ably argued by Hull (*Q. J. G. S.* 1869), I do not doubt—as also that the easterly extension of that barrier may be taken to explain the difference between the Permian deposits of Leicestershire and Notts, and the southerly degradation and attenuation of the latter ; but, so far as I have been able to trace them, I do not find that the Permians of the north-east of England show any tendency to assume a Lancastrian facies going west. There is indeed a change in their character most decided and general ; but that change is a tendency to get thicker and (with local variations) purer going north or north-east, indicating successive increasing subsidences of the Permian north-east basin in such directions. As

* The before-mentioned prevalence of Mountain-Limestone chert in the brecciated Lower Bunter clearly shows that prior to the accumulation thereof the Pennine axis in Derbyshire had not only been formed, but had undergone an enormous amount of denudation.

to the details of this process I hope on a future occasion to be able to give more definite results*.

One word as regards the origin of the lower breccia. This striking rock band (the miners' "mingled" or "plumcake" rock) maintains its average thickness and coarse texture over a considerable area, and must have been simultaneously deposited over several square miles, and in water of variable depth and distance from land. Though no striæ have, I believe, been found, the angularity and confused arrangement of the fragments, the fact that some of the largest have travelled a long distance, the general absence of any attempt at stratification, and the sudden transitions in thickness and texture of the breccia, point possibly to its glacial origin, as droppings, say, from the melting of icebergs or ice-floes. (Occurring, however, along a plane of erosion, no such special theory may seem required to account for its origin.) The same remarks may apply almost equally well to the uppermost or Lower Bunter breccia.

To Richard Johnson, Esq., Engineer to the Great Northern Railway Company, the author desires to express his acknowledgments. The principal section exhibited is founded on the Company's sections he has so liberally supplied; and its completion is due to the facilities given by him for exploring the railway-cuttings from their commencement to their present advanced state.

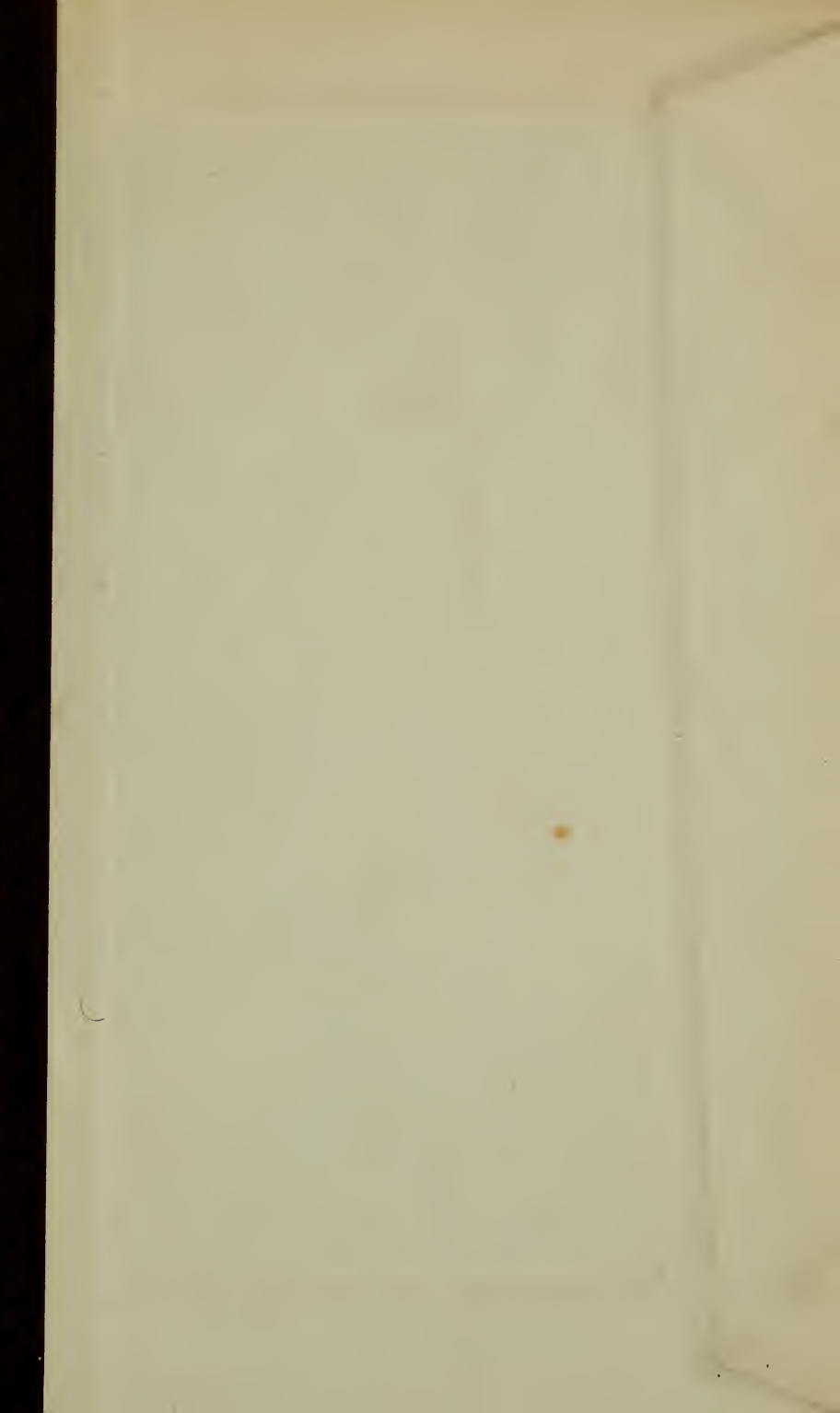
* It will be noticed that along the line of section we have no representative of the Rothliegende. This is only one of many instances in which I have met with proofs of the non-existence of any such formation in Notts or Derbyshire. My limited experience of the so-called Lower Red Sandstone of Durham inclines me to concur with those who would relegate such rocks to the Carboniferous formation, as has been recently done with similar strata in Yorkshire. Hence it appears that the Marl Slate, or in its absence the Lower Magnesian Limestone, forms the true base of the Permian series in the north-east of England.

21 August









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