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THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

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

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CORRIGENDA.

Page 128, line 4 [text] from bottom, *for* "south" *read* "north."

Page 505, line 2 [text] from bottom, *for* "points 3 to 6" *read* "points 4 to 6.'

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1. *On* Dacrytherium ovinum *from the* Isle of Wight *and* Quercy.

By R. Lydekker, Esq., B.A., F.G.S. (Read November 11, 1891.)

[Plate I.]

As far back as 1857 Sir Richard Owen described and figured in this Society's Journal[1] the nearly complete mandible of an Ungulate mammal from the Headon beds (Lower Oligocene) of the Isle of Wight under the name of *Dichobune ovina*. Subsequently it was pointed out by P. Gervais[2] that this species could not belong to the genus *Dichobune* (or *Dichobunus*, as it should be called), but that it was closely allied to *Xiphodon*. At a still later period I myself[3] came to the conclusion that the so-called *Dichobune ovina* should be referred to the genus *Dacrytherium*, established by Dr. H. Filhol[4] on specimens obtained from the Quercy Phosphorites of Central France, and I accordingly adopted for the name of the species *Dacrytherium ovinum*.

With regard to the French specimens on which the genus and species *Dacrytherium Cayluxi* were established by Dr. Filhol, it may be observed that the most important are a cranium and a mandible, which were said to be associated. These specimens were subsequently described in the 'Ann. Sci. Géol.' vol. viii. (1877) pp. 217 *et seq.*, the cranium being represented in pl. xviii. figs. 311–313, and the mandible in pl. x. figs. 254–256. It being assumed that the cranium and mandible were associated, neither was specially distinguished as the type, but since the name *Dacrytherium* was appropriately given from the presence of a large lachrymal fossa in

[1] Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 254, pl. viii.
[2] Zool. et Pal. Françaises, 2nd ed. (1859) p. 159.
[3] Cat. Foss. Mamm. Brit. Mus. pt. ii. (1885) p. 187.
[4] Comptes Rendus, vol. lxxxii. (1876) p. 288.

the cranium, it is manifest that the latter must be regarded as the actual type of the genus and species.

In referring *Dichobune ovina* to *Dacrytherium* I was mainly guided by the character of the cranium, in which one of the most striking features is the great length of the space occupied by the dental series. The mandible referred to *D. Cayluxi* presented, however, several points of difference—more especially as regards the form of the canine—from that of *D. ovinum*, and I accordingly came to the conclusion that there must be two species of the genus.

Thus the matter stood till a few months ago, when Mr. A. Smith Woodward called my attention to a series of specimens from the French Phosphorites which he had brought from the Continent with a view to their being subsequently purchased by the British Museum. Among these specimens was a fairly well preserved cranium of *Dacrytherium Cayluxi*, together with a nearly entire right mandibular ramus said to be associated therewith; both having been obtained from the department of the Lot.

On comparing the cranium with the type-specimen figured by Filhol the specific identity of the two may be inferred from their almost exact similarity, the last five cheek-teeth having a total length of 45 millim. in both specimens. The new specimen is, however, distinguished by the presence of a slight diastema between the small premolariform canine and the first premolar, whereas in the type all the teeth of each side are in contact. Such a variation I can only regard as sexual, since we have fair evidence that more marked variations of a similar nature existed in *Hyopotamus*. The present specimen is broken off in advance of the canine, so that it does not exhibit the most remarkable feature of the genus—viz. the circumstance that the premolariform incisors are continued on in the line of the premolars, so that the first incisors of the two sides are separated from one another by an interval nearly as great as that which divides the premolars of opposite sides.

One feature is exhibited by the present specimen which is not shown in Filhol's figure. In the latter the upper true molars appear to have flattened external surfaces to their outer lobes, like those of typical species of *Anoplotherium*; whereas in reality these surfaces are much incurved and inclined towards the centre of the crown, so that the whole tooth is practically indistinguishable from a molar of *Hyopotamus*. This shows that the upper molars from the Lower Oligocene of Switzerland figured by Pictet[1] as *Hyopotamus Gresslyi*, and subsequently made by myself[2] the type of a distinct species, under the name of *H. Picteti*, really belong to *Dacrytherium* and probably to the Quercy species. One of the upper molars of the specimen under consideration is represented in figs. 1, 1*a* of the accompanying plate.

The lower jaw of the new specimen is represented in the accompanying plate, figs. 2, 2*a*, in which are shown both the outer

[1] Matér. p. la Pal. Suisse, vol. i.—Vert. de la Faune Eocène, Suppl. (1869) pl. xxiv. fig. 5.

[2] Geol. Mag. for 1885, p. 131.

side of the ramus and the oral surface of the teeth. The ramus has lost the summit of the coronoid process and part of the "angle," as well as the extremity of the symphysis. The three true molars, the first three premolars, and the canine are perfect, but the crown of the fourth premolar is broken off, and the incisors are wanting. The jaw agrees in all its proportions with the cranium, this being especially shown by the small premolariform canine, separated by a short interval from the first premolar; so that, altogether apart from the alleged association, I feel no hesitation in referring it to the same species as the cranium. The three remaining premolars are trenchant teeth, the second and third being almost in contact, but the small first one being separated from the second by an interval about the same as that which divides it from the equally small and nearly similar canine.

Compared with the type of *Dichobune ovina*, Pl. I. fig. 3, in which the first and second incisors are wanting on both sides, the present ramus agrees so exactly as not only to confirm my reference of the former to *Dacrytherium*, but likewise to show that both the French and English specimens belong to a single species.

If, however, we compare the mandible represented here with the one figured by Filhol in the 'Ann. Sci. Géol.' vol. viii. pl. x. figs. 254–256, we shall find such marked differences between them as to show that they cannot belong to the same form. Thus in the latter the second and third premolars are larger than in the present specimen, while the canine, instead of being a small, upright, premolariform tooth, is comparatively large, proclivous, and incisor-like; while the incisors themselves are also proclivous. If the length of the dental series in the mandible figured by Filhol be compared with that of the upper dental series, it will be seen at once to be too short, while the proclivous incisor-like canine and incisors are not the sort of teeth, either in place or position, which could be opposed to the corresponding teeth of the upper jaw. I have, therefore, no hesitation in concluding that the mandible figured by Filhol as that of *Dacrytherium* belongs to another form; and consequently that his *D. Cayluxi* is specifically the same as the so-called *Dichobune ovina*. The synonymy of that species will accordingly be as follows, viz.:—

DACRYTHERIUM OVINUM (Owen).

Dichobune ovina, Owen, 1857.
? *Hyopotamus Gresslyi*, Pictet, 1869 (non *Tapinodon Gresslyi*, Meyer).
Dacrytherium Cayluxi, Filhol, 1876.
? *Hyopotamus Picteti*, Lydekker, 1885.
Dacrytherium cayluxense, Lydekker, 1885.
Dacrytherium ovinum, Lydekker, 1885.

This identification of the French with the English species of *Dacrytherium* adds one more to the list of mammals common to the Phosphorites and the Headon beds, and thus tends to confirm the accumulating evidence that the former should be regarded as of Lower Oligocene (Upper Eocene) rather than Middle Oligocene (Lower Miocene) age. It may be added that my suggested identification of *Xiphodon platyceps*[1] with *Dacrytherium* proves to be unfounded, the skull of that species, as pointed out by its describer, clearly having no lachrymal fossa.

In regard to the affinities of *Dacrytherium*, I am still inclined to look upon it as most nearly allied to *Anoplotherium*. The structure of the upper molars connects it, however, rather with *Hyopotamus* than with *Xiphodon*. Moreover, relationship with *Hyopotamus* is suggested by the presence of a descending flange to the angle of the mandible; while in that genus we also find a slight separation of the first upper incisors in the middle line. If, moreover, Dr. M. Schlosser is right in his suggestion that *Dacrytherium* was tetradactylate, we shall have further indications of a certain affinity between this Anoplotherioid and the *Anthracotheriidæ*.

EXPLANATION OF PLATE I.

Figs. 1, 1*a*. Third left upper molar of *Dacrytherium ovinum*, from the Phosphorites. $\frac{1}{1}$ and $\frac{2}{1}$. *pr*, protocone; *pa*, paracone; *me*, metacone; *hy*, hypocone; *pl*, protoconule.

Figs. 2, 2*a*. Outer and oral view of the right ramus of the mandible of ditto; from the Phosphorites. $\frac{1}{1}$. *c*, canine; *p*. 1–4, premolars; *m*. 1–3, molars.

Fig. 3. Oral aspect of the left lower teeth of ditto; from the Isle of Wight. $\frac{1}{1}$.

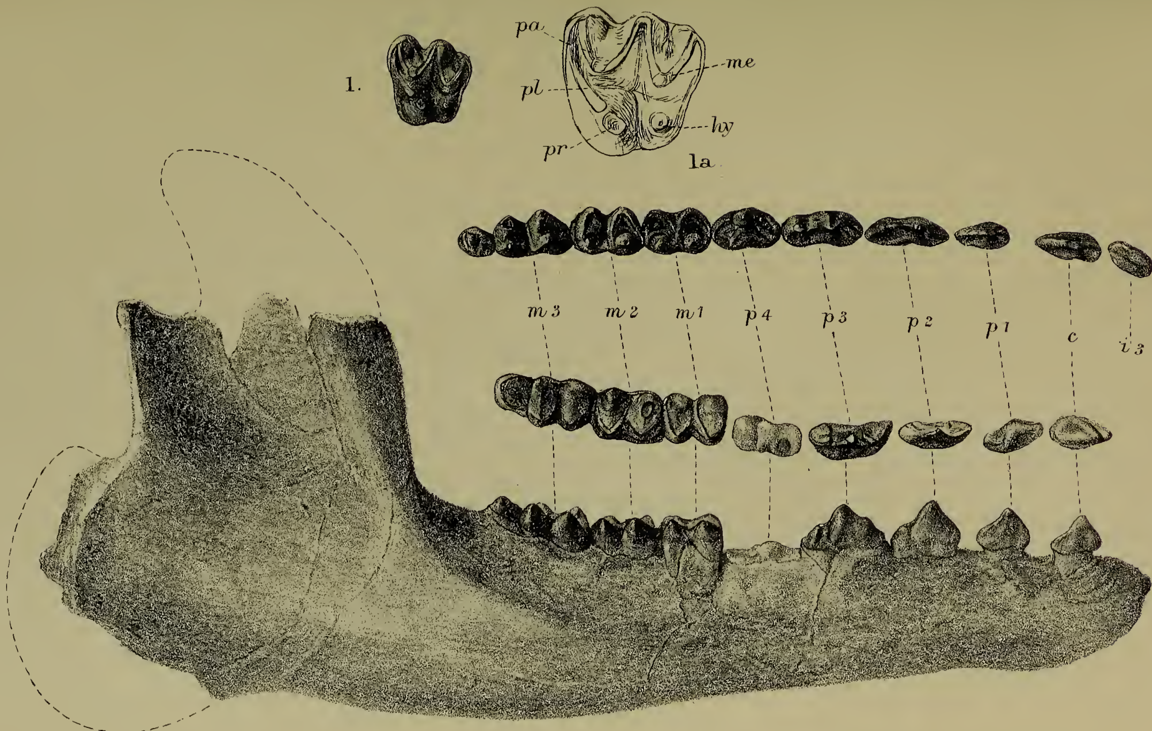
Discussion.

Mr. Charlesworth said that he was wholly unacquainted with the extinct Mammalian genus *Dacrytherium*, but if the now proposed location of *Dichobune ovina* of Owen in the former genus were accepted, this transfer involved the total elimination of the Anoplotherian sub-genus *Dichobune* of Cuvier from the British list, in which it was placed by Sir Richard Owen in the year 1846. It was very much to be regretted that Sir Richard was not present to state his views in regard to the grounds of the proposed transfer, as he had told the speaker twenty years ago that he was then at work upon a new edition of the 'History of British Fossil Mammals,' which edition the speaker feared would hardly now be forthcoming, at least in the life-time of the author. In 1841 Mr. Green, of Bacton, published an account with figures of some Bacton fossil molar teeth, which Sir Richard Owen in the following year, at the Manchester meeting of the British Association, treated of as referable to *Dichobune*. At the conclusion of the meeting Mr. Charlesworth went to Norwich to see the teeth in question, which had passed into the possession of the Norwich Museum; and a re-examination of these teeth proved their supposed Anoplotherian characters to have originated in error. In conclusion, the speaker said that all palæontological history demonstrated the imperative necessity for not accepting finality in the revision of generic identifications until the views advanced by one palæontologist met with confirmation by other workers in the same field of scientific research.

Mr. E. T. Newton felt every confidence in accepting Mr. Lydekker's correction of the synonymy of the forms alluded to in this paper.

[1] Flower, Proc. Zool. Soc. 1876, p. 3, pl. i.

Quart. Journ. Geol. Soc. Vol. XLVIII. Pl. I.



R. Mintern del. et lith.

Mintern Bros. imp.

TEETH & JAW OF DACRYTHERIUM.

Haring p. 4

2. Supplementary Remarks on Glen Roy. By T. F. Jamieson, Esq., F.G.S. (Read November 11, 1891.)

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I. Conditions that preceded the formation of the Glen Roy Lake—the Western Ice.

In order to have a right conception of the manner in which the Glen Roy Lake originated it is necessary to have some knowledge of the state of matters that preceded it. During the Glacial period the ice upon the West side of Scotland seems to have been vastly thicker than it was on the East, owing no doubt to the snowfall having been much heavier in the former district, just as is now the case with the rainfall there. The amount of rain in the West Highlands is twice or three times what it is on the East coast. This is due not so much to the greater height of the hills as to the fact that the clouds of vapour coming from the Atlantic have most of their moisture condensed there.[1] It is there that the wet sponge is first squeezed. The rain-gauge on the top of Ben Nevis has yielded no less than 145 inches of water in the course of a single year, whereas at Laggan, in the upper part of Strath Spey, the average is 46, and on the shores of the Moray Firth only from 25 to 30 inches. It is also important to observe that it is *during winter* that the greatest precipitation takes place. In some seasons as much falls on Ben Nevis in the month of December alone as there does near Inverness in the course of a whole year.

We shall probably not be far wrong in assuming that during the Glacial period most snow fell in Scotland where there is now most rain, and if we consult the valuable maps which we owe to Mr. Symons and Mr. Buchan we shall see that the wettest part of the country lies along the region which extends from the mouth of the Clyde to the Isle of Skye, passing right across the entrance to

[1] Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 334.

RAIN-MAP OF SCOTLAND.

(*Adapted from Buchan.*)

EXPLANATION:

. . . . 25 to 40 Inches

. . . . 40 to 80 "

. . . . 80 Inches & Upwards.

the Great Glen of the Caledonian Canal where Ben Nevis is situated. Here then would be the heaviest falls of snow, and as snow is the mother of glaciers here also would be the heaviest ice. Accordingly, we find ample evidence that all along the West coast from Argyll to Cape Wrath the accumulation was enormous. A line drawn from Ben Nevis past the Moor of Rannoch to the head of Loch Lomond marks the centre of what seems to have been the greatest ice-field in Scotland. Another line drawn from the top of Glen Arkaig northward to Loch Shin indicates the middle of the ice-field which was probably next in importance. The outward movement of the ice, as deduced from the glaciation of the rocks and transport of boulders, seems to have proceeded from these two lines; we may therefore conclude with considerable confidence that the greatest precipitation of snow took place there, and it is interesting to note that this coincides very well with what is now the region of greatest rain. Seeing that these two ice-fields met and coalesced at the western entrance of the Caledonian Canal, it is evident there must have been a great congestion in that quarter, for here was a narrow passage with heavy streams of ice coming into it from the glens on both sides all the way down to the head of Loch Linnhe. The quantity of ice that filled the Great Glen and the mouth of Glen Spean was so great that it eventually overflowed the passes leading eastward into the valleys of the Nairn and the Spey, notwithstanding that many of these passes are actually higher than those to the westward which lead out to the Atlantic. This western ice broke over Strath Errick in great force; it filled Glen Gluoy and flowed out at the top of it; it likewise occupied Glen Roy, and went out to the eastward over the pass at the head of that glen. It also did the same at Makoul in Glen Spean, so that before the era of the lakes the western ice discharged itself over the very same *cols* over which the water flowed at an after period. Some evidence of this was given in my paper on the glaciation of Scotland, to which I would here refer.

It is necessary to have a clear perception of this important feature in the glaciation of Scotland, namely the much deeper accumulation of ice on the West, otherwise it is quite impossible to understand many of the results to which it gave rise. For example, it has often been asked, with some degree of perplexity, how it could be that Glen Roy and other glens to the eastward were empty of ice while glaciers of such magnitude occupied Glen Treig and the valley of the Caledonian Canal. "Is it likely," asks Mr. Milne-Home, "that in this Lochaber district some glens should have been filled with solid ice and others with water?" "Why," says Prestwich, "should the Arkaig hills have their huge glacier and the neighbouring range north of the Spean, at the same time, none?"[1]

Looking merely at the comparative height of the hills, these objections seem perfectly reasonable, but the paradox is solved when we consider the comparative rainfall and reflect what would

[1] Phil. Trans. Roy. Soc. for 1879, vol. clxx. p. 676.

ensue during a Glacial period when that fall took the shape of snow. For, with regard to snow, there is an important circumstance to be kept in view, the full result of which is apt to be lost sight of. Rain runs off as it falls, and there is no storage from year to year; with snow the case is very different. Take two adjoining districts where the snowfall is as two to one. Say that in the course of a year twenty measures of snow fall on A and only ten on B, and that the loss by melting and evaporation amounts to eight measures in each of them. The result is that on B two measures of snow remain for conversion into ice, and on A twelve; so that although the fall is only as 2 to 1 the growth of ice will be as 6 to 1. Let this process go on, not for one year but for a thousand or many thousand years, and it is easy to see how the ice will grow upon the one and gain upon the other. Put A for the West Highlands and B for the East, and this will help to show how it came to pass that there was such an excess of ice on the former. It was the cumulative effect of this storage of the surplus continuing throughout so many ages that gave rise to such strange results, not only in Scotland, but also in Ireland, Scandinavia, and North America. The mass of ice lying over Argyllshire and the West Highlands being immensely thick must of necessity have lingered on for a very long time after the thinner ice to the north-east had melted away, and as this region of thick ice lay right across the mouth of the glens where the Lochaber lakes were situated, it explains in a consistent and reasonable manner that very remarkable circumstance which has appeared so inexplicable to Prestwich, Milne-Home, and many other observers.

II. Level of the Snow-line.

Prof. Prestwich, however, finds a serious objection to this view of the matter on account of "the excessive inequality in the level of the snow-line in closely adjacent districts which it would necessitate."[1]

But the level of the snow-line is a different question altogether, and is regulated chiefly by the summer heat. An excessive quantity of snow would, I imagine, discharge itself below the level of the line as a glacier. Where there was much snow there would be a big glacier; where there was less there would be a smaller one, and where there was little snow there would be none at all; yet the general level of the snow-line might be comparatively regular all along. Permanent snow when it accumulates thickly passes into the form of ice, and this glacier-ice does not conform to the level of the snow-line, but may descend far below it. In West Greenland, where the glaciers come down into Baffin's Bay, the level of the snow-line is more than 2,000 or even 2,500 feet above the sea; but we must not exaggerate its regularity, for Mr. Helland[2] tells us that patches of snow occur here and there far below

[1] *Op. cit.* p. 674.
[2] Quart. Journ. Geol. Soc. vol. xxxiii. (1877) p. 153.

it, down in some places near to the shore, even in August. If three times as much rain falls on Ben Nevis as there does at Laggan, there is surely nothing unreasonable in assuming that the fall of snow would have been in somewhat similar proportion. At all events I must demur to the position that this assumption is not to be made lest we offend the susceptibilities of the snow-line. When the glacial covering was in a state of full growth the whole district may have been above the snow-line, but when it was in a state of decay (as it evidently was at the time of the lakes) the snow-line would have risen very considerably.

III. Lake formed during the decay of the last Ice-sheet.

The state of preservation of the Parallel Roads is such that it is quite clear no glaciers can have gone over them. We must therefore assign their origin to a comparatively late stage of the Glacial period. In another paper [1] I have endeavoured to show that a great development of ice took place in Scotland after the formation of those marine beds along the east coast which contain Arctic shells. This last phase of the period was no time of mere local glaciers issuing from a few of the higher mountains, but the return of severe glacial conditions which spread over the whole country; and it was during the decay of this last mantle of ice that I believe the Parallel Roads were formed. I am therefore unable to agree with Prof. Prestwich when he assigns them to "a phase of the early or first Glacial period." [2]

Evidently the thinner ice away to the north-east must have gone off first, and that part of Scotland which lies between the Moray Firth and the Firth of Forth, round by Aberdeenshire, seems to have become clear a long time before the thicker ice gave way in the western glens. It was this that gave rise to the glacial lakes of Lochaber.

The same or a very similar idea has been well expressed by a Norwegian geologist, Andr. M. Hansen,[3] who applies it not only to the explanation of certain high-lying terraces in Scandinavia, but makes special reference to the Glen Roy problem. He insists that it was the great decaying mass of what he calls the "inland ice," and no local glaciers, that constituted the barriers of the lakes.

IV. End of the two Upper Lines in the Ordnance Map: Explanation simplified.

At the time I wrote my previous paper on Glen Roy there was considerable uncertainty as to where the lines finally terminate.

[1] 'On the last stage of the Glacial period in North Britain,' Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 317.

[2] Phil. Trans. Roy. Soc. for 1879, vol. clxx. p. 677.

[3] 'Om seter eller strandlinjer i store hvider over havet,' Archiv for Math. og Naturvidensk. Christiania, 1885. See also letter in 'Nature,' January 21, 1886, p. 268.

The Ordnance Survey had not then extended to the district, and no good map existed to show the topographical features with accuracy. Agassiz insisted that all the three Glen Roy lines were marked on a certain part of the south side of Glen Spean. "These three terraces," he says, "though in a less perfect state of preservation, are repeated for a short distance at exactly the same level on the southern wall of the valley of Glen Spean, just opposite the opening of Glen Roy."[1] This, however, appears to be a mistake. At least I could find no trace of the two upper lines in any part of Glen Spean, neither have the Ordnance Surveyors or any other person been able to discover them, and I suggested that during the period to which they belong all the lower part of Glen Spean might have been filled with ice, and hence the absence of the two upper lines there. I thought, however, I could perceive a faint trace of the uppermost line in Glen Glaster, even when checking my observation by the spirit-level; but the Ordnance map makes it stop just above the mouth of that ravine and not enter it at all. Nevertheless Mr. Milne-Home[2] in his last paper maintains that it does occur there, so that the matter is not altogether free from doubt. If it does, it is at all events very obscurely marked. Although this may be thought rather a matter of minor detail, yet the point is one of some importance in the explanation of the phenomena, and a good deal turns upon it, because if the water had stood for any length of time in Glen Glaster at the level of this uppermost line we would require to have something blocking the *col* at the top, otherwise the water would have escaped over it, and could never have stood above the level of the middle line which corresponds with the Glen Glaster *col.* In my former paper I assumed that such a block was necessary, and showed that it could be accounted for by the Treig glacier, which during a certain stage of its existence protruded right across Glen Spean and rose to a great height upon the hills on the opposite side of the valley, thus barring the passage to the eastward. But if it turns out that the highest line is really quite absent in Glen Glaster, then this blocking of its *col* is not required. Depending on the accuracy of the Ordnance Survey I shall assume such to be the case. I shall also assume that the middle line does not extend farther down Glen Roy than where the Ordnance map shows it, namely opposite the middle of Bohuntine, and consequently that Agassiz was wrong in supposing that the two upper lines go down to Glen Spean. These assumptions relieve us of certain difficulties and enable us to simplify the explanation, as we shall afterwards see.

I have already mentioned that the era of the lakes must belong to the decay of the last sheet of ice if there was more than one. A change of climate was taking place, the long secular winter had begun to pass away, and when the thaw set in the thinner ice away to the north-east would of course disappear first. The *col* or water-

[1] 'Atlantic Monthly' for June, 1864, p. 730. See also the map in his original paper in the Edin. New Phil. Journ., October, 1842, p. 237.

[2] Trans. Roy. Soc. Edin. vol. xxviii. (1879) p. 97.

shed at the head of the Spey became sufficiently open to admit of water passing out, and as soon as the ice melted out of the top of Glen Roy a lake would take its place, discharging itself over this *col.* Such a lake at first might be superficial—that is to say, resting on the surface of the decaying glacier. Gradually the ice receded farther and farther down Glen Roy and became reduced in height, but the surface of the lake being determined by its outlet would stand at the uppermost line until the icy barrier melted back as far as the mouth of Glen Glaster. As soon as the water gained admission to this side glen it would escape over the *col* at the head of it (if there was no obstruction in the way), and as that *col* is 80 feet below the one at Lochan Spey, the lake would then sink to the level of the middle line which corresponds with the Glen Glaster *col.* There it stood for a time until the ice which yet occupied the lower end of Glen Roy shrank back still farther—far enough to allow of the water communicating with Glen Spean, which it would probably do first over the hollow between Meal Derry and Craig Dhu, near Bohinia. When this event happened the lake would spread into Glen Spean and, if there was no obstruction to the eastward, would drop to the level of the lowest line which corresponds with the escapement at Makoul. Such I think is the most probable explanation, if it be the fact that the two upper lines finally cease at the places shown on the Ordnance map. Dr. Tyndall also took much the same view of the matter in his lecture at the Royal Institution[1], in which he likewise enforced with his usual power of illustration the effect due to the position of Ben Nevis and the western mountains on the vapour-laden winds of the Atlantic.

V. The Alluvium at Bohuntine explained.

Where these two upper lines cease Glen Roy is very narrow, and at this part of it there is a remarkable accumulation of détritus, which commences rather suddenly just near the Gap at the hill of Bohuntine. It is thickest near the Gap, the quantity between that and the mouth of Glen Glaster being greater than it is farther down the valley. This stuff consists of sand, muddy gravel, and silt with a few stones, but there is rather an absence of large boulders. Much of it is well stratified and some of it even finely laminated. Both its nature and the stratified mode of its arrangement show that it has been deposited in water. Now, where did all this stuff come from, and how did it lodge so thickly just here, right opposite the north end of Bohuntine where the two upper lines stop? There are no streams joining the glen between the Gap and Glen Glaster to have brought it in, and that is just the place where it is thickest. Above the Gap, Glen Roy is comparatively empty of détritus until we come to the junction of the Turret. My notion is that this mass of détritus consists of the gravel and mud that fell into the lake from the front of the glacier,

[1] Proc. Roy. Instit. vol. viii. (1876) p. 233.

when it stood across the mouth of Glen Roy during the time of the two upper lines. Here it made a pause, and that accounts for the presence of such a heap of débris at this particular spot, for the laminated character of part of the materials, and also for the rudely stratified arrangement of the whole. It appears to have filled all the bottom of the glen, reaching near the Gap almost up to the height of the lowest line, but has been cut through afterwards by the retiring water. This mass of débris attracted the attention of MacCulloch and other observers; it is particularly noticed also by Prestwich, but so far as I am aware no one has given the foregoing explanation of it. Its existence seems to me to form a most interesting link in the chain of evidence for the glacial theory of the lakes, for it is in complete harmony with that theory and with no other. It also shows, in opposition to the opinion of Prestwich, that the lake must have existed for a considerable length of time.

At the top of Glen Collarig there is a large accumulation of a somewhat similar nature, at the corresponding place where the two upper lines terminate there; in fact the Gap between the hills may be said to be partly filled by it; and it reaches up to even a greater height there than it does in Glen Roy, extending above the level of the lowest line. It is also of a more morainic character, with a larger number of boulders, some of them of fairly considerable size and composed of grey granite, others of gneiss containing traces of a greenish material. These stones should be carefully examined in order to trace where they have come from. I found granite boulders also on the hill of Bohuntine up to the very top.

From the fact that the two upper lines come farthest down Glen Roy on its eastern side, I would infer that the ice-dam was weakest upon that side, and that it gave way there before it did in Glen Collarig. The termination of the middle line on the west side of Glen Collarig is very remarkable: the terrace runs along the side of the hill and stops all at once as if it had been cut away, leaving a projecting mound truncated at its southern end.

VI. The Ice-dam at the mouth of Glen Spean.

During the last stage of the lake the ice-dam retreated gradually from the entrance of Glen Roy until it finally stood across the mouth of Glen Spean from Tiendrish to Corrychoille. The glaciers of Glen Treig, Corry Laire, the Larig Leachach, &c., which formerly all came down and helped to swell the mass of ice in the lower part of Glen Spean, now shrank each of them into the mouth of its own ravine. The Corry N'Eoin glacier, however, seems to have still protruded some distance out, but eventually the water appears to have come close up to its eastern flank, for the lowest Parallel Road is distinctly marked on to Corry Mhaddie, and I thought I could see a small patch of it even on the spur of the hill which separates that ravine from Corry N'Eoin. Here, therefore, we may suppose the lake to have ended, and at its last stage the Corry N'Eoin glacier seems to have gone not very far out, otherwise its right flank would have spread eastward some distance beyond the point where the Parallel Road finally stops. This shows that, although the Corry N'Eoin glacier cut off the western extension of the lake at this side of Glen Spean, it nevertheless played but a very subordinate part in the formation of the ice-dam at its final stage. It was the heavy bed of ice in the valley of the Caledonian Canal that seems to have constituted the main barrier. This ice probably filled the whole valley from Loch Ness down to Corran Ferry, being powerfully reinforced on its eastern side by the glaciers descending from the ravines of Ben Nevis. The lake was nearly four miles broad where the ice-dam stood across it at the mouth of Glen Spean; and in the centre of the valley the water must have been some hundreds of feet in depth. This shows what a powerful barrier was required, and gives an excellent idea of the mass of ice that still lay over the Western Glens, and how slowly it melted away. One of the heaviest beds of all was probably in Glen Arkaig, a glen which has a very capacious basin situated in the region of maximum precipitation.

VII. Subsidence of the Lake: traces of a débâcle.

A question of some interest arises in connexion with these lakes, namely, did the ice-dam give way suddenly, causing a débâcle, or did the water drain off quietly by finding an escape underneath the glacier? Both methods are known to occur in the case of glacier-lakes in the Alps and Himalayas.

When the water dropped 80 feet from the higher to the middle parallel in Glen Roy there was probably a rush into Glen Glaster —a very heavy rush if the drop was at all sudden. The water thus let off would first flood Glen Glaster and then come pouring over its *col* down the hollow at the back of Craig Dhu into the Rough Burn. As in some places there are traces of intermediate shelves between the two upper 'roads,' it is probable that this drop did not take place all at once. Now, at the mouth of the Rough Burn and to the east of it I fancied that I saw some traces of a débâcle. The moraines of the Treig glacier have been broken down and scattered; clusters of great stones are to be seen on the east or lee sides of the granite rocks, looking as if they had been thrown together by a powerful gush of water, being better packed than is usually the case in a moraine, and with the sandy matter washed out of them. Heaps of these big stones may be noticed near the $7\frac{3}{4}$ milestone from Roy Bridge, and also on the moor along the opposite bank of the Spean. The large gap in the lines of moraine, where they should have crossed the Spean near Gorstan, may therefore have been caused in some measure by the rush of water which took place when the lake subsided from the highest to the middle line, or from that to the lowest. On these two occasions the water would sweep eastward and go out by the *col* at Makoul. Its course, however, would depend on how far the Treig glacier extended at the time, because if the ice lay across the valley it would check the rush of water and divert it. Future visitors should devote some time to these interesting points; and here I would draw attention to what has been called the 'delta' of the Rough Burn, a large mound situated where that stream joins the Spean, and which was first noticed by Mr. Milne-Home. The top of it is about 880 feet above the sea, and the level of the river at its foot is 742 feet according to the Ordnance map, giving a height of 138 feet for the so-called delta. An opening in its side disclosed a deep mass of fine silty sand, the top of which I found to be at a level of about 848 feet, but the upper part of the mound above this appears to be composed of very coarse waterworn gravel full of large boulders and blocks, some of them of great size, and it is the rugged nature of the channel, arising from the tumbling down of these large stones, that seems to have suggested the present name of the stream. I have been unable to satisfy myself entirely as to the origin of this upper portion of the mound. It is about 32 feet deep, and if it is débris brought down by the supposed débâcle, then the lower portion must be of earlier date. It would also show that there had been a lake or pool here before the above-mentioned débâcle occurred, and therefore that the Treig glacier must have previously shrunk back from the mouth of the Rough Burn. These are questions that would require careful examination upon the spot, and I would commend them to the notice of future visitors.

Thanks to the exertions of Mr. Milne-Home, who has done so much in connexion with the Glen Roy problem, the Ordnance Surveyors were induced to lay down upon their map, on the scale of six inches to the mile, some of the principal lines of moraine left by the Treig glacier when it extended across Glen Spean. These will be found upon Sheet No. 142 of the six-inch map of Inverness-shire, and a reduced copy is given in one of Mr. Milne-Home's memoirs.[1] The mapping of the Survey quite bears out what I said regarding the extent and range of these moraines, which are probably the finest display of the kind in the kingdom.

It is clear that during the time of the lowest Parallel Road the Treig glacier had retreated as far as the mouth of Loch Treig, because that parallel is well marked on Tom-na-fersit, across the entrance to the lake. As to whether it can be traced round Loch Treig there has been some difference of opinion. Mr. Milne-Home says that it can be so traced. Mr. Jolly, who knows the ground perhaps better than any one, and has examined it from many points of view, says decidedly that it cannot.[2] The Ordnance map does not show it, and I certainly could not satisfy myself of its existence anywhere beyond the entrance to the lake, although Loch Treig seems to have sunk a little by the gradual wearing down of its outlet. My impression certainly is that at the time of the lowest line the front of the Treig glacier lay near the present outlet of the lake. The moraines of the Allt-nam-Bruach were probably formed by the left flank of the Corry Laire glacier, which must have

[1] Trans. Roy. Soc. Edin. vol. xxvii. (1876) pl. xliii.
[2] Trans. Geol. Soc. Glasgow, vol. viii. (1885) p. 89.

coalesced with that of Glen Treig when they advanced into Glen Spean.

When the water dropped from the level of the lowest parallel it seems to have drained away quietly—at all events at first, until it sank out of upper Glen Roy—otherwise it would have carried away the fine old deltas near Dalrioch. Many of the gravel terraces at lower levels near the mouth of Glen Roy and along the Spean down to Loch Lochy may have been caused by the outflowing water when the lake was finally drained. Some of them which I examined were not quite horizontal, but had a decided slope down the valley.

VIII. Nicol's objections answered.

Prof. Nicol, who stoutly maintained to the last that the 'roads' were sea-beaches,[1] urged that there are no well-defined river-channels or 'notches' at the *cols*, such as he says should have been cut by the streams flowing out of the supposed lakes, and Prof. Prestwich seems to be impressed with the importance of this objection. The point therefore demands some notice.

These *cols*, we must remember, are situated on flat surfaces, sometimes of considerable width; it was not, therefore, to be expected that any deeply-cut channel or 'notch' should occur in such spots, for water issuing out of a lake over level ground has no power to cut a trench. To do this it must first gain momentum: the cutting power of a stream is governed by its velocity, and that is determined by its gradient. A river passing over a wide flat surface tends to accumulate sediment rather than to cut into its bed; it is only when it has gathered speed and come to a good trot downhill that it begins to cut; and the rate of erosion will then depend upon the hardness and tenacity of the materials over which the water flows.

The *col* at the top of Glen Gluoy has been described by Sir Thomas Dick Lauder and Charles Darwin. To use the latter's own words, it "is broad and very level." Nicol himself says it "is flat and marshy." It was not to be expected that a deep channel should have been cut under such circumstances. The amount of fall for the whole of the first mile is so gentle that Sir Thomas Dick Lauder states it at "about twelve feet," or 1 in 440. However, when we follow the stream down to Glen Turret, where the descent becomes more rapid, we find ample evidence of erosion. A deep narrow ravine has been cut, and also a huge deltoid mass of détritus carried down into the head of the Glen Roy lake when it stood at the mouth of Glen Turret during the time of the lowest line; so that the evidence here, I think, is all we could expect.

The *col* leading from Glen Roy to Lochan Spey is also situated on a wide level swamp. To quote Nicol's own words, "the bottom is broad and flat."[2] The gradient eastward to Lochan Spey, according

[1] 'On the Origin of the Parallel Roads of Glen Roy,' Quart. Journ. Geol. Soc. vol. xxv. (1869) p. 282; *ibid.* vol. xxviii. (1872) p. 237.
[2] *Ibid.* vol. xxv. (1869) p. 285.

to the Ordnance map, is only about 8 feet in a mile or 1 in 660, which is insufficient to have caused the stream issuing out of a lake to cut a groove of any kind, so that the conditions necessary for the erosion of a well-marked channel are here wanting. Moreover, the place is now overgrown with peat, which obscures any track that might have been left.

The Glen Glaster *col* is also in a flat-bottomed hollow now overgrown with peat. A little to the eastward the glen is narrowed by a low projecting spur from the hill on the north side, and here the rocks have a remarkably bare, washed appearance, as if they had been scoured by a rush of water passing eastward. Looking down the course of the small rivulet which flows away to join the Rough Burn I observed that it ran along the middle, or rather to one side, of a wide peat-overgrown channel, which seemed to have been at one time the bed of a considerable stream. I followed the course of the rivulet along the wide open glen all the way down to its junction with the Rough Burn. Owing to the thick growth of swampy turf the nature of the bottom in this old channel is hidden for some distance, so that I could not discover whether it is pebbly or not; but a little farther eastward the appearances are more distinct. A low escarpment is seen on the north side, and a stratum or *causeway of large waterworn stones* on the south, indicating the former presence of a strong current, while the channel itself is about 70 yards broad and 12 feet deep in the middle. Big boulders of the Glen Spean syenite, probably brought here by the Treig glacier, are numerous all along the side of this hollow from the *col* downwards, and they occur also on the hills adjoining it up even to heights of nearly 2000 feet. From the Glen Glaster *col* down to the Rough Burn is a distance of about two miles, and the total fall between these two points is 53 feet, or about 27 feet per mile, which is equal to 1 in 195. The appearances down here of an old channel are so clear that I can account for Nicol's statement only on the supposition that he had confined his observations to the *col* itself, and had not walked down the glen to the eastward. To demand, however, with him that we should find a long deep trench cut into the hard solid rock, like what we see in some parts of the present bed of the Roy, is surely unreasonable. The Roy has been cutting away at its bed ever since the Glacial epoch, and perhaps before it, whereas the outfall from the lake at the period of the middle line existed only during the time the ice took to shrink back from the mouth of Glen Glaster to Bohinia, about a mile and a half. How long that may have taken, reckoned in years, we cannot tell, but in comparison it must have been a very small fraction of time indeed. I ought to mention that there is a mass of boulder clay at the south side of the Glen Glaster *col*, which is probably the remnant of a larger accumulation of moraine matter that had formerly occupied the hollow, and may have blocked it up to some extent.

As regards the *col* at Makoul, I have already in my previous paper described the evidence of a river having passed out there. I shall only add that I subsequently paid a visit to the locality in order to measure the height which the beds of water-rolled pebbles attain above the bottom of the *col.* This I found to be 25 feet. The *col* itself is 848 feet above the sea at its lowest point, and the highest beds of pebbles I saw beside it reach up to 873 feet, which would seem to show that a large deep river went out here. These pebble-beds lie a little to the eastward of the watershed. The descent or fall from this *col* to the Spey along Strathmashie is for the most part very gentle, and the bottom of the Spey valley itself all along from Cluny MacPherson's castle past Laggan is a swampy meadow which may possibly be the bed of an old lake filled up with silt.

IX. Height and horizontality of the 'Roads.'

Each of the Parallel Roads consists of a sort of terrace or shelf, generally from 40 to 70 feet broad, and sloping towards the middle of the glen at angles varying from 5° to 30°.

Now, in regard to the heights given upon the Ordnance map, it must be borne in mind that the figures refer to points taken along the middle of each terrace, that is to say halfway between the upper and nether border of the ribbon-like mark which runs along the hill-sides. Assuming the vertical measurement of each terrace to vary from 4 to 16 feet, a series of stations taken along the middle would range from 2 to 8 feet below the upper edge, and as the surface of the water probably corresponded with the upper edge of the terrace (or may perhaps have been higher, owing to the crumbling down of débris upon its original upper border) these stations would therefore be from 2 to 8 feet beneath the ancient level of the lake, and lower sometimes than the *col* or outlet to which the road corresponds. The Ordnance figures are consequently somewhat misleading as to the exact height of the water, and this discrepancy in relation to the *cols* has probably been increased by the fact that the *cols* themselves in most cases are now overgrown with peat or turf which has raised their surface higher than it was when the lakes existed. For example, Mr. Milne-Home [1] found the peat on the Glen Gluoy *col* to be 5½ feet thick. It is evident the lake must have rather exceeded the height of its *col*, otherwise the water would not run out; whereas the Ordnance heights, owing no doubt to the circumstances I have mentioned, frequently indicate a Parallel Road as running a few feet lower than its *col.*

These 'roads,' although wonderfully clear when viewed from a distance under favourable light, are nevertheless often very obscure when we come to stand upon them. Sometimes indeed they seem to vanish altogether in ghost-like fashion, so shadowy and vague is the outline of what remains. The clearness of the lines at a distance seems to depend upon some subtle difference in the shade of light or colour, due either to alteration of the angle at which the surface is presented to the light or to some change in the character

[1] Trans. Roy. Soc. Edin. vol. xxvii. (1876) p. 597.

of the vegetation covering it. I have no doubt therefore that the men of the Royal Engineers were often at a loss what spot to fix on as representing the exact middle of the terrace, which is altogether an arbitrary point, there being no definite boundary of either the upper or lower margin.

"It is indeed impossible," as Sir Thomas Dick Lauder long ago remarked, "to perform a mathematically-accurate levelling process on such rude and indefinite subjects as these shelves are."[1] Shoals of débris have come down upon them from above and gaps have been torn by the mountain torrents, slips also have occasionally happened; it is indeed surprising that they are still so visible. In some places mistakes even might have been made as to what actually constituted one of the Parallel Roads, as I shall afterwards show, for spurious markings occur which might readily be confounded with them, and the Government surveyors were not geologists. I therefore think that Prof. Prestwich makes too much of the variations in level recorded on the six-inch map when he argues that the lines are not so rigidly horizontal as he fancies they ought to be if they had been produced by the shore-action of a lake. The Ordnance Surveyors themselves do not seem to have shared in this opinion, for Col. Sir Henry James, who directed the operations, stated that "there could be no doubt as to the general correspondence of the levels of the terraces at different points,"[2] and after the survey of them was concluded he spontaneously wrote to me as follows:—

"Ordnance Survey Office, Southampton,
19th November, 1873.

"I send you to-day an impression of Sheet 63 of the one-inch map of Scotland, which contains Glen Roy and part of Glen Gluoy. This sheet, in outline with contours, has enabled me to lay down the Parallel Roads and to show their extent downwards. I had a contour run at a little above the height of the upper road, and also one at the level of the lower: these served as feelers through the country for an extension of the roads, but nothing was found. I have myself examined the ground and feel certain that you have correctly described the roads and proved that Agassiz's theory was the true one."

The Parallel Roads have been examined carefully with good instruments by many civil engineers and scientific men, and I believe all who have so examined them have been of opinion that the lines represent a horizontal water-level, such as would be formed by the margin of a lake either salt water or fresh. Dr. Tyndall—surely a competent witness—tells us that he had an opportunity of inspecting some of them with a theodolite, and he declares them to be "all sensibly horizontal."[3] I may mention that when standing on the lowest line on Meal Derry (see plate in Lyell's 'Antiquity of Man'), and taking a sight through a good spirit-level to the portions of the same line ranging some miles up Glen Roy, I observed that the most distant parts of it sank slightly, but perceptibly, below the thread of the instrument in such a proportion as might be expected

[1] Trans. Roy. Soc. Edin. vol. ix. (1821) pp. 6 & 7.
[2] Quart. Journ. Geol. Soc. vol. xxviii. (1872) p. 240.
[3] Proc. Roy. Inst. vol. viii. (1876) p. 234.

from the curvature of the earth. A similar observation is also made by Sir Thomas Dick Lauder.[1] I am confident that if Prof. Prestwich had surveyed the lines upon the spot through a good spirit-level or theodolite, instead of through the medium of the six-inch Ordnance map at home, he would never have hazarded the statement which he has made. The undeviating horizontality of the lines is in fact one of the most interesting and remarkable features connected with the phenomena, for it cannot be said that a progressive change of level, or slope however slight, has been established in any direction whatever. The altitude of the lines at their northern and southern and likewise at their eastern and western extremities seems, according to the Ordnance Survey, to be about the same; and the height halfway between corresponds also.

In a former paper[2] I mentioned that I discovered a terrace at the mouth of Loch Treig 30 feet higher than the Parallel Road in the neighbourhood. The Ordnance Survey map on the six-inch scale confirms this observation, and shows that the terrace extends from the mouth of Corry Laire round to Loch Treig, sloping gradually upward near the loch to a height of 896 feet, or fully 40 feet above the general level of the lowest Parallel Road, which is the only one in that locality. It cannot therefore be due to the action of the lake, but may have been a lateral terrace formed in some way by the glaciers of Glen Treig and Corry Laire. The Ordnance map, however, terms it a 'Parallel Road.' The real Parallel Road occurs in the same neighbourhood at its usual height of about 855 feet, so that this higher and sloping terrace is not owing to a superior elevation of that 'road' at this particular place: it is a distinct mark due to some other cause. I point this out because Mr. James Melvin in his paper[3] refers to it as a serious difficulty.

X. Beach-pebbles and Wave-action.

Although it is commonly stated that there is an absence of waterworn pebbles along the Parallel Roads, yet these may be found in some places where the lake was most exposed to agitation by the wind. For example, near the top of Glen Roy, the face of the hill above Leek Roy fronts a long opening down the glen, so that it is exposed to the sweep of the south-westerly gales, and in fact the wind blew with great force when I was upon it. Accordingly we find the two upper shelves very broadly and rudely developed, and there are a good many waterworn stones upon them. The lowest line runs along the base of the hill, and is less remarkable at this point. Again, on the south-west slope of Bohuntine Hill I noticed a great number of waterworn stones and pebbles at and beneath the level of the lowest parallel, which is the only one that occurs there. This part of the hill faces a wide opening towards

[1] Trans. Roy. Soc. Edin. vol. ix. (1821) p. 10.
[2] Quart. Journ. Geol. Soc. vol. xix. (1863) pp. 250 & 256.
[3] Trans. Geol. Soc. Edin. vol. v. (1885) p. 268.

the mouth of Glen Spean, and the waterworn pebbles, I think, are more plentiful than even at the other locality.

The great accumulation of gravel and pebbly débris at Inverlaire and the entrance to Loch Treig must have been caused, not by the action of the lake, but by the glaciers. Probably much of it was ground out of the bottom of Loch Treig by the sole of the glacier which occupied that basin. This heavy mass of débris forms another good link in the chain of evidence in favour of the glacial theory, for how otherwise can it be accounted for at this particular spot?

During strong westerly gales the wind sweeps with great fury through the narrow rocky pass at the head of Glen Roy, as I know from personal experience, and here I remarked that the rocky eminences bore evidence of water-wearing about the level of the two higher lines (the lowest one does not extend so far up), while there are also some waterworn pebbles on them. This observation is confirmed by Dr. Tyndall, who says: "Near the head of Glen Roy the highest 'road' ceases to have any width, for it runs along the face of a rock, the effect of the lapping of the water on the more friable portions being perfectly distinct to this hour."[1]

Apart from the deltas these instances are sufficient to show that the lake must have existed for a considerable time, for the broad shelves of détritus near Leek Roy, with their waterworn pebbles, imply a lengthened action of water, and so does this waterworn rock at the head of the glen.

XI. Formation of the Terraces. Action of the Lake-margin.

As regards the exact mode of operation by which the terraces were formed along the hillsides, this is a point which, I confess, did not engage much of my attention, and what I did say about it requires some correction. Of all observers, Sir John Lubbock[2] seems to me to have treated this matter with most acumen.

In considering the form and dimensions of the 'roads' at any particular spot three elements claim our attention, viz.:—

1. The depth or vertical measurement.
2. The breadth or horizontal measurement.
3. The angle of inclination to the horizon.

The vertical extent seems to represent the range of wave-action, as Sir John Lubbock points out. Accordingly we find it greatest in those places which are most exposed to the wind. It marks the "zone of agitation" in the water. As the Glen Roy lake was narrow and shut in by hills, its surface would not be agitated to any great depth unless in a few places, chiefly near the ends: the action of the waves would therefore be comparatively feeble. The smallness of the vertical measurement affords another good argument that the lines are not sea-beaches, for if so their vertical

[1] Proc. Roy. Inst. vol. viii. (1876) p. 240.
[2] Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 83.

dimensions should have been much greater, because in that case the depth of the slope would have been equal to the vertical range of the waves in a freshwater lake *plus* the variation in level caused by the tide. Now there are some places in the most sheltered parts of Glen Roy (as on the west side above Achavady) where I remarked that the depth of the slope on some of the shelves does not seem to exceed 3, or at the most 4, feet, which is quite inconsistent with the movement of water in a sea-loch or fiord subject to a rise and fall of tide.

The horizontal breadth of a cross-section of the 'roads' will be governed by two elements, the depth of slope and its angle of inclination. For a given depth it will be greatest where the angle is least, and for a given angle it will be greatest where the depth is greatest. The extreme breadth will therefore occur where the maximum depth coincides with the minimum angle.

The angle of inclination seems to represent the slope at which the materials could sustain the action of the waves. For a bank of loose materials that angle is smaller in agitated water than it would be in perfectly still water or simply in the air. This fact explains why the 'roads' dip at a less degree than the hillsides above and below them. The surface on which the lines are traced varies, it is true, greatly in different places, but in those where the 'roads' are best marked the hillsides are generally steep. The amount of the angle would depend chiefly on the nature of the materials and partly also on the force of the waves: the looser the stuff the smaller the angle, and *vice versa*. Accordingly it varies with the structure and composition of the hillsides, and also with the exposure. In some places the surface seems to be nearly flat, or at any rate as low as 5°, but from 12° to 25° is a more common angle,[1] and where it is rock it may reach the perpendicular. The above observations apply to a lake that is not frozen. Some modification would occur if the margin was converted into ice during part of the year and the hills covered with snow. But, as the water would resume its sway during summer and autumn, the result upon the whole would probably be still much the same.

The action of the waves upon a beach forms an interesting spectacle. The impulse given by the wind drives the advancing wave up above the normal level of the water. As soon as the onward impulse is exhausted the water falls back again and constitutes the retreating wave, which, rushing down the slope, meets the base of the one next advancing and checks its onset, causing a turmoil in the water. When the wave curls over and breaks upon the beach there is a downward stroke, which stirs up the bottom still more, and mingles the finer material with the water. The muddy sediment thus suspended has a tendency to float off from the shore and subside into the deeper and quieter parts of the bottom, leaving the washed sand and stones on the beach; but if the fine mud cannot get away it remains suspended in the water until the agitation

[1] See the Ordnance Survey measurements, &c., given by Prof. Prestwich in his memoir, Phil. Trans. Roy. Soc. for 1879, vol. clxx. p. 698.

ceases, and then settles down again. The retreating wave has a tendency to draw the sand and stones down the incline to its outer edge ; if the slope below is steep they will then roll down until their momentum is extinguished by friction, the largest and heaviest stones going farthest. In this way the slope beneath the beach is clothed with a sheet of sediment which accumulates according to the supply of material from above.

On the other hand, the advancing wave has a tendency to carry sand and stones up the beach, and more especially everything light which floats upon the water. Some of these will be stranded where the retreating wave is unable to carry them off again, especially when a storm is subsiding. But where the slope is steep both above and below the beach, as it often is in Glen Roy, this result would seldom happen with the heavy material. The prevailing tendency of the stones in such a case, I think, would be downwards, as Lubbock insists. Accumulation would take place chiefly at the outer edge of the beach and below it, not upon the beach itself.

Such appears to be the effect on the bottom. The action on the bank facing the water is different; in calm weather it is almost *nil*, but during a gale the advancing wave strikes the bank horizontally or obliquely upwards, like a liquid battering-ram, while the surf washes up and down against it, licking hollows in its surface. If the materials are porous and friable the water penetrates them and loosens their cohesion, whilst the shock of the wave dislodges them and sets them in motion. The bank is in this manner undermined and a portion of it brought down. The débris thus tumbled down is spread out by the waves and acted upon as part of the bottom. The result is to cut back the bank until the upward slope of the beach extends as far as the highest limit reached by the waves during storms. The fretting of the water against the hillside in this way would therefore produce an escarpment, or steeper slope, just above the edge of the lake. Although the gradual crumbling down of the materials from above has now almost obliterated this little scarp, yet traces of it may still be perceived in many places, and the protuberance of the front of the terrace beyond the general slope of the hill may also generally be noticed. Both are observable in MacCulloch's 'real profile' of one of the 'roads,' and they have been remarked by other observers. For example, Prof. H. D. Rogers says :—"Seen in profile, as when looked at horizontally, they [the 'roads'] resemble so many artificial hill-side cuttings, the back of each terrace lying within the general profile of the mountain slope, while the front or outer edge is protuberant beyond it." [1]

The action of the lake-margin, then, would produce a flatter surface at its line of contact with the hill and a steeper slope or scarp just above this line; it would transfer part of the matter from the slope above the beach to the slope beneath it, and cover the beach itself with some washed sand and gravel, which are now hidden by turf and fallen débris. The general absence of an ordinary

[1] Proc. Roy. Inst. vol. iii. (1861) p. 342.

beach of well-waterworn pebbles is probably due to the following causes :—

1. The comparatively feeble action of the waves, owing to the lake being narrow and surrounded by hills.
2. The steepness of the slopes, which led to the stones being washed downhill before they had time to be worn, as Lubbock points out.
3. The transient existence of the lakes, whose duration was short compared with that of ordinary lakes, whose beaches have been forming ever since the Glacial period came to a close.
4. The freezing of the lake-margin, which would arrest the action of the water.

XII. Dispersion of boulders from the Glen Spean Syenite.

This rock occupies the bottom of the Spean Valley for some distance to the east of the River Treig, and Mr. Jolly has ascertained that it extends farther to the south-east than is shown in my map, and also rises to a higher level in that direction. It has given off a profusion of fragments whose transport affords an excellent means of tracking the flow of ice in that neighbourhood. These blocks are often of large size, from 5 to 20 feet in length, and extend up the hills on the north side of the Spean to heights of fully 2000 feet above the sea and 1400 feet above the river. They are scattered over Craig Dhu on to the very top; I also traced them up the bed of the Rough Burn all along from its mouth to an altitude exceeding that of any of the Glen Roy lines. I found the rivulet cutting its way through a great depth of unstratified earthy rubbish full of large boulders, many of them belonging to this syenite; whereas the rock in the upper part of the stream is a gneiss full of veins of red granite. The deep mass of moraine-like rubbish ceased somewhat abruptly on following it up the hollow, and from this point there is a fine view into Glen Treig, the mouth of which lies right opposite. Ascending the hill on the west side of the Rough Burn (or 'Allt-a-Chaoruinn' of the Ordnance map) I found its southern slope thickly covered with similar moraine-like débris to a still greater height—to a level of about 1700 feet or more. On reaching the bare rock at the brow of the hill I observed that it was a reddish granite of rather small grain; and on a projecting shoulder of the ridge, at a height of nearly 2000 feet, I met with a large angular block of the syenite, 9 feet in length, lying on the surface of the granite in a place to which it could not have rolled down from above, but must have been transported for some distance. Proceeding westward to the next projecting point, which looks down upon the Glen Glaster *col*, and is called 'Craig Uilleim' on the Ordnance map, I found it to be of gneiss full of granite veins. Perched boulders of granite and syenite occur also on this hill. I noticed none of the syenite boulders on the west side of the Treig, nor about Tom-na-fersit or Inverlaire, neither did I remark them along the road to Bridge of Roy much beyond the western boundary of the parent rock. There are plenty, however, along the foot of the hill on the east side of the Rough Burn, called on the Ordnance map 'Meal Clachach,' which means 'the Hill of Stones.' How far up the hill they go I am unable to say, for I did not ascend it; but along its base there are some splendid examples of erratic blocks, and they continued beyond the boundary of the syenite as far as I went. Looking eastward over the moor on the south side of the Spean it is seen to be covered with them in thousands, as far away as the eye can discern such objects.

It would seem therefore that the fragments of this syenite have been carried towards the north-east, north, and north-west. Many of them must have been lifted far above their original bed, and altogether the display of glacial action here is one of the most interesting and remarkable that I know. It is strange that the mountains along the Rough Burn are nearly as lofty as those in Glen Treig, and yet their territory appears to have been completely invaded by the glaciers of the latter region. A glacier descending the Rough Burn would have carried the moraines and boulders in an exactly opposite direction.

Here again we see that the ice from the region of greatest precipitation has overwhelmed that of the drier region. Although the facts in this Lochaber district are so very strange and paradoxical, yet there is a certain harmony in them all. For whether we look to the glaciation of the rocks, the barring of the lakes, or the transport of boulders, everything points to the same explanation, namely, an excessive thickness of ice in what is now the region of heaviest rainfall.

APPENDIX.

1. *Prestwich's Remarks on the Deltas.*

Prof. Prestwich, in his memoir on Glen Roy, disputes the nature of the so-called deltas, and would explain them to be accumulations of moraine détritus remodelled on the surface by water-action. In particular he criticizes in considerable detail the large bank at the mouth of Glen Turret. The base of this he represents to be "a mass of unstratified light grey sandy clay, from 50 to 80 feet thick, full of angular fragments, including a few large blocks, of the local rocks." [1]

This does not quite agree with my observations. The following is an extract from my notes on the subject made at the time:— "The base of this bank, as far as I could make out (for it is not very clearly sectioned), is *chiefly of laminated silt*, rather sandy and somewhat rough owing to a considerable mixture of small stony débris. Above this there is a broad band of very coarse stony

[1] Phil. Trans. Roy. Soc. for 1879 vol. clxx. p. 673.

détritus, containing many angular pieces of rock from 2 to 3 and perhaps in some cases 4 feet in diameter. This shades off upwards into coarse détritus with fewer large fragments, but the stony débris only partially waterworn, while the uppermost part of all is rather finer and more silty. Stratification lines are scarcely visible in this section, which was the clearest one I saw." This bank fills up all the side of the glen and extends up the Turret to the level of the lowest parallel, presenting to the Roy a steep front which I roughly measured and found to rise about 90 feet above the level of that stream at its base. The general character of the surface is very flat, and corresponds with the part measured, but in some places rises above it. The Turret has cut its way through the bank, and a little farther up has carried away a good deal of its mass.

I have no doubt that the laminated silty portion at the base must have been hidden at the time of Prof. Prestwich's visit by the slipping down of stuff from above, for his description corresponds with the middle part of the bank. It is quite possible there may be some old moraine matter enveloped in the interior of this large bank of stuff, for it is of great extent, but the laminated silty character of its base and the general flatness of its surface (as may be seen from Prof. Prestwich's own view of it and also from plate xv. in MacCulloch's memoir) are against the notion of its being formed by a glacier.

Prestwich further objects that it cannot be a delta because "the accumulation of the main mass is at the most remote instead of the nearest point of discharge." But is not this one of the characteristic features of a delta, and is it not implied indeed in its very name? Another objection is that there is no "sorting of its materials from its head at the Turret Pass to its extremity on the Roy." But this is just what we do not know, for there is an absence of any clear section to instruct us in regard to this point. We have also to remember that we have to do with a glacial climate when there would be much ice in the waters and the margin of the lake would be often frozen, and further that the spot is surrounded by steep hills down which the streamlets in time of flood descend with considerable force. Moreover, when the lake sank from the highest to the middle line, and again from that to the lowest, there would be a sweep of water amply sufficient to move large stones, and perhaps this explains the rough character of the middle zone of the delta. The abnormal size of the deposit is no doubt due in some measure to the overflow of the Glen Gluoy lake having contributed to its formation, as I mentioned in my previous paper.

Again, Prof. Prestwich objects that its surface is not an inclined plane, but to me it appears to approach this as nearly as we could expect in an old worn delta over and through which the Turret had to cut its way. Prof. Prestwich's opinion about these deltas is opposed to that of MacCulloch, Darwin, Chambers, Milne-Home, Lubbock—in fact almost every one who has noticed them.

Owing, no doubt, to some ambiguity in my language Prof. Prestwich has misapprehended what I said about the height of the

Gulban delta. It slopes very gradually back to a level of about 50 feet above Loch Laggan, which would be 14 feet above the average height of the lowest Glen Roy line and not 40 feet as he makes it. Milne-Home states that the steep front of this bank shows a mass of sand and fine clay in horizontal beds. How a wide platform of such materials should be a moraine, as Prof. Prestwich and Mr. Melvin suggest, is not very easy to see.

2. *Prestwich's Theory of the Formation of the 'Roads.'*

This is stated as follows:—"In the Lochaber district, while the exceptional accumulation of ice in the Spean valley heavily barred the entrance of the glens on the north side of that valley, the passes at the head of the glens were also blocked by smaller remnants of the great ice-sheet, and the formation of detrital shelves or terraces is due to the sudden bursting of these minor barriers, when the waters of the lake were discharged with great rapidity until they fell to the level of the *col*. Under these circumstances the mass of loose débris covering the hillsides gave way and slid after the retreating waters, until stayed with greater or lesser abruptness, according to the angle of slope and the volume of the mass, on the discharge ceasing and the waters coming to rest. The shelves so formed, modified slightly by subsequent subaerial action, constitute the 'roads'."[1]

I have no wish to enter into any lengthened criticism of this new theory, because it has been propounded to meet what I believe to be an imaginary difficulty which has really no existence, that is to say the supposed want of regular horizontality in the lines. Prof. Prestwich, however, has elaborated it in much detail, and it is due to a former President of the Geological Society, and the author of one of our most esteemed text-books on the science, that I should state some of the reasons why I cannot accept it.

Even were we to concede the possibility of all these long level lines having been formed by slides of débris in the way Prof. Prestwich explains, it can be shown that there are many places where the conditions he himself lays down as requisite for the purpose did not exist. Two conditions are assumed to be necessary, namely, 1st, a higher slope covered with débris above each line, and, 2nd, a mass of subsiding water sinking down this slope. Now these conditions were wanting in many places. For example, a 'road' is occasionally met with round the top of a knoll, as at Tom-na-fersit and Meal Derry, where there was no slope above to furnish material for the slide. We have likewise no reason to suppose that there was a lake all along Glen Roy above the level of the highest line as the theory requires, neither can it be at all admitted that along Glen Spean, or on the south slope of Bohuntine Hill, there was any mass of water subsiding from a higher level which could have formed the lowest line in the way described. In order

[1] Phil. Trans. Roy. Soc. for 1879, vol. clxx. p. 725.

to meet this difficulty Prestwich is obliged to imagine a barrier of some kind at Makoul, 100 or 200 feet high, of whose existence we have absolutely no evidence whatever. Similar hypothetical barriers are wanted at the other *cols*, all bursting suddenly in order to allow of the lake subsiding rapidly from a greater height.

Granting, however, all the conditions assumed to be necessary, it is not at all evident why there should have been any such regular and universal slide of débris when the water subsided; and even if a slide did take place I have a difficulty in believing that it could have stopped with such precision about the same level all along for so many miles. It seems to me that it must have descended to much more variable depths, according to the degree of slope and downward momentum of the sinking mass. Moreover, seeing that it is admitted there *was* a lake in Glen Roy, there appears to be no good reason why it should not leave behind it a set of beach-lines without needing those slides of détritus which Prof. Prestwich invokes. The existence of the lake even on his own showing could not have been so very transient, for the great barrier of ice he requires at the mouth of Glen Spean could not have melted away very soon. The theory therefore labours under this further objection, that, a lake being admitted, it is not allowed to act along its margin as every such lake must have done.

Discussion.

Prof. Bonney stated that, notwithstanding the skill with which the case in favour of a glacier-barrier had been stated, he considered that the hypothesis of a marine origin for the 'roads' presented less difficulties. He pointed out that the absence of sea-shells might be made a difficulty in terraces in Norway which undoubtedly were of marine origin, and the rarity and alleged horizontality of the 'roads' were not a serious objection. It must be remembered that great earth-movements were admitted to have taken place at a very late date in the earth's history: over 500 feet in Canada and Labrador, 1000 in the Arctic regions, up to 1295 in S. America, not less than 600 and probably much more in Norway; and a considerable uprising was not denied in Scotland and England—certainly some 300 feet in Shropshire, and, as he fully believed, some 1200 at Moel Tryfaen. But he thought the following the most serious difficulty in the glacier-lake hypothesis. The district about Glen Roy was not materially lower than the hill-region to the west, and the rainfall, though less heavy than in it, was still considerable. To form large glaciers in the region of Ben Nevis would require a temperature at the coast not higher than 30° (really, this would hardly be low enough); if so, the temperature on the hills above Glen Roy would not rise above 26° (annual). If then the cold sufficed to form glaciers large enough to choke Glen Roy or Glen Spean, there would be glaciers also in Glen Roy itself, and it would be filled with ice, not water. In fact, with a temperature of 30° at the coast this western district would be something like the Oberland above the contour-line of 8000 feet, except that Ben Nevis would not equal the greater peaks in height.

Mr. Marr observed that no diagram had been made to illustrate the paper; he therefore showed on the blackboard the alteration in the horizontal extent of the terraces as indicated on the new Ordnance maps, and showed how, according to the Author's account, the explanation of the lakes having been caused by glacial dams was thus simplified. The speaker himself believed that this explanation was the correct one; and he cited, in illustration of the extraordinary manner in which valleys were left free of ice in a glaciated district, the remarkable cases described in the 'Meddelelser om Grönland.'

The President agreed that no explanation that had yet been proposed for the Parallel Roads of Lochaber was free from difficulties. Yet he had long felt that these were far fewer and less formidable in the glacier theory than in any other. Had the terraces been marine, there ought surely to be similar terraces in some at least of the hundreds of sheltered glens in the Scottish Highlands, where the conditions for their formation and preservation were at least as favourable as in Glen Roy and its adjacent valleys. And though the absence of marine shells in the Lochaber shelves might not be a serious difficulty, it was hard to understand why such shells should not be found in many localities had the whole country been submerged to the height of the highest Glen Roy 'road.' Then no satisfactory explanation on the marine theory had ever been given of the coincidence of the terraces with well-marked *cols*; while a further formidable objection to this theory lay in the nature and distribution of the détritus of the shelves, which, in his opinion, was very unlike material arranged in a tidal sea, but was quite what might be looked for in a freshwater lake. He thought that the Author's present paper lessened some of the difficulties of the glacier theory by simplifying the grouping of the ice-dams. There still remained the objection that, if the Great Glen and the valleys round Ben Nevis were choked up with ice, Glen Roy and its neighbours could hardly have been filled with water. But this difficulty, which every glacialist must have felt, was probably more formidable in appearance than in reality. As Mr. Marr had pointed out, conditions did actually now exist in Greenland very similar to those which, according to the theory so ably expounded by the Author, formerly existed in Lochaber.

3. *On the* Gravels south *of the* Thames *from* Guildford *to* Newbury. By Horace W. Monckton, Esq., F.G.S. (Read December 23, 1891.)

The greater part of the hill-gravel in the district to which the following communication refers belongs to the Southern Drift of Prof. Prestwich,[1] and a very large portion of the valley-gravels consist of materials mainly derived from the Southern Drift. It is only on the hills between Cookham and Twyford, and at Tilehurst near Reading, that we get the Westleton Shingle of that author or the Glacial Gravel.

The distinctive features of the Southern Drift are given at length by Prof. Prestwich.[2] Briefly it may be said to consist of materials derived from the Wealden area of Kent and Surrey, the Chalk country to the north and west of the Weald, Eocene formations of the neighbourhood and older gravels, or possibly older clay with flints and surface-débris. It is, I believe, the gravel of old rivers which had little or no relation to our present river-system, whilst the gravels of the valleys, terraces, and minor plateaux are the work of rivers having some, though often a distant, relation to those now in existence.

The Southern Drift of the district under consideration may conveniently be divided into three classes. The first includes certain patches on very high ground along the margin of the Wealden area, obviously the oldest gravels in the district. The second consists of material largely derived from the Lower Greensand of the Wealden area and extends as far west as Strathfieldsaye; while in the third, which lies west of that place, there is an absence of such material. It will be observed that in dealing with these gravels the writer rejects all theories which suppose them to have been formed by marine agency. I do not believe that the sea has flowed over this part of England since the oldest of these gravels was formed—probably not since the earth-movements took place which separated the London and Hampshire Eocene basins. The facts which will now be detailed are not, however, affected by this opinion, and are of equal interest whether it be right or wrong.

The gravels with which I am dealing possess an extensive literature. It hardly appears necessary, however, to give an abstract of the various papers and books dealing with them, though many of them will be referred to in the following pages. But I should like at the outset to acknowledge my indebtedness to the paper by Prof. Rupert Jones,[3] to that by Dr. Irving,[4] and to Mr. Whitaker's

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) pp. 84, 120, 155.

[2] *Ibid.* pp. 155, 156.

[3] 'On the Physical Features of the Bagshot District,' Proc. Geol. Assoc. vol. vi. (1880) p. 429.

[4] 'On the Bagshot Strata of the London Basin and their Associated Gravels,' Proc. Geol. Assoc. vol. viii. (1883) p. 143.

'Geology of London'.[1] I also wish to express my thanks for very great assistance in the collection of the facts recorded in this paper to Mr. R. S. Herries and to Messrs. J. H. Blake and F. J. Bennett, of the Geological Survey.

In my comparison of different gravels I have given a description of the general appearance and nature of the stones which form them, and also in several cases an analysis of the smaller material, meaning thereby such as passes through a riddle of half-inch mesh and is retained in one of $\frac{1}{12}$-inch mesh. It is not here asserted that this is a thoroughly satisfactory way of comparing gravels, but it brings out the distinction between the different classes quite sufficiently for my present purpose.

I. The Southern Drift.

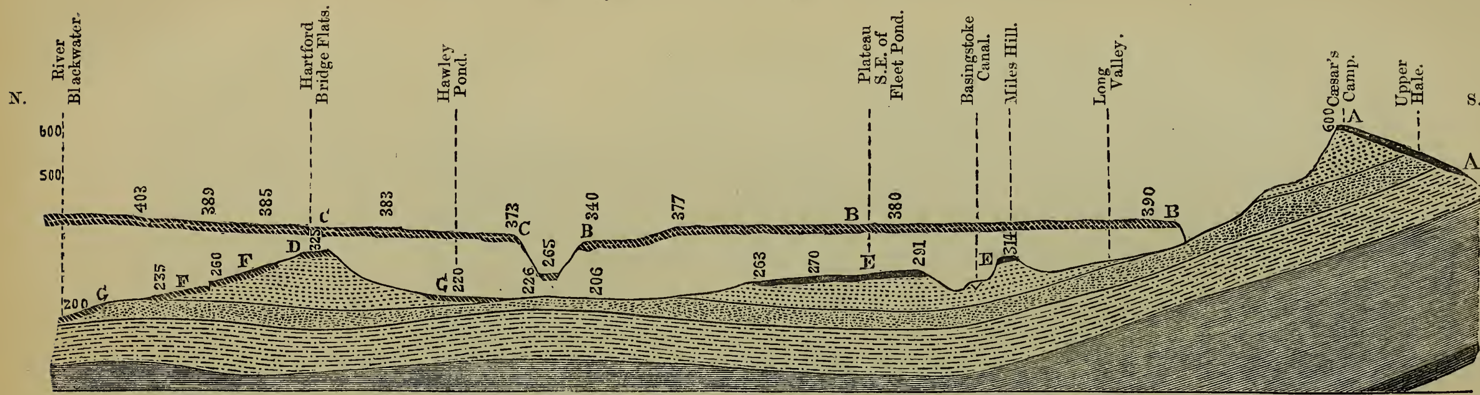
Class 1. *Upper Hale type.*

The Drift edition of Sheet VIII. of the Geological Survey map having been very recently published, no sketch-map is given for this part of the paper. The gravels which I should assign to the Southern Drift are all included in the "Hill Gravel of doubtful age and origin" coloured red, though in places the colouring is extended farther into the valleys than I should be inclined to carry it, and includes some patches which I should call gravels derived from the Southern Drift. The Long Valley, Aldershot, the northern end of the Fox Hills, and the northern side of Hartford Bridge Flats are instances.

In Class 1 may be placed the plateau which, under the names Hungry Hill, Cæsar's Camp, and Beacon Hill, stands out high above the Long Valley, Aldershot. On its southern edge is the village of Upper Hale, not marked on the Geological Survey map, where there are very extensive gravel-pits. This hill is shown in the diagrammatic section, fig. 1, which is along nearly the same line as S. V. Wood's,[2] and parallel to Prof. Prestwich's.[3] The first-named author calls the gravel "gravel of the greatest submergence." The plateau not only overlooks the country to the north, as shown in fig. 1, but also the Wealden area to the south.[4] It varies from 615 to about 470 feet above O.D. I should mention that the levels in this paper are taken from the Ordnance maps, or calculated as correctly as lay in the writer's power from levels given on those maps. In many cases thanks are due to Mr. J. H. Blake for them. The deposit has been described by Prof. Prestwich[5] and by Dr. Irving.[6] To their description the following is supplementary. The gravel is not usually stratified, but here and there a rough stratification is seen near the bottom, of which one instance is given in fig. 2. It is in

[1] Mem. Geol. Surv. 1889.
[2] Quart. Journ. Geol. Soc. vol. xxxvi. (1880) pl. xxi. fig. 3, line B.
[3] *Ibid.* vol. xlvi. (1890) pl. vii.
[4] See Mem. Geol. Surv. vol. iv. (1872) p. 376.
[5] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 161.
[6] *Ibid.* p. 559.

Fig. 1.—*Section from Farnham Park to the River Blackwater.*



The figures indicate levels above O.D. Horizontal scale: 1 inch = 1 mile. Vertical scale: 1 inch = 440 feet.

Gravel with very little Chert.

Gravel with much Chert.

Upper Bagshot.

Middle Bagshot (Bracklesham).

Lower Bagshot.

London Clay.

Reading Beds.

A. Upper Hale Gravel (Southern Drift, Class 1).

B. Fox Hills Plateau (Southern Drift, Class 2).
C. Chobham Ridges (Southern Drift, Class 2).
} Shown in outline. They are from 4 to 5 miles E. of the line of section.

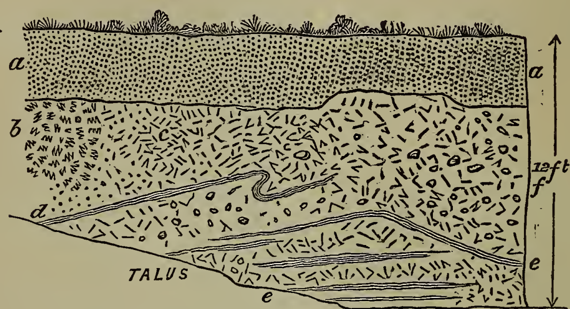
D. Hartford Bridge Flats (Southern Drift, Class 2).

E. Gravels of minor plateaux, mainly derived from gravel of Class 1.

F. Terraces of gravel.
G. Gravel of recent valleys.
} Derived from gravel of Class 2.

places overlain by 2 to 5 feet of reddish earthy clay, and the gravel is itself frequently very clayey. The surface of the plateau is fairly flat, but the sections show that the gravel rests in great hollows in the Bagshot Beds and is 12 feet or more thick in places. On the south there have been extensive slips of both gravel and Bagshot Sand. A large proportion of the gravel consists of very big flints much rolled and waterworn, nearly all brown, though a black one

Fig. 2.—*Section in a gravel-pit at Upper Hale, near Cæsar's Camp, Aldershot.*



a. White sand and stones. No sign of stratification.
b. A reddish earthy mass.
c. A mass of small-sized material.
d. Irregular layer of red sand.
e. Layers of brown sand.
f. Mass of stones; many large rolled flints.

occurs here and there. Many of these flints are 6 inches and some a foot in longest diameter. There is also a great quantity of subangular flints and bits of flint often much worn and decayed. Prof. Prestwich gives 36 per cent. of Tertiary flint-pebbles for this gravel.[1] Dr. Irving, however, cannot recollect ever meeting with "rolled flint pebbles" in it.[2] The present writer found plenty of flint-pebbles in all the pits, many of them black and evidently derived from Eocene pebble-beds, so that there is little doubt that Prof. Prestwich's record is correct. Some blocks of sarsen-stone occur. I examined a sample of the smaller material from one of the pits, and found it to consist of—

a. Subangular flints	25	% of total weight.
b. Flint-pebbles, many of them black	29	" "
c. Quartz	39	" "
d. Chert in very small fragments	·5	" "
e. Ironstone from the Lower Greensand and irony concretions from the Bagshot Beds	6	" "

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 161.
[2] *Ibid.* p. 559, note.

The scarcity of chert and the abundance of small pebbles of quartz are distinctive features of this gravel. The largest quartz-pebbles I found measured 0·6 inch in length and weighed less than $\frac{1}{4}$ oz. The surface of the gravel slopes rather south of west, so that if this be gravel of a river which flowed north earth-movements giving the southerly dip must have taken place since the deposition of the gravel.

Although the North Downs are outside the area with which we are now dealing, it may be well to mention that with this Upper Hale gravel the writer would class that which is worked to the east of Newlands Corner, 600 feet above O.D., which contains an abundance of large rolled flints $3\frac{1}{2}$ to 4 inches in longest diameter, together with subangular flints, flint-pebbles, chert, ironstone from the Lower Greensand, and small quartz-pebbles. The same gravel is well seen at Woodcote Lodge, 678 feet above O.D., $1\frac{3}{4}$ miles N.W. of Gomshall Station,[1] and it may be that the drift of Well Hill, Chelsfield,[2] belongs to this stage.

Class 2. *Chobham Ridges type.*

The gravels of this class largely consist of subangular brown flints, but there is not the abundance of large flints which are found at Upper Hale. In those pits men are constantly seen with hammers breaking up the great stones, but in the other gravel-pits in the Southern Drift, at least in the district with which I am dealing, the hammer is not often used, and large stones are often thrown aside and left in the pit. Besides subangular flints, gravels of the Chobham Ridges type contain flint-pebbles, chert, and small quartz-pebbles, and it is the presence of the chert and the abundance of small quartz-pebbles which distinguishes them from gravels of the Silchester type. On Sheet VIII. of the Geological Survey map, Drift edition, a line of red patches is seen extending from Cæsar's Camp near Easthampstead in the north to the Fox Hills in the south; these patches clearly represent what was once a great plateau and originally part of the valley of a river flowing northwards from the Wealden country. Its southern end is drawn in fig. 1 (p. 31) in outline to show its relation to the other gravels. The surface of this great plateau, which will be referred to in this paper as the Chobham Ridges plateau, is remarkably flat, as one may gather from the following figures, which give the height above Ordnance datum:—Easthampstead Plain 408 to 423 feet, Deer Rock and Penny Hills 415 to 420 feet, Chobham Ridges 376 to 426 feet, Fox Hills, Aldershot, 350 to 390 feet.[3]

On referring to Prof. Prestwich's section, fig. 2, it will be seen that he brings Chavey Down into alignment with the Chobham

[1] See Proc. Geol. Assoc. vol. x. (1887) p. 185.
[2] See Prestwich, Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 157.
[3] Descriptions of the gravels on this plateau by Prof. T. Rupert Jones and Dr. A. Irving will be found in Proc. Geol. Assoc. vol. vi. (1880) pp. 329, 438, vol. viii. (1883) p. 161, and Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 557.

Ridges plateau, but I am inclined to look upon the gravels of the former as of a more recent date than those of the latter, as I will explain presently. Gravel-pit Hill, described by Prof. Prestwich,[1] is a northern spur of Easthampstead Plain, and gravel has been dug there for many years. A few years ago a new pit was opened on this hill at 400 feet above O.D., and in it I have found two boulders of a kind extremely rare in the Southern Drift.

The first was found in 1889, and exhibited at a meeting of the Geological Society on Dec. 18 of that year. Dr. A. Irving has since[2] expressed an opinion that it did not come from the gravel, because I had not found it actually in place, but on a heap of gravel prepared for carting away. As, however, the pit is far out on the moor, away from railways, roads, and even cultivated fields or houses, I for my part have no doubt about it; of course, I should have preferred to find the boulder *in situ*. It is a mass of white vein-quartz which has been broken across diagonally before being embedded in the gravel, and retains externally the bright yellow colour of the gravel. It has portions of irony sand 'pan' adhering to it, showing conclusively that it did not come from the top sand or surface-bed, everything in which is bleached.[3] The boulder measures $6\frac{1}{2} \times 5\frac{3}{4} \times 3\frac{3}{4}$ inches, and its weight is 6 lb. $9\frac{1}{2}$ oz.

The second boulder was found by me some time afterwards lying on the floor of the pit; evidently it had been recently dug out, and its yellow colour and marks of 'pan' show clearly that it was embedded in the gravel. It is not broken, and appears to be a white quartzite, though not a sarsen-stone. It measures $6\frac{3}{4} \times 6 \times 3\frac{1}{2}$ inches, and its weight is 7 lb. $4\frac{1}{2}$ oz.

By the kindness of Col. Cooper King and Prof. Rupert Jones a third boulder was exhibited on reading the present paper. It was found in Col. Cooper King's garden at Camberley in what was (so far as he knew) untouched gravel, but near the surface, and it is consequently bleached. The gravel is one of the terraces or benches on the side of the great plateau. The boulder is of white vein-quartz sheared and recemented; it has been rolled and broken across diagonally in the same manner as the first one, and measures $4\frac{1}{2} \times 4 \times 2\frac{3}{4}$ inches; its weight is 2 lb. $9\frac{3}{4}$ oz.

I saw a fourth boulder of white vein-quartz in the gravel-pit on Ascot Racecourse; it was bleached and lay on a heap of gravel. Measurement: $3 \times 3 \times 2\frac{1}{2}$ inches.

Though I look upon the occurrence of these boulders as interesting, I do not found any argument upon them, and it may be added that the gravel has no resemblance to the Glacial Gravel, whether they come from it or not. Small quartz-pebbles up to $\frac{1}{2}$ inch are common, but I have found none on this plateau measuring as much as an inch in length or $\frac{1}{4}$ oz. in weight.

The large blocks of sandstone called sarsen- or sarsden-stones are

[1] Quart. Journ. Geol. Soc. vol. xlvi. pp. 160, 161, fig. 2.

[2] *Ibid.* p. 558.

[3] See Prof. Prestwich's fig. 2, *ibid.* p. 161, in which the bleached portion is very well shown.

abundant in this gravel, and have been fully described by Prof. T. Rupert Jones and Dr. A. Irving. The largest that the writer has seen was, and probably still is, in a pit 374 feet above O.D., a little east of Round Butt at the southern end of Chobham Ridges, the section in which was as follows :—

1. Earth, 2 feet.
2. False-bedded sand with small stones, 4 feet.
3. Gravel, fairly well stratified, 3 feet shown.

The sarsen-stone probably rested wholly or partly on Upper Bagshot Sand below the gravel, for it extended through bed 3 up into bed 2. It sloped slightly to the east, and although a fragment had been broken off, measured 14 feet 4 inches × 11 feet 9 inches × 4 feet. Close to it was a smaller stone also with an easterly slope. Both were waterworn, as is the case with all sarsens the writer has seen.

I have examined a number of samples from different pits on the great plateau, and the following is a fair example from Wagbullock Hill, 410 feet above O.D. on Easthampstead Plain :—

	Large material.	*Small material.*
Subangular flints	73·8 % of weight.	41·9 % of weight.
Flint-pebbles	22·1 ,,	35·7 ,,
Chert	4·1 ,,	8·9 ,,
Quartz	0 ,,	13·4 ,,

The gravels of the great plateau are in most cases roughly stratified, and even where they are to all appearance without stratification slight signs of bedding are often seen if one obtains a good section through to the Bagshot Sand at a place where the gravel is thick. It seems probable that Dr. Irving has made too much of the question of stratification and contortion,[1] for in the first place the Glacial Gravels themselves are often beautifully stratified, and in the second the example of unstratified gravel at Broadmoor which Dr. Irving mentions[2] is not the only case. Thus there is a good example of a mottled unstratified gravel at 360 feet above O.D., at the southern end of Chobham Ridges, above Deep Cut Bridge. In the large pit 405 feet above O.D., a mile west of Rapley Farm, the upper part of the gravel is much contorted, and on Hartford Bridge Flats, 325 to 333 feet above O.D., to which I now pass on, the gravel is usually unstratified.

These Flats are covered with a sheet of Southern Drift next in importance to that of the great plateau. The diagram, fig. 1 (p. 31), cuts through the eastern end, where the ridge is 325 feet above O.D. or 37 feet lower than Crawley Hill, the nearest spur of the great plateau, and numerous pits and sections occur all along the Flats from 305 to 333 feet above O.D. They show gravel often 11 feet or more thick, usually mottled dark red and white, somewhat clayey, with very little sign of stratification except perhaps

[1] *Op. cit.* p. 561. [2] *Loc. cit.* note.

quite near the bottom. The upper part is frequently much contorted, masses of sand running into it in a most fantastic manner to 6 or 7 feet from the surface of the ground. In composition the gravel resembles that of the great plateau.

Finchampstead Ridges, to the north of Hartford Bridge Flats and about the same altitude, 300 to 333 feet above O.D., is also capped by gravel which, though not mentioned by Prof. Prestwich, doubtless belongs to his Southern Drift. The composition is similar to that of the Hartford Bridge Flats gravel, and it is no doubt of nearly the same age.

I have now dealt with all the large patches of Southern Drift in the Bagshot Heath country, but there is still a series of hills capped with gravel which resembles that of the Chobham Ridges plateau, but contains a far larger proportion of chert. Thus the hills at Windlesham named Pibs Down and Long Down (Pears Hill), 310 feet above O.D., are capped by a very sandy gravel in which about half the stones are chert, and the hills near Ascot are capped with a similar gravel. The writer saw no section at the Soldiers' Pillar (Bowledge Hill), 309 feet above O.D., as it is enclosed, and Goathurst Hill (Goater's Hill), 320 feet above O.D., is overgrown; but I have seen a good section on Chavey Down at 302 feet above O.D., and I believe the gravel on all the Ascot hills is of much the same character. The section showed 3 feet of mottled red and white gravel and sand in irregular patches, very clayey in one place. The gravel consisted of subangular flints and flint-pebbles in about equal quantity, with a good deal of chert and several sarsen-stones, the largest of which was $3 \times 2\frac{1}{2}$ feet. There was also a great number of small pebbles and fragments of quartz up to $\frac{9}{10}$ inch in longest diameter. Another pit, 1166 yards to the east at Burleigh, close to the Schools, mapped as valley-gravel, showed a section in very sandy gravel with abundance of chert, well stratified with much current-bedding. This was at rather a lower level.

The gravel on these hills certainly resembles the sandy and cherty gravel of Windlesham more than the gravel of the Chobham Ridges plateau, and the altitude is nearly 100 feet lower. Prof. Prestwich notes the difference in composition,[1] but his diagrammatic section seems to imply that the two gravels are of the same age; I, however, look upon the Chavey Down gravel as the more recent. Farther west Wick Hill, near Bracknell, 276 feet above O.D., Coppid Beech Lane, 270 to 302 feet above O.D., and Bearwood, 274 feet above O.D., are all capped by this gravel with abundance of chert. A sample of small stuff from the pit at 300 feet above O.D., Coppid Beech Lane, gave the following result:—

Subangular flints	25 % of weight.
Flint-pebbles	24 ,,
Chert-fragments	34 ,,
Quartz, small	15 ,,
Bagshot irony concretions	$1\frac{1}{2}$,,

[1] See Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 100, and pl. vii. fig. 2.

There are several pits in this hill; the gravel in that at the highest point, 300 feet above O.D., is unstratified, but at the end above Amen Corner, about 280 feet above O.D., it is very sandy, well stratified, with current-bedding and over 11 feet thick. It is not easy to say whether these patches of gravel with much chert from Windlesham to Bearwood are contemporaneous or not, but I am inclined to think that they are of much the same age as that of Hartford Bridge Flats.

I now pass on to gravels in Sheet XII. of the Geological Survey map, of which no edition showing drift is as yet published, and I therefore give a sketch-map (p. 38) to show the boundary of the Southern Drift of Class 2. A line between the gravel with and that without chert would run from the north-west towards the south-east in an irregular manner quite regardless of the recent river-system. Farley Hill, 260 to 270 feet above O.D., Heckfield Heath, 270 feet above O.D., and Hazeley Heath, 270 to 288 feet above O.D., are plateaux capped with very cherty gravel of the Southern Drift, whilst Spencerwood Common, 230 feet above O.D., and Riseley Common, 152 feet above O.D., are also covered with cherty gravel, and may be considered as valley gravels derived from the Southern Drift.

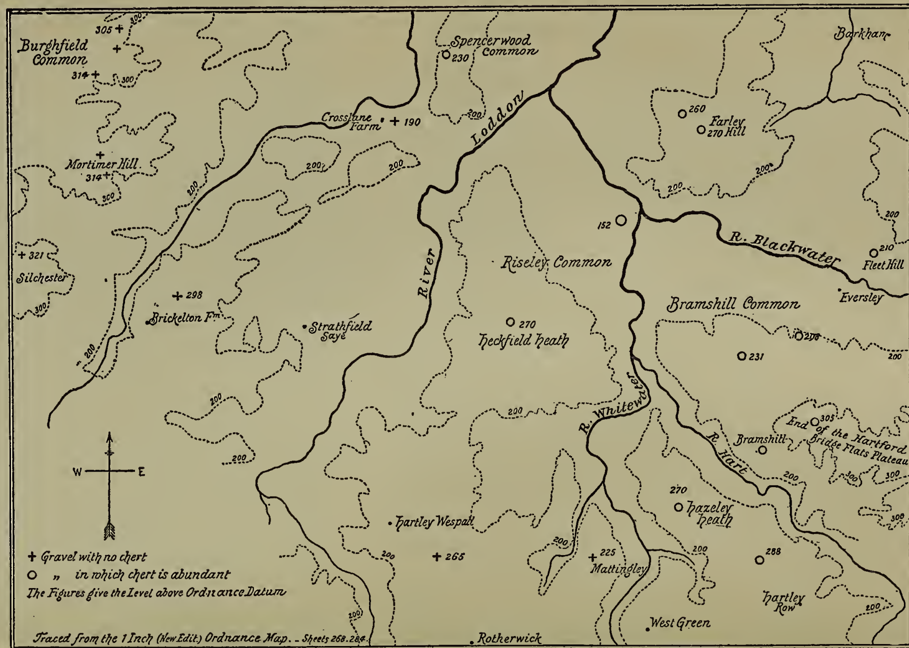
Such are the gravels with chert of Class 2. It may well be that a river flowing from out of the Wealden area laid down the gravels of the great Chobham Ridges plateau, and then cut its channel westwards, the result being the gravels at lower levels of Hartford Bridge Flats, Finchampstead Ridges, Hazeley Heath, Heckfield Heath, and Farley Hill.

Class 3. *Silchester type.*

In this class I include a series of gravels which are distinguished from Class 2 by an absence or great rarity of chert, and from both Classes 1 and 2 by a great scarcity of small pebbles or fragments of quartz. Farley Hill, Heckfield Heath, and Hazeley Heath are good examples of the gravel with chert, and the plateau on a spur of which Silchester stands is the type of a gravel without chert; but between these places there are many hill- and valley-gravels which form a sort of debatable land between the gravel with and the gravel without chert. (See sketch-map, p. 38.) Spencerwood Common, 230 feet above O.D., is capped by a gravel with chert doubtless derived from the Farley Hill or Heckfield area. The gravel-pit near Crosslane Farm, $1\frac{3}{4}$ mile N.E. of Mortimer Station, 190 feet above O.D., on the other hand, shows a gravel in which I found no chert, so it must be derived from the Silchester side. The hill $1\frac{1}{4}$ mile S.W. of the same station, near Brickelton Farm, appears to be capped by gravel without chert, and is therefore an outlier of the Silchester plateau.

There are extensive pits in a valley-gravel without chert at Mattingley 225 feet above O.D., and the hills between Hartley Wespall and Rotherwick and at West Green are apparently capped by a

Sketch-map of the country round Heckfield.



Scale: 1 inch = 2 miles.

similar gravel, though it is true I found one chert pebble on a field near the former place, and there is no good section in gravel at the latter. At Shapley Heath, 319 feet above O.D., there is a patch of gravel in which chert is very scarce, but the gravel differs from that of Silchester, for it contains many small quartz-pebbles.

There is a considerable spread of gravel on Burtley Heath, near Hook, about 250 feet above O.D. It contains many large flints, and a sample of the smaller material gave the following result:—

a. Subangular flints	80 % of weight.
b. Flint-pebbles	11 ,,
c. Quartz	3 ,,
d. A sandstone pebble and some irony pebbles	5 ,,

Of these the subangular flints no doubt came from the Chalk or older gravels, whereas *b*, *c*, and *d* may all probably have come from the Reading Beds. I am inclined to think that this gravel and that of Mattingley have nothing to do with the Southern Drift of the hills, but were brought from the Chalk country to the south at a much more recent date. In any case all the materials occur in the present drainage-area of the Whitewater, along whose valley this gravel lies.

The Silchester plateau is of great extent and varies from about 280 to 328 feet above O.D. The fields round the walls of the Roman town are covered with gravel 321 feet above O.D. (see sketch-map, facing this page); and at Mortimer Hill, 314 feet above O.D., there are some pits about 3 feet deep with water at the bottom, the Bagshot Beds on which the gravel rests being very clayey. There are also pits on Burghfield Common, 305 to 314 feet above O.D. The gravel appears to be unstratified and 4 feet or so thick. A sample of smaller material from the pit 314 feet above O.D. had the following composition:—

Subangular flints very much decayed and broken				89 % of weight.
Flint-pebbles	,,	,,	,,	8 ,, ,,
Quartz-pebbles	,,	,,	,,	3 ,, ,,

I found no chert on this plateau, and there are very few small quartz-pebbles, one or two occurring here and there. Mr. J. H. Blake found one at Mortimer Hill 1·2 inches long and over ½ oz. in weight, and there are a few pieces of the flinty variety of sarsen-stone mentioned by Prof. Prestwich.[1]

Across the River Kennet there is an extensive plateau, the greater part of which is known as Bucklebury Common, 300 to 446 feet above O.D. It is not mentioned by Prof. Prestwich, but appears to be capped by a gravel of the Silchester type. There is a pit close to the Union Workhouse, south of Bradfield, 310 feet above O.D., which shows 10 feet of yellow and ochreous gravel, the lower part of which is stratified. It consists of subangular flints and flint-pebbles. I found no chert, no quartzites of the Glacial Gravel type, and very few pebbles or fragments of quartz. The western end

[1] *Op. cit.* p. 162.

of this long ridge attains a height of over 500 feet at the old camp called Grimsbury Castle, and there is a small pit at the fork of the road 5 furlongs south of the "Castle." Subangular flints, very much worn, broken, and decayed, and flint-pebbles form nearly the whole of the gravel. There are a few fragments of flinty sarsen similar to that which I noticed on the Silchester plateau.

The next gravel-capped hills to the west are Snelsmere East Common and Snelsmere Common, but it is not proposed to include them in the present paper. My survey of the Southern Drift is, therefore, now completed. It will be seen that I have followed Prof. Prestwich pretty closely,[1] though I have ventured to include in the Southern Drift the gravels at several localities which he does not mention.

II. The Westleton Shingle.

This is the Pebble Gravel of the Geological Survey map. Its classification with the shingle at Southwold and Westleton was, I believe, first suggested in print by Mr. Whitaker in his 'Guide to the Geology of London,' 3rd ed. (1880) p. 57.

Bowsey Hill, 467 feet above O.D., and Ashley Hill, over 400 feet above O.D., close to it, are capped by this gravel. There are a good many subangular flints, but it consists mainly of flint and quartz-pebbles, and is very different from the Southern Drift above described at Coppid Beech Lane, 300 feet above O.D., and 7¼ miles to the south. If, as Prof. Prestwich thinks, the Southern Drift now at the lower level is the older of the two, great northerly elevation must have taken place since both were deposited.

III. Glacial Gravels.

The Tilehurst plateau, 290 to 341 feet above O.D.,[2] between the Rivers Kennet and Thames, a little west of Reading, is in my opinion capped by an outlier of the great stretch of Glacial Gravel which extends northwards from Caversham on the opposite side of the Thames. I base my opinion that this is Glacial Gravel on its character as a plateau-gravel, taken together with its composition, in which it differs greatly from the other classes of gravel; thus pebbles of red quartzite, weighing over ½ lb., are abundant. I also think that when the gravel was formed the present valley of the Thames above Reading cannot have been in existence. The reader will probably agree that this gravel is not older than the climax of the Glacial Period, and, as the valley through which the Thames flows above Reading is now about 160 feet deep, one can form some idea of the amount of denudation which has taken place since that time.[3]

[1] See his account of the district, *op. cit.* pp. 159–162.
[2] See O. A. Shrubsole, *ibid.* p. 589, § 2, Norcot Brickyard.
[3] *Cf.* Prestwich, *ibid.* p. 149, fig. 13.

If this is Glacial Gravel, it is also clear that Tilehurst is close to the original boundary of that formation; for all around, excepting on the north, are plateaux nearly the same height above the sea, but capped with Southern Drift, which is older than the Glacial Gravel, and would have been covered by it had it extended so far. Thus, about $3\frac{1}{3}$ miles to the west is the pit 310 feet above O.D. near Bradfield; across the Kennet, to the south, only $3\frac{3}{4}$ miles off, are the pits on Burghfield Common 314 feet above O.D., and some 7 miles away on the south-east is Bearwood, 274 feet above O.D. All these localities have been described above, and at none of them have I found a single red quartzite-pebble.

Not only are the red quartzite-pebbles absent from the plateau-gravels, but except in the immediate neighbourhood of the Thames they are not found in the valley-gravels. This seems to me a very serious difficulty in the way of those who argue for the presence of the sea in this part of the Thames Valley in Glacial times; indeed, none of the facts just given seem to harmonize with what I may call "the Thames Straits theory" advocated by Dr. Irving.[1]

IV. Gravels of the Valleys, Terraces, and Minor Plateaux.

It is probable that the rivers flowing from the Wealden area and from the Chalk country west of it, to which the Southern Drift is due, continued to exist after the plateaux above described were formed, and that some of the gravels of the terraces and minor plateaux were also formed by them. Indeed, if I am right in holding that the sea has not flowed over this part of the country since the plateau-gravels were deposited, this must be so, the present rivers being in some complicated manner truly descended from the original streams which began their course as the country was for the last time raised out of the sea.

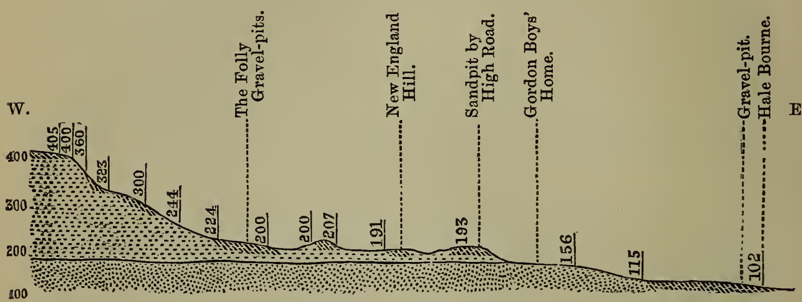
The division between plateau-gravels and river- and valley-gravels is consequently an arbitrary one, but in part of the area at least it has a real value, for the streams which formed the gravel of the high plateaux drained an area in the Weald, outside the drainage-system of the present rivers of the district. In the west, however, all the materials forming the gravels of Silchester and Bucklebury Common might be obtained from the Chalk and Tertiary formations of the present drainage-area of the River Kennet.

As a rule, however, the gravels of the terraces, valleys, and minor plateaux have been derived from the immediate neighbourhood. This is very clearly shown in the following example on the eastern side of Chobham Ridges, where there is an excellent series of sections on the Lightwater Road. The diagram (fig. 3, p. 42) shows the relative position of these sections. It extends from the great plateau of Chobham Ridges down one of the lateral valleys to the stream named the Hale Bourne, which flows through Chobham village. At the top of the ridge a road-cutting 400 feet above O.D.

[1] *Op. cit.* p. 561.

shows the Southern Drift, 6 feet thick, resting on Upper Bagshot Sand. At 360 feet above O.D. there is a small patch of gravel probably washed down from above at a very recent period. At 300 feet above O.D. there is rather a larger patch, and to the north of the line of section and not shown in it is a gravel-capped hill, 300 to 320 feet above O.D., forming a minor ridge. It is at the foot of White Hill, close to Folly Cottage, and is not mapped. The gravel is 8 feet or more thick, and of the same character as the

Fig. 3.—*Section from Chobham Ridges to the Hale Bourne, near Chobham.*



Horizontal scale: 1 inch=1 mile. Vertical scale: 1 inch=440 feet.

[The figures indicate levels above O.D.]

For symbols, see fig. 1, p. 31.

Southern Drift. I noticed two sarsen-stones in it, one 2 feet long with 2 feet of gravel below, and 5 feet above it the other, $1\frac{1}{2}$ feet long, only 2 feet from the surface. Both were tilted towards Chobham Ridges. I look upon this as merely a gravel derived from the Southern Drift which caps the Ridges. Lower down there is the large patch of gravel, 200 to 224 feet above O.D., shown on the Geological Survey map and in the diagram (fig. 3). The section, just one mile west of the sign-post at the top of Chobham Ridges, is as follows:—

Peaty soil, 9 to 13 inches.
Yellow and greenish sand, no doubt washed down from the Upper Bagshot Beds, 14 to 34 inches.
Gravel, 18 to 25 inches.

In the gravel are many sarsen-stones, bits of ironstone from the Southern Drift, and a number of ferruginous concretions, some of which are casts of univalve and bivalve shells from the Upper Bagshot Beds.

A little farther east there is a low plateau or collection of mound-like hills 190 to 207 feet above O.D., called New England Hill on the Geological Survey map, Sheet VIII. These hills are capped with gravel, and a section is seen in the sandpit by the side of the high road close to the Gordon Boys' Home (not marked on the map). It is as follows:—

1. Gravel—Surface-bed of red and green mottled gravel resting irregularly on—
   Yellow sand with layers and patches of stones, green sand in places, 8 feet.
2. Yellow sand—Upper Bagshot.

A sample from one of the layers of stones in bed 1 contained 10·8 per cent. in weight of irony concretions from the Upper Bagshot, and Mr. R. S. Herries and the writer found several casts of shells in place in this gravel, all obviously derived from that formation. We could not find any of these casts in the Upper Bagshot, bed 2 in this pit, and there can be little doubt that they come from the higher beds which originally existed between this hill and Chobham Ridges, two miles to the east, such casts being common near the top of the Ridges.

The pebble-bed which forms the base of the Upper Bagshot crops out near here, and consequently the sheet of gravel at the side of the present stream (Hale Bourne) is very pebbly. There is a pit 102 feet above O.D. close to Clapper's Farm, as shown in fig. 3, facing this page.

Accumulations of sand such as that just described are very common in the Bagshot country and may easily be mistaken for the Bagshot Beds themselves. A very good example near Walton is described by Mr. Hudleston,[1] and there is another near Addlestone Station, where the Lower Bagshots are exposed in a cutting bedded horizontally, while at the station-end of the section they are cut off by a sandy drift very irregularly bedded. The best example of this sandy drift which I have seen is in the great sandpit at Chavey Down, where the section is as follows:—

1. Earth; few stones; a little gravel in places............ 2 ft.
2. Sandy Drift .... 4 ft. 6 in. to 8 ft.
   consisting of—
   a. Irregularly bedded yellow and white sand.
   b. Sand full of blocks of yellow and white sand and bits of clay lying at all angles; one of these blocks measured 1 ft. 8 in. × 10 in.
3. Lower Bagshot. Yellow sand with numerous clay laminæ, with irony concretions; bedding nearly horizontal, but slightly curved under the Drift at the north-western edge of the pit.

The sand-bed 2 does not cap the hill, but rests on its north-western face, and its top is about 290 feet above O.D. The blocks of sand contained in it are clearly derived from the Lower Bagshot Beds, and I should say the whole is of Glacial origin, but do not pretend to decide on the exact process of its formation.

There is a somewhat similar deposit in the Brick and Tile Company's brickyard, north of Bracknell, which I at one time thought was Bagshot Sand, but which Dr. Irving rightly calls gravel.[2] I do not, however, follow that author in his views as to the lacustrine

[1] Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 152.
[2] *Ibid.* vol. xlvi. (1890) p. 562.

deposits of hypothetical extra-morainic lakes near Warfield and Finchampstead. If I rightly understand to what beds he refers, I should say they are Bagshot Beds, and in this view Mr. R. S. Herries concurs.

Irony concretions from the Bagshot Beds constantly occur in the gravels of the Bagshot country, but it is not often that they can be identified as casts of shells as in the instance already given. In the pit in Lower Bagshot Sand, close to Easthampstead Church, the sand is overlain by gravel full of these Bagshot concretions, and amongst them I found a portion of a cast of a univalve, no doubt a relic of the Middle Bagshot Beds which once existed there.

The derivation of the minor plateau- and terrace-gravels from the gravel of higher plateaux in the immediate neighbourhood is particularly clear where two classes of plateau-gravel approach one another. Thus, in fig. 1, p. 31, there is the gravel of Upper Hale with very little chert, and that of the great plateau and Hartford Bridge Flats with abundance of chert; so the derivative gravel of Miles Hill and the Fleet Pond plateau has little chert, for it was mainly derived from the Upper Hale gravel; while the rest of the terrace- and valley-gravels have abundance of chert, for they were derived from Hartford Bridge Flats or from the great plateau.

I have already described a similar example where the gravels of the classes 2 and 3 of the Southern Drift approach one another near Silchester, and we see the same thing in the Thames Valley near Reading. I made a rough examination of a sample of smaller material from the gravel-pit close to the mouth of the River Kennet and found it to consist of:—

a. Subangular flints from the Chalk, Southern Drift, or older gravels	43 °/₀	of total weight.	
b. Chalk-pebbles and fragments from the Chalk	10	„	„
c. Flint-pebbles from Tertiary pebble-beds or older gravels	2	„	„
d. Quartz from Tertiary pebble-beds or older gravels	8	„	„
e. Quartzite-pebbles from the Glacial Gravel	1	„	„
f. Fragments of ironstone, fragments of fossils from the Oxford Clay or Oolitic rocks, possibly derived from Glacial Gravel	17	„	„
g. Bits of *Ostrea* and other shells in sandstone from the Tertiary Beds of Reading	19	„	„

Amongst the larger material are many quartzites and fragments of old rock from the Glacial Gravel. Many of these stones have originally come from a distance, but the whole of them may have been derived for this gravel from the Chalk, Tertiary Beds, and older gravels of the present drainage-area of the Thames, and indeed from the immediate neighbourhood.

The Glacial Gravels are found in place at 314 feet above O.D. on the Tilehurst plateau, and at various levels up to 500 feet above O.D. on the northern side of the Thames Valley. Now, if the sea has flowed in the Thames Valley since these gravels were deposited, we surely should find débris from the Glacial Gravel in the valley of the Loddon and its tributaries to the south, whereas in fact this is not the case. I have visited a number of localities with a view to see how far south of the Thames in the Reading district such débris have been spread. Plenty of quartz and quartzite-pebbles up to $4\frac{1}{2}$ inches in longest diameter were to be found in the gravel-pit $3\frac{3}{4}$ miles from Reading on the Twyford road, and pebbles of a similar kind occur near Earley Court. But even as near the Thames as the gravel-pit by the railway $\frac{1}{4}$ mile N.W. of Earley Station I found no signs of Glacial débris, the gravel being composed of the usual subangular flints, flint-pebbles, chert, and small quartz-pebbles from the Southern Drift. I therefore feel forced to reject the theory which assigns the contortions observed in clay-beds near Wokingham to bergs or floes of ice which floated in waters that filled the valley up to 240 feet above O.D.[1]

In conclusion, the theory which I have adopted is that all the gravels in the area here dealt with were formed after it had for the last time risen above the sea. As soon as denudation began valleys were formed and gravels spread out in them. By degrees the sides of the valleys were destroyed, the gravel came to protect the ground on which it lay, and so stood out as a hill.[2] Then the gravel itself was attacked and carried down by degrees to lower levels, where it was again spread out and again protected the ground on which it lay, becoming a terrace, a spur, or a minor plateau, and thus the process has been repeated even to the present day.

I also believe that the Glacial Gravels in the area dealt with never extend more than a mile or two south of Reading, and that none of the gravels in that area are of marine origin.

Discussion.

The Chairman, whilst complimenting the Author on his analysis of the Southern Plateau-gravels, observed that there was at least one point wherein Mr. Monckton agreed with his persistent opponent, Dr. Irving, viz., in the belief in their fluviatile origin. He doubted if there was anyone present likely to contest that view. As regards West Surrey such had always seemed to him the most probable hypothesis, and he had pointed out how, through the operations of nature, the shallow valley-expanse of one period had become the gravel-capped hill of another. The Southern Gravels under this new test seemed, on the whole, still to retain their local origin independent of Northern Drift and of foreign materials; but he could not help regarding with a certain degree of uneasiness the three quartzose boulders on the table. Mr. Monckton had not, so far as he gathered, ventured to draw any inference from their presence.

[1] Dr. A. Irving, Proc. Geol. Assoc. vol. xi. (1890) p. clx.

[2] See T. Rupert Jones, Proc. Geol. Assoc. vol. vi. (1880) p. 438; A. Irving, *ibid.* vol. viii. (1883) p. 161; Monckton & Herries, *ibid.* vol. xi. (1889) p. 23; W. H. Hudleston, *ibid.* vol. xii. (1891) p. 100.

One of them was said to be bleached, which pointed to the action of peat.

Mr. W. Whitaker said that the paper was an outcome of that lately read to the Society by Prof. Prestwich, which he thought was a highly suggestive one, and likely to lead to such good supplementary work as this. The sudden way in which a gravel that contains a large number of northern stones gives way to another that contains hardly any such, but a large number of southern ones, is remarkable, especially as the two gravels occupy like positions and at like levels.

He regarded the small quartz-boulders as coming from the Plateau-gravel, as there seemed to be nothing else from which they could come; moreover, one of them seemed to have come from the bottom of the deposit, one side having the dark colour of the gravel, and the other side being of a light colour, as if it had rested on the Bagshot Sand.

Whether the Author was altogether right in referring all the gravels to river-origin was perhaps questionable. Many of them contained no trace of any organisms; but though this was the case with those classed as Westleton Beds, it should be remembered that where the pebbly gravels of that age did contain fossils, these were decidedly marine.

He wished to state that the classification, by the Geological Survey, of various high-lying gravels as Plateau-gravels was often akin to a confession of ignorance. In the absence of evidence that can settle their age, it is useful to have a class for the reception of such doubtful beds, which, whilst not pledging one as to age, clearly indicates position.

Dr. Hicks suggested that some of the boulders referred to may have been deposited by floating ice in a lake formed by the damming up of some part of the Thames Valley by ice and drift. The recent discovery of chalky Boulder Clay at a low level in the Thames Valley proves conclusively that parts at least of the Valley had, as he had previously contended, been scooped out before the close of the Glacial period.

Mr. R. S. Herries thought there was no reason to suppose that the various sheets of Plateau-gravel on either side of the Blackwater had ever been continuous. That being so, he thought their elongated shape was evidence of their fluviatile origin. The materials of which they were composed strengthened this opinion. The Westleton shingles were very different, and more likely marine.

Prof. Grenville Cole pointed out, in reference to Mr. Monckton's discovery of pebbles of chalk in the Reading Gravels, how in some areas, as at Headley in Surrey, decayed flints may easily be mistaken in the field for chalk.

Mr. Monckton, in reply, said that he had worked on the lines laid down by Prof. Prestwich, and had attempted to fill in details. He agreed with what Mr. Whitaker had said as to the existence of a bleached bed at the top of the gravels, and he compared it to the "top sand" described by Mr. Hudleston at Walton Heath. He thought it very probable that, as Mr. Whitaker had suggested, the white surface of the quartz-boulder had rested on Bagshot Sand, and the brown side had been in the gravel. As to the age of the gravels he considered that the Upper Hale Gravel was the oldest, and that the Chobham Ridges and Silchester Gravels were probably nearly contemporaneous.

4. *The* Bagshot Beds *of* Bagshot Heath. By Horace W. Monckton, Esq., F.G.S. (Read December 23, 1891.)

In the 'Geological Magazine' for August 1891 Dr. Irving advocates the adoption of a twofold division of the beds of the Bagshot Series of the London Basin, and in the 'Proceedings of the Geologists' Association' for July 1891 Mr. Hudleston (p. 102) suggests a slight alteration in the system of subdivision at present adopted for that series. I must say I am opposed to these changes, and I may at once point out that Dr. Irving himself uses the terms "Middle Beds," "Middle Group," and "Lower and Middle Group" in the paper referred to—very good evidence, I think, of the practical convenience of the threefold division now in use.

I think that a good deal of the controversy which has arisen in relation to these beds is due to the unfortunate adoption by Dr. Irving of the well-section at Wellington College as the type, instead of the much more satisfactory section at Goldsworthy Hill originally adopted by Prof. Prestwich in 1847.[1] I call the well-section at Wellington College unsatisfactory for several reasons, one of which is that two accounts apparently of the same well are given in the 'Memoirs of the Geological Survey,' vol. iv. (1872) p. 425, which differ in material details. If they do both relate to the same well I should prefer the account given by Prof. Rupert Jones to that of the well-sinkers, even though they preserved a series of specimens.

There is one slight alteration which I think Dr. Irving, Mr. R. S. Herries, Lieut. Lyons, and myself are all agreed should be made in the classification in Prof. Prestwich's section at Goldsworthy Hill, viz., the top of the hill should be included in the Middle Bagshot—for remains of the Upper Bagshot basement pebble-bed occur on Hook Heath close by.[2] With this amendment we have three very well-defined divisions of the Bagshot Beds:—

1. Upper Bagshot.—Entirely sand, with a pebble-bed at the base; marine shells of Lower Barton age abundant in places; 228 feet or more thick at Chobham Ridges.
2. Middle Bagshot.—Clays, and yellow and green sands with pebbles and marine shells of Bracklesham age (locally abundant); about 50 feet thick at Goldsworthy.
3. Lower Bagshot.—Yellow sands with irregular argillaceous beds; no fossils except plants yet satisfactorily recorded in the area south of the Thames; 130 feet thick at Goldsworthy, but of very variable thickness elsewhere.

The greater part of the controversy relating to the Bagshot Beds refers to the dividing line between the Middle and Lower Bagshot, and this perhaps is *mainly* due to the adoption of a well-section as a type where the junction line cannot be studied, in preference to Goldsworthy Hill, where it can. It is shown at that place in a

[1] Quart. Journ. Geol. Soc. vol. iii. p. 382, fig. 3.

[2] See Lyons, Quart. Journ. Geol. Soc. vol. xlv. (1889) pl. xxi.; Monckton and Herries, Proc. Geol. Assoc. vol. xi. (1889) p. 16.

sandpit near the railway-cutting described by Mr. R. S. Herries and myself in 1886.[1]

Unfortunately, neither Dr. Irving nor Mr. Hudleston say definitely in what manner they would treat the Goldsworthy section, but I believe that Dr. Irving would include the whole hill in his 'Lower Freshwater Series,' *i. e.*, the Middle and Lower Bagshot combined, and that Mr. Hudleston would retain the name 'Middle Bagshot' for everything down to the bottom of bed 4 and place all below it (down to the London Clay) in the Lower Bagshot.

To readers who have not Prof. Prestwich's section at hand for reference the following extract may be useful:—

	feet.
"b. *Middle Bagshot Sands.*	
"1. Coarse greenish sand with a few flint pebbles	2
"2. Foliated sandy clays of various shades of brown	11
"3. Grey clay with traces of lignite	1
"4. Green sand; upper part light-coloured and clayey, the lower part pure and dark-coloured. Numerous teeth and bones of fishes and turtles, casts of *Turritella sulcifera* and *Venericardia planicosta*, &c.	16
"5. Compact lignite	1
"6. Light-coloured compact sandy clay, passing downwards into dark grey clay. The upper part is irregularly pierced with green sand-tubes	6
"7. Light and dark brown and liver-coloured very compact foliated clays, with traces of vegetable impressions	8
"c. *Lower Bagshot Sands.*	
Light yellow siliceous sands with irregular light-coloured argillaceous beds. Traces of vegetable impressions	130
"d. *London Clay* (upper part of)."	

Quart. Journ. Geol. Soc. vol. iii. (1847) pp. 382, 383.

No doubt Mr. Hudleston's suggestion has this advantage: it includes the clay with vegetable remains in the Lower Bagshot, which I think we all agree is of freshwater origin, and leaves the beds with the fish-remains and marine shells in a separate division. If it were possible to draw a satisfactory line at bed 5 I probably might not differ from Mr. Hudleston, but in my experience the clays of beds 6 and 7 are so intimately connected with the green sands containing marine shells that I feel bound to hold to Prof. Prestwich's line of division and include the clays 6 and 7 in the Middle Bagshot. The fact is that though more or less green sand always seems to occur in the position of bed 4, it is in beds of a very irregular shape, often running down into the underlying clays of bed 6, and in one instance at least temporarily vanishing altogether. The best illustration the writer has seen of the changeable character of these beds was on and near the railway between Ascot and Bagshot.

In the railway-cutting one mile south of Ascot Station there was about 9 feet of dark green sand with casts of shells in abundance,[2] and in the brick-field a little to the north-west, close to the bridge over the railway, the Middle Bagshot Beds have been dug for many

[1] Quart. Journ. Geol. Soc. vol. xlii. p. 414.
[2] W. H. Herries, Geol. Mag. for 1881, p. 171.

years. In 1870 the section seems to have shown 6 feet or more of green sand between two clay beds, the whole forming the Middle Bagshot, and resting on fine, nearly white sand, Lower Bagshot.[1]

About the end of September 1881, the workings had been carried farther into the hill to the west and showed:—

Northern end of Section.

	ft.	in.
Surface earth	0	6
1. Yellow laminated sand and clay	3	6
3. Green sand	7	0
	11	0

Southern end of Section.

	ft.	in.
Surface earth	1	0
1. Yellow laminated sand and clay	3	6
2. Yellow more clayey bed passing down into a finely laminated liver-coloured clay	6	6
4. Green laminated clay more or less sandy	3	6
	14	6

On Feb. 18, 1882, the writer visited the locality with Mr. R. H. Wright, who made a sketch of the northern face of the pit. The section showed:—

0\. Earth.
00\. Changed bed of yellow sandy clay, 2 ft. 6 in.
1\. Yellow and grey clay in laminæ evenly bedded with white and green sand from 7 ft. 4 in. on the east to 9 feet on the west, where there is a bed of light-coloured sand with very little clay at the base.
2\. The wedge-shaped bed of green sand 3 ft. 6 in. at the east end of the face and thinning away to nothing on the west, so that bed 1 rests on bed 3.
3\. Very dark, nearly black laminated clay, with a good deal of green sand in many places; the clay tinged red in places; bottom not shown. Much iron pyrites and traces of plant-remains.

The fine white sand of the Lower Bagshot was dug at a somewhat lower level. I visited the section in company with Dr. Irving on Aug. 19, 1887, and found it had been cut much farther back into the hill and was one of the finest sections of the Middle Bagshot I have seen. We made careful measurements, and the details have been published by Dr. Irving, Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 166. The wedge-shaped bed of green sand, which was 7 feet or more thick in 1881 and was seen to thin to nothing in 1882, doubtless represents the green sand full of casts of shells so well seen in the railway-cutting close by (to the S.E.), and the bed no. 4 of the Goldsworthy section. Besides this wedge-shaped bed there are many small patches and scattered grains of green sand throughout the Middle Bagshot Beds of the section, while green sand occurs in the Tower Hill brick-field to the west, and signs of it are found on the Ascot Hills to the north-west.

The writer ventures to suggest to Mr. Hudleston that an attempt to draw the line between the wedge of green sand and the dark clays which contain patches of green sand would be very unsatisfactory, and it is far better to include them, as Prof. Prestwich does, in the

[1] See Mem. Geol. Surv. vol. iv. (1872) p. 332.

Middle Bagshot, more especially as we find very similar unfossiliferous clays between the fossiliferous green sand-beds in the corresponding part of the Bracklesham Series at Whitecliff Bay in the Isle of Wight. With reference to Dr. Irving's proposal to include the Middle Bagshot of Prof. Prestwich in his 'Lower Freshwater Series,' I would point to the abundance of marine fossils in the green sand-bed at Ascot and Goldsworthy, and other places, nor does it seem to me that his reference to shells thrown on to new sand-banks by wind in the Rhone Delta [1] is really relevant to the point at issue. The casts of the large *Venericardia planicosta* and *Corbula gallica* are abundant in the Ascot cutting with valves closely shut, and therefore the probability is that they lived where we now find them.

Though Dr. Irving speaks of the fossil shells being broken and worn, he does not prove that they were so broken or worn before they were embedded, and I possess a cast of *Corbula gallica* from Ascot which tells the following history :—The shell was buried in the sand with its valves shut tight and unbroken. The shell was crushed and broken into fragments and afterwards destroyed; now the cast alone remains. Had the shell remained and not the cast it would have been in fragments, and Dr. Irving might have then called it broken and worn.

It may be added that the authorities of the Museum of Practical Geology, Jermyn St., have accepted the best part of my collection of Upper Bagshot fossils and also a set from the Middle Bagshot collected by Mr. Herries and myself.

The brick-field just described furnishes to my mind a very satisfactory answer to the argument used by Dr. Irving to prove the thinning out of the bed of green sand to the north of Wellington College. The argument is this:—The green sands, or 'green-earths' as he calls them, diminish in thickness from 36 feet in a well at Ambarrow near Wellington College, and 41 feet in the Wellington College well, to 18 feet one mile north of the former. Therefore, if we restore them northwards with a proportionate rate of attenuation, they will thin out altogether.[2] I do not know whether Dr. Irving would adopt the similar calculation that as the earths above alluded to are 36 feet thick at Ambarrow and have thickened to 41 feet at Wellington College 5 furlongs to the north-east, therefore at Bill Hill, Bracknell, 35 furlongs to the north-east, they will be 71 feet thick. Probably he would not, nor should I. In the first place, I must be allowed to doubt whether the 41 feet of green sand at Wellington College were wholly green sand, and the 36 feet at Ambarrow are, according to Dr. Irving's own section, largely made up of grey sand and clay; and secondly, looking at the irregularity in the shape and occurrence of beds of green sand at Ascot and other places, an argument such as Dr. Irving uses is hardly applicable to strata so variable.

[1] Geol. Mag. for 1891, p. 361.

[2] See 'Recent Contributions to the Stratigraphy of the later Eocenes of the London Basin,' by Dr. A. Irving, Wellington College, 1891, p. 7.

Dr. Irving, in his numerous papers, seems very anxious to prove an overlap of the Upper and Middle Bagshot Beds over the Lower Bagshot. At one time he suggested an overlap on to the London Clay, but, with the exception perhaps of Wokingham, he appears to have abandoned this contention so far as the Bagshot country is concerned.

The result of long-continued and careful investigation is that I am unable to find any existence in the Bagshot country of the overlap of either the Upper Bagshot Beds or of the Middle Bagshot Beds, but I am inclined to think that there are considerable variations in the thickness of the Lower Bagshot Beds, and to a certain extent also of the Middle Bagshot Beds.

In Dr. Irving's 1887 paper,[1] he criticizes the method which Mr. R. S. Herries and myself had adopted in 1886,[2] saying that underlying our method was the assumption that mere contiguity or proximity to the London Clay is evidence of Lower Bagshot horizons; but this can hardly be deemed quite correct. Our process consisted in taking admitted sections as types and comparing those in dispute with them. We found good sections of the junction between the Middle and Lower beds at Goldsworthy Hill and at St. Ann's Hill which are still open and in good order. The finest Lower Bagshot sections now open are, however, those in the railway-cutting and the sandpits at Redan Hill, Aldershot. In 1885 Dr. Irving had claimed them as Upper Bagshot, so that we were unable to refer to them as typical sections, but the evidence for their Lower Bagshot age is now so overwhelming that I find them at my service for that purpose.[3]

Three and a half miles to the north-east of Redan Hill, on the same line of railway, there are the finest sections in the country of Upper Bagshot Sand at and near Tunnel Hill, so that here we have two sets of excellent type-sections with which to compare those in question. Now, at first sight both the Redan Hill and the Tunnel Hill sections look like yellow sand—indeed so much alike are they that, as before said, Dr. Irving mistook that at Redan Hill for Upper Bagshot. But on careful examination it is seen that there are differences. Thus at Tunnel Hill (Upper Bagshot) there is little sign of stratification excepting in broad fairly even bands of variously-tinted sand, there is no false- or current-bedding nor any laminæ of clay, and there is an abundance of irony concretions which in places are casts or have impressions of shells. At Redan Hill and the adjoining pits (Lower Bagshot) there is much false- or current-bedding, clay laminæ are abundant in many places, and no cast of a shell has yet been found, though irony concretions are not uncommon.

In my experience and in that of Mr. R. S. Herries these characteristics are wonderfully persistent, and though they may not be infallible I should have the greatest hesitation in classing a false-bedded sand with pipeclay laminæ as Upper Bagshot, or in calling a

[1] Quart. Journ. Geol. Soc. vol. xliii. p. 374. [2] *Ibid.* vol. xlii. p. 402.
[3] *Ibid.* p. 410; *ibid.* vol. xliii. p. 431.

yellow sand full of casts of marine shells Lower Bagshot. In his paper of 1887 [1] and in his last paper,[2] Dr. Irving deals with this question; but, as a matter of fact, neither Mr. Herries nor I say that the presence of pipeclay seams is conclusive evidence of a Lower Bagshot horizon (see this Journal, vol. xliii. (1887) p. 378), but that it distinguishes the Lower from the Upper Bagshot—a very different thing.

I now propose to describe the localities in dispute:—

Farley Hill, mapped as Lower Bagshot, but claimed by Dr. Irving as probably Middle capped by Upper Bagshot.[3] He adds that further exploration is needed, and I was so fortunate as to find a small section at the top of the hill in a gravel-pit showing 6 feet of yellow Bagshot Sand with many white clay laminæ below the gravel. This is certainly not Upper Bagshot, and it proves there is none of that division on the hill. It is like ordinary Lower Bagshot, and though admitting that one or two sections in the Middle Bagshot not unlike it are to be found, still I should say that if it stands alone no one will hesitate to regard it as Lower Bagshot Sand.

Bearwood, mapped as Lower Bagshot. Described by Dr. Irving as "an outlier of Upper Bagshot Sands on London Clay,"[4] and shown in his diagram[5] as Upper Bagshot Sand with a pebble-bed at the base resting on London Clay.

On Aug. 25, 1887, I visited the locality in company with Dr. Irving, and he pointed out four places where he claimed Upper Bagshot Sand above the pebble-bed:—1, a hole in Coombe Wood; 2, the loamy sand above the pebble-bed in the pit of which a section is given;[6] 3, some small holes in a wood north of Birtle Heath; 4, a large sandpit near Dowles Farm.

On Jan. 15, 1888, I wrote to him expressing the opinion that the Dowles Farm sandpit was below the pebble-bed, and not 20 feet above it as he had thought, and was Lower Bagshot.[7] This Dr. Irving now admits,[8] and as the sands at Birtle Heath are clearly on the same horizon as the Dowles Farm pit, the only possible Upper Bagshot left is that in the hole in Coombe Wood and in the pebble-pit. But in both layers of whitish clay occur, and they are in my opinion clearly not of Upper Bagshot age.

Dr. Irving further says in his 'Recent Contributions,' p. 16, that there is Lower Bagshot Sand underlying the clays and pebble-bed shown in the diagram (*loc. supra cit.*).[9] The idea of an overlap here or of Upper Bagshot Sand resting on London Clay seems therefore to fall to the ground; but a difficult question remains, namely, whether the pebble-bed with the clayey beds both above and below

[1] Quart. Journ. Geol. Soc. vol. xliii. p. 378.
[2] 'Recent Contributions,' &c., 1891, p. 13.
[3] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 177.
[4] Geol. Mag. for 1887, p. 111.
[5] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 388, fig. 2.
[6] Geol. Mag. *tom. cit.* p. 116.
[7] *Ibid.* p. 114.
[8] 'Recent Contributions,' &c., 1891, p. 15.
[9] See also Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 176.

it may not be Middle Bagshot. The difficulty is increased by the existence of a somewhat similar bed of clay at the Hatch brickyard, described by Mr. Hudleston.[1] As, however, it will be shown later on that both blue clay and pebbles do occur in admittedly Lower Bagshot beds, there is no conclusive reason against the pebbles and clays here and the clays at the Hatch brickyard being of that age. Neither Mr. Herries nor the writer ever doubted that the Dowles Farm sandpit was Lower Bagshot. We never saw a Middle or Upper Bagshot section in any way resembling it.

Wokingham. I think that there is now no suggestion of Upper Bagshot here.

Coppid Beech Lane (also called Buckhurst). Mapped as Lower Bagshot; a considerable thickness of Upper Bagshot is shown in Dr. Irving's diagram in vol. xliii. of this Journal. See also p. 386 of that vol. There is a road-cutting extending nearly to the top of the hill showing yellow sand with clay laminæ, and there was last year an excellent section in a pit on the south side of the high road, just above Amen Corner, in a triangle formed by cross-roads. The section was as follows in September 1890:—

1. Gravel 4 feet, resting very irregularly on
2. Yellow and orange-coloured sand, very beautifully false-bedded, with many layers of white clay (Bagshot Beds), 5 feet.

The section was 150 feet long and a very good one. I never saw any bed like that shown in it in either the Upper or Middle Bagshot, and have no doubt that the whole hill is Lower Bagshot.

Bracknell. Mapped as Lower Bagshot, but Upper and Middle Bagshot are claimed here by Dr. Irving. The evidence appears to me clearly sufficient to show that there is no Upper Bagshot here, for there is green sand, either Middle Bagshot or débris of that formation, at the highest point, Bill Hill. It is possible, therefore, that a small Middle Bagshot outlier occurs there. Here, as in the other cases, I quite agree with Dr. Irving that it is more satisfactory to argue the question out on the ground than at a distance, and I have been over it again and again both alone and with Mr. W. H. Hudleston, Mr. J. H. Blake, and Mr. R. S. Herries. It is not easy to explain in a few words how very clear the matter really is when one walks from the Easthampstead Cæsar's Camp to Bracknell.

The green sands of the Middle Bagshot crop out above the 300-feet contour at Cæsar's Camp, there is no sign of them at Easthampstead Church hill, 285 feet above O.D., but at Bill Hill (Bracknell) we find some green sand at the top of the hill over 300 feet above O.D. This interesting fact was discovered by Mr. Herries in 1888, and independently by Mr. Whitaker, I believe, in 1890.[2]

Everything below the green sand of Bill Hill appears to be Lower Bagshot, and there are thoroughly satisfactory Lower Bag-

[1] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 448.
[2] *Ibid.* vol. xlvii. *Proc.* p. 4.

shot sections at Easthampstead Church, Bill Hill, and in the Bracknell railway-cutting.

The Ascot Hills, mapped as Lower Bagshot. In Dr. Irving's section (vol. xliii. of this Journal) he shows a great thickness of Upper Bagshot on these hills, the top of which he marks 'Goathurst Hill,' and in 1888 he says "the Ascot Hills have a capping of Upper [Bagshot] Sands, the base of which (about 300 feet O.D.) etc." [1] The result of my investigations is to convince me that there is no Upper Bagshot, but that there may very probably be a small patch of Middle Bagshot on Goathurst Hill, and possibly another on Long Hill. I feel, however, doubts about this, as it appears probable that the patches of green sand which do occur are remains of Middle Bagshot that once existed there but have been eroded away.

In 1890 I saw a satisfactory section in a new reservoir, at the *c* in 'Ascot Priory' on the new one-inch map, and a quarter of a mile south of the junction of the roads at Chavey Down, at the top of the hill, 320 feet above O.D. It showed a considerable thickness of gravel resting on yellow false-bedded sand, evidently the same bed as that shown in the large sandpits close at hand, the sections in which extend up to about 304 or 305 feet above O.D. The whole is very clearly Lower Bagshot. The top of Goathurst Hill, 667 yards N.E., is the same height as the reservoir, and on its western slope there was at one time a brick-field. In this old brick-field, 310 feet above O.D., Mr. Herries and I found (March 17, 1888) some green sand. I think it was not in place, but probably had come from the top of the hill, which is overgrown with vegetation. It is only the topmost 20 feet which is obscure, and part of it is gravel seen in old workings. There is no evidence of Upper Bagshot, but there is, I think, a small capping of Middle Bagshot. At the bottom of the hill to the north there is an excellent Lower Bagshot section, and there is another farther east opposite the Royal Kennels, Ascot, 275 feet above O.D. In the latter the clay layers are very well marked, and one is $3\frac{1}{2}$ inches thick.

The above evidence makes it clear that there is no overlap of the Upper Bagshot on the northern margin of Sheet VIII. of the Geological Survey map as claimed by Dr. Irving in the Geol. Mag. for 1887, p. 115 (2), nor any Upper Bagshot at Farley Hill,[2] at Bearwood, Coppid Beech Lane (Buckhurst), Bracknell, or Goathurst Hill, Ascot.[3] I admit that there may be Middle Bagshot capping the hills at Bracknell and Ascot. There is still the contention that Middle Bagshot exists at Farley Hill, Bearwood, Wokingham, Coppid Beech Lane, and Wick Hill, Bracknell, to be dealt with. Now, I admit that it is easier to distinguish between the Upper and Lower than between either of them and the Middle Bagshot. The question at present, however, is only between the Middle and Lower Bagshot, and I would point out, to begin with, that at none of the places above mentioned has any green sand been found. Not only are

[1] Quart. Journ. Geol. Soc. vol. xliv. p. 170.
[2] *Ibid.* p. 177.
[3] *Ibid.* vol. xliii. (1887) p. 388, diagram, fig. 2.

thick beds of green sand absent, but patches and pockets of green sand and even scattered green grains are wanting, yet these are all usually found in Middle Bagshot sections. But Middle Bagshot without green sand would no doubt be so like Lower Bagshot that perhaps we should fall back on the balance of probabilities; now, as the evidence of overlap elsewhere in this area has broken down, when we find a bed resting on London Clay which may be Middle or may be Lower Bagshot, I should say the balance is in favour of its Lower Bagshot age, and I deny that such a statement involves any *petitio principii.*

This question takes us back to the Wellington College well. Dr. Irving first described it in 1883,[1] and again with further details in 1885. On both occasions he described bed 14 as Bagshot or partly Bagshot, and in 1885 said "we seem to find a passage from the London Clay into the Bagshot Sands."[2] In his diagram in 1887,[3] he put bed 14 into the London Clay without giving reasons. He now says there is no evidence of a passage bed here.[4]

In the note on page 145 of the Proc. Geol. Assoc. vol. viii. (1883) he says that a new section of the first 30 feet of the well has been opened, and the pebbles in bed 6 are more abundant than in bed 3. But according to his figures bed 6 is 39 feet from the surface. I mention these points to show what an unsatisfactory type-section this is. One most important problem in connexion with this well-section is the location of the bottom of the Middle Bagshot, taking the Goldsworthy section as the type. Now, looking at Dr. Irving's latest account of the section ('Recent Contributions,' p. 11), it seems possible that the base of the Middle Bagshot is some 6 inches below the top of bed 10, and that the clay and sand below should be correlated with the Lower Bagshot of Goldsworthy.

North-west of Wellington College is the South Eastern Railway, where there are some sections which have been productive of much discussion. The following diagrammatic sections along it have been published:—

1. 1883, Monckton, Quart. Journ. Geol. Soc. vol. xxxix. p. 351. Dip as stated in the note is too high, making Middle Bagshot too thick; outcrop of various beds fairly correct.
2. 1883, Dr. Irving, Proc. Geol. Assoc. vol. viii. p. 150.
3. 1885, Dr. Irving, Quart. Journ. Geol. Soc. vol. xli. p. 498. In both these the pebble-bed 3 is shown north of the station, whereas I believe only débris of the pebble-bed occur there. Anticlinals are shown north and south of the Wellington College station wrongly, as I think.
4. 1886, Monckton and Herries, Quart. Journ. Geol. Soc. vol. xlii. p. 407. The dip north of the station is rather too high, as Dr. Irving has pointed out. The parts of the diagram where there were no sections were left blank, but the pits

[1] Proc. Geol. Assoc. vol. viii. p. 144.
[2] Quart. Journ. Geol. Soc. vol. xli. p. 495.
[3] *Ibid.* vol. xliii. p. 388, fig. 1.
[4] 'Recent Contributions,' p. 12.

described by Dr. Irving show that the clay no. 9 should be carried on northwards. This clay I believe to represent the bottom bed of the Middle Bagshot at Goldsworthy. On that point we are, I think, all agreed, and it is my belief that, so far as this diagram is concerned, the only difference between Dr. Irving and myself is whether this clay crops out south of the place where Mr. Herries and I have marked sand under the letter *d*, or whether it continues through the hill and crops out a little north of the letter *d*.

5. 1887, Dr. Irving, Quart. Journ. Geol. Soc. vol. xliii. p. 388, fig. 1. In this diagram the anticlinals both north and south of the station are given up and the bedding made horizontal, but I do not agree with this any more than with the supposition of anticlinals, for the bed of green sand is well seen in the cutting north of the station as shown in the diagram by Mr. Herries and myself in 1886, whereas Dr. Irving does not allow that it rises above the line. There is also a mistake at the words 'Nine-Mile Ride,' where the railway-cutting is drawn as gravel with a considerable thickness of Middle Bagshot beds below the level of the line; while in fact the railway-cutting is in Lower Bagshot sand capped by gravel, as has always been contended by Mr. J. H. Blake, Mr. R. S. Herries, and myself, and as Dr. Irving now admits ('Recent Contributions, &c.' p. 13, note B).

6. On Nov. 12th, 1890, Dr. Irving exhibited at the meeting of the Society a revised version of the sections along the South Eastern Railway. I regret to say that, owing to the smallness of the scale, I could not see it well enough when speaking to deal with it properly, and my remarks published in this Journal (vol. xlvii. *Proc.* p. 3) referred therefore to the diagram of 1887, no. 5 of the present list, which was also exhibited. At the meeting on June 10th, 1891, the new diagram was exhibited drawn to a large scale, and I took the opportunity of pointing out exactly how far I agreed with it. The chief difference between Dr. Irving and myself seemed to be that to which I have already alluded, viz. whether the basement-bed of the Middle Bagshot seen in the clay pit at the Old Roman Road crops out near the second signal-post north of Wellington College station, or whether it runs on somewhat farther north, and whether the beds at Wokingham are Lower Bagshot, as I think, or partly Middle Bagshot, as Dr. Irving contends. The sands in the well *d* in the diagram by Mr. Herries and myself[1] were certainly clayey, especially in the upper part, but I saw no clay like that in the claypit by the Roman Road. which is a little north of the figure 9 in that diagram. I admit also that there are some loamy sands at Wokingham, but the mere fact that clays occur is not by any means strong evidence against Lower Bagshot age.

[1] Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 407, fig. 1.

To prove the occurrence of clay in the Lower Bagshot I need only refer to the following sections; in addition to which I may remind geologists of the bed of pebbles underlain by blackish clay, so well shown in the railway-cutting at Virginia Water Station, which is undoubtedly Lower Bagshot, and is not at all unlike the Bearwood section.

Aldershot Well at D lines.—Lyons, Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 434.
Aldershot Town Brickyards.—Dr. Irving, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 501.
Ash.—Dr. Irving, Proc. Geol. Assoc. vol. ix. (1886) p. 415.
Brookwood Well.—Dr. Irving, Geol. Mag. for 1886, p. 353.
Goldsworthy Hill.—Prof. Prestwich, Quart. Journ. Geol. Soc. vol. iii. (1847) p. 382.
Walton Railway-cutting.—Mr. Hudleston, Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 157, fig. 5, bed 2.
Stroude.—Monckton and Herries, Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 404.

Now my contention is that all probability is in favour of the Lower Bagshots north of Wellington College containing clay beds as they do elsewhere, and that Dr. Irving is not justified in treating every clay bed he finds as Middle Bagshot and thus producing the alleged thinning-out of the Lower Bagshot Beds. I am inclined to think that, if the type-section at Goldsworthy be strictly adhered to, the Geological Survey map has given too great an extension to the Middle Bagshots in the Wellington College district, and that the clay bed worked for brickmaking at California, near Finchampstead, should be included in the Lower Bagshot. See Monckton and Herries, Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 409, fig. 2. In this instance Dr. Irving agrees with the mapping.

In conclusion I should like to say that it is not easy to explain in a short space the whole evidence relating to each of the numerous localities dealt with in this paper, but that I am always happy to go over the ground with those interested in the questions to which I have referred.

Discussion.

The Chairman remarked that the absence of any antagonist would preclude this paper from being fully discussed. As regards the alleged overlap or overlaps he had concluded that they were non-existent, and that if appearances seemed, in some cases, to justify such an interpretation, these were more likely to be due to lateral changes from clay to sand, or *vice versa*, in a series thus constituted. He never put forward the view to which the Author had alluded with any idea that it should replace the threefold division of the Bagshots, but simply to draw attention to the undoubted fact that there were two totally distinct series within the area—an upper fossiliferous one which was wholly marine, and a lower unfossiliferous one of probably freshwater origin. The curious way in which the sands and clays of this latter seem to replace each other has probably been the cause of so much divergence of opinion.

Mr. R. S. Herries thought that the chief difficulty in the way of drawing a line between the Middle and Lower Bagshots at the base of the green sands was the inconstant nature of these sands. The clays below them, on the other hand, were very constant and easily recognized, and therefore formed a convenient line of division.

5. *A* Comparison *of the* Red Rocks *of the* South Devon Coast *with those of the* Midland *and* Western Counties.

By Prof. Edward Hull, LL.D., F.R.S., F.G.S. (Read November 25, 1891.)

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I. Introduction.

In September last I found it possible to carry out a long-standing engagement with the Rev. Dr. Irving to visit South Devon in his company, and to form an opinion upon his views regarding the age and succession of the great series of red rocks which are exposed to view in such magnificent sections along the coast to the east and west of the estuary of the River Exe. On reading Dr. Irving's paper, published in this Journal in 1888, it appeared to me that he had gone very far towards establishing his proposition that the brecciated beds forming the base of the whole series, and resting discordantly on the Devonian rocks, were really the representatives of the Lower Permian breccias of the Midland and Western counties, but I was little prepared for the—I might almost say—overwhelming evidence that such is the case upon an examination of the coast sections extending from Oddicombe Bay to and beyond Teignmouth and Dawlish.

Having examined these basement-beds of the series, we continued our survey of the coast and inland sections of the succeeding strata eastwards to Sidmouth—terminating with the Keuper marls underlying the Cretaceous beds which form the cap of Salcombe Hill, and which break off in a lofty and precipitous cliff seawards; so that the whole structure of the ridge is laid open from the summit to the water's edge. The result of this *reconnaissance* has been to enable me to confirm in all the main points Dr. Irving's view, and to correlate the series with the Permian and Triassic succession as developed in the Midland and Western counties.

It is not my intention to do over again what has been so well done before, and describe the successive strata lying between the Devonian rocks of Torquay on the one hand and the Cretaceous beds of the coast east of Sidmouth on the other, further than is necessary to explain my reasons for supporting Dr. Irving's views with only one important (and somewhat doubtful) exception. Much less do I intend to enter into controversy with any previous writer on the age and relations of these red beds. Having had opportunities, through many years of Survey work, of becoming acquainted with the structure and details of the red rocks of the

Midland and Western counties, I have long felt that this work would be incomplete if I did not turn this experience to some account in attempting to correlate the generally representative series of Devonshire with that lying along the borders of Wales and extending into the Midland counties of England. The opportunity for so doing has at length been given, and I proceed as briefly as possible to summarize my conclusions.

The typical district with which, as it seems to me, the Devonshire sections are comparable in the northern area, is that lying along the Severn Valley in parts of Worcestershire and Salop, about Enville and Bridgenorth. The actual continuity of the series between the northern and southern areas has (as is well known) been interrupted by the Palæozoic ridge—which comes to light from beneath the Liassic and Oolitic beds in Somersetshire—composed mainly of Carboniferous rocks, and which in some places was never submerged during the whole Permian and Triassic periods. Under such conditions it would have been by no means surprising if the representative series to the north and south of this dividing ridge had been so different as to render any correlation of the members impossible. It is, therefore, with pleasurable surprise that one finds sufficient evidence in the succession and composition of the strata on both sides to admit of a general correlation of the whole series, with very few doubtful intervals, and amply sufficient to determine the relations of all the most important divisions. In fact, in crossing the strike of the Triassic series a few miles inland from the Devonshire coast, we might often imagine ourselves in some part of Staffordshire, Shropshire, or Worcestershire, so remarkably similar are the beds themselves, and the features of the landscape which are the outward manifestation of them.

The general succession of the post-Carboniferous series in the Western Midland district north of the old Palæozoic ridge may be thus stated :—

TRIAS	Keuper Series.	Red Marl passing downwards into Lower Keuper Sandstone (with base of Calcareous Breccia).
	Bunter Series.	Upper Mottled Sandstone (Upper Bunter). Pebble-beds and Conglomerate (Middle Bunter). Lower Mottled Sandstone (Lower Bunter). (?)
LOWER PERMIAN (Rothe-todte-liegende).		Purple Sandstones, Marls, and unconsolidated Breccia made up of fragments of Palæozoic rocks from marginal lands.[1]

In my short description of what I consider the representative series in Devonshire, it will be convenient to commence with the

[1] Sometimes (as in the Abberley Hills) the Permian beds are represented by breccia only. The most complete series is to be found at Enville in Salop; see 'Triassic and Permian Rocks of the Midland Counties,' Mem. Geol. Survey (1869).

lowest beds, and follow the section upwards; and it may be stated that Dr. Irving—by whom the writer was accompanied—had not had a previous opportunity of examining the sections which we first visited together in the neighbourhood of Torquay.

II. Lower Permian Breccia forming base of Series.

Torquay District: Oddicombe Bay.—The cliffs which bound the coast at Babbacombe and Oddicombe Bays rise to a height of about 300–400 feet, and display a magnificent section of red and purple breccia, resting on either hand against the slopes of Devonian limestone, which were evidently hollowed out into the form of a bay or river channel, and afterwards filled in with the détritus now

Fig. 1.—*Cliff-section above Oddicombe Bay.*

B. Lower Permian. Brecciated red sandstone and unconsolidated shingle, resting against the face of
D, a Palæozoic cliff formed of highly inclined Devonian limestone.

[The above sketch is taken from one made on the spot. The strata (B) are shown in the line of strike, north and south. At right angles thereto there would be no doubt a small dip.]

forming the brecciated beds, lying at the base of the whole series of red rocks.[1] The pebbles of which they consist are chiefly Devonian limestone, purple grits from the same formation, and smaller numbers of vein quartz and decomposed slate (probably Carboniferous). We also found a pebble of grey granite with black mica. Some of the pebbles are several inches in diameter and rounded, but the majority are subangular, and all are enclosed in an incoherent red sandy material, often calcareous.

Proceeding northwards towards Exmouth, another remarkable cliff-section bounds the coast at Labrador Hotel, equally lofty, and furnishing a great variety of fragmental blocks and stones, some over a foot in diameter. They consist of red and purple grits in varying proportions according to locality, Devonian limestone,

[1] These brecciated beds with their associated igneous rocks were described by Sir H. T. De la Beche in his 'Report on the Geology of Cornwall, Devon, &c.,' pp. 193 *et seq.*, and classed under 'the Red Sandstone Series.' The occurrence of contemporaneous volcanic rocks is highly suggestive of their Permian age.

porphyrite, quartz, &c. The whole mass has a rude stratification, and the blocks and pebbles are generally subangular and embedded in a red sandy paste. Sections are also shown by the Teignmouth roadside, one of which, at a bend near Higher Gable, exhibits unconsolidated breccia, absolutely indistinguishable from the Lower Permian breccia of Shropshire or Worcestershire as it occurs in some places. The sections above described are continued along the coast above Teignmouth and in the railway-cuttings, but need not be here further referred to, as having been already so well and so often described. The whole series must be of great thickness, perhaps approaching 1000 feet—although the dip is generally slight.

As regards their geological position, there can be no doubt that they are representatives of the Lower Permian stage. To this opinion one is impelled both by their remarkable resemblance to the beds of that age in Salop, Worcester, and Warwickshire; and also by their position, lying as they do directly on the Palæozoic rocks in a highly discordant position, and at the base of the whole series of red strata of Devonshire. The conditions which obtained in the border districts, north of the old Palæozoic ridge, appear to have been reproduced in the Devonshire area, along the borders of the old land formed of Carboniferous, Devonian, and older rocks, which had been disturbed and eroded at the close of the Carboniferous epoch, and from the waste of which these brecciated masses were constructed.

I may add that there is nothing in the appearance of this breccia at all resembling the Bunter Sandstone either of Central England or of Germany. On the other hand, it is strikingly like the Lower Permian breccia of both countries.[1]

III. The Triassic Beds (*Bunter Series*).

On crossing to the eastern side of the estuary of the Exe we come upon an entirely different series of red beds admittedly newer than those of the western shore of this estuary, with a general easterly dip and occasionally dislocated by small faults;—not so great as to disarrange the order of succession, or such as to render the relations of the beds obscure. The lowest visible beds of this series occur at Exmouth, and are laid open in the little section forming the old sea-cliffs before the last general elevation of the sea-bed. These consist of soft, bright, red sandstone with oblique lamination, occasionally streaked with white and parted by marly bands. Above this sandstone comes a thick deposit of purple marl with bands of soft white sandstone, and this again is succeeded by soft bright-

[1] The description of Sir R. I. Murchison for the breccia of the Rothe-todte-liegende near Eisenach might be applied to those of Devonshire:—'These great bands, often of vast thickness, ought, strictly speaking, to be termed breccias. . . . For, whatever be the included material, whether quartz-rock, mica-schist, old porphyry, granite, or greywacke slate, the fragments are usually angular; none of them presenting the aspect of having been rolled on a beach or rounded by the action of the waves.' Quart. Journ. Geol. Soc. vol. xi. (1855) p. 421.

red sandstone of considerable thickness, which at the angle of the bay is traversed by a fault with a downthrow to the east of 25–30 feet, noted by Mr. Ussher. Red marls of considerable thickness again succeed this sandstone, and are ultimately surmounted by the well-known Budleigh Salterton Conglomerate. Between this Conglomerate and the Permian breccia we thus have an intermediate group of soft bright-red sandstones and red marls several hundred feet in thickness, and the question arises, to what formation are they to be referred? Dr. Irving regards this group as an upper division of the Permian formation—possibly a representative of the Zechstein in its marly condition (as it occurs in Lancashire). But no bands of limestone, no traces of fossils occur in it. On the other hand, the sandstones bear a strong resemblance to the 'Lower Red and Mottled Sandstone' (or Lower Bunter) of the Geological Survey, and had it not been for the presence of the thick beds of marl with which these sandstones are intercalated there would have been little uncertainty regarding their geological position. For my own part I am disposed, though with hesitation, to consider this series as the representative of the Lower Bunter, and to regard the beds of marl as of local origin, constituting a divergence from the normal type of this division as it is represented in the Western counties of England. The contrast in character between this group of beds and the great brecciated series west of the estuary of the Exe seems too great to admit of the view that it is in any way an upper member of the same series; on the other hand, the sandy strata are strongly suggestive of Lower Bunter affinities.

IV. The Budleigh Salterton Conglomerate and Sandstone (*Middle Bunter*).

Whatever difference of opinion may exist between Dr. Irving and the writer regarding the Exmouth beds above described, we are quite of one mind as to the geological position and relations of the remarkable conglomerate and overlying beds of pebbly sandstone of Budleigh Salterton. Any one familiar with the Middle Bunter Conglomerate of Staffordshire, Leicestershire, and Worcestershire, and other parts of the Midlands, can scarcely fail to recognize its representative in the Budleigh conglomerate; the resemblance in fact amounts to identity in character, and, as it seems to me, in stratigraphical position with respect to the overlying series of red beds presently to be described. As regards characters, here we have the conglomerate made up mainly of those peculiar red, purple, and liver-coloured quartzites which are so characteristic of the Bunter conglomerate of the Midland counties; and this resemblance has been strengthened by the occurrence in the pebbles themselves of fossils of Silurian and Devonian types in both districts, described by Salter [1] and Davidson [2] from the collection in the cabinet of the

[1] Quart. Journ. Geol. Soc. vol. xx. (1864) p. 286.

[2] *Ibid.* vol. xxvi. (1870) p. 70; see also paper on the same subject by A. Wyatt Edgell, *ibid.* vol. xxx. (1874) p. 45.

Rev. W. Vicary of Exeter, and in those of the Rev. P. B. Brodie from the neighbourhood of Birmingham.[1] While I do not assert that the occurrence of these forms in the derivative pebbles is, in identification of geological position, of equivalent value to their occurrence in the rocks themselves, it does seem to me that the coincidence is suggestive of the pebbles being torn from the same unsubmerged lands at the same period, rolled about, and finally laid to rest contemporaneously, though possibly in disconnected inland lakes or seas. Their presence north and south of the old ridge of Palæozoic rocks, which was not finally submerged till the close of the Triassic period, confirms the view I have long held, that this ridge itself was the source from which they were mainly derived; and thus it would seem that a fringe of rolled shingle stretched away both north and south over the floor of the submerged land of the Midland counties and of Devon and Dorset at some special stage of the period of gradual subsidence corresponding in time to that of the Middle Bunter. There can be no doubt, however, that some of the fossils of the Budleigh Salterton Conglomerate had their source in Normandy and Britanny.

The conglomerate extends northwards into the country along a ridge of high ground by Yattington, Woodbury Common, and Fen Ottery Hill, by the great British Camp (*Alauna Sylva*) and Aylesbeare Hill, dipping gently eastwards, and giving origin to landscape-features constantly reminding us of those formed in the Midland counties by the Bunter conglomerate.

The Budleigh Salterton Conglomerate, which may reach 100–150 feet in thickness, passes below soft red sandstone with honeycomb weathering, well displayed in the magnificent coast-section, and these beds again are overlain by red pebbly sandstone as far as the mouth of the river Otter. The whole belongs to one group, representative of the 'Pebble-beds' (Middle Bunter) of the Geological Survey.

V. The Upper Red and Mottled Sandstone (*Upper Bunter*).

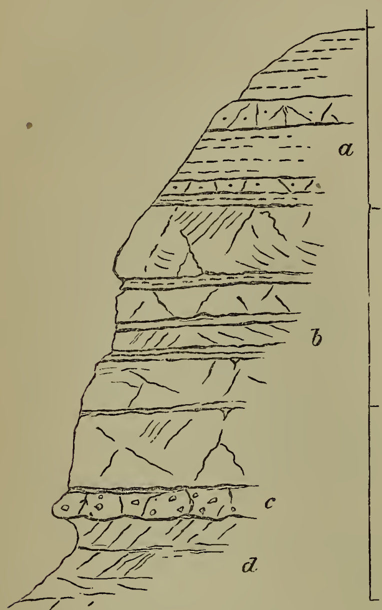
The Upper division of the Bunter is very clearly seen at Sidmouth in numerous sections in roadsides and pits. As Dr. Irving has shown, it is brought up by a fault visible in the cliff at Chit Rock, west of the village, where the Keuper marls are thrown down against it on the west. This member of the Bunter Series is very similar to its presumed representative in the Midland and Western counties, consisting of soft laminated red, yellow, and variegated sandstone. Its position, between the Keuper beds on the one hand and the Pebble-beds on the other, serves to identify the division with that of the Midland counties, both as regards petrographical characters and order of succession. Along the eastern bank of the Sid, where it opens out on the beach, the Upper Mottled Sandstone is seen underlying the pebbly basement-bed of the Lower Keuper Sandstone.

[1] *Op. cit.* vol. xxxvii. (1881) p. 430.

VI. The Keuper Series.

The Keuper Series is laid open to view in the fine range of cliffs along which the high ridge of Salcombe, capped by Cretaceous beds, terminates at the coast-line. Dr. Irving has shown that the sandstones and marls at the base gradually pass upwards into the red marl with gypseous bands, about the geological age and position of which there can be no controversy. The basement of the series appears

Fig. 2.—*Cliff-section at Sidmouth, showing Keuper basement-beds resting on Upper Bunter sandstone.*



a. Red marls with thin sandstones.
b. More massive light-red and white freestone, current-bedded, with bands of red marl and shale.
c. Basement-bed of Keuper. Hard calcareous breccia, 2 ft. thick.
d. Soft red sandstone, current-bedded.

to occur in a thin bed of conglomerate in the cliff, just where the wooden bridge crosses the stream, at its opening on the bay. Below this pebbly bed, which seems to be consolidated by a calcareous cement, the soft red sandstone of the Upper Bunter, traversed by planes of oblique bedding, may be seen ; and over this several thick beds of light red, grey, and yellowish sandstone, with partings of marl; the whole (with its brecciated base) bearing a very strong resemblance to the representative beds in some parts of the Midland counties.

With the Keuper Series our work of identification ends, so far as regards the Devonshire red rocks. From what has been here said, it will be seen that, with one or two not very important exceptions, the writer concurs in the interpretation which Dr. Irving has given of this series, and believes with him that we have reproduced in Devonshire the representatives of the Permian and Trias which enter into the structure of so large a portion of the district bordering Wales and Shropshire, and which extend into the Midland counties. It is very remarkable that, notwithstanding the interposition of the dividing ridge of Palæozoic rocks which underlies East Anglia, and emerges from beneath the Jurassic strata in Somersetshire, the representative beds on either side should bear so close a resemblance to each other.

In conclusion, I tabulate below what I consider to be the strata representative in South Devon of those in the Western Midland counties. As the latter have already been tabulated on p. 61 they need not be repeated here:—

TRIAS	Keuper Series	Upper and Lower.	Red marl with gypsum passing down into Lower Keuper Sandstone with calcareous breccia at base.
	Bunter Series	Upper	Soft variegated sandstone of Sidmouth.
		Middle	Budleigh Salterton pebbly sandstone and conglomerate.
		Lower	Red marls and soft variegated sandstone of Exmouth.
PERMIAN		Lower	Purple breccias of Oddicombe Bay and Teignmouth.

6. Supplementary Note *to the* Paper *on the* 'Red Rocks *of the* Devon Coast-section' (Q. J. G. S. 1888). By the Rev. A. Irving, D.Sc., B.A., F.G.S. (Read November 25, 1891.)

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I. The Base of the Keuper in Devon.

In my former paper I took for the basement-limit of the Keuper what we might fairly call the base of the 'building-stones.' Prof. Hull, on a visit with me to Sidmouth in the summer of 1891, suggested that the bed of breccia below the footbridge over the Sid would make a better basement-line for the Keuper formation, and bring the classification more into harmony with the lines of demarcation adopted by himself and others for the Midlands and elsewhere. Though I had noted this bed and referred to it in my paper, its character as a distinct basement-breccia had not impressed itself upon me, since I regarded it as nothing more than one of the intercalated lenticular masses of the Bunter Sandstone.

A closer examination reveals, however, its true character. It contains angular and subangular fragments of grit and quartz, enclosed in a dull brick-red matrix. What mainly deterred me from adopting this breccia as a basal line for the Keuper was the very marked current-bedded structure of the 10 to 15 ft. of coarse Bunter-like sandstone, which follows the breccia in the upward succession on the face of the cliff. This, however, is not a real difficulty, because—as Prof. Hull pointed out to me on the ground—this structural character is not at all uncommon in the basement-beds of the Keuper below the Waterstones in other areas. On looking into the literature of the subject a little more closely since my visit to Devon with Prof. Hull, I find that the description of the Frodsham Beds of Cheshire by Mr. Strahan [1] applies so exactly to the beds above the breccia on the east of Sidmouth that it is impossible to feel any further hesitation in accepting them, together with the breccia, as the true Keuper basement-beds in Devon as in Cheshire.

Whether the breccia-line is continued to the west of Sidmouth at the foot of the High Peake cliffs [2] I am not able to say positively, until I have an opportunity of more closely examining the cliffs there with special reference to this point. There is, however, no reason in the nature of things why the breccia should be continuous, but rather the reverse. The absence of it would certainly

[1] Geol. Mag. for 1881, pp. 396 *et seq.* 'On the Lower Sandstone of Cheshire,' by A. Strahan, M.A., F.G.S.

[2] In Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 283, Mr. Ussher mentions a 'conglomerate bed . . . which crops out below High Peake Hill.'

make the exact divisional line between the Keuper and the Upper Bunter somewhat obscure, which is exactly what happens in the Hawkstone and Grinshill district of Salop.[1]

This, however, leaves us face to face with a stratigraphical question, which is not met by what is stated in my previous papers; the question, namely, whether the Amphibian and Reptilian remains described by Mr. Whitaker in this Journal,[2] those described by Mr. Metcalfe,[3] and those found by Dr. Johnston-Lavis,[4] do not necessitate the downward extension of the Lower Keuper Sandstones, so as (following Mr. Ussher and Sir A. Ramsay [5]) to include the beds which contain those remains, and with this the recognition of the thin breccias, described by myself and other authors on the east side of the river Otter, as the basement-line for the Keuper Sandstone. Some reason for an affirmative answer to this question might be found in the identification of these remains by palæontologists as those of *Hyperodapedon*,[6] and the assignment by Prof. Hull and others [7] of all the beds, in which remains of *Labyrinthodon* and *Hyperodapedon* are known to occur in the Midland area, to the Lower Keuper Sandstone.

But against this difficulty we may fairly urge the following arguments:—

(1) The improbability of such an inequality of development of the basement-beds of the Keuper on the east and west of Sidmouth as this would require.[8]

(2) The fact that in Germany quite similar beds occur in the Upper Bunter, which in section after section is seen *visibly underlying the Muschelkalk*, and very frequently contains Labyrinthodont footprints (as in the Jena district, at Karlshafen on the Weser, at Kissingen, at Würzburg, in the Tauberthal, and at Hesseberg near Hildburgshausen), while the skull of the Labyrinthodont *Trematosaurus Brauni* (Burm.) was found in the Bunter near Bernburg, and the remains of *Labyrinthodon Rütimeyeri*, described by Wiedersheim, were found in the Bunter Sandstones of Riehen near Basel.[9]

The extreme poverty in organic remains which marks the English Bunter does not hold good, then, for the same formation in Germany, where (it is to be remembered) the interpolation of the Muschelkalk makes the *demarcation of Bunter and Keuper a matter of certainty*, and furnishes an important index of horizons, which we do not possess in such a well-defined form in the British series.

[1] Hull, 'The Permian and Triassic Rocks of the Midland Counties,' Mem. Geol. Surv. (1869) p. 64.

[2] Vol. xxv. (1869) p. 152.

[3] *Ibid.* vol. xl. (1884) p. 257.

[4] *Ibid.* vol. xxxii. (1876) pp. 278 *et seq.*

[5] *Ibid.* p. 283.

[6] Prof. Seeley simply describes Dr. Johnston-Lavis's 'find' as *Labyrinthodon*, *ibid.* pp. 278 *et seq.*

[7] Mem. Geol. Surv. *supra cit.* pp. 4–6; also App. *A*, p. 120.

[8] This, however, may receive explanation from the faulting at Ladram Bay. I hope to examine this more closely ere long.

[9] See Credner, 'Elemente der Geologie,' 6th ed. (1887) p. 544.

Again, the fact that the Devon Red Rocks are in the same latitude as those of Central Germany, and the further fact that they were deposited in a basin shut off along the line of the Mendips from the Triassic basin of the Midlands (and therefore probably accessible to warmer oceanic currents producing shore-conditions more favourable to the life of these huge Amphibians and Reptiles), would lead us to expect to find more traces of them in the Devon Bunter, linking it palæontologically with the Bunter of Germany, of which Dr. Credner remarks that "the frequency of footprints of these Amphibians is quite a special feature."[1] The thin bed of breccia east of the Otter-mouth might seem to militate against the beds being Upper Bunter, but not really so, since Prof. Hull has described a similar case in the beds of that sub-formation at Stourport.[2] While recasting this paper, I have received from the Rev. Dr. Dixon[3] a specimen of a breccia from the east side of the Otter at Harpford, so closely resembling that which I have accepted for the base of the Keuper on the east bank of the Sid that I am inclined to attach great importance to it, as tending to settle this moot-point for the country to the east of the Otter. At the same time we must not overlook the fact of the frequent occurrence of fragments (angular and rounded) of red marl in the sandstones, which agrees with my own observations of the Bunter (in former years and again during the past summer) in the North Midlands, and with the remark of Credner that they are a quite characteristic peculiarity of the Bunter Sandstone.[4]

Dr. Johnston-Lavis describes the rock-zone, in which he found Labyrinthodont remains, as consisting of a "much coarser sandstone containing here and there masses of marl,"[5] a very Bunter-like character indeed.

As to the occurrence of pseudomorphs after rock-salt noted by Mr. G. W. Ormerod in these beds (and quoted by Mr. Whitaker[6]), as evidence of a Keuper horizon, this proves nothing at all, since, as Dr. Credner remarks, "very frequently the bedding-planes of the thinly-stratified marly sandstones of the Upper Bunter are covered with cubic pseudomorphs after crystals of rock-salt,"[7] at (*e.g.*) Waltershausen and the Singer Berg, in the Thüringerwald, and in Franconia.

The diagnosis of the 'Upper Sandstones,' which Mr. Ussher

[1] *Op. et loc. cit.*: 'Ganz eigenthümlich ist die Häufigkeit von Fährten gewisser Amphibien in dem Buntsandsteine.'

[2] Mem. Geol. Surv. *supra cit.* p. 62.

[3] Formerly a Fellow of this Society.

[4] 'Elemente der Geologie,' 6th ed. (1887) p. 542: 'Die Sandsteine umschliessen so häufig rundliche oder eckige Partieen von Thon (Thongallen), dass diese als eine ganz charakteristische Eigenthümlichkeit des Bunten Sandsteines zu betrachten sind.'

[5] Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 277.

[6] *Ibid.* vol. xxv. (1869) p. 157.

[7] 'Elemente der Geologie,' 6th ed. (1887) p. 543: 'Sehr häufig . . . sind die Schichtungsflächen der dünngeschichteten, mergeligen Sandsteine des oberen Buntsandsteines von würfeligen Pseudomorphosen nach Steinsalz bedeckt.'

has given in his valuable paper in this Journal,[1] as they are developed across the country between Watchet and the south coast, and his further description of them[2] with their variegated colouring, their "pockets of red clay," their lenticular bands of marl, their occasional assumption of a strongly calcareous character, their frequent current-bedding, and the occurrence of a conglomerate in the sandstone at Minehead, point in the aggregate to *strong affinities with the Upper Bunter of Germany*, with its shales, clays, and marls, its occasional conglomeratic beds, its changes of colour following the stratification, its interstratified calcareous, dolomitic, and marly strata (occasionally fossiliferous).[3] The frequently *micaceous character* of these coarse sandstones (which I have recently observed) is another important point of agreement between these beds and the Upper Bunter of Germany, which Dr. Credner describes as rich in mica (*glimmerreich*) wherever the sandstone *facies* is well developed.[4]

Lastly, Mr. Vicary, of Exeter, has recently drawn the attention of Prof. Hull and myself to the fact that the grains of the sands above the great Pebble-bed are generally very angular, and in a note to me he mentions the mouth of the Otter, Ottery, and Kentisbear, as localities where this is observed. Under the microscope this angularity seems to be largely due to a deposit of secondary quartz, partly as siliceous cement of the grains, sometimes as exceedingly well-defined pyramidal crystals upon them. This is a striking point of similarity between these beds and the German Buntsandstein, of which Dr. Credner notes that "the siliceous cement forms at times minute clear quartz-crystals upon the surfaces of the roundish grains of quartz";[5] and again, "infiltrated silica is often deposited upon the quartz-grains, and quartz-crystals have formed around them. Such crystalline-quartz sandstones are distributed in Thuringia, in the Black Forest, and in the Vosges."[6]

For comparison I have examined samples of the Bunter sand from Nottingham Forest and from Bramcote, Notts. The lithological resemblance of these in the presence of mica and of secondary quartz, and in other respects, with the beds which I have ventured to assign to the Upper Bunter in Devon is remarkable.

For the reasons here given, I adhere, then, to my previous reading of the sandstone series (the 'Upper Sandstones' in part of Mr. Ussher) which crop out at the foot of High Peake, and are continued to the mouth of the Otter; and I do this with the more confidence, from the advantage I have had, during the past summer, of inspecting many sections of them inland in company with Prof. Hull.

[1] Vol. xxxii. (1876) p. 378.
[2] *Ibid.* p. 380.
[3] See Credner, 'Elemente der Geologie,' 6th ed. (1887) pp. 545, 546.
[4] *Ibid.* p. 545; see also p. 546 for localities where this micaceous character is very marked.
[5] *Ibid.* p. 541: 'Das kieselige Zement bildet zuweilen winzige wasserhelle Quarzkryställchen auf der Oberfläche der rundlichen Quarzkörnchen.'
[6] *Ibid.* p. 542.

II. The Permian Age of the 'Lower Red Sandstones' of Devon.

The roughly-bedded breccias east of the Exe (*e. g.* at East Wonford, near Heavitree) form a good base from which to work the sandstone series, and the breccias are seen to pass into the sandstones by concordance of dip and by their recurrence *in the sandstones* at higher horizons, as, *e. g.*, at Bishop's Clist, where two brecciated beds, each 2 to 3 feet thick, are seen in the roadside ascending the hill east of the Clist, interstratified with strongly current-bedded sandstones.[1]

In the pit at Sandy Gate, nearly a quarter of a mile west of the Clist, a similar dip is maintained. The only indication of the dip is the occurrence of irregular irony bands, the sandstones being so strongly current-bedded as otherwise to disguise the dip. The western face of the pit shows a vertical wall of rock 90·feet high. The sandstones are of an uniformly deep red colour.

In the coast-section east of Exmouth the laminated marly sandstones come on at first very feebly between the massive sandstones, lying, according to Mr. Pengelly,[2] *conformably* on the breccias just outside Exmouth. These develope into massive and shaly beds of marl, in the upward succession, gradually increasing in proportion to the sandstones, until the marls supersede the sandstones altogether, and form a continuous deposit several hundred feet in thickness (500 according to Mr. Ussher), as they are seen, quite of the Permian type of the Midlands, passing under the Budleigh Salterton Pebble-bed in the sea-cliff. Similarly, the sandstones are at first feebly developed between the breccias from Petitor to Dawlish, showing a passage from the breccias into the sandstones, just as the sandstones graduate upwards into the marls. In spite of the somewhat Bunter *facies* of some of the sandstones, as they are seen in the coast-section and in road-sections inland (which may be accounted for by some leaching-out of the irony colouring material), they do not seem to have that character in such fresh sections as that at Sandy Gate; and for the reasons given above the difficulty of recognizing them as Permian is trifling, as compared with that which we have to face if we regard the marls (described above and in my former paper) as an abnormal development of Lower Bunter. The Sandstone-Marl series of Devon seems to correspond very well with the Lower Permian of the Vale of Eden and the country north of the Solway; while they are evidently connected with the breccias west of the Exe by a steady transition, and with them answer remarkably to the description given by Sir Archibald Geikie[3] of the more prevalent *facies* of the Permian, as well as to that given

[1] Mr. Whitaker, 'On the Succession of the Beds of the New Red on the South Coast of Devon,' Quart. Journ. Geol. Soc. vol. xxv. (1869) p. 154, has noted a similar recurrence of the breccias in a thin bed at Straight Point on the coast.

[2] Quoted by Mr. Whitaker, *loc. cit.*

[3] 'Text-book of Geology,' pp. 750, 751.

by Dr. Credner[1] of the Rothliegendes. Dr. Credner emphasizes the presence of such hard interbedded shales as indicating Rothliegendes character and age. His words are:—"Die Schieferletten oder Röthelschiefer, ein blut- bis bräunlichrother, sehr eisenoxydreicher Schieferthon (=shale), ist ein für das Rothliegende *ganz besonders charakteristisches Gestein* und tritt in oft mächtigen Zwischenlagerungen zwischen den Konglomeraten und Sandsteinen auf."[2]

The fact, moreover, that some of the sandstones have a Bunter *facies* is paralleled in other parts of England. Thus Mr. Fox-Strangways speaks of the so-called 'Middle Marl' (between the Upper and Lower Magnesian Limestone) as consisting of "red marls and soft red sandstone, which in some sections is excessively like that of Triassic age."[3] But the position of these beds in relation to the limestones leaves no doubt as to their Permian age. Further, there seems to be a close resemblance between the sandstones interstratified with the Lower Marls of Devon and the 1500 feet of soft red or variegated sandstones of Collyhurst and Stockport, described by the late Mr. Binney in various papers read at Manchester in the years 1841 to 1862. On the other hand the occurrence of hundreds of feet of purple-red marl of a distinctly Permian type below the great Pebble-bed in Devon would be (though a normal Permian feature) an altogether abnormal feature of the Lower Bunter, as compared with the uniform development of sandstones of that division in the Midland counties and in the Severn country.[4]

In his paper 'On the Chronological Value of the Triassic Strata of the South-western Counties'[5] Mr. Ussher points out (p. 466) that of the 850 feet, which he assigns to the sandstones and marls between the breccia-series and the great Pebble-bed, the lower portion "may be regarded as a passage-series [from the marls, which he estimates at 500 feet] into the lowest division" [the breccias]. He also states (*loc. cit.*) that he "traced, between Thorn St. Margaret and Wiveliscombe, in very clear sections, a *downward passage from the Lower Marls* through an intercalated series of marls and clays with beds of sand, the latter predominating downwards, into the sandstones generally representing the basement-beds in that neighbourhood." Another remark of Mr. Ussher (*loc. cit.*) that "in their northerly extension these beds gradually attenuate; and they [the 850 feet of sandstones and marls] do not probably exceed 200 feet, taken together, to the north of Thorn St. Margaret," gives, I think, strong support to the evidence of the unconformity at the base of the great Pebble-bed for which I contended in my former paper. Prof. Hull[6] describes a similar instance of the attenuation of the Permian Series in the Severn country, from 1500 feet of

[1] 'Elemente der Geologie,' 6th ed. (1887) pp. 509–511.
[2] *Ibid.* p. 510.
[3] Mem. Geol. Surv. (1873) 'Geology of the Country North and East of Harrogate,' p. 11.
[4] See Hull, Mem. Geol. Surv. (1869) 'Triassic and Permian Rocks of the Midland Counties,' chap. v. pp. 32–44.
[5] Quart. Journ. Geol. Soc. vol. xxxiv. (1878) pp. 459 *et seq.*
[6] 'Triassic and Permian Rocks,' &c. p. 32.

Lower Permian Marls at Enville to 1000 feet at Bridgenorth, and a few feet only at Stockton, six miles farther north.

There is one more point, and that a lithological one, for which I am indebted to the Rev. W. Vicary, of Exeter. He informed Prof. Hull and myself that the sandstones west of, and therefore stratigraphically below, the great Pebble-bed are, so far as his observations served, uniformly made up of *rounded grains*, which marks an important distinction between them and the sandstones above the Pebble-bed, as described above. He mentions (in a note addressed to me) Exmouth, Topsham, Exminster, Clist St. Mary, and Broad Clist as localities where the grains are all, or nearly all, rounded. The specimen which he sent me from one of these localities agrees remarkably in this respect with two others which I have since received from my friend the Rev. Dr. Robert Dixon, Vicar of Aylesbeare, who, at my request, obtained them from the road-section at Bishop's Clist and from the pit at Sandy Gate. The grains from the latter place are smaller than those from the former, where they are associated with breccia-beds, but in both cases the grains are remarkably and nearly uniformly round.

For the reasons here given I must request Prof. Hull to allow me to adhere to the view put forward in my previous paper,[1] as to the "lower sandstones" being "merely the transitional assortment of materials between the breccias and the marls," and of Permian age. I am inclined, however, on further consideration of the subject, and from recent inspection of sections inland, to qualify the statement on p. 157 of my paper, that the sandstones "form apparently an *upward extension* of the more uniformly brecciated series," and to regard the sandstones as (in part at least) parallel with the breccias, the two passing horizontally into one another and having the same stratigraphical relation as the Penrith Sandstone has been shown by Mr. J. G. Goodchild to bear to the Brockram;[2] and as in Central Germany the Ober-Rothliegende Conglomerates (Geinitz) bear to the Lower and Middle Zechstein, the two visibly overlying the Lower Rothliegendes, as, for example, in the hills about the Wartburg.

It follows that the break between the Permian and Trias of Devon is marked by the absence of the Lower Bunter of the Midlands and the Severn country, as that between the Bunter and Keuper is marked by the absence of Upper Bunter in the Nottinghamshire area; thus presenting a parallel case to those which Prof. Hull has described on the southern flank of the Clent Hills,[3] at the Loggerheads;[4] again about Manchester and Stockport, where the Pebble-beds form the base of the Triassic Series;[5] and in the districts mentioned in Shropshire, Staffordshire, and Derbyshire.[6] Parallel instances of the failure of the Lower Bunter are also met with in

[1] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 160.

[2] See my paper 'On the Classification of the European Rocks known as Permian and Trias,' Geol. Mag. for 1882, p. 223.

[3] 'Triassic and Permian Rocks,' &c. p. 17, fig. 4.

[4] *Ibid.* p. 25, fig. 5.

[5] *Ibid.* p. 41.

[6] *Ibid.* pp. 48, 49, 59.

some parts of Germany, *e. g.* in Eastern Thuringia and on the south-east of the Black Forest.[1]

[It may be well to draw attention here to a recent paper[2] by Dr. H. B. Geinitz, of Dresden, on the Permian fauna (represented by 16 species) and the flora (3 species) found in a "series of rocks consisting for the most part of red shaly marls of various colours, with which red, often very ferruginous, sandstones and conglomerates, and even thin layers and nodules (*Knollen*) of dolomitic limestone, are interstratified (*wechseln*)."[3] On these fossil remains the author remarks: "The assemblage of the fossil remains refers this group of variegated marls (*der bunten Mergel*) to the Upper Zechstein or 'Upper Magnesian Limestone,' which is here replaced (*vertreten wird*)"[4] by the marls, shales (*Schieferthon*), and sandstones, &c., as described above.

May not the sandstones and marls below the Pebble-bed equally reward the minute scrutiny of local geologists?—(Dec. 22, 1891.)]

III. The Age of the Breccias.

All we can say of them with certainty is that they are post-Carboniferous in the Permian sense. It has been suggested to me by Mr. Jukes-Browne that, if Permian, they must be late Permian, because they contain fragments of the igneous rocks of South Devon, which are intrusive in the Carboniferous of that region, and therefore younger than that series. We need probably a good deal more field-work to determine definitely the true relation of the intrusive felspathic igneous rocks of the district to the breccias before we can feel quite satisfied with the evidence this may afford. The argument here referred to was advanced in former years to prove the Triassic age of the breccias by Mr. Pengelly. My own acquaintance with them is insufficient to warrant me in doing more than make the suggestion that in the Crediton Valley at least we seem to have true volcanic agglomerates, indicative of contemporaneous volcanic action. But we are here confronted with the wider question, as to the vertical range of the Carboniferous, which is represented by the anomalous South Devon series. On this point Mr. Etheridge has remarked:—"South of the Mendips . . . . . . we enter quite a different local series of Carboniferous beds, with little coal and little limestone; a series as unlike the great Carboniferous series of the other side of the Bristol Channel, in South Wales, as is the Devonian type of Old Red Sandstone of Devon to the Old Red of Breconshire and Scotland."[5] So far as I know, there is no evidence to show that the younger Carboniferous rocks (including at least the whole of the Coal Measures) are represented in Devon at all. If, then, none of the Devon Carboniferous are younger than the Millstone Grit of the

[1] Credner, 'Elemente der Geologie,' 6th ed. (1887) *loc. supra cit.*

[2] 'Ueber die rothen und bunten Mergel der oberen Dyas bei Manchester,' Naturwissenschaftl. Gesellsch. *Isis* in Dresden, 1889.

[3] *Op. cit.* p. 1.

[4] *Loc. cit.* p. 9.

[5] 'Stratigraphical Geology' (Phillips's Manual, 1885 ed.), p. 220.

typical areas, we surely have an ample time-interval in that long period, to which the Coal Measures testify, both by their thickness and their genesis, for all the phenomena which have been observed in connexion with the great Dartmoor upheaval and its associated intrusive series. For aught we know, the time-interval represented by the great unconformity at the base of the Permians of the North of England may be only a portion of that time which is represented in Devon. If this be so, there would seem to remain no valid reason why the great Breccia-sandstone series of the Devon Red Rocks should not be the true equivalents of the Lower Rothliegendes both in time and position in the sequence. It is even possible that those portions of them which filled up the fiords and creeks of the more ancient 'Devonian' land (*e. g.* at Babbacombe Bay) may be even older than the Rothliegendes of some districts, where it lies unconformably upon the Carboniferous coal-bearing strata of Central Europe.

On the other hand, it is by no means certain that the igneous rocks associated with the breccias are older than they. Prof. Hull has reminded me that "the contemporaneous volcanic rocks of the breccias, so well described by De la Beche, are strong evidence of the Permian age of these beds;" and what I have seen in the field, particularly in the Crediton Valley, referred to in my 1888 paper (p. 159), points to the existence of true volcanic agglomerates forming locally integral portions of the Breccia series.

Contemporaneous volcanic action being unknown in the British Trias, as it is altogether unknown in the Trias of Germany, such an occurrence of volcanic activity in the Trias of Devon would be altogether abnormal, except for the Alpine Trias, which presents a totally different *facies* from the Trias of Germany and Britain. In the absence of evidence derived from fossil remains in the Breccia Series of Devon, we have to rely mainly upon their strong lithological resemblance to the Permian breccias of the Western Midland counties and to the German Rothliegendes, upon which I laid particular stress in my former paper.

The argument from this is seen to be considerably strengthened by any evidence of contemporaneous volcanic activity in the Devon series, which is paralleled by that met with in the Permians of Ayrshire and of the country north of the Solway; while in Germany (in Thuringia, in Saxony, in the Harz region, in the region south of the Hunsrück, in the Odenwald, in Silesia, in North-eastern Bohemia, in the Black Forest, and in other localities) such igneous rocks as quartz-porphyry, granite-porphyry, palatinite, porphyrite, and melaphyre, with their associated tuffs and breccias, are so commonly interstratified with, or intrusive in, the sedimentary rocks of the Rothliegendes, as to present quite a special feature of that formation, where the age of these sedimentary rocks is abundantly proved by their fossil remains.

The association in places of manganese ores with the breccias of Devon is another point of resemblance between them and the Rothliegendes, in which these ores are worked at several localities, notably in Thuringia and in the Harz.[1] So general is the occurrence of contemporaneous igneous rocks in the Rothliegendes that Naumann long ago divided that formation into the three stages of "anteporphyritic, porphyritic, and post-porphyritic."[2]

I have only to add that it is a matter of the greatest gratification to me that my assignment of the Breccia Series of Devon to the Permian, for reasons given in this and my former paper, is confirmed by the judgment of so competent an authority as Prof. Hull, after examination of them in the field.

Discussion.

Mr. H. B. Woodward remarked that, if the Authors had more fully studied the literature of the subject, their papers (by no means long) would have been considerably curtailed. The chief point of interest was Prof. Hull's opinion on the correlation of the Devonshire deposits with those of the Midland counties. Concerning the identification of beds by lithological characters, he observed that the Lower Breccias of Devonshire varied according to the nature of the bordering rocks from which they were derived. In places, too, they included beds of limestone-conglomerate resembling the Dolomitic Conglomerate of the Mendips and the 'Brockram' of Westmorland. Correlation by lithological characters was the more hazardous, if, as Prof. Hull had stated, there was a great barrier of old rocks separating the Midland area from that of Devonshire. He asked if there was any positive evidence that the breccias of Shropshire and Worcestershire were Permian? He saw no objection to the lower beds in Devonshire being of Permian age—the subject had been discussed again and again; but at present there was no actual proof that this was the case, and no fresh facts had been advanced by the Authors. If their classification of the rocks was correct, then it furnished an additional argument in favour of the view that our Permian and Triassic rocks formed one great Poikilitic Series.

Mr. Hudleston considered that it might be necessary in some cases to recapitulate evidence already adduced in support, for instance, of such a view as the probable Permian age of the breccias at the base of the Red Rocks. The inference drawn by the Authors from the abundance of contemporary volcanic material seemed a fair one; and the Devonshire geologists had been accumulating a considerable mass of evidence in the same direction, though their interpretation might not be the same. We had been told that the Red Rocks were one series, and when the speaker first became acquainted with Devonshire geology the whole was regarded as of Keuper age by great authorities. He very much wished that some one would enlighten him as to the grounds for this assumption.

[1] Credner, 'Elemente der Geologie,' 6th ed. (1887) pp. 514–521.

[2] See Appendix to Dr. H. B. Geinitz's 'Zur Dyas in Hessen,' Festschr. des Ver. für Naturk. zu Cassel, 1886; see also reference to letter from Geinitz in the Author's paper on 'the Permian-Trias Question,' in Geol. Mag. for 1884, pp. 321 *et seq.*

Mr. Topley agreed with Mr. Woodward in thinking that little new light had now been thrown on the subject of the classification of the Red Rocks in the S.W. of England. No doubt the reason for classing the lower beds and contemporaneous porphyrites, &c., as Trias had been that there was a continuous sequence downwards from undoubted Keuper. Perhaps here, as probably also in the N.W. of England, the whole set of Red Rocks forms one series, and any subdivision made in them must be artificial, though no doubt convenient. He would be glad if the lower set of beds could be removed from the Trias and classed with the Permian. This seemed a reasonable suggestion; it would also harmonize the distribution of the igneous rocks with what occurs in Scotland. He could not, however, admit that this was a conclusive proof of their Permian age. The existence of contemporaneous igneous rocks in the lower series had long been known; so, too, had the occurrence of fragments of Dartmoor granite. He did not believe that much weight should be allowed to lithological similarities or differences in correlating these beds with those of other areas. In Staffordshire the 'Pebble-beds' were well known as forming thick beds of coarse conglomerate; but near Liverpool these beds were mainly sandstone, and throughout the Mersey Tunnel no pebble, even as large as a pea, had been noticed. At the deep boring for the Wolverhampton Waterworks a thick bed of marl had been found in the middle of the Pebble-beds, although no such bed occurred along the outcrop.

Prof. Boyd Dawkins remarked that in his opinion there was clear evidence of an overlap, and therefore of a break in the section at the point where the strata were covered by the Budleigh Salterton Pebble-beds, and he believed that the break between the older beds and the Triassic strata was at this point. From the correspondence between this section and those of Lancashire and Middle England, he had little doubt but that the Lower Red Rocks were Permian, although the fact could not be accepted as proved without palæontological evidence. He did not believe that the Red Rocks presented a complete series without break in any part of the British Isles. In Lancashire and Staffordshire the Permian strata are so marked off from the Trias that in the Survey maps they are defined by faults of great magnitude; while, at least in the neighbourhood of Manchester, they in part represent a junction by overlap.

The President mentioned that when, some twenty-five years ago, he found the remains of a group of Permian volcanoes in the South-west of Scotland, he consulted his colleague, Sir Andrew C. Ramsay, as to whether the contemporaneous volcanic rocks described by De la Beche in the New Red Sandstone of Devonshire might not be Permian. But at that time no evidence had been given to warrant the separation of the Red Rocks of Devonshire into two series, and he accepted the general opinion, though he would have been glad to place the volcanic relics of the two regions on the same geological horizon. He had since then examined the coast-sections between Torquay and Sidmouth, which had been so well and so often described. He was quite willing to regard the older portion of the

Red Rocks as Permian, but it did not seem to him that the Authors had brought forward any fresh evidence to enable a definite judgment to be given on the question.

Prof. Hull reminded Mr. Woodward that the determination of the Permian age of the Breccias and associated strata in the Midlands and the West of England had been arrived at by the Geological Survey after years of careful investigation, in which the late Director-General, Sir Andrew Ramsay, took a leading part; and remarked that if he was sceptical as regards the geological age of these rocks, it was not surprising that he should be so as regards their representatives in Devonshire.

Replying to the general observation that the Red Rocks of South Devon appeared to be a continuous series, he reminded the speakers that apparent consecutiveness or conformity of stratification did not necessarily imply *continuity* of deposition; of this we had an example in the case of the Cretaceous and Eocene limestones of Egypt and Palestine, which, although conformable over large areas, were really separated by a wide gap in time, as the whole of the species (as stated by Zittel) were different in these two sets of calcareous strata.

In conclusion, Prof. Hull maintained that the evidence for the Permian age of the Lower Breccias of Devonshire was cumulative, and, strengthened by the existence in them of contemporaneous volcanic rocks, quite unknown in the Trias of Britain, was sufficiently strong to carry conviction to his own mind. As regards the question in which there was a little difference of opinion between himself and Dr. Irving, viz. the relations of the Exmouth beds under the Budleigh Conglomerate, that was of secondary importance, as this Conglomerate might very well form the base of the Bunter Sandstone, as it does in Staffordshire and other parts of Central England; and he hoped that the point would be determined by careful mapping of each individual set of beds in the field.

The Rev. A. Irving remarked of the discussion, that many of the criticisms were based on negative reasoning, and ignored a great deal of positive evidence, which he had put forward in previous papers on the Red Rock Series; that it was waste of time to find fault with nature because these leaves of her great stone-book were palæontological blanks; that the double principle of lithological similarity and comparative reasoning had been somewhat lost sight of by several speakers (the latter, for instance, in the evidence derived from contemporaneous igneous rocks in the breccias, being almost unique in its cogency in this case); that he had been rather amused to find the old 'Poikilitic' error of continuity of sequence (which he had himself fallen into in former years, and recanted, after more extensive work in the field in England and Germany) cropping up again. He was happy to find that Prof. Boyd Dawkins's view as to the evidence of a distinct break in the series at the base of the Pebble-bed, by comparison with what is known in the Lancashire-Cheshire area, was so entirely in accord with his own, which he had strengthened by citation from Prof. Hull's memoir of facts showing a thinning-out of the Permian marls and sandstones in the Severn country similar to that which Mr. Ussher had shown to occur in Devon. He reminded the President that Sir A. Ramsay had anticipated him (the Author) in suggesting that the breccias were of Permian age, and, in conclusion, expressed his satisfaction at the warm interest in the question evinced by the discussion.

Prof. Blake also spoke.

7. *On the* Os Pubis *of* Polacanthus Foxii. By H. G. Seeley, Esq., F.R.S., F.G.S., Professor of Geography in King's College, London. (Read November 25, 1891.)

The evidence of the systematic position of the Wealden fossil *Polacanthus* has not been very precise. Mr. Hulke in 1881 regarded the dermal armour as closely resembling that of *Scelidosaurus*; and the dermal spines were compared with those of *Acantholis*, *Stegosaurus*, and *Omosaurus*, with indications of some differences of structure. It is to the Wealden *Hylæosaurus* that *Polacanthus* was most closely allied, the resemblance in their dermal spines being very close, and their tibiæ are stated to be remarkably alike. These views were adopted by Prof. Marsh, who in January 1882 placed *Polacanthus* in the Scelidosauridæ, immediately after *Hylæosaurus*.

When the great tuberculate shield which covers the pelvic region in *Polacanthus* became known in 1887 by the skill of Mr. J. Lingard in fitting it together and of Mr. Richard Hall in removing the matrix, Mr. Hulke described the pelvis,[1] and found the ilia so blended with the dermal bones that their exact form was not made out.[2] The remains of the *os pubis* are said to be too fragmentary to give the shape of that bone; but it was thought that indications were recognizable of its division into posterior and anterior parts. I was unable to recognize any indication of that bone on the shield, and the lettering on Mr. Hulke's figure only refers to the ischium and acetabulum. Further search fortunately resulted in detecting the missing pubis as an isolated specimen, collected by Mr. Fox with the other remains, east of Barnes Chine, in the Isle of Wight, in 1865. It appears to be indicated in Mr. Lydekker's 'Catalogue of Fossil Reptiles in the British Museum,' Part I. p. 190, by the description "a dermal scute bearing a short spine." This bone I regard as the anterior portion of the left pubis, the short spine being the proximal portion of the post-pubis; together they prove that the pubis in *Polacanthus*, while showing differences, was constructed substantially upon what may be termed "the Iguanodont plan." The most obvious difference is that the anterior pre-acetabular portion is relatively shorter than in any genus hitherto described.

The thin anterior plate of the pubis, which was vertical and compressed from side to side, thickens as it extends backward to form the superior articular surface for the ilium, the margin of the acetabulum, and the small inferior articulation with the ischium, which was not sutural.

From its inferior internal side is given off the so-called post-

[1] Phil. Trans. Roy. Soc. vol. clxxviii. B, pls. viii., ix.

[2] The outline of the ilium is shown in pl. ix. (*op. cit.*), except that the inner anterior border of the bone is less clearly defined in the drawing than in the specimen.

pubis. It is directed downward and backward, from in front of the acetabulum, from which it is separated by a narrow notch. Only about $1\frac{1}{2}$ inch of its length is preserved, but this shows it to be a vertically compressed, slightly oblique rib-like process, sub-ovate in section, being about $1\frac{2}{10}$ inch deep by $\frac{6}{10}$ inch wide. The notch which divides it from the acetabulum is much narrower than in *Iguanodon*; and the process is not prolonged on to the inner surface of the pre-acetabular part of the bone with the same convexity of surface as in *Iguanodon*, but is flattened in the way shown in fig. 1, facing this page.

The articular surface on the pubis for the ilium is situate at the upper hinder angle of the bone, above the acetabulum, which it meets at about a right angle. It is oblique to the superior contour, being inclined backward; is subtriangular in form, rugose, convex, about 2 inches wide and nearly as deep; it manifestly fitted on to the descending pubic process of the ilium, though, owing to compression of the shield, it does not now make a close union.

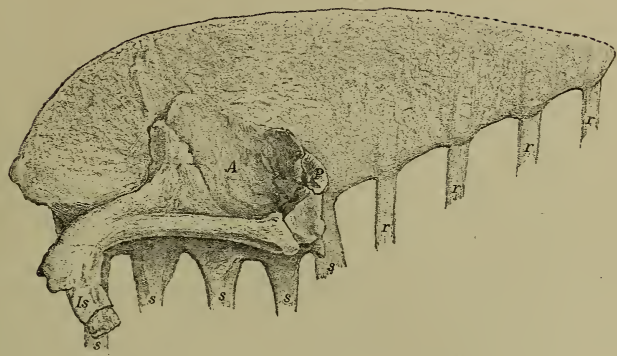
The acetabular surface of the pubis is below and behind its iliac articulation. It is oblong, $3\frac{1}{2}$ inches in length, smoothly concave as it extends downward and backward, is inclined somewhat obliquely outward, and terminates inferiorly in a defined margin, below which is an oblique compressed rounded lip, which presumably connected with the ischium. The lateral acetabular margins are subparallel, the external side being flattened; and the internal side, which extends about 1 inch farther backward, is more concave in the vertical direction. The transverse measurement below the iliac articulation is under 2 inches, whilst inferiorly, towards what I regard as the ischiac surface, it exceeds 1 inch.

The ischiac articulation, when seen from behind, is small and semi-ovate, being convex below; it is oblique, so that its depth is twice as much on the inner as on the outer border. It is convexly rounded, both from side to side, and from the acetabular margin downward. In no other specimen have I seen this surface so well preserved.

The anterior blade of the pubis is directed forward and downward from the acetabulum, and slightly outward. It is relatively short when compared with the pre-acetabular part of the bone in *Iguanodon*, *Camptosaurus*, and allied genera, with which it may be compared on account of the similarity in form and condition of the base of the posterior element of the pubis. It does not show the anterior antero-posterior widening seen in *Iguanodon* nor the forward curve at its extremity figured in *Camptosaurus*. It is obviously shorter and relatively deeper than the same element in *Stegosaurus*, which has the post-acetabular part of the bone almost as wide as the pre-acetabular part. This blade is oblong in form, compressed, and becomes thinner as it extends forward. Its length, measured from the external acetabular border, is $6\frac{1}{4}$ inches; from the hindermost posterior border of the acetabulum the length is $8\frac{1}{2}$ inches. The depth of the bone is about 5 inches in the articular region, 4 inches in the middle in front of the post-acetabular element, and

POLACANTHUS FOXII.

Fig. 1.



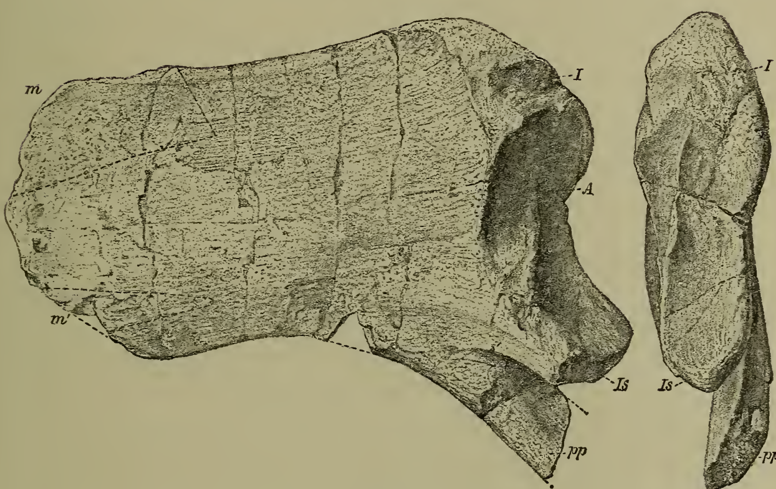


Fig. 2.

EXPLANATION OF FIGURES.

1. Right ilium and ischium, $\frac{1}{10}$ natural size.
   To the right in the figure is seen the shield, with the dorsal ribs (*r*) passing under the anterior blade of the ilium; to the left are the 5 sacral ribs (*s*) meeting the acetabular region of the ilium. *P* = position of attachment for the pubis; *A* = acetabulum; *Is* = ischium.

2. Left pubis: external aspect and posterior aspect. $\frac{3}{8}$ natural size.
   The anterior blade of the bone is directed slightly outwards.
   I = surface for ilium; *A* = articular surface for the pelvic acetabulum; *Is* = articular surface, presumably for the ischium; *pp* = posterior process of pubis, fractured; *m m'*, on the internal visceral surface are two V-shaped impressed articular surfaces, here indicated by dotted lines.

3 inches deep in front. Its anterior end curves a little outward, as in other genera. The antero-superior margin of the blade is nearly straight, compressed and sharp; the terminal contour is convex. The infero-posterior margin may be slightly broken in front; it is concave in the hinder part of its length, being prolonged continuously on to the post-acetabular process.

An angular impress, ill-defined, is seen on the inner side at the anterior extremity of the pre-acetabular plate, but there is no specimen among the remains of *Polacanthus* which can be identified as being the pre-pubic bone. No pre-pubic bones are known in *Omosaurus*, though it is manifest from the size and width of the pelvis that the pubes could not have met each other.

On the whole, the pubic bone seems to be in many respects intermediate in its characters between *Omosaurus* and *Iguanodon*.

The ischium in its singular curved form is only paralleled by *Triceratops*, which is stated by Baur to be identical with *Agathaumus*. But in *Polacanthus* the bone is wider, with a curious outward process extending from the acetabulum over the ilium, shown in the figure, and the pubis is dissimilar.

The ilium of *Polacanthus* throughout its extent is blended with the shield, so that the preservation of the shield has apparently resulted from the support of the thin underlying bony framework on which it rests. Possibly the definition of the ilium may have become slightly more evident than when the specimen was first reconstructed; but from the acetabulum a line diverges outward and forward, separating darker thicker tissue external to it from the paler substance of the shield on which the ribs rest. I take the great anterior triangle of darker tint to represent the thin blade of the anterior process of the ilium. It is seen to be superimposed upon four of the ribs which are obscured beneath it; but there is no strong demarcation to separate the bone of the ilium from the shield, and the two are blended, much like the rib and costal plate of a Chelonian. Still its limits are seen. The pre-acetabular process seems to form one half the length of the bone, and to approximate both in shape and outward development to the corresponding part of the ilium of *Omosaurus*. The post-acetabular process was relatively short and truncated; its form is shown in fig. 2. It extends nearly to the posterior margin of the shield, and, owing to removal of scutes, is seen exposed in this position on the dorsal aspect in Mr. Hulke's plate.[1]

The length of the right ilium, which is the more perfect, appears to be 35 inches, but it may have extended a little farther forward.

From this arrangement it results that, while most Ornithischia have the ilia vertical, in *Polacanthus* they are horizontal. The margins, which are usually highest here, are bent outward and downward with the convexity of the shield so as to descend lower than the acetabulum.[2] From this condition the acetabulum has a trans-

[1] Phil. Trans. Roy. Soc. vol. clxxviii. B (1887) pl. xviii.

[2] A similar type of ilium unconnected with a shield is catalogued under *Cetiosaurus* in the British Museum, Cat. Foss. Rept., Part I. p. 143.

verse position vertical above the femur, and is in a way imperforate. It is noticeable that, while the sacral ribs form 5 lateral buttresses to support the acetabular part of the ilium, several presacral ribs (in no way modified) extend between the external armour and the ilium, for the more anterior are seen through the thin pre-acetabular plate of the ilium. And this indicates that armour, ribs, and ilium blended late in life.

There is a very close resemblance in the ilium between *Polacanthus* and *Omosaurus*; for *Omosaurus* has a similar large horizontal acetabulum, while the pre-acetabular plate is of similar form, and extends horizontally forward and outward, and the post-acetabular part is similar. There is also a manifest resemblance in the forms of the sacral ribs, and in their mode of attachment to the sides of the vertebræ to which they belong, although in *Polacanthus* they tend to a slightly more anterior position. In *Omosaurus*, however, external armour on the trunk is unknown.

Other resemblances to *Polacanthus* are found in the Gosau fossil *Cratæomus*. When that type was described in 1881 I had not seen any of the remains of this armoured Wealden fossil. But I drew attention to a figure by the late Mr. J. E. Lee[1] from the Wealden of the Isle of Wight, which shows a dermal plate with tubercles upon an osseous base, as similar to armour of *Cratæomus*.[2] Mr. Lee's fossil may have belonged to *Polacanthus* or a nearly allied genus. The dorsal vertebræ of these genera are very similar, as is evident on comparing Phil. Trans. Roy. Soc. 1881, pl. lxx., and Quart. Journ. Geol. Soc. vol. xxxvii. pl. xxx. fig. 3. The femur in both corresponds in type and in many details. If there had been any grounds for referring the remarkable plates to *Cratæomus*[3] which Bunzel had figured as the ilium of *Danubiosaurus* the resemblance might have been carried further. It has been shown that those remains consist of a rib-like lower part, with which is blended a superimposed thick smooth armour, like that of a Chelonian. Without re-examination it may not be possible to form a definite judgment on these remains, but there seems some likelihood that they may prove to be portions of the ilia of *Cratæomus* with confluent smooth armour extending forward from the acetabulum. *Polacanthus*, however, has no such smooth scutes, and all the armour of *Cratæomus* which can be compared with it is either tuberculate or rugose with vascular impressions.

Ornithischians with smooth armour, however, existed in the Wealden deposits. And the British Museum acquired in the Beckles Collection a portion of the acetabular region of such a fossil which differs from *Polacanthus* in the far greater thickness of the ilium above the acetabulum, in the forms of the confluent sacral ribs constricted from front to back, and in the absence of all trace of ornament from the smooth and relatively thin dermal shield above the ilium as preserved. The species is larger than

1 Ann. Mag. Nat. Hist. vol. xi. (1843) pl. i., and 'Note-book of a Naturalist.'
2 Quart. Journ. Geol. Soc. vol. xxxvii. (1881) pl. xxviii.
3 *Ibid.* p. 694.

Polacanthus Foxii, and shows that the Wealden fauna contained more than one type of heavily-armoured Saurian.

It is not improbable that the dermal bone figured[1] from Gosau, which was referred to *Cratæomus*, and compared in form to the horn core of an ox, may be the horn upon the frontal bone. If so, it establishes a striking difference between that genus and *Struthiosaurus*, which has a small skull, without anything to indicate supra-orbital horns such as have been suggested for *Cratæomus*. Cope has compared it to *Monoclonius* or the horn of *Agathaumus*,[2] and Marsh to the horn of *Triceratops*.[3] On this comparison Zittel[4] has placed *Cratæomus* in the suggested sub-order Ceratopsia. The bone may possibly be a link of alliance between *Agathaumus* and *Cratæomus*. But I do not discover evidence of stronger affinity between those genera than is manifest between *Cratæomus* and *Polacanthus*, or between *Polacanthus* and *Omosaurus*. So that I am led to associate all those genera in near alliance, in the Scelidosaurian division of the order Ornithischia.

[*Note.*—The pubis of *Polacanthus* has been freed from the matrix by Mr. Richard Hall, since this paper was read.—December 31, 1891.]

Discussion.

Mr. Lydekker said there was no doubt that the bone in question was an imperfect left pubis of *Polacanthus*; and it was important as confirming the relationship of that and the allied genera to the Iguanodonts.

He agreed with the Author in considering that the present distinctness of the ilium on the under surface of the shield of *Polacanthus* in the British Museum had only recently appeared, and was probably due to more complete desiccation. He remarked that the ilium being situated internally to the ribs was a character found elsewhere only in adult tortoises, and that it was probably due to the impact of the shield on the ribs rendering it impossible for another bone to grow between the two.

The speaker was glad to hear that the Author was convinced of the close alliance between the American *Agathaumus* (*Triceratops*) and *Struthiosaurus* (*Cratæomus*) of the Austrian Cretaceous, an alliance which he himself had already indicated in his 'Palæontology.' All this confirmed his view as to the close affinity between all the *Dinosaurs* of N. America and Europe.

[1] *Op. cit.* pl. xxviii. fig. 4.
[2] E. D. Cope suggested this identification to me in 1886.
[3] Geol. Mag. for 1889, p. 207; *ibid.* for 1891, p. 193.
[4] 'Handb. der Palæontol.' Band iii. Abth. i. p. 753.

8. High-Level Glacial Gravels, Gloppa, Cyrn-y-bwch, *near* Oswestry. By A. C. Nicholson, Esq. (Read December 9, 1891.)

[Communicated by Wm. Shone, Esq., F.G.S.]

The Gloppa (spelt 'Glopa' on the Ordnance map) is a small farm, about two miles north-east of Oswestry, situate on the eastern slope of the ridge of Carboniferous rocks (Millstone Grit) which forms the western boundary of the Northern Shropshire and Cheshire Plain, and upon this and adjacent farms the gravels and sands are spread out. The main mass is comprised in a ridge of eskers about 1000 yards long, and appears to rest immediately upon the Millstone Grit, the beds of which formation crop out directly to the westward, and dip here about 20° to 25° E. and S.E., the average slope of the hill being about 10°. The portion of the deposit worked out forms but a small part of the whole, although about 33,000 tons of material have now been extracted.

A pit was opened here in the year 1888 for the purpose of getting sand for the filter-beds on the Oswestry works of the Liverpool Vyrnwy Waterworks, and since that date I have had it under observation; it is not now being worked.

The deposit ranges here from about 900 to 1160 feet above sea-level, but the main mass is from 1000 to 1150 feet, the sandpit worked being 1070 to 1130 feet. The highest point at which I have found marine shells in the drift is 1120 feet; the other recorded instances of such drift at similar heights in Great Britain being Moel Tryfaen (1330 to 1360 feet), Prestwich's Patch, Macclesfield (1150 feet); and in Ireland there is Three Rock Mountain (1100 to 1200 feet). I have noted similar gravel on Selattyn Hill, two miles to the north along the Millstone Grit ridge, at a height of 1250 to 1300 feet, but found no shells at that locality, there being but a small exposure a few feet deep. Similar deposits occur at various points along the Millstone Grit ridge, such as Frondeg and Halkyn, and have been noticed by the late D. Mackintosh and others.

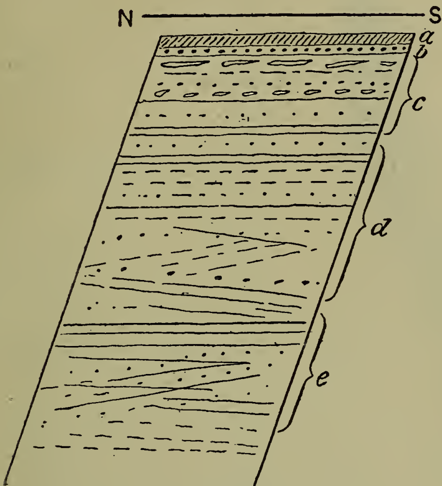
Nearer Oswestry, but at much lower levels (400 to 550 feet), occur a series of eskers of somewhat similar character, as at Old Oswestry gravel-pit, but these are undoubtedly of more local origin, although they contain a large admixture of northern erratics. These have been described by the late D. C. Davies in the Proc. Geol. Assoc.[1] In the same paper Mr. Davies gave two sections, figs. 10 and 11, on the Oswestry Racecourse, evidently parts of the Gloppa deposit as shown in some old pits long since closed.

The greatest depth exposed at Gloppa has been about 60 feet; the base has not been reached, but it is hardly probable that the

[1] Vol. iv. (1875) part vii.; see figs. 8 and 9.

depth would exceed 100 feet at the utmost, and the section would be approximately as follows :—

Fig. 1.



Grit beds below.

	ft.	in.
a. Soil 6 in. to 1 ft. 0 in.	1	0
b. Rough ground with many local boulders	1	0
c. Patches and thin bands of clay, red and grey, blue clay with slaty fragments, gravel with erratics, loam and shingle, very few shells	10	0
d. Beds of shingle, loam, and gravel, full of erratics and many large boulders, shells comparatively abundant	20	0
e. Beds of loam, fine shingle with shells and erratics, but on the whole more finely stratified and of finer material than *d*; worked down to about ...	25	0

The clay-patches and bands near the surface can hardly be said to be continuous, although the upper layers under *b* are all more or less argillaceous and sufficiently so to prevent the percolation of rain-water.

The following measured sections are illustrative of the whole deposit :—

A.	ft.	in.
Soil	1	0
Thin red and grey clay-bands with fine sand..................	4	0
Gravel..............................	0	6
Loamy sand	2	0
Fine gravel.........................	0	6
Loamy sand	2	0
Fine gravel and sand	1	1
Sand	0	5
Shingle	0	8
Finely laminated sand	0	5
Fine gravel.........................	0	2
Finely laminated sand	0	8
Sand and gravel in fine layers .	4	0
	17	5

B.	ft.	in.
Soil, thin clay-bands, gravel, and sand.........................	3	2
Gravel..............................	1	6
Fine sand	1	4
do. with fine partings......	2	0
do. with pebble layers ...	3	8
Sand	1	4
Sand layers and gravel, finely stratified.........................	3	0
	16	0

Gravel below.

The deposit may be said roughly to dip from N. and N.E. to S. and S.W.

On the north-eastern slope the beds presented in places the appearance of having been abruptly cut off, and the surface of the

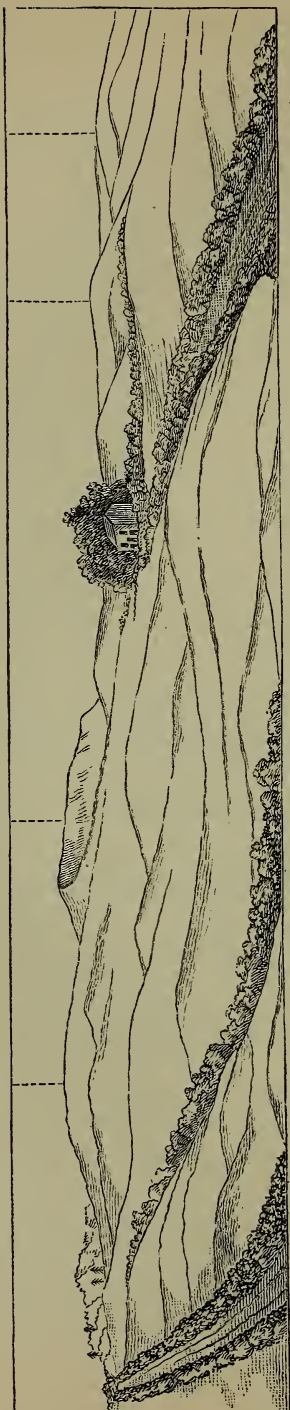


Fig. 3.—General view, looking westward.

The numbers indicate heights above Ordnance datum.

gravels has the eroded appearance generally characteristic of such deposits. There is occasionally much contortion of the layers, and current-bedding is frequent, as shown in the figure (2) facing this page, reproduced from a photograph.

The accompanying outline-sketch of the surface of the ground (fig. 3) may be found interesting.

There are numerous large boulders consisting of limestone, sandstone, various granites and syenites, slates, greenstones, porphyritic trap, &c., the boulders and larger pebbles being commonly striated and many polished. The bulk of the gravel consists of rounded and subangular stones, the larger stones being angular and subangular; they are in a general way similar to the boulders of the Lower Boulder Clay of Cheshire as described by the late D. Mackintosh.[1] The bulk of the stones may be set down as Silurian grit and argillite, then felspathic trap rocks, greenstone, granites similar to those of Ennerdale (?), Eskdale, and Criffel, &c., syenite, felsites, Carboniferous Limestone, Millstone Grit, and vein-quartz. Some Coal Measure shales and sandstones and Permian and Triassic sandstones have been noticed, also a few Chalk flints and a trace of Liassic shale.

These gravels may probably be correlated with the well-known drift de-

[1] Quart. Journ. Geol. Soc. vol. xxviii. (1872) p. 388.

[*To face* p. 88.

Fig. 2.—Section in Gloppa Gravel-Pit.

Note.—This is a reproduction of a photograph of the middle portion of the sandpit. In the neighbourhood of the contorted beds on the right hand the fragment of *Elephas* was found; the current-bedding here shown is highly characteristic of this deposit.

posit of Moel Tryfaen, which contains a similar fauna of much the same general character, together with striated erratics and boulders.[1]

They differ from the middle sands and gravels of Cheshire, Lancashire, and Shropshire, as described by various observers,[2] in that they contain numerous large and small polished and striated erratics, and also in the general character of the mollusca, which have thicker shells than the Cheshire specimens.

At the end of this paper a list of the fossils that I have found in the drift is given, all the species of which, with the exception of one or two of the older fossils, I have myself collected. They occur chiefly in the middle and lower beds in the fine shingle and gravel, though they are not uncommon in the sandy layers. Their condition varies much: thus, there are many fragments much broken, rolled, and striated, some very fragmentary, but the

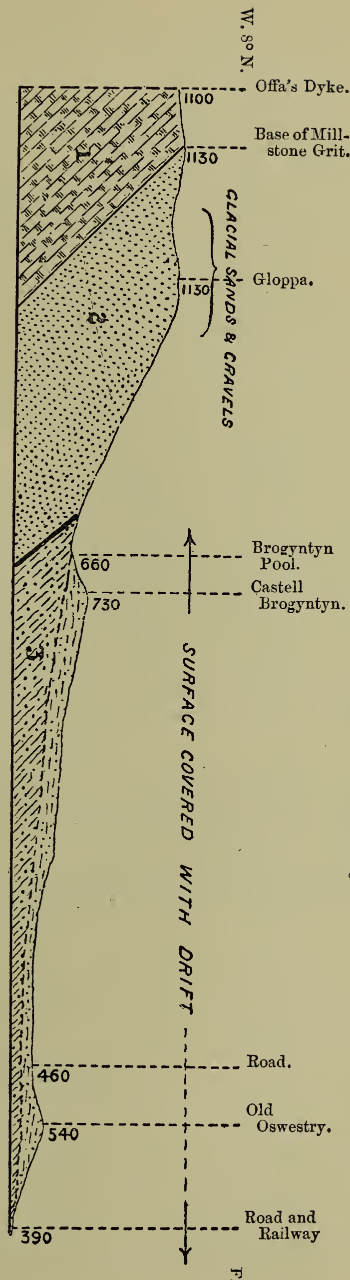


Fig. 4.—*Section from Gloppa to Old Oswestry.*

Horizontal scale: 2 inches = 1 mile. Vertical scale: 1 inch = 880 feet.
The numbers above the section indicate heights above Ordnance datum.
1. Upper Carboniferous Limestone Beds. 2. Millstone Grit. 3. Lower Coal Measures.

[1] See D. Mackintosh, 'Age of Floating Ice in North Wales,' Geol. Mag. for 1872, p. 15.

[2] *Cf.* paper by W. Shone on 'Glacial Deposits of West Cheshire,' Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 383.

bulk are in fairly good condition, and entire single valves of *Astarte*, *Mactra*, *Tellina*, &c., are common. A perfect specimen of *Fusus antiquus*, 3 inches long, was found, and the univalve shells are often well preserved.

Amongst the finds was a small "shelly lump" consisting of numerous shell-fragments consolidated in a sandy matrix, resembling a solidified beach-sand.

Another notable find was a portion of a tusk of *Elephas* (*primigenius* ?), which was discovered in contorted strata in the upper part of the deposit. The fragment was about 15 inches in length; it was unfortunately broken up by the workmen, but several small pieces were secured.

The sand in the gasteropod shells has been examined for foraminifera, but none have so far been discovered therein.

I have searched the lower-level gravels already mentioned as occurring at Old Oswestry for shells, but have only obtained there *Turritella terebra*, *Purpura lapillus*, and *Mactra* sp. The fragments in that locality are for the most part comminuted to such a degree as to be quite undefinable.

It may appear doubtful whether the Gloppa deposit has been derived from a pre-existing Boulder Clay; the writer is inclined to think that the weight of the evidence is to the contrary, although it may be quite probable that part of the fauna is derived. The only true Boulder Clay that I have seen in the immediate neighbourhood is at a level of 700 feet. This clay contains numerous striated and polished boulders, some of them running to 18″ × 12″ × 5″, but so far as I have been able to ascertain there are no northern erratics; the boulders and pebbles are all such as can be matched in the Welsh Hills lying to the S.W. and N.W.

I have, in conclusion, to express my thanks to Messrs. Clement Reid, R. D. Darbishire, and E. T. Newton, for valuable assistance rendered in the identification of the shells; also to Mr. Wm. Shone for much help and advice.

The accompanying sketch-section (fig. 4, p. 89) of the ground from Gloppa to Old Oswestry may be of interest.

Appendix.

List of Mollusca, etc., from the Gloppa Drift.

N.B.—In the first column I have noted the occurrences at Gloppa; in the second column are given the species recorded at Moel Tryfaen (see W. Shone's paper, Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 394).

I have indicated in the third column the occurrences of the various species now living in Liverpool Bay (*vide* 'Fauna of Liverpool Bay,' Report 1 (1886), pp. 247–266, Liverpool Marine Biology Committee).

The letters v. r. mean that 1 to 3 specimens have occurred; r., 3 to 10; f., frequent; c., common; a., abundant.

	Gloppa.	Moel Tryfaen.	Liver-pool Bay.
1. Arctic and Scandinavian species not living in British seas.			
Leda pernula, Müller	r.	r.	
Astarte borealis, Chemnitz	c.	c.	
„ *crebricostata*, Forbes	v. r.	v. r.	
Dentalium abyssorum, Sars	r.	v. r.	
Natica affinis, Gmelin	r.	r.	
Tellina calcarea (*T. proxima*, Brown)	v. r.	r.	
Cardium grœnlandicum (Chemnitz) [1]	?	...	
Pleurotoma pyramidalis, Stimpson	?	v. r.	
Trophon clathratus, Linn.	f.	f.	
„ „ var. *scalariformis*, Gould.	r.	f.	
„ „ var. *Gunneri*, Lovén	r.	f.	
2. Northern type of British species which inhabit Arctic and Scandinavian seas in common with our own.			
Mytilus modiolus, Linn.	r.	v. r.	c.
Lacuna crassior, Montagu	v. r.	...	c.
„ *divaricata*, Fabricius	...	v. r.	a.
Cyprina islandica, Linn.	c.	c.	r.
Astarte compressa, Mont.	f.	c.	...
Buccinum undatum, Linn.	f.	f.	c.
Trophon clathratus, Linn., var. *truncatus*	...	f.	r.
Pleurotoma rufa, Mont.	v. r.	v. r.	c.
„ *turricula*, Mont.	f.	f.	c.
Sipho (*Fusus*) *gracilis*, Da Costa	v. r.	v. r.	c.
Puncturella Noachina, Linn. (one specimen only)	v. r.	...	...
3. Southern type of British species which inhabit more southern seas in common with our own.			
Arca lactea, Linn. (2 specimens)	v. r.	...	v. r.
Cytherea chione, Linn. (several well-preserved hinge-fragments)	r.	...	...

[1] One specimen only found, which is probably *Cardium grœnlandicum*.

List of Mollusca (continued).

	Gloppa.	Moel Tryfaen.	Liverpool Bay.
4. General British species.			
Anomia ephippium, Linn.	r.	...	c.
Ostrea edulis, Linn.	r.	v. r.	c.
Pecten opercularis, Linn.	r.	r.	c.
,, *varius*, Linn.	v. r.	...	r.
Mytilus edulis, Linn.	c.	f.	a.
Nucula nucleus, Linn.	f.	...	c.
Pectunculus glycimeris, Linn.	v. r.	v. r.	r.
Lucina borealis, Linn.	v. r.	...	...
Cardium echinatum, Linn.	f.	r.	c.
,, *fasciatum*, Mont.	?	f.	v. r.
,, *edule*, Linn.	c.	c.	a.
,, *norvegicum*, Spengler	...	r.	r.
Astarte sulcata, Da Costa	f.	...	v. r.
,, ,, var. *elliptica*	?	f.	...
Venus exoleta, Linn.	?	v. r.	r.
,, *lincta*, Pulteney	v. r.	...	r.
,, *ovata*, Pennant	v. r.	...	...
,, *gallina*, Linn.	v. r.	v. r.	a.
,, *casina*, Linn.	v. r.	v. r.	r.
Tapes virgineus, Linn.	...	v. r.	v. r.
,, sp.	v. r.	...	...
Tellina balthica, Linn.	a.	c.	a.
Psammobia ferroensis, Chemnitz	f.	...	r.
Donax vittatus, Da Costa	...	v. r.	c.
,, sp.	v. r.	...	...
Mactra solida, Linn.	f.	r.	c.
,, ,, var. *elliptica*	?	v. r.	...
,, *subtruncata*, Da Costa	v. r.	...	r.
Lutraria elliptica, Lamarck	r.	...	c.
Solen, sp.	v. r.	...	c.
Corbula gibba, Olivi	...	v. r.	r.
Mya truncata, Linn.	f.	f.	a.
,, ,, var. *uddevallensis*	...	v. r.	...
Saxicava rugosa, Linn.	...	r.	a.
,, ,, var. *arctica*	v. r.	v. r.	...
Pholas crispata, Linn.	r.	...	r.
,, *dactylus*, Linn.	v. r.	...	...
Dentalium entale, Linn.	r.	v. r.	r.
Fissurella græca, Linn.	...	v. r.	r.
Littorina rudis, Maton	...	v. r.	a.
,, *littorea*, Linn.	f.	f.	a.
Rissoa costata, Adams	v. r.	...	...
Turritella terebra, Linn.	a.	a.	a.
Trichotropis borealis, Brod. & Sow.	...	v. r.	...
Aporrhais pes-pelicani, Linn.	r.	v. r.	r.
Purpura lapillus, Linn.	c.	f.	c.
Murex erinaceus, Linn.	f.	r.	r.
Natica catena, Da Costa	v. r.	...	c.
,, *Alderi*, Forbes	v. r.	...	r.
Trophon barvicensis, Johnston	...	v. r.	v. r.
,, *Fabricii*, var. Monro	...	?	...
,, *muricatus*, Mont.	v. r.	...	v. r.

List of Mollusca (continued).

	Gloppa.	Moel Tryfaen.	Liver-pool Bay.
Fusus antiquus, Linn.	c.	c.	c.
,, ,, ,, *monst. contrarium* [1]	v. r.	...	...
Nassa reticulata, Linn.	f	r.	r.
,, *incrassata*, Ström.	v. r.	v. r.	r.
Pleurotoma nebula, Mont.	?	v. r.	r.
CIRRIPEDIA.	2 or 3 species, very fragmentary, probably *crenatus*, *Hameri*, & *porcatus*.		
Balanus crenatus, Brug.		r.	a.
,, *Hameri*, Ascanius		v. r.	...
,, *porcatus*, Da Costa		...	...
SPONGIDÆ.			
Cliona, sp. in shells	v. r.	v. r.	...

Older Fossils in Gloppa Deposits (identified by Mr. Sharman).

SILURIAN	Various species of mollusca and brachiopoda. A Trilobite (not identified).
CARBONIFEROUS LIMESTONE	Crinoid stems.
	Lithostrotion junceum.
	,, *irregulare.*
	,, sp.
	Amplexus, sp.
	Clisiophyllum, sp.
	Syringopora, sp.
COAL-MEASURE SANDSTONE	*Stigmaria*, sp.
	Productus semireticulatus.
	,, sp.
LIAS	*Cardinia Listeri.*
	,, *crassissima.*
	Gryphæa, sp.
GAULT	*Avicula gryphæoides.*
CHALK	*Cyphosoma*, sp.

Also a doubtful fragment of a Secondary shell (*Ostrea* ?).

DISCUSSION.

The SECRETARY read the following remarks sent by Mr. CLEMENT REID, who was unable to be present:—

"The fauna, as far as I can judge, agrees fairly with that of Moel Tryfaen, and contains a similar mixture of species belonging to various depths and indicating different climates. There seems to be no reason for accepting either of these faunas as contemporaneous with the deposit in which it is now found; for, besides the difficulties already mentioned, it will be observed that a large proportion of the shells belong to a sandy bottom, not to a steep rocky coast, such as would

[1] There is a notice of this reversed species occurring in Middle Pleistocene Gravel at Worden Hall, near Leyland, Lancashire; see paper by R. D. Darbishire, Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 38.

be exposed to the sea by the submergence of these hills. The good state of preservation of the abundant Lias fossils [1] is another reason that makes me hesitate to accept any of the associated Pleistocene species as contemporaneous with the gravel. If Lias fossils can be carried for considerable distances up-hill without injury, the same mode of transport will account for the presence of the newer fauna.

"Whatever may be one's opinion as to the contemporaneous or derivative origin of the fossils, Mr. Nicholson's careful record of the sections, and his collection of boulders and shells, will provide valuable material for future work. I hope he will be able to add still further to our knowledge of this interesting deposit."

Dr. Hicks wished to know the position in the section where the Mammoth tusk was found, as it was clear to him that the find was not only an important one, but that it would have a direct bearing on the question of the age of the remains found by him under a drift containing similar shells at the entrance to the Cae-Gwyn Cave in the Vale of Clwyd.

Prof. Hull regarded this communication as of very high interest, as corroborative evidence of the submergence of the centre of the British Isles afforded by the Wicklow shell-beds and those of Moel Tryfaen and the Macclesfield Hills. The shells were in a remarkable state of preservation, and appeared to have lived in a sea traversed by currents and containing rafts of ice, or small icebergs, which had deposited the boulders amongst the beds of sand, as described by Mr. Nicholson.

Mr. Shone drew attention to the somewhat remarkable fact that, both in Great Britain and Ireland, the shell-bearing High-Level Glacial Sands and Gravels have as yet been found only upon the outskirts of the mountainous areas. This would appear to suggest that these areas, in their more central portions, were covered with ice at the time the fossiliferous High-Level Glacial Sands and Gravels were being accumulated.

Prof. Blake enquired what relation the deposits described might have to the great terminal moraine described by Prof. Carvill Lewis, which, as he drew it, did not pass far from the spot. The details of the stratification, like those of Moel Tryfaen, seemed indicative of melting from ice.

The President thought that the Author, by the careful collection of his facts, and the avoidance of theory regarding them, had provided valuable additional material for the discussion of the vexed question of the extent of the Glacial submergence. The deposit described in the paper had been first brought to the President's notice by a late Fellow of the Society, Mr. R. S. Wyld, Jun., who sent him some of the shells. He urged Mr. Wyld, who was the resident engineer of the Liverpool Waterworks near Oswestry, to collect the shells and write a paper on the subject for the Society; but death removed him before he had time to carry out this proposal.

[1] The Lias fossils are not abundant, but very rare.—A. C. N., January 12, 1892.

The Author took the opportunity of thanking Prof. Judd for an inspection of the Moel Tryfaen collection at South Kensington.

With reference to Mr. Reid's letter and the President's remarks, he explained that he had purposely refrained from introducing theory into his paper, deeming it best to place upon record a statement of facts.

He joined with the President in expressing regret at the early death of Mr. Wyld.

In reply to Dr. Hicks, the Author stated that the gravels were stratified, although very irregularly, and current-bedding was very frequent. The fragment of *Elephas* had been found, judging from the particulars stated by the workmen (it having been discovered at the time a great mass of material had slipped down from the face of the pit), in the upper part of the deposit, and perhaps it was of younger age than the bulk of the mollusca, although it was quite probable the fragment had been transported to Gloppa by the same agency as that which had transported northern erratics. There was no trace of a shell-beach, or of well-defined zones of occurrence of any particular species of mollusca.

The Author agreed in the main with Prof. Hull as to the origin of the deposit under water; and in reply to Prof. Blake, he stated that there was no Boulder Clay in connexion with this deposit, nor does it seem to have any connexion with the local Welsh drift. He had not had the advantage of reading Prof. Carvill Lewis's papers on terminal moraines; but, so far as he could judge from the evidence, this deposit did not confirm that theory, or, rather, that theory was not applicable to this particular deposit.

9. *The* Subterranean Erosion *of the* Glacial Drift, *a* probable cause *of* submerged Peat- *and* Forest-beds. By Wm. Shone, Esq., F.G.S. (Read December 9, 1891.)

The Drift of the N.W., N.E., and Central England covers a large area of the Triassic Series, composed of interstratified hard and soft rocks, giving rise to very unequal denudation of the various members of the series. The Triassic area is consequently of an undulating character, and the Drift which covers it like a mantle partakes of the undulating nature of the rocks it overspreads. The Drift upon the sides of the valleys has, at short intervals, been cut into minor valleys by the rain coursing down their slopes. The minor valleys *cut out of the Drift* should be carefully distinguished from the larger valleys *covered with Drift*, for the latter appear to follow the contour of the pre-Glacial land surface.

Every minor valley has its small streamlet, which in dry weather is most frequently a very insignificant watercourse; during heavy falls of rain, however, such tiny rivulets become swollen into large and rapidly-flowing brooks, charged with densely turbid water derived from the clays, sands, and gravels of the Drift.

The section (fig. 1) is across two such minor valleys. At the S.S.E. end is situated the sandpit, with a face of the pit at right angles to the line of section. Under the surface-soil the pit has a covering of Upper Boulder Clay (varying from 2 to 6 feet in thickness) resting upon Middle Sands and Gravels. About 6 feet beneath the base of the Upper Boulder Clay there was a band of clay a few inches thick in the underlying sands and gravels. After a very heavy fall of rain in November 1890 I found the sands and gravels between these two beds of clay to be full of large holes, through which the subterranean water that had percolated between the clay-beds had escaped. Where the sands and gravels had been forced from under the Upper Clay, many tons of the latter had fallen into the bottom of the pit.

This occurrence led me to consider what would have become of the sudden rush of subterranean water through the sands and gravels lying under the Upper Boulder Clay had there been no artificial outlet into the sandpit. If it had found an outlet along an inclined plane it would have forced along the fine sands and gravels from beneath the more impervious clay to the place of escape. The search for the probable direction of the underground drainage resulted in finding a natural outlet N.N.W. of the sandpit into streamlet No. 1 of the section.

The streamlets Nos. 1 and 2 flow in a westerly direction until intersected by a much larger and longer stream, into which many such streamlets fall.

Along the line of section at B–B the sands and gravels crop out from under the clay. At such points springs are of frequent occurrence, and if these are caught in troughs deposits of sand quickly accumulate in the receptacles. After heavy rains the quantity of sand deposited by even tiny springs is very considerable.

Where the drainage is insufficient to maintain permanent springs, a stratum of a soft puddly nature is produced by the constant oozing-out of underground water. There are other outlets which are active only during the continuance of very heavy rain, acting as storm-overflows for the ordinary underground drainage.

One and all, however, issue from underground charged with matter derived from the subterranean erosion of the clays, sands, and gravels under or through which they have passed. Waste so constant cannot have continued for a long period of time without leaving evidences of its effects.

For instance, in Ithell's sandpit (see fig. 1), the sands and gravels beneath the Upper Boulder Clay have been proved for 30 feet without reaching the rock (Bunter Pebble-beds). If the clay, sand, and gravel were of a uniform thickness across the whole line of section from S.S.E. to N.N.W., the clay would be upon the horizon A–A, and the sand and gravel should crop out at Z–Z instead of at B–B It should be noticed that the height of the clay from ridge to ridge is uniform throughout, so that an observer at either end has an uninterrupted view across.

If A–A represents the

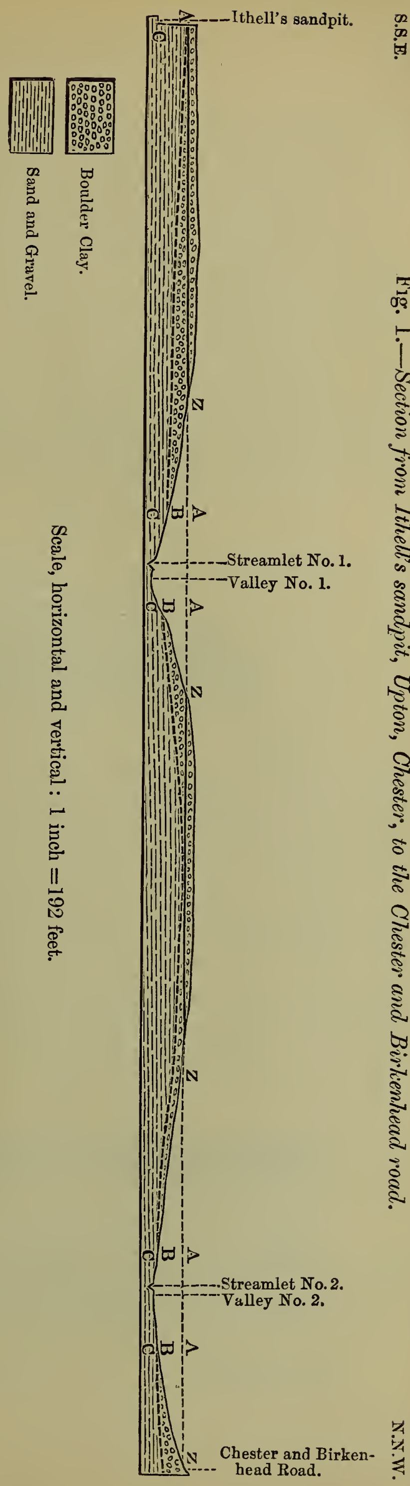


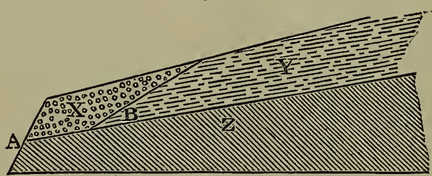
Fig. 1.—*Section from Ithell's sandpit, Upton, Chester, to the Chester and Birkenhead road.*

former line of junction of the clay with the sands and gravels, the latter must have been removed to the extent of the difference between A and B, the present outcrop in each valley. In valley No. 1 the clay has subsided 18 feet, and in valley No. 2 30 feet. The total length of the section is only 480 yards.

It is characteristic of subterranean erosion that its action is lateral; it is greatest at the point of escape and least at the farthest distance from it, while the interval between these two extremes becomes an inclined plane of subsidence. I believe this fact accounts for the occurrence of the present outcrops of the sands and gravels in the section at B–B instead of at Z–Z, the difference being the measure of the subterranean erosion of the Drift.

Subterranean erosion is frequently intermittent, and especially so if an impervious stratum rests upon a pervious one. Thus the accompanying diagram (fig. 2) illustrates a very familiar example. The

Fig. 2.

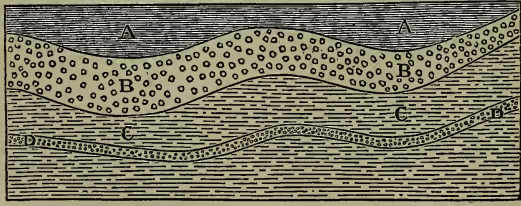


X. Clay. Y. Sand and Gravel. Z. Rock.

overlying clay, by the removal of the sands and gravels between A and B, has brought down the clay X upon the rock Z, effectually stopping any further subterranean erosion until the barrier of clay between A and B has been removed by subaerial denudation.

The sands and gravels beneath the clay are not eroded in a uniform manner, the finer sands and gravels being most easily removed. The stratification of these beds is most variable, and current-bedding very frequent, this giving rise to constantly changing deposits of light sands intermingled with beds of coarse sands and gravels on the same horizon. In sandpits it may be often observed that the surface-soil is of very unequal depth, as in the following diagrammatic section of Ithell's sandpit at Upton, Chester:—

Fig. 3.



A. Surface soil. | C. Sand and Gravel.
B. Boulder Clay. | D. Bunter Sandstone pebbles.

The soil A–A rested on the undulations of the Upper Boulder Clay B–B, and the latter on the undulating surface of the Middle Sands and Gravels C–C, whilst a curved layer of local pebbles of Bunter Sandstone (D) followed the curvature of the beds A, B, C. These lines of curvature, so frequent at the junction between the Upper Boulder Clay and the Middle Sands and Gravels, have been often, I think, erroneously interpreted as evidences of unconformity, contemporary erosion, or contortion. I venture to express the opinion that such appearances are in the vast majority of instances the results of the subterranean erosion of the heterogeneous deposits of the Glacial Drift.

While I have so far confined myself to the subterranean erosion of the Drift sands and gravels, I do not wish to be understood to limit its action to these deposits. I believe subterranean erosion to be a factor capable of explaining many difficult problems not alone in the present but also in the past, especially with regard to the formation of Coal-beds.

If it be established that the Drift sands and gravels commonly occurring under the Upper Boulder Clay have been subject to subterranean erosion, thereby causing a lateral subsidence of the clay, it follows that in low-lying districts submerged Peat- and Forest-beds would be the natural consequence. Such conditions do prevail along the low belt of land forming the coast-line of the N.W. of England and Wales from Lancaster to Great Orme's Head, and submerged Peat- and Forest-beds are matters of common occurrence. After storms remnants of such beds are often laid bare between high- and low-water marks along the whole of this coast, and between the Ribble and the Dee these exposures have been watched and noted by careful observers for many years. Perhaps the best sections are those exposed from time to time between the Dee and the Mersey, on the Cheshire shore at Leasowe.

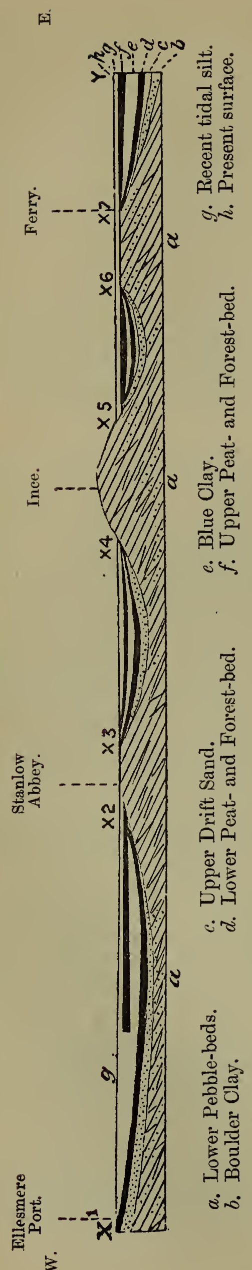
Mr. G. H. Morton, in the first edition (1863) of his 'Geology of the Country around Liverpool,' gives a section of the Peat- and Forest-beds at the locality mentioned.[1]

The strong resemblance which Mr. Morton remarks between the Peat- and Forest-beds and the Coal Measures may be due to like causes in the past and present. In other words, what will explain the origin of submerged Peat- and Forest-beds may also be helpful in clearing away many difficulties in connexion with the origin of Coal-beds. Mr. Morton further states that, on "approaching the embankment from Dove Point, the two lower old Forest-beds gradually amalgamate, and then both are represented by one carboniferous bed, the three feet of silt between having thinned out until lost."

The section given by Mr. Morton in his admirable second edition (1891) of 'The Geology of the Country around Liverpool,' on the Manchester Ship Canal between Ellesmere Port and Ince Ferry,

[1] *Op. cit.* p. 48.

Fig. 4.—Section from Ellesmere Port to Ince Ferry.



will, I think, throw much light upon the section at Dove Point, now unfortunately destroyed by the encroachments of the sea.

Mr. Morton states that the Peat- and Forest-beds "occur in the depressions between the rock-exposures, and they extend with little variation along the middle; but as they approach the sides and ascend the slopes they become thinner, and gradually end before reaching the rock" (p. 265). He also states that "there is frequently a difference in the height of the peat on opposite sides of the Canal, and constant indications of the varying contour of the old land-surfaces; but it is evident that those of the rocky eminences have been continuous with the lower and upper beds of peat" (*loc. cit.*). Having carefully watched the progress of this section of the Canal, I can testify to the accuracy of Mr. Morton's observations. He has kindly allowed me to make use of this section; and I am greatly indebted to him for this favour, because it enables me to base my explanations of the causes of submerged Peat- and Forest-beds upon his independent observations. However opposite, therefore, my conclusions as to the causes of submerged Peat- and Forest-beds may be to his, there is no difference between us as to the stratigraphical position or description of the section.

The section of the Ship Canal from Ellesmere Port to Ince Ferry is about three miles long, and is cut through marshes forming the left bank of the Mersey, into which they drain. The section exposes the solid basement upon which the Glacial and post-Glacial beds repose. Mr. Morton gives the following details of the section at Ince Ferry:—

			ft.	in.
Recent Brown and Blue Clay			5	0
Post-Glacial	Upper Peat- and Forest-bed		5	0
	Blue Clay		10	0
	Lower Peat- and Forest-bed		1	3
Glacial ——	White sand, on Boulder Clay		10	0
			31	3

On referring to fig. 4, it will be seen that in the short distance between X^7 and Y the Peat- and Forest-bed bifurcates into Upper and Lower Peat- and Forest-beds, with a wedge-shaped deposit of Blue Clay 10 feet in thickness at Y and rapidly thinning out towards X^7. Along the whole line of section, at the points X^1 to X^7, the Upper and Lower Peat- and Forest-beds become united, and at these places, it should be noticed, they rest close upon the rock.

Whatever, therefore, was the cause of the submergence of the Peat- and Forest-beds between X^1 and X^2, X^3 and X^4, X^5 and X^6, X^7 and Y, it did not disturb the continuous growth of the united Peat- and Forest-beds at the points X^1 to X^7. The conclusion to my mind is inevitable that, whatever caused the submergence of the Peat- and Forest-beds in the hollows between the bosses of Bunter Sandstone could not have altered the level of the solid basement of rock on which the Peat- and Forest-beds repose. That conclusion would require the abandonment of the generally-accepted theory that post-Glacial submerged Peat- and Forest-beds are evidences of changes of level due to a downward movement of the solid basement of rock upon which they rest. If no such movement has taken place, then the operative cause must be one that could act similarly, yet independently, within the limited area of each rock-basin between Ellesmere Port and Ince Ferry.

It must be borne in mind that the Ship Canal along this line of section runs parallel with the Mersey and intercepts the drainage of the marshes into it. During the construction of this section of the Ship Canal serious landslips have occurred. They have been confined, so far as my observation extends, principally to the land side of the cutting, or that side which receives the drainage percolating from the higher ground towards the River Mersey. Powerful pumping-engines were stationed at short intervals and kept working day and night in order to keep the cutting clear of water. Have we not here a sufficient explanation of the submerged Peat- and Forest-beds?

The mingled Peat- and Forest-beds increase in thickness towards the centre of the rock-basins formed by the Bunter Sandstone bosses of Ellesmore Port, Stanlow Abbey, Ince, and Ince Ferry. Through these four channels the subterranean drainage of the land in the rear of the section escaped into the River Mersey. The underground water must accumulate most in the centre of each rock-basin, and consequently exert its greatest force in the lower portions of each hollow, with the result that the mingled Peat- and Forest-beds would increase in thickness towards the centre of each rock-basin until submerged and buried under the Blue Clay which divides the Upper and Lower Beds.

In brief, the stratigraphical history of this most interesting section appears to me to be as follows:—The Lower Forest-bed flourished upon Glacial Drift very little above the water-level of the district. By subterranean erosion the level was gradually lowered between the points X^1 and X^2, X^3 and X^4, X^5 and X^6, X^7 and Y, until the site of the forest became a peat-morass, which was eventually covered with Blue Clay. The time came when the drainage was interrupted and subterranean erosion ceased; then the Upper Forest-bed spread out from the points of continuous growth (X^1 to X^7) across each rock-basin. It flourished until the cause of the interrupted drainage was removed, when subterranean erosion again became active and the Upper Forest-bed sank below the water-level, while peat-mosses grew on its site, until in turn they were buried under tidal silt—the rate of subterranean erosion at present being more rapid than the increase of the thickness of the peat by growth.

The principal characteristic of subterranean erosion is lateral subsidence. Intermittent action follows as a natural consequence. This is especially the case when an impervious bed rests upon a pervious one, as in fig. 2 (p. 98). The liability of subterranean erosion to be interrupted along any inclined plane of underground drainage is, in my opinion, the cause of the bifurcation of the Peat- and Forest-beds; while the thinning-out of the deposits which separate them into Upper and Lower towards each point of bifurcation shows that the subsidence in each case was gradual and lateral.

Mr. T. Mellard Reade published, in the 'Proceedings of the Geological Society of Liverpool' for 1871–72,[1] a number of very valuable sections of the post-Glacial deposits of Lancashire and Cheshire, from which the general tendency of Peat- and Forest-beds to subside laterally is very obvious. I have omitted to mention the numerous theories advanced to account for submerged Peat- and Forest-beds—not, however, from any want of courtesy towards the authors. The views I have attempted to prove are so contrary to current opinion upon this subject as to constitute a new departure, and should therefore be judged (I submit) independently, according to the facts.

[Lyell, in his 'Principles,' vol. ii., described a submarine forest at Bournemouth, and attributed its position to "the undermining of the sandy strata on which" it rested. He considered that "the sea, in its progressive encroachments, eventually laid bare, at low water, the foundations of this marshy ground; in which case much of the sand constituting these foundations might have been washed out by the rapid descent of the fresh water through them at the fall of the tide."[2] My experience of the N.W. of England submarine Forest-beds is that they became first submerged by subterranean drainage towards the nearest freshwater

[1] *Op. cit.* p. 36 *et seq.* and plates ii.–iv.
[2] *Op. cit.* 12th ed. (1875) vol. ii. p. 538.

stream at a time when the sea was so far away as to exercise no influence due to the rise and fall of the tide. On the coasts of Lancashire and Cheshire the encroaching sea has washed out the previously submerged Peat- and Forest-beds. These submarine forests occur *in situ,* rooted in solid Boulder Clay; like forests cannot now, however, thrive so near the sea. See also the Rev. W. B. Clarke's paper, Proc. Geol. Soc. vol. ii. (1838) p. 599.

With regard to the Axmouth landslip, referred to by Mr. H. B. Woodward in the discussion, it was attributed to the action of "numerous springs issuing from the loose sand" (Upper Greensand), which had "gradually removed portions of it."[1] According to the principle of subterranean erosion, this landslip was caused by the movement, particle by particle, of the whole mass of quicksand laterally towards the nearest points of escape. Such so-called "springs" are an effect—not a cause—of subterranean erosion.—January 14th, 1892.]

Discussion.

Prof. Hull was disposed to accept Mr. Shone's views regarding the changes of level of the Upper Boulder Clay in the district referred to, and observed that a similar view had long since been entertained to account for the submergence of the peat deposits on the coast of the Wirral promontory.

The Rev. Edwin Hill added that the sinking of surface-clay from such erosion of sand beneath would accelerate denudation of the surface of the clay. But in beds deposited on an uneven subsurface, simple shrinking would produce a similarly uneven position.

Mr. H. B. Woodward mentioned that Conybeare had referred to similar undermining of sandy strata as a chief cause of the Great Landslip at Lyme Regis. He asked the Author if he had considered the fact that Boulder Clay rests on an irregular surface of the underlying strata, whether sands or clays, and often plunges abruptly into hollows excavated during its accumulation.

Mr. Shone, in reply, stated that he thought the term "subterranean erosion" was perhaps preferable to "subterranean denudation." He was glad the Society had received his conclusions so favourably. He maintained, and had endeavoured to prove, that wherever water percolated through such unconsolidated beds as clays, sands, and gravels along an inclined plane, it was constantly carrying the lighter materials of such strata towards the nearest point of escape. The nearer the approach to the point of escape, the greater became the power of subterranean erosion. This was more especially the case where clay rested upon sand and gravel. He believed it was the cause of that lateral subsidence so characteristic of submerged post-Glacial Peat and Forest-beds. Landslips were the extreme rather than the ordinary effects of subterranean erosion. He also remarked that the subterranean removal of sands and gravels frequently resulted in causing the appearance of contorted Drift.

[1] Lyell, 'Principles,' 12th ed. (1875) vol. i. p. 541.

10. *On the* Plutonic Rocks *of* Garabal Hill *and* Meall Breac.

By J. R. Dakyns, Esq., M.A., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S. (Read January 27th, 1892.)

[Communicated by permission of the Director-General of the Geological Survey.]

The schists of the Southern Highlands of Scotland have been traversed in many places by igneous rocks. Sills and dykes are widely distributed throughout the district, and here and there, as for example in Glen Tilt, Glen Lednock, and near the head of Loch Lomond, extensive areas are composed of plutonic rocks. Our object in this communication is to describe some of the phenomena which may be observed in the last-mentioned locality.

The plutonic rocks in question form the belt of high ground stretching in a south-west direction from Inverarnan. They vary considerably in chemical and mineralogical composition. Different parts of the mass can be proved by the phenomena of veins and inclusions to belong to slightly different periods, but regarded as a whole it must evidently be referred to one geological epoch. Whenever two portions in juxtaposition are seen to differ in age, the more acid, so far as our observations go, is invariably the younger. Thus the veins are more acid and the inclusions more basic than the material surrounding them.

Rather more than half a mile above Inverarnan tonalite (quartz-diorite) appears in the bed of the Arnan and on each side of the stream. From this point it extends in a south-westerly direction for about $2\frac{1}{4}$ miles, as shown on the accompanying map, and possesses a fairly uniform character. Garabal Hill, south-west of Inverarnan and immediately south of the place where tonalite appears in the Arnan valley, is composed of diorite. In some places, as, for instance, west of Garabal Hill, a sharp line can be drawn between diorite and tonalite, but in other places the transition from one rock to the other is so gradual that it becomes impossible to draw such a line; consequently parts of the area mapped as diorite between Garabal Hill and Loch Garabal might just as well have been mapped as tonalite. On the whole, the south-eastern portion of the plutonic belt is more basic than the north-western.

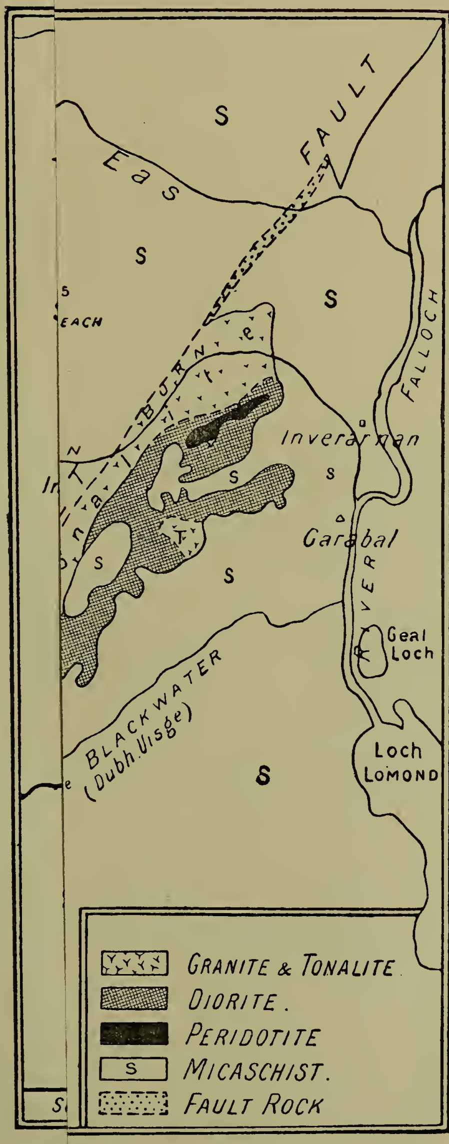
Loch Garabal is the loch situated nearly a mile south of the summit of Ben Damhain.[1] Immediately north-east of this lochan there is a small area of ultra-basic rock (marked as peridotite on the map). Another small patch of similar rock occurs in the diorite north of Garabal Hill. The limits of this rock are fairly well defined.

Immediately north of the first-mentioned patch of ultra-basic

[1] It has no name on the one-inch map. On the six-inch map it is designated Lochan Strath Dubh-uisge (the lochan of the Blackwater Valley), but it is better known, at least to fishermen, by the name that we have adopted.

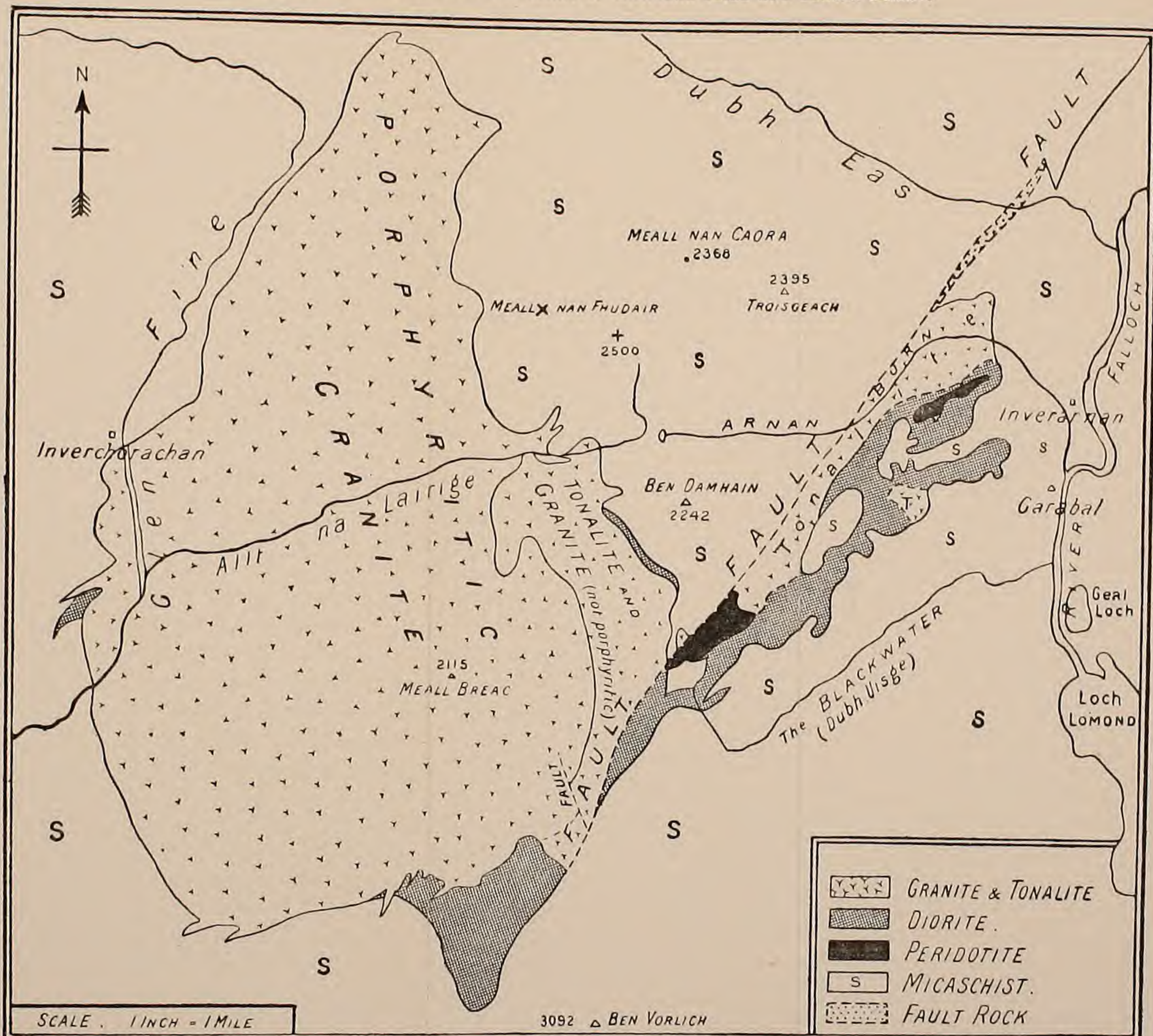
[*To face* p. 104.

Meall Breac.



:h, is the highest hill in the immediate
ance Map, but it is over 2500 feet.

Sketch-Map of the Plutonic Area of Garabal Hill and Meall Breac.



Note.—The × marks the top of Meall-nan-Fhudair, which, with the exception of Ben Vorlich, is the highest hill in the immediate neighbourhood of the granite, east of Glen Fine. The height is not indicated on the Ordnance Map, but it is over 2500 feet.

rock we enter upon the schist of the country which forms Ben Damhain and the district north of the Arnan for several miles. On the west side of Ben Damhain and north-west of Loch Garabal we have a rock precisely like the tonalite of the Arnan. This rock becomes more basic northwards, and on the slope of Ben Damhain there is a narrow band of diorite between the schist and the tonalite. Westward, however, the tonalite passes into granite which finally becomes porphyritic, owing to the presence of large crystals of orthoclase measuring often two inches across.

In some places a sharp line can be drawn between the porphyritic and non-porphyritic granite or tonalite, as shown on the map, but in others, as, for example, west and south-west of Loch Garabal, the porphyritic character comes on quite gradually. The tonalite and non-porphyritic granite extend northwards as far as the Allt-na-Lairige, a stream in Argyllshire on a line with that of the Arnan, but whose waters flow in the opposite direction. North of the Allt-na-Lairige the plutonic mass consists entirely of porphyritic granite.

The boundary on the east of Ben Damhain is a well-marked fault. In other places the original intrusive junctions are often admirably exposed; both granite and tonalite may be seen in contact with the surrounding schists, and the junctions are of the same character in both cases. That on the east of Lochan Ben Damhain may be taken as a type. As the plutonic area is approached veins of tonalite or diorite make their appearance; these increase in number and interlace with each other to such an extent that masses of schist become isolated in the plutonic rock. A farther advance in the same direction across the boundary shows that the included fragments gradually disappear.

As the map indicates, the area occupied by granite is largely in excess of that occupied by diorite. Taking the whole plutonic area as amounting to 12 or 13 square miles (say $12\frac{1}{2}$), 10 of these are occupied by granite and only $2\frac{1}{2}$ by diorite. Diorite, therefore, forms only $\frac{1}{5}$ of the total area. The area occupied by ultra-basic rock is exceedingly small, amounting at the most to $\frac{1}{8}$ square mile.

A consideration of the distribution of the different types of rock within the area brings out the fact that diorite is found only near the margin, and especially along the south-eastern margin. We have never seen it surrounded by granite except as small inclusions. It is especially worthy of note that south and east of the main plutonic mass there are several exposures of diorite entirely surrounded by schist and unaccompanied by granite. Except along the fault, the schist of the country is penetrated by veins of granite or diorite, as we have already stated.

Now, the greater part of Ben Damhain and the southern slope of Troisgeach are occupied by a peculiar type of schist. The special character of this schist is the occurrence of patches of felspar frequently about the size of peas. These often weather out as roundish lumps and give the rock somewhat the appearance of a pebbly grit. That the felspars are not really pebbles is proved by their irregular outlines under the microscope and the fact that they contain the other constituents of the rock as inclusions. No doubt they have been developed *in situ.*

Andalusite is found in certain places to be a constituent of this peculiar rock, and may with some confidence be attributed to contact-metamorphism. This naturally suggests the conclusion that the felspars are also the result of the same action; but, as telling against this view, we have to note that the felspathic character of the schist is most pronounced at some little distance from the outcrop of the plutonic rock, that it dies out westward as one approaches the granite, and that nothing of the kind has been observed along the sixteen miles of boundary extending from the Allt-na-Lairige west of Meall nan Caora, down and across Glen Fine, and so round by the southern margin to Garabal Hill. These difficulties in the way of accepting the view that the felspathic schist is due to contact-metamorphism may possibly be removed by taking into consideration the varying character of the original rock, and the course of the plutonic rock beneath the surface; but, as we have no further evidence on these points, we must leave the question at present undetermined. One other point may, however, be mentioned in this connexion. The area occupied by this peculiar type of schist is characterized by excessive folding. The detailed mapping of certain well-marked bands along Troisgeach and the western side of Ben Damhain has proved that actual inversion has been produced in certain places.

The prevailing structure of the plutonic rock is granitic, but at one point on the north side of Loch Garabal, near the junction of tonalite and schist, a gneissose structure may be observed. The planes of foliation curve round included fragments, and the longest diameters of the fragments correspond in direction with the general trend of the foliation. There is no evidence that any portion of the plutonic rock has been affected by the earth-movements which have operated so powerfully upon the schists, and we may therefore, with much confidence, attribute the foliation in this case to movements anterior to final consolidation.

Taking all the facts into consideration, there seems no escape from the conclusion that we have in this area the record of a series of events connected with the consolidation of a vast subterranean reservoir of molten rock. Having regard to the whole mass, it seems probable that the process was a continuous one; but if we consider only certain limited portions it was unquestionably discontinuous, for more acid material has frequently found its way, in the form of veins, into already consolidated rocks of a more basic character. The complex includes rocks which range in composition from ultra-basic to acid. The ultra-basic rocks are represented by wehrlites (olivine-diallage rocks), picrites (olivine-augite rocks), serpentine (possibly representing dunites, saxonites, and lherzolites), and finally, a peculiar rock, to which it is difficult to give a definite name, consisting essentially of enstatite, diallage, brown hornblende, and biotite.

The acid rocks are represented by porphyritic and non-porphyritic biotite-granites. Between the two extremes we have numerous intermediate varieties which may be grouped under such terms as augite-diorite, diorite, tonalite (quartz-mica-diorite), and hornblende-biotite-granite.

The first rocks formed were peridotites; then followed diorites, tonalites, and granites, in the order of increasing acidity. The most acid rock known occurs as narrow veins in the granite and tonalite. It consists of felspar and quartz, and is almost entirely devoid of ferro-magnesian constituents.

Facts similar to those referred to in this communication may, as we have already stated, be observed in other parts of the Southern Highlands. Thus, in the classic area of Glen Tilt there is a mass of plutonic rock which is partly acid and partly basic in character. As a rule the one type passes gradually into the other—granite merges into diorite—but occasionally one rock veins the other, and when this takes place, the granite is always seen to be the younger of the two.

In the opening paragraph of this paper we referred to the dykes and sills which abound in many parts of the Southern Highlands. These, like the great plutonic masses, range in composition from acid to basic; so that we are compelled to include most of them under the general and ill-defined term, lamprophyre. With the exception of some of the felsitic dykes, which are seen to issue from the granite, it is impossible to trace these lamprophyres to their source; but, looking at the general parallelism of the phenomena presented by the dykes and the plutonic masses, we feel convinced that they are both parts of the same series of events.

We will now proceed to describe the physical, mineralogical, and chemical characters of the principal rock-types.

1. Specific Gravity.

The specific gravity of the principal rock-types is given in the following list. It must of course be remembered that the specific gravity of the peridotites has been reduced by serpentinization.

Serpentine, north-east of Loch Garabal, 2·76.

Augite-serpentine rock, north-east of Loch Garabal, 3·32.

Diallage-olivine-serpentine rock, north-east of Loch Garabal, 3·00.

Enstatite-augite-hornblende-biotite rock, north-east of Loch Garabal, 3·15.

Augite-diorite, north-east of Loch Garabal, 3·04.

Diorite, west side of Ben Damhain, 2·96.

Augite-diorite (much plagioclase), north-east of Loch Garabal, 2·81.

Quartz-mica-diorite (tonalite), south-west of Ben Damhain, 2·76.

Hornblende-granitite, junction with porphyritic granite, hill south of Allt-na-Lairige, 1½ mile from head of burn, 2·67.

Porphyritic granite, hill south of Allt-na-Lairige, 1½ mile from head of burn, 2·62.

Eurite, vein in tonalite, S.W. side of Ben Damhain, 2·59.

2. Colour and Texture.

The texture of the rocks is granitic. Colour varies from black in the peridotites and serpentines to nearly white in the thin veins of eurite. The general colour of any intermediate rock is of course determined by the relative abundance of the ferro-magnesian and felspathic constituents. The grain of the rocks is in most cases sufficiently coarse to enable the individual constituents to be easily recognized. The orthoclase of the granites is of a pale flesh colour. The granite with large crystals of orthoclase is the only rock which is distinctly porphyritic; for the tonalites, diorites, and peridotites are composed of individuals having fairly uniform dimensions. A pseudo-porphyritic aspect is given to some of the peridotites by the serpentinization of the olivine.

3. Mineralogical Composition.

The following minerals enter into the composition of these rocks:—

(a) *Essential Minerals.* Iron ore, olivine, enstatite, augite, diallage, hornblende, biotite, plagioclase, orthoclase, microcline, quartz.
(b) *Primary Accessories.* Sphene, apatite, zircon.
(c) *Secondary Accessories.* Serpentine, epidote, chlorite, mica.

(a) *Iron Ore.*—In the ultra-basic rocks the iron ore occurs mainly in the anastomosing strings which traverse the olivine. It has no direct connexion with the process of serpentinization, for it is found alike in the perfectly fresh and in the altered mineral. The distribution of these veins in the serpentinized rocks is a valuable criterion for the estimation of the amount of olivine originally present. Apart from the veins in the olivine, we find iron ore occurring as allotriomorphic grains and more rarely as crystals (octahedra). In one or other of these forms it is present in all rocks, but it is, of course, far more abundant in the basic than in the acid rocks. In the latter it can only be regarded as an unimportant accessory.

The general absence of titanic acid, or its presence only in very minute quantities, has been established by chemical analysis, so that the iron ore must be non-titaniferous.

Iron ore may occur as inclusions in any of the other constituents, and it is the only mineral present in these rocks of which this can be said.

Olivine.—This mineral is present in the form of colourless, allotriomorphic grains, generally more or less serpentinized, but in a few cases perfectly fresh. The serpentinization of olivine has been so frequently described that no detailed account of it is necessary on the present occasion. It is of a perfectly normal character. The anastomosing veins of magnetite have already been described. In addition to these we find occasionally in the centre of an unaltered grain of colourless olivine a small patch which is rendered cloudy by the presence of innumerable, minute, dust-like particles, thickly scattered through the clear olivine-substance. Olivine has been found only in the highly basic rocks. Some of the serpentines have been formed by the alteration of rocks composed almost entirely of this mineral. Inclusions of olivine occur in the other ferro-magnesian constituents. Iron ore is the only mineral found in the olivine itself.

Enstatite.—This mineral has been observed only in one or two of the ultra-basic rocks. It is fresh and for the most part free from inclusions. The characteristic pleochroism is well seen, but the colours are not strong. The mineral is allotriomorphic with respect to olivine, but idiomorphic with respect to brown hornblende and biotite.

Augite and Diallage.—In the ultra-basic rocks this mineral is pale brown in thin section. Prismatic and sometimes also pinacoidal cleavages are well developed. Parallel rows of minute rod-like inclusions are present in some sections. Cross-sections, giving the prismatic cleavages and showing the characteristic interference-figure, are sometimes seen to contain two rows of inclusions making angles of 45° with the cleavages and at right-angles to each other.

In addition to the pale brown pyroxene of the ultra-basic rocks we find also a pale green mineral in the augite-diorites. This variety is generally bordered irregularly by green hornblende. The augite occurs usually in allotriomorphic grains. Twinning is not uncommon, and sometimes indications of idiomorphism have been observed.

Hornblende.—Two varieties are represented, brown hornblende in the ultra-basic rocks and green hornblende in the intermediate and acid rocks.

The brown hornblende is generally allotriomorphic, especially with reference to olivine and pyroxene. It is sometimes seen to be idiomorphic with respect to plagioclase.

Pleochroism.[1]

α (n_p) pale brown.
β (n_m) brown.
γ (n_g) rich brown.

Green hornblende occurs as allotriomorphic grains and also as crystals. Perfect idiomorphism is very rare and has been observed only in certain basic inclusions in the granite; but traces of the forms $\{110\}$ and $\{010\}$ are not uncommon in the tonalite. Twinning of the normal type is fairly common.

Pleochroism.

α (n_p) pale green or brown.
β (n_m) brownish green.
γ (n_g) green.

Iron ores, apatite, zircon, and sphene occur as inclusions.

[1] α, β, and γ stand respectively for the greatest, mean, and least axes of elasticity. The notation in parentheses is that now used by French authors.

Biotite.—There are two varieties of dark mica corresponding with the two varieties of hornblende. Both are nearly uniaxial. The biotite of the ultra-basic rocks occurs in large ragged plates, containing inclusions of olivine.

Pleochroism.

α (n_p) } pale brown.
β (n_m) }
γ (n_g) rich reddish brown.

The biotite of the intermediate and acid rocks occurs in small plates, several of which are frequently grouped together. It rarely shows definite crystallographic outlines.

Pleochroism.

α (n_p) } pale brown.
β (n_m) }
γ (n_g) very dark brown, almost opaque.

There is an absence of the red tinge which is characteristic of the biotite of the basic rocks. Chlorite containing grains of epidote arises as the result of the alteration of biotite.

Plagioclase.—Amongst the ultra-basic rocks this mineral has been observed only in the enstatite-augite-hornblende-biotite rock. It plays the rôle of groundmass and serves to bind together the ferro-magnesian constituents, so that they weather out as knots. A section through one of these knots shows a few, apparently isolated patches of twinned plagioclase, having the same optic orientation over a large area. Notwithstanding the fact that the knots may measure as much as three quarters of an inch in diameter, the actual amount of felspar present is very small in comparison with that of the ferro-magnesian constituents. In the granitic rocks the plagioclase shows a tendency to idiomorphism, and this is especially the case when it is in contact with quartz or microcline. Broad lath-shaped sections, terminated by well-developed crystallographic planes meeting in salient and re-entering angles, may occasionally be observed where felspar is in contact with interstitial quartz.

Orthoclase and *Microcline.*—The potash-felspar occurs in crystals, crystal fragments, and allotriomorphic grains. The large crystals of the porphyritic granite are often Carlsbad twins having the forms $\{110\}$, $\{001\}$, $\{010\}$, and $\{\bar{1}01\}$. In thin section a zonal structure is frequently seen. Sphene, iron ores, hornblende, biotite, and oligoclase occur as inclusions in the porphyritic crystals, and iron ores, sphene, and apatite may be seen as inclusions in the hornblende which is itself included. *Microcline* plays the rôle of groundmass in some of the more acid rocks.

Quartz.—This mineral is present in fairly large irregular patches having uniform optic orientation (interstitial quartz), as aggregates of allotriomorphic grains, and as a constituent of micro-pegmatite. It contains minute cavities, some of which carry movable bubbles. The inclusions are sometimes arranged in planes which may be followed from one grain to another. Most of the cavities containing bubbles appear to be scattered irregularly through the grains, not grouped along secondary planes.

Interstitial quartz is found in the more basic of the intermediate rocks, and granular quartz in the acid rocks. Micro-pegmatite and granular quartz are found in the veins of eurite. A small quantity of micro-pegmatite is also found in some of the rocks of intermediate composition. In this case it forms tufts on the margins of oligoclase, and the felspar associated with the quartz is twinned like that of the main grain or crystal to which the tuft is attached.

(b) *Primary Accessories.*—Apatite is absent from the ultra-basic rocks, but occurs in all the other members of the series. Well-formed prisms terminated by the basal plane are not uncommon. Sphene is present in two forms: as colourless grains zoning iron ores in the augite-diorites, and as brown pleochroic crystals, giving the lozenge-shaped sections due to the form $\{\bar{1}23\}$, in the tonalites and granitites. Minute crystals of zircon are not uncommon in the intermediate and acid rocks. They occur as short, doubly terminated prisms, rich in crystal-faces.

(c) *Secondary Accessories.*—Serpentine arises as a result of the alteration of olivine. Epidote and chlorite have been formed in connexion with the alteration of biotite, and possibly also hornblende. The felspars have been more or less altered in certain rocks, and whenever the alteration-product is capable of resolution it is seen to consist of minute interlacing scales of mica.

The distribution of minerals in the rocks which have been examined microscopically is represented in the following Table (p. 112).

The Table merely gives the qualitative composition of the rocks examined. It does not indicate the relative abundance of the different minerals. If this were done the evidence of a transition from the ultra-basic to the acid rocks would be strongly emphasized. Nevertheless, it must be borne in mind that the area as a whole appears to be relatively poor in typical basic rocks—that is, in rocks containing about 50 per cent. of silica. Gabbros, which are so common in some plutonic areas, are here conspicuous by their absence. The basic rocks in this district are represented by augite-diorites. It is instructive to compare the general distribution of the different minerals in the different rocks. For this purpose it is convenient to arrange the rocks in the order of specific gravity, which, of course, corresponds very closely with that of silica-percentage, if we make allowance for the reduction of specific gravity consequent on serpentinization. Then, commencing with the most basic rocks and proceeding through the series, we observe that as olivine dies out pyroxenes increase in importance. These in turn are replaced by hornblende and biotite. Next the hornblende decreases relatively to the biotite, and finally, in the eurite-veins, the ferro-magnesian silicates have in places entirely disappeared. If we turn to the quartzo-felspathic constituents, and consider their distribution in the same way, we see that plagioclase first makes its appearance; then follows orthoclase, and lastly

Table illustrating the Mineralogical Composition of the Rocks.

	a.											*b.*			*c.*			
	Iron Ores.	Olivine.	Enstatite.	Augite (Diallage).	Brown Hornblende.	Green Hornblende.	Biotite.	Plagioclase.	Orthoclase.	Microcline.	Quartz.	Sphene.	Apatite.	Zircon.	Serpentine.	Epidote.	Chlorite.	Sericite.
1	×	...	...	...	...	...	...	...	...	...	...	...	...	...	×			
2	×	...	...	?	...	...	...	...	...	...	...	...	...	...	×			
3	×	...	...	×	...	...	...	...	...	...	...	...	...	...	×			
4	×	×	...	×	...	...	...	...	...	...	...	...	...	...	×			
5*......	×	×	...	×	×	...	...	...	...	...	...	...	...	...	×			
6	×	×	...	×	...	×	...	×	...	...	...	...	...	...	...			
7*......	×	×	×	×	×	×	×	×	...	...	...	...	...	...	...			
8	×	×	×	×	×	...	×	×	...	...	...	...	...	...	...			
9	×	...	...	×	×	...	...	×	...	...	...	×	...	...	...			
10	×	...	...	...	...	×	×	×	...	...	...	×	×	×	...	×	×	...
11	×	...	...	...	...	×	×	×	...	...	...	...	×	×	...	...	...	...
12*......	×	...	...	...	...	×	×	×	...	...	...	...	...	...	...	×	×	×
13	×	...	...	...	...	×	×	×	...	...	...	×	×	...	...	×	×	×
14	×	...	...	...	...	×	×	×	×	...	...	...	×	×	...	×	×	×
15	×	...	...	...	...	×	×	×	×	...	×	...	×	...	...	×	×	×
16	×	...	...	...	...	×	×	×	×	...	×	×	×	...	...	...	×	×
17	×	...	...	...	...	×	×	×	×	...	×	...	×	...	...	×	×	×
18*......	×	...	...	...	...	×	×	×	×	...	×	×	×	×	...	...	...	...
19	×	...	...	...	...	×	×	×	×	...	×	×	×	...	...	×	×	×
20*......	×	...	...	...	...	×	×	×	×	...	×	×	×	...	...	...	...	...
21*......	×	...	...	...	...	...	×	×	×	...	×	×	×	×	...	...	×	×
22	×	...	...	...	...	×	×	×	×	...	×	×	×	×				
23	×	...	...	...	...	×	×	×	×	×	×	×	×	×				
24	×	...	...	...	...	×	×	×	×	×	×	×	×	×				
25*......	×	...	...	...	...	...	...	×	×	...	×	...	...	...				

The rocks which have been analysed are indicated by asterisks.

(4041) 1. Serpentine. North-east of Loch Garabal.
(4017) 2. Serpentine with thin veins of chrysotile. Same locality.
(4018) 3. Augite-serpentine rock; altered picrite (Rosenbusch). North-east of Loch Garabal.
(4019) 4. Olivine-diallage-serpentine rock; altered wehrlite (Rosenbusch). North-east of Loch Garabal.
(4020) 5. Olivine-diallage rock, partly serpentinized; altered wehrlite. North-east of Loch Garabal.
(4021) 6. Augite-diorite. North-east of Loch Garabal.
(4022) 7. Enstatite-diallage-hornblende-biotite-olivine rock. Loose block. North-east of Loch Garabal.
(4023) 8. Knot in the above.
(4025) 9. Augite-diorite. W. side of Ben Damhain.
(4024) 10. Biotite-diorite. North-east of Loch Garabal.
(4026) 11. Biotite-diorite. $\frac{1}{3}$ mile N.E. of Loch Garabal.
(4028) 12. Biotite-diorite. W. side of Ben Damhain.
(4029) 13. Biotite-diorite. E. of Loch Garabal.
(4030) 14. Biotite-diorite. $\frac{1}{2}$ mile south of Loch Damhain.
(4027) 15. Quartz-biotite-diorite (Tonalite). North-east of Loch Garabal.
(4031) 16. Hornblende-granitite. Head of Allt-na-Lairige.
(4032) 17. Hornblende-granitite. Near junction with schist on the south side of Ben Damhain.
(4033) 18. Hornblende-granitite. South-west of Ben Damhain.
(4035) 19. Tonalite or hornblende-granitite. $\frac{3}{4}$ mile up Arnan Burn.
(4036) 20. Hornblende-granitite. Hill S. of Allt-na-Lairige; near junction with porphyritic granitite.
(4037) 21. Porphyritic granitite. Same locality.
(4038) 22. Porphyritic granitite. Near the head of Allt-na-Lairige.
(4034) 23. Lenticle in porphyritic granitite. Near the head of Allt-na-Lairige.
(4039) 24. Granitite. $1\frac{1}{2}$ mile from the head of Allt-na-Lairige.
(4040) 25. Eurite. Vein in hornblende-granitite or tonalite. South-west side of Ben Damhain.

(The numbers in parentheses are those of the Survey Collection.)

microcline. Quartz comes in with orthoclase. We may therefore arrange the essential minerals in the following order, based on their distribution in the different types of rock in which they are most important:—

Olivine.
Pyroxene.
Hornblende.
Biotite.
Plagioclase.
Orthoclase and quartz.
Microcline.

It is instructive to note that when the minerals pyroxene, hornblende, biotite, plagioclase, microcline, and quartz make their first appearance, they play the rôle of groundmass; in other words, they are allotriomorphic or ophitic with respect to the other constituents.[1] It is only when a mineral has, so to speak, established itself as an important constituent that it begins to show traces of idiomorphism.[2]

This leads us to consider another point of great interest: namely, the order of formation of minerals in individual rocks.

The determination of this order is based on a consideration (1) of the inclusions, and (2) of the relative perfection of crystalline form in the different constituents. If the minerals in any rock-specimen resulted from the consolidation of a magma having the same composition as the specimen, and if the minerals separated out one after the other, each having its own definite period, there would be no difficulty in determining the order in unaltered rocks. These conditions, however, and especially the latter, are rarely realized. Two minerals may be both idiomorphic and allotriomorphic with respect to each other in the same rock.

The facts indicate that the only order we can establish is that in which the different constituents commenced to form. We may suppose that the whole period covered by the process of consolidation of the rock is divided into a number of shorter periods, during which each of the individual constituents was separating out. These shorter periods overlap, and it is this overlapping which tends to obscure the operation of the natural law. The overlapping reaches its maximum in the plutonic rocks.

If now we consider the most basic rocks we find that iron ores preceded olivine, olivine preceded pyroxene, pyroxene preceded hornblende and biotite, and all the ferro-magnesian constituents preceded plagioclase. From the other rocks in the series we may infer that plagioclase preceded orthoclase, microcline, and quartz. We obtain then the following as the order in which the principal constituents commenced to form:—

[1] This is well seen as regards pyroxene in 4020; biotite and hornblende in 4022; plagioclase in 4023; microcline in 4034; quartz in 4027. See page 112, *supra*.

[2] This remark applies only to those minerals which enter largely into the composition of the rocks.

Iron ores.
Olivine.
Pyroxene.
Hornblende.
Biotite.
Plagioclase.
Orthoclase, microcline, and quartz.

These minerals are not all present in any one rock, but by piecing together the evidence furnished by different rocks we can establish the general order for the entire group.

Now it will be seen at once that there is a striking resemblance between the order in which the minerals commence to form, and their general distribution in the different kinds of rock. This fact will be referred to again after the chemical composition of the rocks has been described.

So far we have been referring to the essential minerals. The accessory minerals, sphene, apatite, and zircon, are absent from the ultra-basic rocks, but they occur in the other members of the group. They are often idiomorphic, and they are present as inclusions in the other minerals with which they are associated. If we regard the whole area as the result of the consolidation of a large plutonic reservoir, this would indicate that, although they are the first to form in a magma having the composition of the rocks in which they occur, they were not the first to form in the original magma.

4. Chemical Composition.

Owing to the great kindness of Mr. Player, we are able to give a cries of analyses of typical specimens.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	38·6	46·0	47·5	62·6	62·3	66·6	75·8
Al_2O_3	3·7	6·8	15·6	17·7	18·6	17·4	13·7
Cr_2O_3	·1	·2	·1				
Fe_2O_3	7·6	3·0	2·6	1·2	1·5	1·1	·5
FeO	7·8	7·5	7·1	3·3	3·0	2·1	·3
CaO	7·7	8·1	9·8	4·6	4·3	2·2	·5
MgO	27·7	23·9	11·7	3·4	2·5	1·2	trace
Na_2O	...	·8	1·4	2·5	1·9	3·1	1·9
K_2O	·2	·9	1·5	3·7	4·8	4·6	6·5
Loss on ignition	6·4	2·4	2·4	·7	·6	·9	·3
	99·8	99·6	99·7	99·7	99·5	99·2	99·5
Sp. Gr.	3·00	3·15	2·96	2·76	2·67	2·62	2·59

I. (5). Olivine-diallage rock; partly serpentinized. North-east of Loch Garabal.
II. (7). Enstatite-diallage-hornblende-biotite-olivine rock. Loose block. North-east of Loch Garabal.
III. (12). Biotite-diorite. W. side of Ben Damhain.
IV. (18). Hornblende-granitite. South-west of Ben Damhain.
V. (20). Hornblende-granitite. Hill south of Allt-na-Lairige; near junction with porphyritic granitite.
VI. (21). Porphyritic granitite. Same locality.
VII. (25). Eurite. Vein in hornblende-granitite or tonalite. South-west side of Ben Damhain.

The diagram facing this page expresses the molecular relations of the different bases and silica according to the method employed by Mr. Iddings.[1]

Molecular proportions of silica are represented by the abscissæ; those of the bases by ordinates. The scale for the ordinates is three-fourths of that for the abscissæ, and the distance between two of the ordinates (IV. and V.) is somewhat exaggerated. The diagram enables us to follow the changes in the relative molecular proportions more conveniently than the table of analyses.

As the silica increases magnesia falls from a very high position in the peridotites to almost nothing in the eurite-veins. The fall is not, however, uninterrupted. Two rocks very close together as regards amount of silica (IV. and V.) differ in a manner opposed to the general law.

Lime first rises and then falls. After the fall has set in, it acts in sympathy with magnesia; a local rise occurring at the same time in both constituents. Both ferrous and ferric iron fall on the whole, but there is a local rise corresponding to the local rise in magnesia.

Alumina rises and then falls, but not to any marked extent. There is a rapid local fall corresponding with the abnormal rise in lime, iron, and magnesia. It is clear that the ferro-magnesian constituents are, relatively to the felspathic constituents, more abundant in IV. than in V.

Soda rises and then falls. Its maximum is considerably to the right of that for lime. Potash rises throughout the series, except at the point where magnesia rises. It is interesting to compare the two alkalies. First the soda increases more rapidly than the potash; then the relations are reversed. Between V. and IV. the potash falls as the soda rises; between IV. and VI. they rise together; and between VI. and VII. the potash rises as the soda falls.

It is of course quite easy to connect the variations in the chemical constituents with the changes in mineralogical composition. First of all the ferro-magnesian constituents decrease as the felspathic constituents increase, and then a change takes place in the felspathic constituents and free quartz is introduced.

Anorthite-molecules decrease relatively to albite- and orthoclase-molecules, and finally albite-molecules decrease relatively to orthoclase-molecules.

5. Relations between Mineralogical Composition, Chemical Composition, and Geological Age.

Field evidence has established the fact that the rocks rich in ferro-magnesian constituents have preceded those poor in these constituents, and that rocks in which anorthite-molecules enter largely into the composition of the felspars have preceded those in which

[1] 'The Mineral Composition and Geological Occurrence of certain Igneous Rocks of the Yellowstone National Park,' Bull. Phil. Soc. Washington, vol. xi. pp. 191–220.

[*To face* p. 116.

DIAGRAM

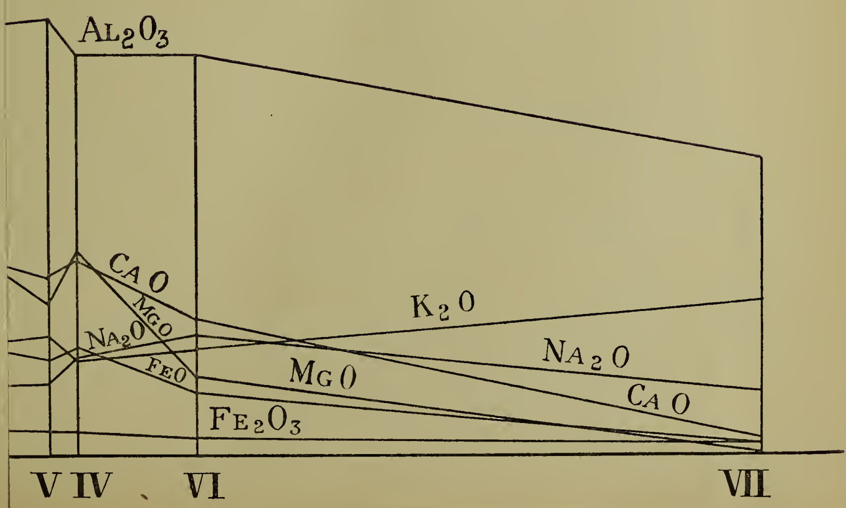
SING MOLECULAR RELATIONS

F BASES AND SILICA

IN CERTAIN

PLUTONIC ROCKS.

BY J.J.H. TEALL.



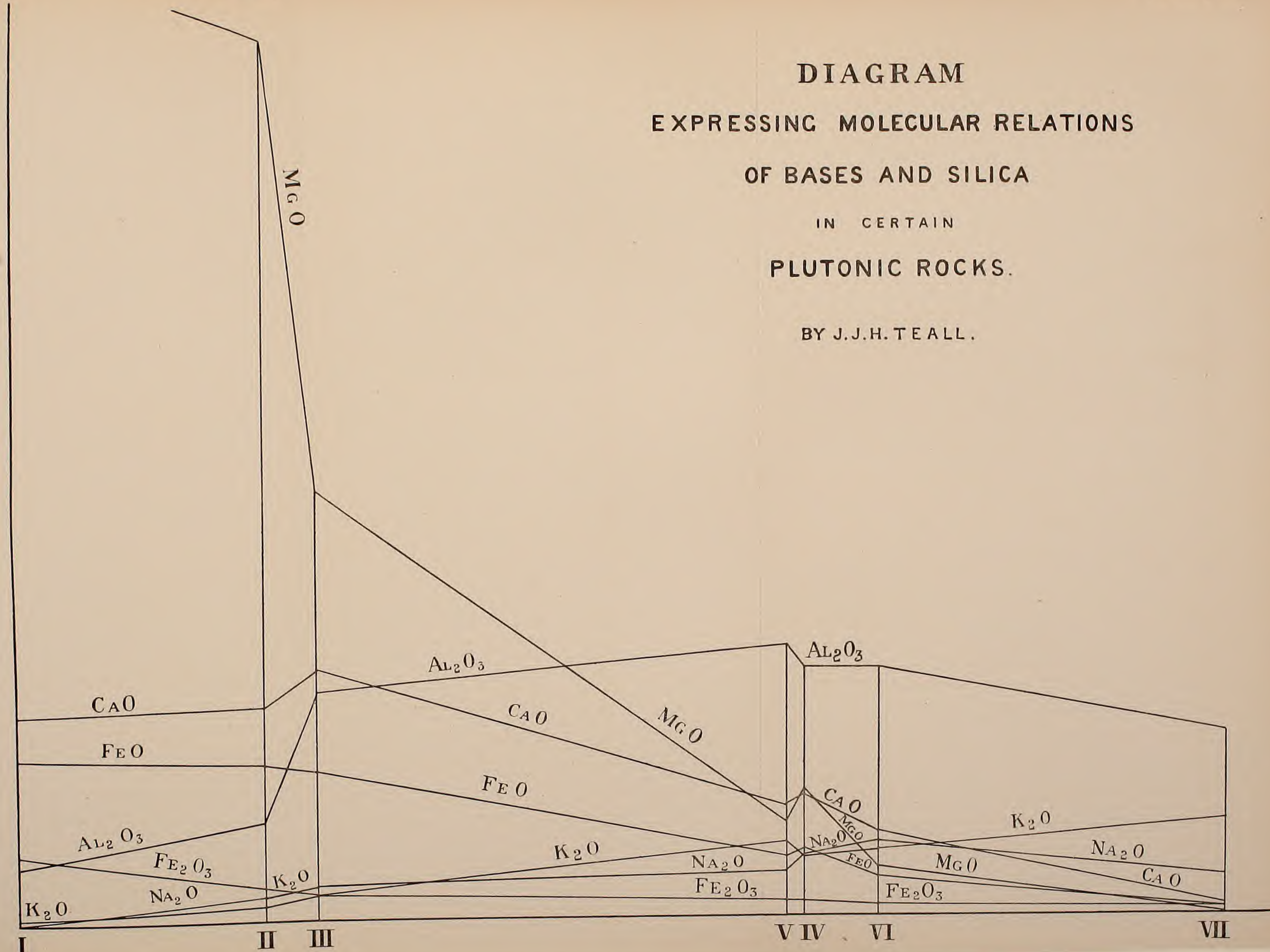


DIAGRAM
EXPRESSING MOLECULAR RELATIONS
OF BASES AND SILICA
IN CERTAIN
PLUTONIC ROCKS.
BY J.J.H. TEALL.
MgO
CaO
FeO
Al2O3
Fe2O3
K2O
Na2O
I
II
III
V
IV
VI
VII

alkali-molecules play an important part. Moreover, the microscopic examination of thin sections has proved that iron ores precede olivine, that olivine precedes the other ferro-magnesian constituents, and that the ferro-magnesian constituents as a whole precede felspar and quartz in the individual rocks. Now, if we suppose that the area represents a vast subterranean reservoir which has become differentiated during the process of consolidation,[1] we see at once that there is a natural connexion between the two classes of facts above referred to. The peridotites are the oldest rocks, because the minerals of which they are composed are the first to form in a consolidating plutonic magma, such as the one with which we are at present concerned. Iron ores and olivine are the first minerals to form. Their development at any point must leave the surrounding magma poorer in certain molecular groups. Diffusion will tend to restore homogeneity, and so the first-formed crystals may increase in size. Other causes, such as Soret's principle, or the subsidence of the first-formed crystals by gravity, may also operate and assist in producing heterogeneity in the original magma. As the process of consolidation progresses, other minerals make their appearance, and rocks of a more complicated composition are the result. The last rock of which we have any record is composed essentially of quartz and orthoclase. It occurs in the form of contemporaneous veins, and probably represents the mother-liquor remaining after the other constituents have separated out. If we take the alkali as the basis for calculating the relative proportions of quartz and felspar in the eurite-veins, we have the following result from analysis VII. :—

Felspar	58·34
Quartz	41·66
	100·00

This leaves, however, about 3 per cent. of alumina unaccounted for, so that in all probability the alkali has been somewhat reduced by alteration. It has been suggested that the micro-pegmatite of plutonic rocks is an eutectic compound in Guthrie's sense,[2] and that the composition is

Felspar	62·05
Quartz	37·95
	100·00

The facts here described tend rather to support than to negative this view.

In conclusion, it may be interesting to call attention to certain speculations which are suggested by a consideration of the facts we have been describing. Progressive consolidation of one reservoir

[1] [The essential point of the hypothesis is that the various rocks are the result of the differentiation of an originally homogeneous magma. The precise locality where the differentiation took place is more or less uncertain. That it was not always the place where the rocks are now found is proved by the phenomena of veins and inclusions.—J. J. H. T., Feb. 27th, 1892.]

[2] 'Brit. Petrogr.' (1888) p. 402.

gives rise to the formation of magmas more and more acid. Now, if plutonic rocks represent the subterranean aspects of volcanic phenomena, there should be a resemblance between the sequence of plutonic and the sequence of volcanic rocks. Given one reservoir and continuous cooling, there should be one sequence. The basic rocks should precede the acid rocks. This has been the case in many regions, but the rule is by no means without exceptions. The exceptions may be due to the existence of two or more reservoirs, or to the accession of heat or fresh material during the process of consolidation. Taking all the facts into consideration, it does not seem unreasonable to suggest that with one reservoir undergoing continuous consolidation there will be one definite sequence.

Another speculation of considerable interest is suggested by the facts before us. The consolidation of a plutonic magma may give rise to rocks of which there are no volcanic equivalents. Such rocks may result from the separation of minerals from a magma having a very different composition from that of the rocks in question. The absence of volcanic representatives of the typical peridotites and their rarity as dykes may be due to this. Again, since magnetite is the first mineral to form, it is quite possible that it may arise on a large scale as a product of the consolidation of a plutonic mass without ever existing as an actual magma. The view that certain magnetic iron ores are of plutonic origin is one which has been maintained by Wadsworth. If we look at the diagram representing the composition of the rocks which have been analysed we see that the maxima for alumina, lime, and soda lie within the limits of the diagram. The maximum for magnesia is evidently near the left-hand limit, but somewhat beyond. The maximum for iron is not even approached within the limits of the diagram. From what we know as to the order of formation of the minerals and the influence of this in determining the character of the rocks, we may speculate on the constitution of the diagram to the left. Lime and alumina would fall. Magnesia and iron oxide (magnetite) would rise. Then magnesia would fall, iron oxide still continuing to rise. When the point of origin was reached we should have a rock composed of magnetite.

As possible rocks not represented in our series we may therefore mention magnetite-rock and magnetite-olivine rock or cumberlandite of Wadsworth.

The view that subterranean reservoirs (magma-basins) of homogeneous molten material may become differentiated into local magmas of varying composition by the operation of various imperfectly understood processes is rapidly gaining ground. Prof. Rosenbusch deals with this subject in a paper 'Ueber die chemischen Beziehungen der Eruptivgesteine,'[1] and Prof. Brögger has applied the idea to the explanation of the sequence of rocks in the Christiania district.[2] It is also worthy of note that Prof. Brögger's

[1] Tschermak's 'Min. u. petr. Mitth.' Band xi. (1889) p. 144.

[2] 'Die Mineralien der Syenitypegmatitgänge, etc.,' Zeitschr. f. Kryst. u. Min. Band xvi. (1890) p. 80.

sequence agrees in the main with that suggested by the facts described in this communication.

A most interesting extension of the same principle has been recently made by Prof. Vogt of Christiania.[1] This observer shows that ore-deposits similar to those of Ekersund in Norway and Taberg in Sweden must be regarded as the result of concentration in strongly basic magmas. He discusses the various known causes which may operate to produce such concentration, and inclines to the view that the most important are those which act independently of the separation of constituents in the form of crystals or crystalline aggregates. He recognizes the existence of three such causes:—

(1) Soret's principle, which, as he points out, is a necessary consequence of Van 't Hoff's theorem relating to osmotic pressure.[2]

(2) The principle of Gouy and Chapéron.[3]

(3) Magnetic attraction.

The last cause he considers can come into operation only after concentration has been started in some other way. It may then produce an increase in the amount of concentration and an extension of the space in which such concentration is taking place.

Prof. Vogt, therefore, regards the formation of actual magmas having the composition of the ores as a possibility. This view was not contemplated by us; but the facts described by him lend great support to it. Thus the Ekersund deposits occur as dyke-like masses in a variety of norite (labradorite-rock) extremely poor in ores and ferro-magnesian silicates.

As illustrating the differentiation which may be produced in a magma by diffusion-processes, Prof. Vogt describes a dyke near Huk in the Christiania district. This dyke is an acid orthoclase-porphyry in the centre and a somewhat basic kersantite at the margins. The transition from one type of rock to the other is perfectly gradual, and seeing that the margins represent the parts which must have been kept cool by the passage of heat into the surrounding rock, it seems reasonable to attribute the concentration of basic minerals at the margin to the operation of Soret's principle. In the plutonic area described in this communication the basic rocks are found at the margin, but they do not form a continuous zone.

Another case of the association of ores with eruptive rocks, in such a way as to suggest that the former results from segregation processes taking place in the latter, has been described by Mr. Orville A. Derby.[4]

In conclusion, we may call attention to a case which bears a very close resemblance to that which we have described. On the east

[1] 'Om dannelsen af de vigtigste i Norge og Sverige representerede grupper af jernmalmforekomster,' Geologiska Förening i Stockholm, Förhandl. Band xiii. (1891) p. 476. [See Abstract in Geol. Mag. for 1892, p. 82.]

[2] 'Die Rolle des osmotischen Druckes in der Analogie zwischen Lösungen und Gasen,' Zeitschr. f. phys. Chemie, Band i. (1887) p. 481.

[3] 'Sur la concentration des dissolutions par la pesanteur,' Ann. de Chim. et de Phys., sér. 6, tome xii. (1887) p. 387.

[4] 'On the Magnetite Ore Districts of Jacupiranga and Ipanema, São Paulo, Brazil,' Amer. Journ. Sci. vol. xli. (1891) p. 311.

side of the Brocken[1] mass of granite in the Harz there is a narrow zone in which hornblende-biotite-granite, augite-hornblende-granite, augite-diorite, diorite, and quartziferous biotite-augite-gabbro may be observed. These several varieties shade into each other so that it is impossible to make sharp distinctions. The well-known gabbro of Harzburg occurs to the north of the granite-mass, and associated with it is a quartziferous biotite-augite-gabbro exactly similar to that found in the above-mentioned basic zone. Taking the whole area occupied by plutonic rocks into consideration there is, therefore, every type of rock intermediate between granite on the one side and diorite or gabbro on the other.

Discussion.

Dr. Hatch said it was evident that this was a most important paper. Until it was published it would be impossible to discuss the conclusions arrived at; suffice it to say that they are in accord with the researches of Wadsworth, Brögger, and Vogt. That iron-ore deposits can be formed by processes of segregation from igneous masses during consolidation was a conclusion that would interest both mineralogists and geologists.

Prof. Bonney expressed his regret at the absence of the Authors, and his sense of the value of the paper. He thought, however, that the case which they described was somewhat exceptional, and the inferences from it must not be pressed too far, for so far as his experience went transitions from one kind of igneous rock to another were rare.

Mr. Barrow, in the absence of the Authors, pointed out that this complex formed a part of the great series of granitic eruptions (granitite and diorite), of which the best known were the Dee-side Granite and the Moor of Rannoch Diorite. They were older than the Old Red Conglomerate, for boulders of them occurred in vast numbers in that formation; while they were more recent than the metamorphism, and part of the normal faulting, of the Central Highlands. The complexes varied very much, in some cases consisting mainly of acid rock with a marginal fringe of more basic material (such as the one here described); in others the main mass was essentially diorite, more or less completely fringed with granitite. One of the latter type occurred at the head of the South Esk in Forfar. A minute examination had shown that in some cases the acid granitite had been intruded into the diorite in such a way as to leave a very small portion of the latter rock intervening between the former and the bounding walls of the complex, here consisting of gneisses. In such a case the thin patch of diorite had not only been consolidated before the later intrusion, but its temperature was too low for the granitite to re-fuse it, and there was a clear contact-junction. But on the side of the newer intrusion,

[1] Dr. K. A. Lossen, Zeitschr. d. deutsch. Geol. Gesellsch. Band xxxii. (1880) p. 206.

farther from the outer walls of the complex, the granitite and diorite have completely amalgamated on their edges. Another part of the complex exhibits a still stranger phenomenon. A vent-like mass of light grey diorite has penetrated a more basic mass, containing numerous porphyritic crystals of hornblende. At the junction of the two we can see that the newer rock has torn out the pasty magma of the older and arranged the porphyritic crystals of hornblende in parallel planes, but apparently without injuring them. The phenomena seem to point to the fact that the segregation mainly took place in a deep-seated magma before intrusion into the present position of the complex. Further, while the law of decreasing basicity was clearly true of the rock 'masses,' the reverse was the case with the dykes. The quartz-porphyries, so far as the speaker knew, were cut by the lamprophyres and were always the older rocks. This seemed to point to the whole of the phenomena being due to the remelting of an old magma. The irruptions commenced with the re-fusing of the base, and ended, in the dyke-stage, with its reconsolidation.

11. *On the* Hornblende-schists, Gneisses, *and other* Crystalline Rocks *of* Sark. By the Rev. Edwin Hill, M.A., F.G.S., and Prof. T. G. Bonney, D.Sc., F.R.S., V.P.G.S. (Read January 27th, 1892.)

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Introduction.

A paper on the Geology of Sark by one of the Authors has already appeared in this Journal.[1] In 1889 he introduced the other to the island. Their visit was a very short one, but in 1890, after working at the Lizard hornblende-schists, as to the genesis of which they felt doubtful, they entertained some hope that a careful study of those of Sark might help in solving the riddle; so they determined to examine carefully *de novo* all the more important sections in Sark. They spent nearly a fortnight there shortly after Easter 1891, weather and tides being on the whole alike favourable. The present communication gives the results of this work and of the study of the specimens collected on that and former occasions.

As Mr. Hill's paper was published so lately as 1887, the Authors beg leave to refer to it for a general account of the physical structure and petrology of Sark; but it may be well to summarize at the outset the facts bearing most on the present investigation:—

(1) The gneisses and hornblende-schists of Sark are fairly markedly foliated, and sometimes also are rather conspicuously banded.

(2) These structures, whatever be their genesis, are older than the intrusion of the two great granitic masses and of the 'greenstones,' mica-traps, and other dyke-rocks.

(3) Thus these structures, for reasons indicated in former papers, are of great antiquity. The rocks in which they occur may be classed, with reasonable probability, among the Archæan gneisses and schists.

(4) The planes of foliation, as described by Mr. Hill, generally dip both at moderate angles and outwards from the middle part of the island. This structure has no connexion with the faults, gene-

[1] Vol. xliii. (1887) p. 322. Mr. Hill wishes to state, with regard to the present paper, that he has taken part only in the field-work.

rally not of a great throw, which are as common in Sark as at the Lizard. It gives no indications, macroscopic or microscopic, of being a result of crushing, for it has no real resemblance to the pressure-structures of the Alps or of the North-west Highlands, already described in the pages of this Journal. It is, in short, a 'stratification-foliation,' not a 'cleavage-foliation.'

(5) At first sight, it seems more natural to interpret the structure as indicative of an original sedimentation, in a rock which has subsequently undergone such great chemical changes as to cause a re-crystallization of the constituents.

In Sark, as stated in Mr. Hill's paper, a fairly coarse, reddish biotite-gneiss, moderately foliated but not banded, is lowest in position and apparently the oldest. This is exposed for a considerable distance along the eastern side of the island, at, and south of, Creux Harbour, and occasionally on the western, in, and to the north of, Port du Moulin, and to the south as far as Port à la Jument.[1] This is overlain by a series of stratified aspect, varying from a hornblende-schist, very like some of those at the Lizard, to a banded biotite-gneiss, which is generally more compact in structure and greyer in colour than the subjacent one. Occasionally the second member presents a rather close resemblance to some of the banded rocks in the Granulitic Group at the Lizard. Associated with this series, and commonly rather low down in it, is a dark-green rock, consisting almost wholly of distinctly crystallized hornblende, to which we shall frequently refer in the following pages. Sometimes the banded gneiss appears to form a zone between the basement-gneiss and the hornblende-schist, sometimes it seems to replace the latter,—that is the two rocks apparently occur in a rather lenticular fashion, and shade off one into another, often so gradually that in some localities it is almost impossible to separate them. So closely are they related that Mr. Hill, in writing his paper, deemed it needless to attempt a distinction, and was content —as Prof. Bonney had been in his first paper on the Lizard—to designate the whole series as 'hornblende-schist.'

Part I.

(1) *Description of the Gneisses and Hornblende-schists.*

Time will probably be saved by giving a brief description of the three types of rock mentioned above. As the purpose of this paper is petrological rather than petrographical, the authors have thought it needless to spend much time in trying to identify every microlith or to ascertain the precise species of every felspar. They have, however, carefully studied the microscopic structure of the more important rocks, and have intentionally suppressed many minera-

[1] It is mentioned in Mr. Hill's paper, though it is not identified with the Creux Harbour gneiss, but after a closer examination we find it difficult to separate one rock from the other. The only difference perceptible is that the Port à la Jument gneiss is a shade more micaceous and the felspar is paler in colour. [For localities mentioned in this paper, refer to the map facing p. 124.]

logical details which could have been easily inserted, because they believe that these are repulsive to the ordinary geologist, and tend to divert the attention even of experts from the main issues.

(a) *The Basement Gneiss.*—Mr. Hill has already described the macroscopic character of this gneiss,[1] so that it is only necessary to call attention to one or two details which are brought out more clearly by study with the microscope. The felspar (plagioclase, microcline, and probably orthoclase) is not idiomorphic, and seldom shows in any part a rectilinear boundary. The outline of the grains is more or less irregular or wavy; they vary in diameter roughly from ·01″ to ·05″ or a little more, about ·03″ being a common size; not seldom they seem to enclose small rounded grains of quartz. The latter mineral, however, occurs commonly in grains about the same size as the felspar, but often of a more elongated form. The flakes of biotite (commonly altered into the usual green mineral, with dark lines of iron oxide between the cleavage-planes) are rather irregular in outline and usually about ·02″ long. A slight tendency to aggregation in streak-like patches is exhibited by all these minerals, but it is more conspicuous in the quartz and the mica than in the felspar. We find occasionally a grain exhibiting a micrographic intergrowth of quartz and felspar. In short, the structure of the rock closely resembles that of the more granitoid bands in the Granulitic Group at the Lizard, and, as has been remarked of the latter, is very different from that of an ordinary granite, being most nearly approached by some of the fine-grained vein-granites. Indications of mechanical disturbance subsequent to crystallization may be seen occasionally, but usually are inconspicuous.

(b) *The Hornblende-schists.*—For the macroscopic aspect of these rocks we may again refer to Mr. Hill's paper. The more typical varieties appear to occur in greater bulk along the western coast of the island, and especially about Port du Moulin, from near Saignie Bay to south of Port à la Jument. Most of these are so like macroscopically to the hornblende-schists of the Lizard that we have only examined a few specimens under the microscope. These, both in structure and mineral constituents, correspond so closely with the Lizard rock that it is enough to refer to the descriptions which have been already published.[2] Occasionally, however, as in Port à la Jument, they are rather more distinctly and broadly banded than at the Lizard, and this variety calls for a fuller description.[3] In it bands consisting mainly of dark lustrous hornblende and of almost white quartzo-felspathic rock are repeatedly

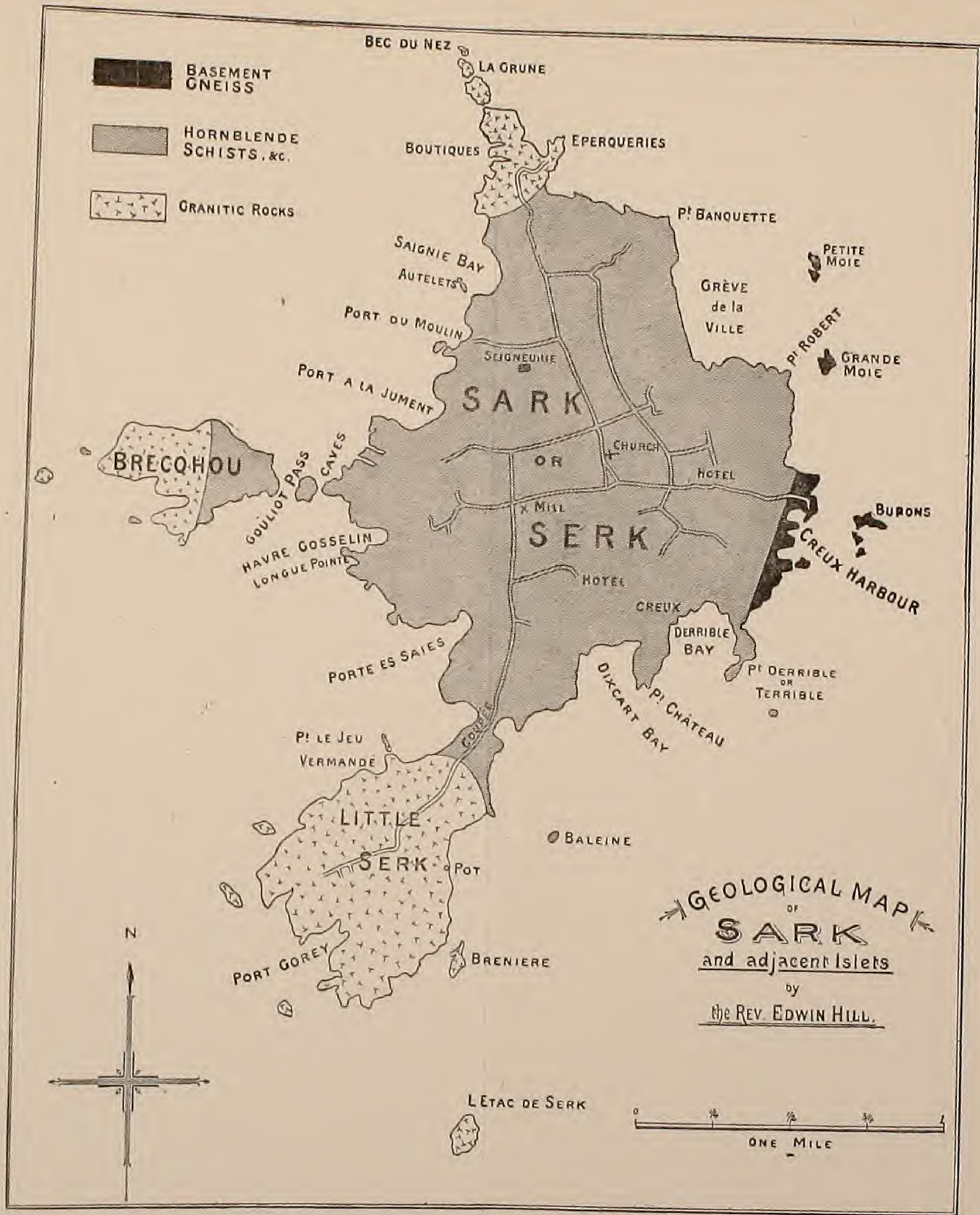
[1] He called it, from the locality about which it is most developed, the 'Creux Harbour gneiss.' We satisfied ourselves of its occurrence in the Burons and other islets of this part of the coast. As a rock practically identical occurs in the same position on the west coast, we now employ a more general term.

[2] Bonney, Quart. Journ. Geol. Soc. vol. xxxix. (1883) p. 1; McMahon, *ibid.* vol. xlv. (1889) p. 519. See also *ibid.* vol. xlvii. (1891) p. 478.

[3] The specimen was broken from a large block, one of several at the base of the crags in the southern bay at Port à la Jument, and the rock occurs, so far as we could ascertain, rather low down in the thick mass of hornblende-schist.

[*To face* p. 124.

ies' read 'Port ès Saies.']



[*Note.*—For 'Porte es Saies' read 'Port ès Saies.']

interchanged. They run for considerable distances with much uniformity, just like alternating layers of dark clay and fine sandstone in a stratified rock. Occasionally the light bands are more than ·75″ thick, but both vary from about this thickness to mere lines.

The dark bands, on microscopic examination, are found to contain a considerable amount of felspar, and do not materially differ from the corresponding parts of the ordinary hornblende-schist, except in the presence of an occasional grain of quartz, which is not common in the latter. The white bands, however, consist of decomposed felspar, of a considerable proportion of quartz, and of rather small flakes of a ferro-magnesian mica, somewhat altered, with only an occasional grain of hornblende. These two rocks resemble in structure that of the granitic and hornblendic bands in the Granulitic Group at the Lizard, the one passing sharply into the other in exactly the same way. The dark bands also correspond with the hornblende-schists of the latter region, but in these the white bands, which are usually thinner and frequently (as is sometimes the case here) not very well marked, consist, so far as we know, mainly of felspar, and rarely contain quartz. Sphene (in one case abundantly), apatite, and epidote occur in the Sark hornblende-schist, but we have not yet found the colourless augite of the Lizard. The dominant hornblende and felspar occur in grains, not seldom both slightly elongated, and showing a parallel ordering, as is frequent at the Lizard, whilst occasionally the structure seems on the verge of becoming ophitic.

(c) *The Banded Gneisses.*—By this name we may designate a rather important group of rocks, evidently in close association with the last, excluding, however, for the moment one or two rocks to which the term is equally applicable, since, for reasons which will appear, they require to be separately noticed.

The group as a whole is characterized by more or less micaceous bands, alternating with those which consist mainly of quartz and felspar. The numerous varieties may be roughly grouped about two types: the one, moderately coarse in texture, marked by rather clearly defined bands, and fairly rich in biotite; the other, finer-grained and less micaceous, in which the banding is indicated macroscopically as a difference of tint rather than by conspicuous predominance of a particular mineral. The latter type, not unfrequently, could be very nearly matched by specimens from the Granulitic Group of the Lizard (though these usually are rather redder in colour), but we have not met with the former there, although one of the gneisses which occur in the islets south of Polpeor bears some slight resemblance to it. Of the two types the coarser appears to be the commoner in Sark. It is the dominant rock on the north-eastern coast from the margin of the Eperqueries granite to beyond La Grève de la Ville; also in Derrible and Dixcart Bays, and probably to the south, until the granite of Little Sark sets in. On the western side it occurs in similar relations to the latter rock, extending northwards by Port ès Saies and Havre Gosselin to the southern side of Port à la Jument. North of that, the finer-grained type is more common, though the coarser also occurs, *e. g.* to the N. of Saignie Bay, and the former, so far as we have noticed, seems to underlie the hornblende-schist; apparently, however, its thickness is variable. The most characteristic examples are to be seen about Port du Moulin and in Saignie Bay. But, as already said, we do not consider any very precise subdivision to be possible; nevertheless a recognition of the distinction may be of some use for general purposes.

The coarser rock consists of layers of rather dark brownish and pinkish-grey colour. In some localities, as on the north-eastern coast, on the west side of the Coupée and at Port ès Saies, these layers are wonderfully 'gnarled';—in others (*e. g.* about Dixcart Bay) the rock appears to have been somewhat crushed after the characteristic structure had been assumed. As an example we may select a beautifully wrinkled specimen from the southern side of Port ès Saies. In this the dark layers (as is not infrequent) slightly predominate over the light. The former occasionally are about $\frac{1}{4}$ inch in thickness, the latter generally rather less, but of course the 'wrinkling' has produced local thickening and thinning. The structure is beautifully exhibited in a slice rather more than $2'' \times 1''$ prepared for microscopic examination. It is obvious, at a glance, that the contortions have been produced after the rock, whatever may have been its origin, had become banded and crystalline. By following up the micaceous bands we can see that the mica-flakes, which once lay roughly in the direction of the bands, have been twisted up and disturbed, till occasionally a 'strain-slip' cleavage all but sets in.[1]

The chief constituents of this rock are quartz, felspar (orthoclase and plagioclase[2]), and biotite, with some iron oxide and a fair amount of apatite. The paler layers consist mainly of quartz and felspar, the darker of felspar and mica. The felspars are granular in form, and occasionally enclose small rounded grains of quartz. The latter mineral has a tendency to occur in rather elongated patches; in fact one may infer that the structure of the rock was originally very similar to that described above, except perhaps that the felspar grains may have been a little less irregular in outline. But that the rock has undergone some mechanical disturbance is evident, not only, as already mentioned, from the arrangement of the mica-flakes, but also because the felspar grains are not seldom parted by a crack, which has been subsequently filled up; the patches of quartz occasionally exhibit a tendency to streak out, and this mineral here and there occurs in aggregated granules, which is a sure indication that there has been a certain amount of fracture, followed by cementation and reconsolidation.

[1] Obviously there is nothing unusual in this. In the course of my work elsewhere I have come across every stage, from undisturbed banding to the setting up of a cleavage-foliation under strain, in gnarled gneisses, as described in my Presidential Address, Quart. Journ. Geol. Soc. vol. xlii. (1886) *Proc.* pp. 68–72.—T. G. B.

[2] Microcline does not occur in the slides examined.

In the more fine-grained variety of gneiss the bands (pale reddish grey and greenish grey) are broader, but less distinctly defined. Microscopic examination shows it to consist of quartz, felspar (orthoclase and plagioclase), flakes of a green mineral (most of which is an altered biotite, but possibly a little fibrous hornblende is also present), apatite, a little sphene and iron oxide, and a few grains of pyrite. The banding is due to slight differences in the proportionate amounts of the constituents. The grains of the first two minerals are commonly about ·03″ in diameter, though smaller occur; the flakes of the third are about the same length. The grains present the slightly irregular outline already mentioned, and enclosures of quartz occasionally occur in the felspar. The rock exhibits little or no sign of having suffered from mechanical disturbances subsequent to consolidation; and its structure is identical with that of many specimens from the Granulitic Group of the Lizard.

(2) *Included masses of Hornblendic Rock and their relations.*

Masses of a somewhat coarsely crystallized rock may be seen in several places on both sides of the island, which on closer examination appear to consist almost wholly of a lustrous deep-green hornblende. These, in some places, might be regarded at first sight as the ends of intrusive 'tongues,' which had been afterwards somewhat compressed by earth-movements, but, as will presently be seen, many cases cannot be thus explained. These hornblendic lumps are not restricted to any very definite horizon. At the same time they appear to be most common either just above the basement-gneiss or at no great height up in the overlying series. They are well exhibited in the cliffs all about Port du Moulin, and on the opposite coast between Creux Harbour and Derrible Bay.

In these lumps the colour of the hornblende is a rich green. Of two slides examined microscopically, one, from Point Derrible, consists (except for a few granules of iron oxide) only of hornblende. The other (from just N. of Port du Moulin) contains in parts of the slice (a large one) a very few granules of quartz, with a linear arrangement, and a grain or two of felspar. The hornblende crystals are often fairly idiomorphic, with characteristic cleavage, and generally exhibit some tendency to a parallel ordering. They are on the whole rather uniform in size, often being about ·06″ long and ·04″ wide (in a transverse section). In a thin slice they are of a fairly strong green colour and dichroic, the tint varying from a pale sap green to a rather deep green. The rock obviously is the 'hornblendite' of certain authors.

It is by no means easy at first sight to determine the relations of this peculiar rock to its associates, and difficult to express in a description, necessarily brief, the effect produced by the cumulative evidence of numerous instances. Perhaps the best method, after a few general remarks, will be to describe in detail one or two sections to which, as they appeared to be the most suggestive, we gave much attention.

This hornblendic rock occurs in masses varying in volume from several cubic yards downwards. In form these exhibit every gradation from lenticular lumps and angular irregularly-shaped blocks on the one hand to shreds and streaks on the other. That in certain cases the rock has been shattered and pierced by an intrusive rock of a very different mineral character seems beyond question. The most conclusive evidence is afforded by the cliffs south of Dixcart Bay, when they are examined from a boat. One crag (? Noir Bec), about 80 feet high, is a gigantic breccia from crest to foot. When the hornblende-rock occurs in angular masses the intruder is a pale flesh-red granite, poor in mica, but as the former rock becomes more lenticular in outline, the latter becomes greyer, more micaceous, and rather darker in colour, until at last the two are associated in a manner curiously resembling a kind of current-bedding,[1] and suggestive of stratification rather than of intrusion. Masses of this coarse hornblendic rock also occur (though less frequently and, as we think, usually of a lenticular form) among the normal hornblende-schist.

(a) *Section at the eastern corner of Point Derrible.*—This section, unlike many of those on the east coast, can be easily examined from the land, when once the rocky *arête* linking the promontory to the mainland has been passed.[2] Here we find masses of various shapes and sizes scattered irregularly in a sort of matrix of a reddish, more or less gneissose rock. Parts of the latter exhibit a very regular alternation of bands of pale, reddish quartzo-felspathic rock (an 'aplite,' rather rich in felspar), and a dark hornblende- or biotite-hornblende-rock, the thickness of each varying from 3″ or 4″ downwards. In the lighter-coloured rocks a few thin, dark bands may generally be seen, and in the darker a few reddish lines. Sometimes the hornblende-rock is separated by veins of the aplite, sometimes by a corrugated banded gneiss, as above mentioned. In the lower part of the section dark gneiss, micaceous or hornblendic, dominates; higher up the pale-red aplite bands are more abundant. The one rock, however, appears to pass gradually into the other. That the hornblende-rock is the older, and has been brecciated by the intrusion of the aplite (from which the banded gneiss cannot be separated), seems to be indubitable.

(b) *Section near Port du Moulin.*—On the south side of Port du Moulin a natural arch [3] leads to the rocky shore, at the base of the crags between this and the next recess called Saignie Bay. After passing through the arch we soon come to a projecting mass of rock

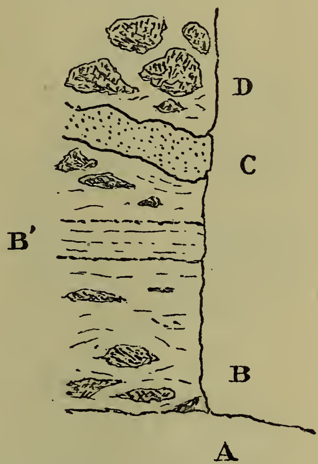
[1] So explained by Mr. Hill, Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 324.

[2] At one part of this a little care is required, and an inexperienced climber might get into difficulties.

[3] This is dry only at half tides. It must be remembered that the rise is rapid and the cliffs between the two bays are probably inaccessible. At high water the waves break against them.

which forms a sort of step or terrace, three or four yards high above the shingle, &c., to the top of which it is easy to climb (fig. 1). It consists wholly or almost wholly of the 'basement-gneiss' (A), above which, forming as it were the lowest 'course' of the actual cliff (B), come some bands of pale-coloured aplite, including 'lumps' or 'streaks' of the hornblende-rock, followed by a fairly constant mass of gneiss, consisting of pale grey or buff-coloured quartzo-felspathic and dark micaceous layers, each of which may be of any thickness from about an inch downwards, but are very commonly about $\frac{1}{3}$ inch thick. Still, thin lines of mica commonly occur in the quartzo-felspathic bands and *vice versa*. A hand-specimen is exactly like hundreds of other banded gneisses, in which there is so little fissility that a specimen is easily broken off with the broader face transverse to the plane of the apparent bedding. Here and there in this gneiss is an elongated 'eye' or even a thin streak of coarse hornblende, identical with that in the apparent fragments. One band of gneiss, about two feet thick (B′), could be traced for some yards, being defined, top and bottom, by a seam from half an inch to an inch thick, consisting generally of foliated, dark hornblende-rock.[1] Above and below this band lumps of the latter rock occur. The whole mass from the top of the terrace is from 2 to 3 yards thick. It is limited by a band of rather fine-grained grey gneissoid granite (C), which, from its variable thickness (from 1 to 2 feet) and slightly irregular course, seems to be undoubtedly an intrusive rock. Over this, for about a couple of yards more, we again find the dark hornblende-rock traversed by some granitic veins (D). Here, however, the former in some places

Fig. 1.—*Diagrammatic sketch of relations of rocks at base of cliff, N. of Natural Arch, Port du Moulin.*

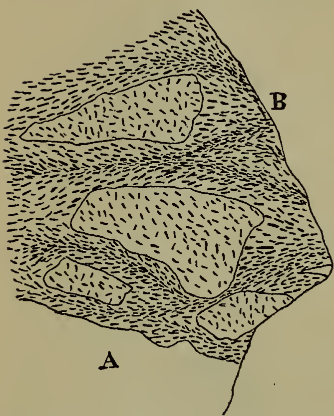


A. Basement-gneiss.
B. Aplite-bands, with eyes and streaks of hornblende-rock, passing into grey banded biotite-gneiss, with occasional streaks of hornblende, reverting at the top rather to the character of the lower part. 6 to 8 feet.
B′. Fairly regular band of gneiss, defined at top and bottom by a streak of hornblende. Nearly 2 feet.
C. Vein of rather fine-grained grey granite, slightly gneissoid.
D. Nodular hornblende-rock, seemingly running into bands, with some gneissoid bands, becoming more bedded in aspect in about 2 yards, and passing up into the normal hornblende-schist.

[1] From this a specimen was taken, the microscopic structure of which will presently be described.

exhibits a very peculiar structure (fig. 2). It, too, appears to be composite; fairly angular masses of a brighter green hornblende-rock, without any distinct foliation, being included in a somewhat foliated and darker-coloured mass of the same material. This in the upper part of the mass appears to go 'stringing' out, and to assume a more definitely bedded aspect. Over this brecciated portion, the cliff, so far as can be seen, consists of banded hornblende-schist, often of the usual character, but sometimes rather gneissoid in aspect.

Fig. 2.—*Hornblende-rock with brecciated structure, north of Natural Arch, Port du Moulin.*



A. Granite. B. Hornblende-rock.

The sketch is diagrammatic, and exaggerates the distinction between the two varieties of hornblende-rock.

The microscopic structure of these several rocks must now be briefly noticed. In a rather large slice both the light and the dark green varieties of the hornblende-rock can be studied. The difference between them is very slight. In the latter the crystals are perhaps slightly larger than in the former; certainly they are more distinctly orientated, are of a richer colour—those in the former having a pale sea-green tint—and they are more dichroic. With the darker rock, as already mentioned, a little quartz and felspar are associated. The lighter one seems to be pure hornblende, but this distinction may be accidental.

A slice from the gneiss (B′ in fig. 1) shows that the chief constituents are quartz, felspars, and biotite; as accessory minerals (all small and sparse), we find a little iron oxide, apatite, sphene, epidote (?), zircon (?), and possibly a grain or two of tourmaline. The quartz contains rather numerous, very minute enclosures; the felspar is somewhat decomposed, but the twinning of plagioclase is frequently quite distinct; the biotite generally is in good condition. It exhibits a slight parallelism, and dominates, as a matter of course, in certain bands. In the irregular form of the grains of quartz and felspar, in the occasional encircling of the one by the other, or their micrographic association, and in the not unfrequent elongation or slightly streaky aggregation of the grains we have an exact repetition of the structure (noticed above) which is frequently found in the gneissoid bands of the Granulitic Group at the Lizard, and in other rather fine-grained banded gneisses. Another slide, cut from a rather darker variety, in which some streaks of hornblende occur, shows a similar mica-gneiss, containing 'stratulæ' of hornblende identical with the rock described above, the only difference being that in the present case the last-named mineral is associated with more quartz and felspar, and in places is intercrystallized with a certain amount of biotite.

A third specimen of the gneiss, showing bands of pale reddish (quartzo-felspathic) rock and of one more micaceous, differs from the first in that some of the felspar grains are rather larger than the rest, as in a slightly porphyritic rock, and that in the more micaceous band a few grains of green hornblende occur. These are very irregular in form, and are associated with flakes of brown mica or some rather minute and fibrous hornblende. Their appearance is suggestive of a partial destruction of a large crystal (fig. 3).

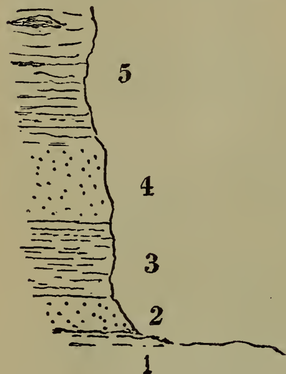
Fig. 3.—*Hornblende, apparently partly replaced by and associated with biotite.*

Magnified 50 diameters.

Hornblende dotted; biotite faintly lined; quartz and felspar left white.

It may be well, before drawing an inference from this section, to notice briefly the evidence to be found in Port à la Jument. There many lenticular pieces of the usual hornblende-rock (generally rather smaller in size than in the last case) occur in a banded gneiss, consisting usually of light quartzo-felspathic and dark micaceous layers of various thickness, as above described; the mass of hornblende-rock sometimes resembles torn-off slabs, sometimes appears to have been drawn out like a viscid mass; here and there in the gneiss a thin band of hornblende can be traced for several feet, interbedded with the compact granitoid component. In places, however, a fairly coarse granitoid rock appears to break in among the others. Beneath the whole is a low terrace of the basement-gneiss. The annexed diagrams will serve to show the association in one of the more uniform parts (fig. 4) and the mode in which gneissoid or granitoid rocks enfold the lumps of hornblende in one of the more irregular parts (fig. 5).

Fig. 4.—*Relations of gneissoid, &c. rocks a little above the shore in Port à la Jument.* (*N. of the path.*)



1. Basement-gneiss.
2. Granitoid rock, parted from (1) by a crack or a hornblendic (?) seam. About 8 inches.
3. Banded biotite-gneiss, rather quartzose, about 10 or 12 inches.
4. Granitoid rock, about 15 inches.
5. Banded biotite (or hornblende) gneiss, with occasional lenticular masses of hornblende-rock and bands of greyish red gneissoid or granitoid rock. It forms one mass, extending upwards for some yards.

(c) *Conclusions.*—From these observations, and others which it would be tedious to describe in detail, we conclude that a basic rock, now represented by the hornblendic rock, is the oldest. This was shattered by the intrusion of a rather acid rock, represented by the veins of felspathic aplite. By this it was sometimes softened and drawn out, and portions of it (probably small in size) occasionally were actually melted down. In this case the constituents derived from the hornblende, when the mass consolidated, combined with some of those in the material of the aplite, and thus much of the biotite was produced.[1]

The whole mass probably continued to move, slightly and slowly, during crystallization, and to this both the macroscopic banding of the gneiss and its peculiar microscopic structure are due.[2] In short, we find here (with certain obvious but theoretically unimportant differences) another instance of the process which we are now satisfied must have occurred in more than one banded rock at the Lizard.

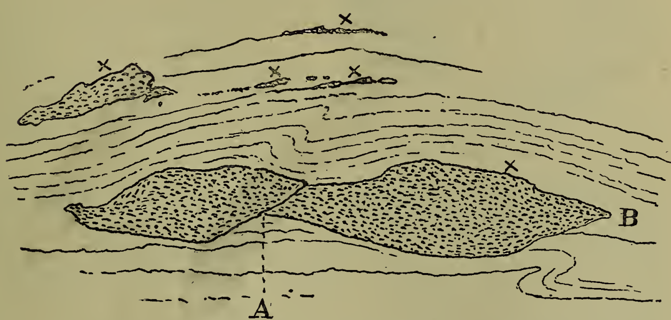
But how is this gneissic series (which seems to be not easily separable from the ordinary hornblende-schist and gneiss) related to the basement-gneiss? Is the last only the main mass of the magma,

[1] K. A. Lossen (Congrès Internat. Géol., Comptes Rendus de la 4me Session (1888), p. 184) speaks of alteration-products rich in biotite occurring in diabases (at the expense of pyroxenes) when diabase has been broken into by granite or gabbro. Also C. Callaway (Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 480) asserts the formation of biotite from hornblende through chlorite, as the result of shearing in a hornblendic granite; but obviously these cases are different from the mode of production which we describe.

[2] Namely, not only the arrangement but also the forms of the grains of quartz

from which the granitic bands above mentioned have proceeded, or is it distinct from them? The difference between the two rocks is not great, and the fact that this brecciated mass, on both sides of the island, appears commonly to occur immediately above the basement-gneiss might be urged in favour of the former thesis. At the same time we occasionally met with masses of the coarse hornblende-rock at considerable distances from the basement-gneiss, both in the normal hornblende-schist and in the banded gneiss, and we found it, as already said, almost impossible to draw any definite line of separation between these two rocks and the distinctly brecciated parts.

Fig. 5.—*Relations of granitoid and gneissoid bands to hornblende-rock in Port à la Jument.*



× Fragments (in places passing into streaks) of hornblende-rock.
A to B measures 15 inches.

The evidence in the sections described above was not to our minds conclusive. At the same time the basement-gneiss seemed always to maintain a character of its own, to be sometimes distinct from the overlying rock, and to suggest at others a slight fusion or confusion of its upper surface with that rock, such as might occur during an intrusion under exceptional circumstances, rather than an identity with the granitic or gneissic veins. These also, where they are most distinctly *veins* and most granitic in character, are aplites (as has been said), considerably lighter in colour and poorer in mica than the basement-gneiss. Moreover the basement-gneiss occasionally (as in Port du Moulin just north of the path leading to the shore) contains included masses which closely resemble the hornblende-schist. Again, once or twice south of Port

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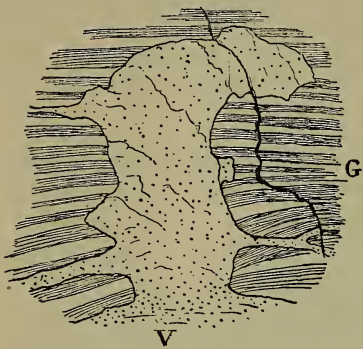
and felspar, which, as has been so often pointed out by one of the Authors, differ, in the absence of idiomorphic crystals and in their peculiar outlines, from those in ordinary holocrystalline igneous rocks. The brecciated aspect of the hornblende-rock may be due to a shattering of the mass at the time of the intrusion, and a certain amount of mineral change in the outer, more disturbed, and more heated portions.

du Moulin, the banded gneiss is distinctly cut by veins (subsequent to the date of its structure) which macroscopically resemble closely the basement-gneiss. More than one instance of this may be seen in Pégâne Bay.[1] Here is a very rough diagram (for to represent the original accurately would require either hours of work with the pencil, or a photograph). The rock of the vein also exhibits in places a slight foliation, so that in a hand-specimen it would be regarded as a gneiss. On microscopic examination we find nothing to separate it from the basement-gneiss, except perhaps that it contains rather less biotite. Among the felspar is some microcline. Perhaps, however, the most important fact to which this vein testifies is that here, in an undoubtedly intrusive rock, we find precisely the same structures, viz. the irregular forms of the quartz and felspar, the inclusion of the one by the other, and their occasional micrographic association, as those that are characteristic of the gneissic rocks which have been so often discussed.[2]

Fig. 6.—*Granite vein, slightly foliated, intrusive in banded gneiss. Cliff, Pégâne Bay.*



V. Granite vein. G. Banded gneiss.

Thus, taking account of all the cases observed, our interpretation of the history of these and other banded gneisses seems justified, and on that assumption we think it most probable that the basement-gneiss, instead of being, as it has hitherto been supposed, an older rock than the hornblende-schists and banded gneiss, is really newer, though the difference in age need not be great.

Here it may be well to notice some cases in Guernsey which corroborate our explanation of the banded structure in these crystalline rocks,[3] viz. that it is due to a fluxional movement anterior to

[1] Pégâne Bay is immediately south of Port du Moulin, and is reached thence by passing through a cleft and round the next promontory, over rocks laid bare by the falling tide.

[2] A parallel case occurs in a headland on the north side of the west bay below the Coupée. Here we find a diorite intrusive into the gneissic rock. In one part it is a mottled pink and green rock, some of the felspars being rather longer and redder than the others; in another part a few yards away the red grains remain, but appear in a rather streaky groundmass consisting of the other felspar and of hornblende, recalling some of the streaky 'augengabbros' (though less definite than they) of the Lizard. The one variety shades imperceptibly into the other, and there is nothing to suggest a crush, for though the gneiss may have suffered from one, that clearly was anterior to the date of the intrusion.

[3] It must not be forgotten that sometimes a slight foliation is exhibited by veins of dioritic or granitic rock, intrusive (as mentioned below) in the hornblendic and gneissic group, where there is no sign whatever of any subsequent disturbance, and also in the granitic masses at the N. and S. ends of Sark.

the final consolidation of the mass. At Point Norman we find that the curious ledges into which the rock weathers are caused by the 'streaking' of the normal rock (a diorite) by a rather more felspathic and fine-grained variety.[1] Again, a quarry in the 'bird's-eye' diorite,[2] south of the Saumarez monument, shows a curious interstreaking of slightly different varieties, cloudlike stratulæ of a more hornblendic rock occurring in a more felspathic one. Another case occurs on the shore to the north of St. Peter's Port, about 20 yards south of Hogue à la Perre battery. Here, in a mass of 'bird's-eye' diorite, the normal rock is occasionally streaked with lighter-coloured bands, the latter being formed by a finer-grained, slightly more felspathic rock, in which now and again a crystal of the larger hornblende may be seen, and the latter mineral has a tendency to occur in streaky clouds.[3] Obviously the rock is of igneous origin, and these bands are not the result of subsequent mechanical disturbances, but must be due to the mixture of two slightly different magmas.[4]

But we are indebted to Messrs. W. Sharp and J. Whitehead, F.G.S., of Guernsey, for a still better example. In some of the 'bird's-eye' quarries a rather foliated variety of the rock occurs, called 'longrain' by the workmen. The specimen, sent to us, is a slab about 6″ × 3″ square, composed of a layer of 'longrain' and one of a pale grey felspathic rock. The breadth of the latter layer is slightly under half an inch, and that this is its whole thickness is proved by a 'skin' of the hornblendic variety on the outer surface of the slab (a joint face). The other (fractured) surface, that of the 'longrain' layer, exhibits the usual, generally parallel ordering of the hornblende crystals, and it has an interrupted silky lustre.[5] Under the microscope the hornblende in the dark layer is moulded on the

[1] Quart. Journ. Geol. Soc. vol. xl. (1884) p. 408.

[2] The name given by the quarrymen to the variety with porphyritic crystals of hornblende.

[3] One band was about 2″ wide; it was followed by a more hornblendic band (without distinct 'eyes') about ·5″, and that by a felspathic streak on an average about ·25″ wide. Then came, as at the bottom, perfectly normal rock. After rather less than a yard the white band is succeeded by a band like the second named.

[4] We quote these instances because they occur within a few miles of Sark; it will be enough to refer to the paper by Prof. Bonney and Major-General McMahon on the Lizard (vol. xlvii. (1891) p. 464) for others, and the former author wishes to add that during his last journey in the Alps he has obtained evidence corroborative of the views advanced in that paper with regard to the banding of the gabbro.

[5] [It was suggested by Mr. Barrow in the discussion that the planes visible in the hornblende on the flat surface of the 'longrain' were pinacoids, so the specimens in our possession have been carefully examined. As the felspar crystallized first, the faces of the hornblende crystals are often not well formed, but those of the primary prism are certainly better developed, in this and in the hornblende-rock, than either pinacoid (the orthopinacoid is often, as usual, suppressed); the surfaces visible on the flat sides of the 'longrain' are those of cleavage-planes. As the hornblende crystals lie with their longer axes roughly in one plane, the rock obviously cleaves more easily in this direction.—T. G. B., February, 1892.]

felspar, shows characteristic cleavages, is generally of a light raw-umber colour slightly tinged with green, is dichroic, changing from a rather more yellow tint of the aforesaid colour to an olive brown, and is darkened rather irregularly with disseminated opacite.[1] Small crystals of apatite and grains of iron oxide (? in part ilmenite) are fairly common, each, when small, being not seldom enclosed in the hornblende. Both are comparatively rare in the lighter layer. Sphene occurs, but is rare. The felspar in both parts is fairly idiomorphic. It exhibits multiple twinning on the albite and pericline types, the former being the commoner; that in the darker layer seems less well preserved, but gives tints of a higher order, and its extinction-angles seem to be larger; those in the lighter do not generally exceed 21° measured from the trace of the composition-plane. Hence it seems probable that the felspars in the former are labradorite, in the latter are nearer to andesine or oligoclase. In the former also quartz is rare; in the latter it is not uncommon in the intervals between the felspar. Biotite is present, and its mode of occurrence is remarkable. In the dark layer generally it is not common, but is abundant at the junction with the light one in a kind of selvage about one tenth of an inch thick, the flakes usually ranging from about ·01″ to ·03″ in length, though they are sometimes smaller. They cling to, and seem to penetrate into, and to be formed within the hornblende grains (*cf.* fig. 3, p. 131), which in this part as a rule are comparatively free from opacite and of a more distinctly green colour. In some cases the mica actually seems to replace part of a hornblende crystal.[2] In the lighter layer biotite also occurs, but it is not abundant; here it is occasionally associated with grains and flakes of hornblende, which have a 'residual' aspect. Both hornblende and felspar throughout exhibit a slight orientation. Occasionally there are some signs of strain,[3] but none of crushing. A careful study of this rock has suggested the following inferences:—(1) that the biotite is not so old as the hornblende; (2) that it was formed in part at least at the expense of the hornblende, but that this took place before the final consolidation of the mass; (3) that some movement, probably slight, occurred during

[1] Not a little of this consists of minute belonites; these lie roughly at right angles, and seem to have no relation to the existing cleavages. Is it possible that they indicate planes which have disappeared and that the mineral originally was augite? As bearing on this it may be noticed that some grains of a brownish mineral, one being rather large, appear in the lighter band in one slide. In colour it is a light brown, but is not very clear, parts being of a slightly darker tint and more dichroic than the rest; a cleavage is perceptible, but unfortunately does not aid much in determining the mineral. Here and there the latter is associated with grains of iron oxide and a little green hornblende, and the large grain is pierced by the felspar, and so of later consolidation. This mineral presents some resemblance to sphene, but is more probably a variety of augite.

[2] It may be noticed that at the selvage the felspars commonly are smaller than elsewhere.

[3] In one case a crystal of felspar appears to have been ruptured by a strain, and the intervening space is occupied by a felspar of somewhat different nature, through which, however, the bands of multiple twinning are continuous though they are less distinct.

the last stage, and that this produced the slight foliation; (4) that the rock exhibits an imperfect mixture of two magmas of somewhat different chemical composition, and this mixture may possibly be the result of a quasi-intrusive process on the part of the more felspathic magma, though very probably neither was it perfectly fluid nor the dark one perfectly solid.[1]

We trust then that we have demonstrated from the evidence discussed above that a rock, which macroscopically and microscopically would be recognized as a perfectly normal banded gneiss, can be produced by fluxional movement in a mass, as yet either unconsolidated or imperfectly consolidated, and consisting of somewhat different materials.[2]

This rock exhibits, as has been pointed out, many distinctive characters. But we find similar characters in a large number of gneisses and crystalline schists. For instance, they are present in the group of the banded gneisses, which, as described above, are so abundant in Sark, and in parts of the hornblende-schist (making allowance for differences which are caused where that mineral predominates). We must not be rash in drawing conclusions, for we have not attempted to examine all the varieties of the gneiss and of the hornblende-schist. We have only studied the types which were most characteristic of the one, and those which promised to be most fruitful of results in the other. But each case leads us to the same conclusion. Allowing for the slight effects of subsequent mechanical disturbances, the banded gneiss described in section (*c*) appears to us structurally inseparable from that of which the origin has been, in our opinion, demonstrated. Again, the broad-banded variety of hornblende-schist described in (*b*) is produced by the interstreaking of a granitic and dioritic rock, and so is really more closely related to one of the normal members of the Lizard Granulitic Group than to one of the Hornblendic Group. Yet from this variety, which must be similarly explained, it does not seem possible to separate the normal hornblende-schist of the island, in which the materials appear to be more completely mixed, so that a slight foliation, but not a banding, has been produced by the fluxional movement.

Thus our investigations, so far as they go, are in favour of assigning an igneous origin to these banded rocks (gneisses and

[1] We do not suppose that when the intrusion occurred the rocks were exactly in their present position, but that they have moved onwards together.

[2] After this paper had been forwarded to the Society my attention was called in conversation to a section in Reyer's 'Theoretische Geologie,' p. 810, where he makes some valuable remarks on the occurrence of similar structures (*Schliere*).

[Reference should also be made to the cases quoted by Mr. Lawson in his paper printed in the 'Comptes Rendus, Congrès Internat. Géol.' (1888) p. 143, and described at greater length in his memoir on the 'Geology of the Rainy Lake Region'; but the possibility of such a process had been present for some time previously in my own mind, and I may say that the conclusions in this paper have been arrived at independently. Indeed, the absence of an important link in the chain of reasoning in the first paper caused me to pay less attention to it than the second showed it to deserve. Be it understood that I make no claim to priority.]—T. G. B.

hornblende-schists) of Sark, however closely they may simulate stratification.

As an hypothesis to explain the whole series—but this, it must be remembered, is advanced only as an hypothesis—we suggest that formerly two magmas existed, the one now represented by the aplite or granite of the veins and the bands similar in composition, the other by the lumps of coarse hornblende; that after the latter had become solidified, at least locally, the more acid rock came in, brecciating it here, more or less melting it there, the two flowing on together, at any rate in places, and producing the structures which have been described in this paper. In some cases, as in the more finely banded gneisses and the more uniform masses of hornblende-schist, the one magma or the other dominates, though in it a small portion of the other may have been dissolved, but in others it by no means follows that either the one rock or the other was wholly liquid. From what has been said, it is obvious that very probably the crystals in the lumps of coarse hornblende-rock had been formed anterior to this period, but other parts of the same rock may have been partially melted. The more granitic rock also may have contained its own crystalline constituents at the time of its intrusion, so that in the mass as a whole almost every stage may have existed from a viscous fluid to a holocrystalline solid.[1]

By what interval of time the phases, described above, were separated, there is nothing to show. It is not, however, very probable that a distinctly acid rock, such as the aplite, would follow immediately after one no less distinctly basic such as the 'hornblendite' or certain parts of the hornblende-schist. Nor is it possible to say at what depth beneath the surface these fluxional movements occurred. Some of the phenomena are suggestive of a comparatively unimpeded flowing over a considerable area, but the crystalline condition of the rocks indicates a rather slow cooling, so that we must assume either exceptional conditions, if the depth below the surface was great, or a much more rapid increase of crust temperature than now prevails generally, if it was but small. There is nothing to connect the movements with any known epoch of mountain-making; they were long anterior to the great post-Carboniferous disturbances.[2]

[1] To prevent misunderstanding, it may be well to state that the Authors (after another visit) adhere to their opinion as to the origin of the foliation in the great mass of gneiss forming the southern part of Guernsey and are fully convinced that this is a pressure-structure, the original rock having been a porphyritic granite. It may be of interest to mention that in a dyke of diabase which cuts the 'wriggling' banded gneiss on the western shore, rather to the south of the actual ridge of the Coupée, they found 2 or 3 fragments of an *augen* gneiss, which reminded them of the rock of Lihou or Lerée Bay in Guernsey. This is the only case where they have seen anything in Sark to recall these, the oldest rocks, as they fully believe, in the Channel Islands.

[2] Hill, Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 387–89; Bonney, *ibid.* vol. xliii. (1887) p. 319.

Part II. The later Intrusive Rocks.

Among the gneissoid rocks mentioned above it is not unusual to find intrusive veins which are very closely welded to, and sometimes seem almost inseparable from, the rocks into which they break. They are generally moderately coarse, mottled reddish and greenish granitic or dioritic rocks, with a superficial resemblance to the basement-gneiss (being often slightly foliated).

In some cases, as stated above (p. 134), they probably are that rock, in others they are less quartzose. One from the cliffs south of Port du Moulin is a mica-diorite, rather rich in apatite, and containing a little quartz. So is another from Saignie Bay, but it contains one or two zircons. Another from Grève de la Ville is much the same, but with rather more quartz, and more nearly allied to the granite. A fourth from Dixcart Bay, which breaks into a hornblende-schist, is not very different, only it contains hornblende as well as biotite. These, however, probably are not much more recent than the rocks in which they occur. So we pass on to those intrusive masses which are distinctly of a later date. These have been already briefly described by Mr. Hill,[1] but we are enabled to add a few particulars which may be of interest.

First, as regards the great masses of granitic rock which form the northern and the southern parts of the island. Undoubtedly, as affirmed by Mr. Hill, these are intrusive into the group of hornblende-schists and bedded gneisses; of this we obtained further proofs.

It is, however, doubtful whether the southern mass should continue to be designated a granite. It became evident on closer study in the field that quartz was not conspicuously present, and microscopic examination shows the rock to be a diorite, containing a fair proportion of biotite, quartz occasionally occurring as an accessory. Apatite is rather conspicuously present, but we do not purpose to enter into the minor petrographical details. The Brecqhou rock also appears to be rather a quartziferous diorite than a true granite. There is rather more quartz and biotite in the rock at the northern end of Sark, so it may be left with the hornblendic granites until it has been submitted to a more minute petrographical study, but it is not unlikely that it will prove to be, more strictly speaking, a tonalite.

Mr. Hill drew attention to the rarity of dykes of felstone or fine-grained granite. To the dyke of the Boutiques caves mentioned by him (which cannot be distinguished from that on the headland) we may add a rather similar, but slightly more compact-looking rock, forming a dyke near the Port on the south side of Brecqhou, another narrow compact dyke on the eastern end of Point Derrible, and a third on the Burons which is a little darker in colour.

The Boutiques dyke, on microscopic examination, exhibits some rather small felspars, crowded with fibrous secondary microliths, and giving bright tints with the crossed nicols, set in a mosaic of quartz and felspar, the structure of which sometimes approaches to

[1] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 332.

micrographic. In this is a fair amount of biotite, with some white mica in small flakes, the former being rather dirty-looking. The rock is a quartz-felsite. The specimens from the other dykes do not contain distinct grains of quartz, but, so far as can be determined without microscopic examination, they are quartz-felsites, a little hornblende being probably present, at least in the Brecqhou dyke.

We also found on the south side of the western bay at the Coupée a dyke, about 3 yards wide, of a moderately fine-grained granite of a reddish colour.[1]

As Mr. Hill pointed out, dykes of greenstone abound in Sark, as in the other islands. To their petrographical details a memoir might be devoted; they are generally rather compact,[2] sometimes, at the edges or in thin offshoots, so much so as to suggest a former glassy condition; more rarely fairly coarse, not often porphyritic.[3] They are doubtless diorites or diabases (generally hornblendic), but we have not thought them as a rule worth microscopic study, and will only mention one, since it is slightly exceptional.

The specimen is from a dyke which cuts the dioritic rock of Little Sark (just mentioned), running up the cliff in Vermandé Bay and attaining a thickness of at least 20 feet. It is a dark slate-grey (with a faint reddish tinge) in colour, sufficiently coarse in texture to have a slightly 'speckled' aspect, rough in fracture, with occasional amygdules of rather irregular form and a dull sea-green colour. Under the microscope we find that the groundmass exhibits an ophitic structure, the plagioclase felspar occurring in crystals which average about ·06″ in length; the augite, which is in smaller grains and less abundant, being generally rather decomposed and often replaced by viridite. The larger felspars are very much decomposed, the amygdules are irregular in outline and bordered by a thin zone of a pale green chloritic mineral, and occupied mainly, if not wholly, by calcite.

The handsome rock intrusive in the granite at the Eperqueries Landing deserves a little fuller notice than it has yet received.[4] The porphyritic felspars in this rock are sometimes about half an inch long, and do not diminish in size at the edges of the dyke. Under the microscope, they are seen to be crowded with secondary microliths, which make an exact determination of the species impossible, but probably most, if not all, are plagioclase. A fair amount of biotite, more or less altered, occurs in small ground flakes,

[1] In Mr. Hill's collection is a moderately coarse grey granite which he obtained some years since on Little Sark in the part occupied by the above-named diorite. Microscopic examination shows this to be a true granite. We had not time to search for it during our last visit, but we suspect this will prove to be intrusive in the diorite.

[2] But, in many of these, examination with a lens shows them to be probably holocrystalline, with a minute ophitic structure.

[3] There is a fairly porphyritic dyke on the S. side of Brecqhou, E. of the Port; but the most remarkable is the well-known dyke at the Eperqueries Landing.

[4] As it also cuts through a greenstone dyke it must be a rather late intrusion.

with iron oxide, sphene and a little apatite; small crystals of felspar are numerous,—of these most are plagioclase, but some in their form and their twinning on the Carlsbad type suggest orthoclase. The intervening groundmass shows a frequent approach to a micrographic or spherulitic structure. Thus the rock is a mica-porphyrite.

A rather similar but less coarsely porphyritic rock occurs on Brecqhou, on the E. side of the Port, and a dyke, rather like that at the Eperqueries Landing, but too rotten for examination, runs up the cliff S. of the Coupée (W. side). As pebbles rather like the Eperqueries rock are not rare on the shore about here, the identification is rendered more probable.

In 1889 we discovered, on the shore at Port du Moulin, one or two blocks of a variety of picrite;[1] but time and tide prevented us from seeking the rock *in situ*. On our next visit we searched carefully. At last, at the base of a slightly projecting crag which lies roughly east of the Great Autelet, two or three small humps of a similar rock were seen projecting from the shingle. The height of the part exposed is not more than a couple of feet, and it can only be traced for a very few yards; but another low boss was visible among the shore-boulders some fifteen yards away. The rock occurs in the banded gneiss, the layers of which it somewhat distorts, so it is clearly intrusive; but it does not, as is usual with the ordinary greenstone dykes, run up the cliff. The eye is attracted to it by a rather unusually rounded outline, like a seal's back, and by a peculiar aspect, the dull greenish-grey rock being mottled with light-coloured blur-like spots.[2] The rock, as in the boulder, though soft is not easily broken, as it is tough, and 'pounds' under the hammer. A freshly fractured surface presents some slight varietal differences from the rock of the boulder. The groundmass of the latter is rather more like that of an ordinary dark serpentine. This is rather paler, more fibrous in aspect, and speckled with small glittering crystals, but is less distinctly porphyritic. There are some corresponding microscopic differences. In the boulder, a considerable amount of olivine still remains unchanged, but this is not so in the specimen from the rock *in situ*. That mineral is replaced by a number of secondary products, minute serpentinous minerals of more than one kind. There are also numerous brown, subtranslucent grains, of earthy aspect; these probably are an impure chalybite, and replace the magnetite which in the other rock is abundantly associated with the partially serpentinized olivine. The rock *in situ* contains also a larger quantity of hornblende; this mineral varies from a rather light green, fairly dichroic hornblende (occurring in crystals with ragged outlines, but showing distinct and very characteristic cleavages) to a fibrous colourless actinolite. On the other hand there is less of the micaceous constituent. This rock, in short, is much more difficult to describe since (to use a homely term) " it is

[1] T. G. Bonney, 'On the occurrence of a variety of Picrite (Scyelite) in Sark,' Geol. Mag. for 1889, p. 109.

[2] This especially attracted my eye to the boulder in Port du Moulin.—T.G B.

in such a mess." Alteration of the original constituents has been carried much further than in the boulder, but there is no reason to doubt their general identity, for it is well known that these very basic rocks sometimes vary considerably in different parts of the same mass.

We also found, on the shore at Port à la Jument, one or two large boulders which correspond more closely with the rock of the intrusive mass,[1] though they are more distinctly porphyritic, large patches of rather silvery pale hornblende occurring like the well-known schiller-spar from Baste.

As the outcrop which we found is so limited in extent, and as Port du Moulin is bounded by projecting crags or skerries, we suspect that there must be other outcrops of this picrite below low-water mark.[2]

Mr. Hill mentioned the occurrence of a dyke of kersantite at Port du Moulin, with traces of another. We can now increase the number of mica-traps by four. One forms a small dyke in the cliffs on the W. side of the Coupée. Another occurs in Saignie Bay, running up the cliff just north of the narrow track leading down to the shore, on which it also crops out. It is about four feet wide, and, where best preserved, is a very fine-grained dark rock, weathering brown, at first sight not unlike a basalt, but with a slightly rougher and more glittering surface, owing to the presence of many minute scales of mica.

A third instance is a dyke between the two northern entrances of the Gouliot caves. In the cliffs it appears to be only about half a yard thick, but it seems to broaden out on the rocky shore, and may perhaps attain to six feet. It is a very characteristic, dark-grey, slightly speckled mica-trap, and the mica crystals are more conspicuous than in the last rock.

A more curious variety occurs by the side of the beach in the inmost recess of Havre Gosselin. Here a rather foliated dioritic rock, mottled red and green, is intrusive in the usual hornblende-schist, which is rather gneissoid in character. The former is cut by a dyke of compact greenstone, and the two are severed by a

[1] There is a very strong macroscopic resemblance, but in the slice examined from the Port à la Jument specimen there is no *proof* that olivine has formed one of the constituents; hornblende, as above described, occurring in a sort of paste of minutely crystallized secondary products. The brown grains do not occur here.

[2] In the description published in the 'Geological Magazine' it is suggested that the rock might come from 'the important vein of serpentine and steatite, with asbestos and talc,' which, according to Prof. Ansted, 'has been traced crossing the central part of Sark near Port du Moulin.' From the above description it will be obvious that this rock cannot be the one mentioned by Prof. Ansted, and we are unable to make out to what rock he is referring. Probably the authority for his statement is a passage in Macculloch's paper on the Channel Islands (Trans. Geol. Soc. vol. i. (1811) p. 18). The words of the latter observer seem to imply that the dyke occurs *in* Port du Moulin. We think no such dyke can now be seen, and as his visit was a hurried one we should suppose some accidental error, if he did not speak of a *lapis ollaris* being obtained above the cliffs and used by the inhabitants. It is possible that some old excavations in the woods or fields may have escaped our notice.

second dyke of mica-trap, half a yard or so thick. The last has a rather rough fracture; the surface glitters with small scales of mica and shows in parts a curious colour-mottling, which is caused by spots of a purplish brown tint, with rounded outlines more or less connected, like sections of small reniform concretions, the intervals between them being occupied by a dark greenish material. As the rock weathers, the contrast in colour becomes a little more marked, and ultimately the aggregated spots weather out like a roughly pisolitic rock; the diameter of the more globular being about a quarter of an inch. Here and there, however, the structure passes into a more streaky one.

In these mica-traps[1] the usual brown mica is plentiful, with the crystalline outlines commonly well defined. Another mineral also occurs with a porphyritic habit, the largest and best-defined forms being in the Havre Gosselin rock. The sections indicate that this mineral has belonged to the monoclinic or orthorhombic system, more probably the former. They are defined by a dark line, and occupied by a more or less granular aggregate of secondary minerals. Among these is a carbonate—calcite, or probably a mineral intermediate between this and normal dolomite, besides variable amounts of viridite, chlorite, opacite, and a clear granular mineral, with rather low polarization-tints, not unlike some forms of chalcedony, though possibly one of the zeolitic group; but in some there is little besides the first named. An altered mineral of this habit is rather common in mica-traps; probably it has been one of the pyroxene group.[2] In the kersantite of Port du Moulin there is a fair amount of a colourless augite (generally in very bad preservation), with some larger irregular-shaped grains of a mineral now consisting of an aggregate of fibres giving bright tints with crossed nicols, but suggestive of the former presence of a rhombic pyroxene. Grains of iron oxide are present in all, and apatite certainly in the first and second. Lath-like crystals of a felspathic

[1] The Coupée dyke is very much decomposed. We have examined a specimen from a boulder, which was in a rather better condition, but as even this is by no means well preserved a minute description is needless. There are the usual flakes, more or less regular in form, of brown mica with numerous granules, generally in irregular clots, of iron oxide, in great part limonite. The supposed pyroxenic constituent, mentioned in the other cases, is wanting, unless it be represented by one or two irregular spots occupied by aggregates of serpentinous aspect. The present appearance of the rock suggests that it had formerly a glassy base crowded with tiny microliths of plagioclase. The latter can still be traced with more or less distinctness in the granulated brown matrix. The most remarkable feature in the slide is a rather oblong, somewhat rounded spot, about ·70″ by ·45″, with fairly definite boundaries, which is conspicuous from its paler colour and the presence of three larger clots of iron oxide. This is occupied by a matrix like the rest, in which, however, the felspar microliths are rather more distinct, and occasionally show a tendency to a tufted grouping; there are fewer mica flakes and larger clots of iron oxide, though of the latter there are more disseminated granules. Probably it is an included lump of a slightly less basic variety of the rock.

[2] Bonney and Houghton, 'Mica-traps from Kendal, etc..' Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 167. The mineral figured by Fouqué and Lévy ('Minéral. Microgr.' pl. xxvii.) and referred to bastite, presents some resemblance to the above-named.

mineral can be recognized in the Saignie Bay rock, but the alteration of the rest of the matrix makes it difficult to say whether there was also a glassy base, or whether the whole was rather minutely crystalline. Probably it belonged to the kersantite division.

So far as can be ascertained, the matrix of the Gouliot caves dyke, if not minutely holocrystalline, has been crowded with lath-like crystallites of felspar, exhibiting sometimes a slightly tufted arrangement, so that this also is a member of the same group. In both these rather larger crystals of felspar have probably been fairly common, but they are now too decomposed to admit of more than conjectural recognition.

The Havre Gosselin rock contains the largest and best-defined representatives of the supposed pyroxenic constituent, and appears, when viewed by ordinary light, to have a glassy base, the pisolitic structure being indicated by rather irregular-shaped patches of clear brown glass, separated by similar material of a sap-green colour. Neither exhibits a trace of radial structure. The former, generally at the edge, sometimes here and there within, becomes slightly granular in structure, as if the colouring matter had begun to aggregate, thus clearing the glass; the green part is more uniform. In both are trichites and granules of opacite, with rather numerous thin belonites. Felspar microliths appear rare, but in one of the streaky portions mentioned above, in which also the colouring matter has begun to separate out, they are fairly common though very minute. At the same time, when the crossed nicols are used, indications of an extremely minute devitrification are perceptible, at any rate in all the brown parts of the slide; still, that it has been once a glass seems indubitable. A porphyritic structure is visible to the eye in a specimen collected by Mr. Hill from another part of this dyke, small white crystals about one-tenth of an inch long being scattered about. But the microscope shows them to be rather larger examples of the supposed pyroxenic constituent. In this specimen the base (which in part is still a true glass) is nearly all brown in colour, being rarely green and giving a very faint indication of the globular structure in only one corner of the slide. Probably this rock belongs to the same general group as the others.[1]

The last described dyke, by its mode of occurrence, indicates that in all probability these mica-traps are later in date than any other igneous rock in the island. In Britanny and in Cornwall and Devon, the mica-traps are found cutting rocks as late as Carboniferous, but are probably pre-Mesozoic in age. The mica-traps of the Channel Islands most likely belong to one and the same series of disturbances as these.[2] The more the geology of the region is studied, the more close appears to be the connexion of those two districts with that group of islands.

[1] The group of the mica-traps in the matter of nomenclature seems to suffer from excess here and defect there, not much less than when Prof. Bonney wrote in 1879.

[2] Generally they cut crystalline rocks, but one in Alderney is intrusive in *grès feldspathique* (Hill, Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 384).

Note by Prof. T. G. Bonney.

In papers published previous to 1890[1] I have supposed banded gneisses and schists—rocks in which a 'stratification-foliation,' as I termed it, exists—to have originated, as a rule, from detrital deposits. Misunderstanding may be prevented by indicating in general terms to which of these rocks I now conceive this hypothesis of crystallization from a molten condition, but under exceptional circumstances (of which the intrusion of one rock into another, so as to render it plastic, may or may not be one), can be applied in order to explain their differences from normal igneous rocks.

They are:—The ordinary banded 'Laurentian' gneisses of Canada and of Greenland (so far as I have seen them); similar gneisses in Norway, in certain parts of the Alps, and in the Scotch Highlands, especially the North-western district; the Granulitic Group at the Lizard, and a portion, at any rate, of the Hornblendic Group;[2] perhaps also a few rocks in Wales; in short, those holocrystalline rocks, fairly coarse, in the description of which I have laid stress upon their banded structure and the peculiar forms of their mineral constituents.

But I still maintain that sundry other gneisses and certain schists (among them often chloritic and actinolitic) are due to the crushing of ordinary igneous rocks—granites, dolerites, &c. Representatives of this group occur, as I have described, in America, Norway, the Alps, Scotland, the Malvern Hills, and locally in other parts of England, in Wales, Britanny, Normandy, and Guernsey. In a word, whenever I have already admitted pressure to be the dominant agent in producing 'schistosity' in a rock, I have nothing to alter.

Also, I still maintain that certain schists are metamorphosed sediments—*e. g.* the calc-schists which graduate into marbles, most quartz-schists, and mica-schists, with their varieties, some chloritic schists, and the like. Examples of these occur in South Devon (Start district), Scotland (chiefly, so far as I know, in the Central Highlands, but with these I am less familiar), in Anglesey, in Norway (if I can trust my memory), and abundantly in many districts of the Alps—the group, in short, which I have designated the Upper Schists in my notices of that chain.[3] Some gneisses ultimately may be proved to have been originally sediments, but the number of these is certainly much less than I formerly supposed it to be, and in the present state of my knowledge I think it better to leave the question open.

In short, I think there are at least three modes in which a

[1] The list may be diminished by referring for papers of earlier date to my Presidential address to this Society for the year 1885; since then, to vol. xliii. (1887) p. 301 (Britanny), vol. xlv. (1889) p. 67 (Alps), vol. xlvi. (1890) p. 187 (Alps); also lecture to British Association at Bath ('Nature,' vol. xxxix. p. 89).

[2] After what I saw in Sark, I think it possible that the difficulties which prevented me in 1890 from adopting the hypothesis of fluxion might disappear if I could again examine these hornblende-schists.

[3] Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 96, 98.

'crystalline schist' may be produced, and feel some confidence that by patient working we shall be able, as a rule, to distinguish the one from the other;[1] though often we may not be able to say more than that pressure has been the last agent of alteration, and has obliterated any earlier record. Very probably also important changes[2] may be produced, as an indirect rather than a direct result of pressure (that is, by modification without crushing), through the recrystallization of the mineral constituents of a rock. But, with my present knowledge, I incline to consider this a subordinate cause of change.

Discussion.

Major-General McMahon congratulated the Authors on the result of their examination of the Sark rocks. It was gratifying to find that their work at Sark confirmed the results arrived at by them and himself at the Lizard. With reference to a fact stated by the Authors regarding the genesis of biotite in some of the Sark rocks, he might mention that he had observed several instances in the Himalayas where the contact-action of granite had converted diorite into a mica-trap in which biotite was very abundant.

Prof. Judd congratulated the Society on the new light thrown on the geology of the Channel Islands by the researches of the Authors.

Mr. Hudleston, after referring to the excellent work of Mr. Hill on the Channel Islands, said it was evident that his former paper on Sark left some open questions which seemed to invite further investigation. The origin of the hornblende-schists both there and at the Lizard had long excited attention, and good petrologists had held that they might have been basic tuffs. At Sark they were not associated with serpentines, &c., to any extent. The application of the new philosophy seemed to point to alterations in a plutonic complex, and the suggestion that the lowest in the series might not be the oldest in date gave rise to speculations of much interest. Unless it could be shown from their geognostic relations on the mainland that these rocks were of Archæan age, their petrology alone could scarcely be held to prove it.

Mr. Barrow drew attention to the strong resemblance of the

[1] I have not referred to 'contact-metamorphism' because the effects produced by it on sedimentary deposits can be readily distinguished, as a rule. For instance, a 'mica-schist' from Skiddaw, Britanny, Normandy, &c., produced by a large mass of granite, differs much from such a mica-schist as we find in the 'Upper Group' in the Alps. So far as I have been able to judge, no very important changes are produced by the intrusion of molten masses into rocks already crystalline, probably because their constituents are already in a stable condition.

[2] I refer to such changes as the replacement of labradorite by scapolite, to which Prof. Judd has called attention in a suggestive paper (Min. Mag. vol. viii. (1889) p. 186), certain cases of the formation of uralite, &c., but not to the ordinary processes of decay, hydration, and even renovation. Heat, pressure, and water are the chief agencies of metamorphism, and we must be content at first if we can distinguish and classify the more striking and common phenomena which have been produced by them.

specimens exhibited to the 'Eastern Gneisses' of the Highlands. One in particular—the rock locally known as 'longrain'—closely resembled a hornblendic gneiss that he had recently mapped in Forfarshire. The characteristic appearance of this type of gneiss is due to the presence of large numbers of hornblende crystals with conspicuous development of the pinacoid faces; it thus differed fundamentally from a hornblende-schist, in which such faces were almost totally absent. Tracing the outcrop of this rock, he found it passed gradually into a normal hornblende-schist, and that its gneissose aspect was due to thermometamorphism—this phase only existing when the basic rock was either penetrated by or in close proximity to the more recent and more acid gneisses. The change from schist to gneiss was essentially an aggregation of the constituents of the finer-grained mass. The needles of actinolite in the schist are aggregated to more or less definite crystals of hornblende, with marked pinacoid faces, in the gneiss. The tiny felspar grains gradually coalesce and form well-striated plagioclase, the species of which can be easily determined. The sphenes tell the same tale. The quartz is especially important, because there is usually a fair amount of it in this type of hornblende-gneiss, and it is obviously of the same age as the general structure of the rock. If the Authors claimed that a similar structure might be produced during consolidation, geologists were fairly entitled to ask for instances, from unmetamorphosed areas, in which rocks, as basic as these gneisses, contained free quartz as an essential constituent.

The Rev. Edwin Hill mentioned, in reply to Mr. Hudleston, that an overlying pre-Cambrian granite indicated the great age of the hornblende-rocks. The beautiful Guernsey specimen which had attracted the speakers' attention is called 'longrain.' He acknowledged a change of opinion on Sark. When he formerly worked there the existing hypotheses for the origin of such rocks were only pressure, rolling out, and successive deposition. The first two were clearly inapplicable, and so, though seeing difficulties, he had had to choose the third. General McMahon's papers on the Lizard had now provided a fourth, and this on examination proved to be applicable to Sark.

Prof. Bonney thanked the speakers for the reception accorded to the paper. He said that, as the serpentines and gabbros were intrusive in the crystalline schists at the Lizard, their absence in Sark did not count for much. Mr. Barrow's remarks were of great interest, but he thought instances of contact-alteration among crystalline rocks were less frequent than the speaker supposed, and were not generally applicable to the cases in the paper, which hardly fell under ordinary contact-phenomena. He thought that the criticism regarding free quartz was founded on a slight miscomprehension of what had been said.

12. *On* PART *of the* PELVIS *of* POLACANTHUS. By R. LYDEKKER, Esq., B.A., F.G.S. (Read December 23rd, 1891.)

AMONG the specimens lately acquired by the British Museum from the collection of the late Mr. Beckles, of Hastings, is one to which my attention has been directed by my friend Mr. A. Smith Woodward. It bears the number R. 1926 in the Museum Register; and, like the majority of Mr. Beckles's specimens, is evidently from the Wealden. Mr. Charles Dawson, who has had so much experience in Wealden fossils, has been good enough to examine the specimen, and considers that it is almost certainly from the Isle of Wight, and not from Hastings.

One glance at the specimen is sufficient to show that it is the central part of a Dinosaurian ilium, with portions of the sacral ribs still attached to its inner surface. It belongs to the right side, as proved by the position of the ischial tuberosity; and while both extremities of the ilium are wanting, the acetabular region is fairly well preserved. The pre-acetabular portion of the ilium forms a roof-like expansion; while the post-acetabular process is compressed and comparatively thin. The upper border of the ilium is straight. The broken portions of the sacral ribs (five in number) are triangular in section, and have deep indentations between them; so that they form buttress-like structures of great strength. The whole contour of the ilium and sacral ribs is quite unlike that obtaining in *Iguanodon* and its allies. It appears most likely that the pre-acetabular portion of the ilium when entire was greatly expanded laterally, as is the case in *Stegosaurus*.

The point of especial interest connected with the specimen is, however, the presence of a large flat plate of bone, somewhat more than ½ inch in thickness, resting on the upper border of the ilium, from which it is separated by the intervention of a thin layer of matrix. This bony plate is evidently a portion of a dermal armour, and thus suggests comparison of the specimen with the dorsal shield of the Dinosaur from the Wealden of the Isle of Wight described by Mr. Hulke as *Polacanthus Foxii*.[1]

Such a comparison shows that the present specimen undoubtedly belonged to a closely allied, if not specifically identical Dinosaur. It is true, indeed, that in the specimen described by Mr. Hulke what remains of the pelvis and sacrum is crushed almost flat on to the under surface of the dorsal shield. Still, however, there is sufficient preserved in the former to show that the ilium and sacral ribs are of the same type as in the specimen under consideration; the triangular cross-section of the sacral ribs being especially noticed in Mr. Hulke's description of his specimen. Moreover, when compared with the pelvis and sacrum of the much larger Kimeridgian Dinosaur described by Sir R. Owen as *Omosaurus*, which belongs to the same group as *Polacanthus*, the present specimen again presents a

[1] Phil. Trans. for 1887 (B), p. 169, pl. viii. [The name *Polacanthus* (Hulke, 1881, *ex* Owen), as has been pointed out to me, is preoccupied by *Polyacanthus*, Kuhl, 1831, and ought, therefore, to be changed.—Feb. 1892.]

POLACANTHUS, sp.

Fig. 1.

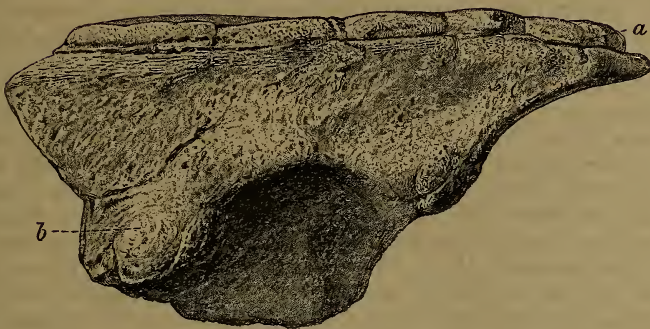


Fig. 2.

EXPLANATION OF FIGURES.

Outer (fig. 1) and inner (fig. 2) views of the imperfect right ilium and sacral ribs, with part of the dermal armour. $\frac{1}{4}$ natural size. a = dermal shield; b = tuberosity for ischium.

close general resemblance, especially as regards the form of the sacral ribs, and the deep pits by which they are separated from one another; these pits being apparently roofed over by an inward extension of the upper part of the ilium. The same features are noticeable in the apparently generically identical American Dinosaur of which the pelvis and sacrum are figured by Prof. Marsh as *Stegosaurus*.

The chief characteristics of the specimen under consideration are shown in the accompanying figures.

As the result, then, of my study of this specimen, it appears that it indicates a Dinosaur which may be referred to *Polacanthus*; and the question then arises whether or no it is specifically identical with the typical *P. Foxii*.

Now, so far as the crushed condition of the pelvis and sacrum of the latter admits of forming a definite opinion, the corresponding portions of the present specimen appear at first sight to be of a decidedly more massive type. It is quite possible, however, that the crushing and maceration which these bones have evidently undergone in Mr. Hulke's specimen may have somewhat exaggerated these apparent points of difference, and that the two ilia are not very different.

A more important point of distinction remains to be noticed. As is beautifully shown in Mr. Hulke's plate, the upper surface of the dorsal shield of *P. Foxii* carries a number of bosses for the articulation of the large spines found in association with the figured specimen. In Mr. Beckles's specimen, on the contrary, the corresponding surface of the dermal armour is perfectly flat, without the faintest trace of such bosses. It might be urged that the absence of these bosses is due to the effects of rolling on the shore; but the other parts of the specimen do not show signs of excessive rolling, and it would surely require a great deal of such action to remove all traces of these bosses if they ever existed.

It appears, however, impossible to be absolutely certain in regard to this point; but if subsequent 'finds' should prove that in this Dinosaur the dermal armour was smooth, I would suggest that the species might be appropriately named after its discoverer, Mr. Beckles.

It is unfortunate that both extremities of the ilium of this specimen are broken away, so that we cannot determine the relative lengths of its pre- and post-acetabular processes; but in spite of this deficiency the specimen itself is of importance, as showing more clearly than hitherto the close affinity existing between *Polacanthus* and the larger Dinosaurs described as *Omosaurus* and *Stegosaurus*.[1] The remarkable character of the dermal armour of the latter, as lately restored by Prof. Marsh, amply serves, however, to establish its generic distinctness from *Polacanthus*.

[1] [Since this paper was sent in to the Society Prof. Seeley (*supra*, pp. 81–85) has more fully described the ilium of *Polacanthus*, and indicated the relationship of the genus to *Stegosaurus* and the so-called *Omosaurus*. I doubt, however, whether he has allowed sufficiently for the effect of crushing. He considers the present specimen (*supra*, p. 84) as generically distinct from *P. Foxii*.—Feb. 1892.]

13. *On a* NEW FORM *of* AGELACRINITES (LEPIDODISCUS MILLERI, *n. sp.*) *from the* LOWER CARBONIFEROUS LIMESTONE *of* CUMBERLAND. By G. SHARMAN, Esq., and E. T. NEWTON, Esq., F.G.S. (Read January 6th, 1892.)

[Communicated by permission of the Director-General of the Geological Survey.]

[PLATE II.]

DURING the Geological Survey of parts of Cumberland and Northumberland (Sheet 106, N.W.) by Mr. Hugh Miller, a large series of fossils was obtained by the Survey collector, Mr. J. Rhodes, from the Lower Carboniferous rocks; and among them are two referable to that rare and interesting group of Echinoderms, the Agelacrinitidæ. The only representatives of this group hitherto recorded from British deposits are *Agelacrinites Buchianus*, from the Bala Beds, described by Forbes,[1] and *Lepidodiscus Lebouri*, from the Carboniferous Limestone, described by Mr. Percy Sladen;[2] our specimens are evidently closely related to the latter species. It is very desirable that some account of such rare fossils should be placed on record, more especially as we believe them to represent a new species.

Both the specimens are attached to valves of *Myalina*, and both are from the River Irthing; but one is from near Lamport, on the Northumberland side of the river, and the other from near Waterhead, on the Cumberland side. The example from Lamport is too imperfect for description, but that from Waterhead is in a very perfect state of preservation, and is alone alluded to in the following remarks. The test is extremely flat, and forms an almost circular disc about $\frac{4}{10}$ inch (1 centim.) in diameter. There is a distinct marginal zone, the width of which is about one fifth of the diameter of the entire test. Five rays or arms radiate from near the centre, curving outwards towards the circumference; but they end at the inner edge of the marginal zone, and do not extend along this margin for any appreciable distance. The curve of one arm is reversed, so that the two which surround the pyramid are turned towards each other, and the interradial space thus enclosed is somewhat larger than any of the others. The arrangement of the median arm-ossicles is not very distinct; but for the most part they appear to be wedge-shaped, and though interlocking do not reach quite across the arm, though it is possible that some may do so.

The pyramid is well shown; it is placed in the middle of its interradial space, and apparently possesses 9 or 10 triangular plates.

The scale-like plates, with which the surface of the test is covered, are imbricated, and ornamented with microscopic granules.

[1] Mem. Geol. Surv. vol. ii. (1848) part ii. p. 521.
[2] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 744.

At the outer edge of the test the plates are small, closely set, and probably fixed; passing inwards they increase in size, the largest series defining the inner edge of the outer zone; while those of the interradial spaces are of medium size, and are pressed upwards against the arms, so that their edges form margins to each of the rays, doubtless due to post-mortem pressure. The imbrication of the plates is from without inwards, the inner margins of the plates being free.

The nearest allies of this fossil are doubtless *Lepidodiscus Lebouri*, Sladen,[1] *L. cincinnatiensis*, Röm.,[2] and *L. squamosus*, Meek & Worthen,[3] but as detailed comparisons of these and other species, as well as full references, are given by Mr. Sladen, our present purpose will be best served by merely giving the chief characters of our specimen, and of the three nearly-related forms, as follows:—

Lepidodiscus squamosus.

1. Arms 5, long, extending along margin.
2. Arm-plates in double rows.
3. Pyramid at one side of interradial space.
4. No outer border seen.
5. Diameter 1·70 inch.

Lepidodiscus cincinnatiensis.

1. Arms 5, long, extending along margin.
2. Arm-plates in double rows.
3. Pyramid near outer edge, touching end of arm.
4. Outer border indistinct and narrow.
5. Diameter 0·77 inch.

Lepidodiscus Lebouri.

1. Arms 6 [? abnormal], long, extending along margin.
2. Arm-plates in single rows.
3. Pyramid at one side of interradial space.
4. An outer border.
5. Diameter, when perfect, somewhat over 1 inch.

Lepidodiscus, n. sp.

1. Arms 5, short, *not* extending along margin.
2. Arm-plates, in part at least, in double rows.
3. Pyramid in middle of interradial space.
4. A broad distinct outer border.
5. Diameter 0·40 inch (1 centimetre).

A comparison of the above characters shows that our new specimen differs from all the others in having short arms, and the pyramid in the middle of the interradial space, also in its much smaller size. It further differs from *L. squamosus* and *L. cincinnatiensis* in

[1] *Op. et loc. cit.*
[2] See Geol. Surv. Ohio, vol. i. part 2, Palæont. p. 55, pl. 3. f. 6.
[3] Proc. Acad. Nat. Sci. Philad. 1868, p. 357.

having a definite, broad, outer border; and from *L. Lebouri* in having only 5 arms, and the arm-plates in a double row.

The specimen figured by Bronn as *L. cincinnatiensis*[1] is much more like our specimen.

As it seems probable that the sixth arm of *L. Lebouri* is abnormal, it can scarcely be taken as a specific character; but if there were only five arms the pyramid might be in the middle of the interradial space, and the species would then differ from ours only in its larger size, longer arms, and, seemingly, in a different arrangement of the arm-plates.

Until it can be shown that the differences above pointed out are only such as may be due to age or individual variation, this new British specimen must be held to be specifically distinct, and we propose to associate our colleague Mr. Hugh Miller with the species by naming it *Lepidodiscus Milleri*.

EXPLANATION OF PLATE II.

Lepidodiscus Milleri, n. sp., from the Lower Carboniferous Limestone, near Waterhead, River Irthing, Cumberland. Preserved in the Museum of Practical Geology.

Fig. 1. Test, natural size.

Fig. 2. Test, enlarged $8\frac{1}{2}$ diameters. The plates seen on each side of the arms in this figure are too definitely marked off from those of the interradial areas; they are without doubt the upturned edges of some of the interradial plates.

Fig. 3. Portion of an arm, enlarged, to show plates; partly diagrammatic.

Fig. 4. Portion of outer band of test, to show arrangement of plates, enlarged 28 diameters.

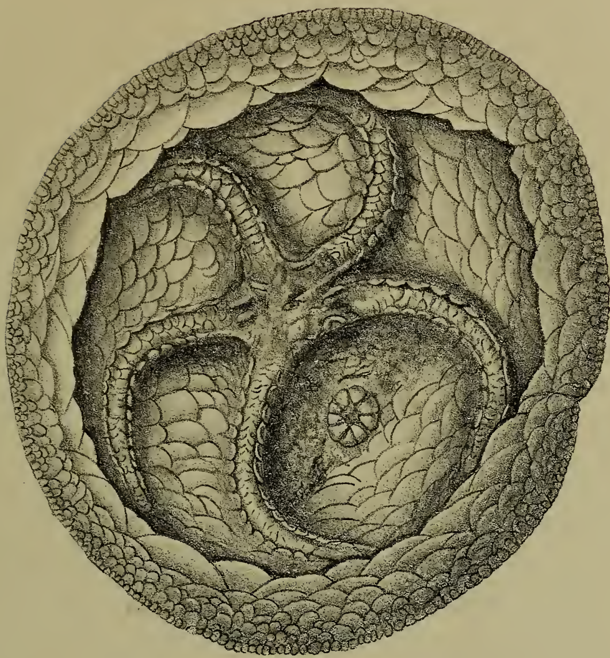
Fig. 5. Granular ornament of plates, enlarged 70 diameters.

Discussion.

Mr. Bather entreated the Authors not to revive the obsolete termination *ites*, but, following Angelin, Lovén, P. H. Carpenter, Steinmann, S. A. Miller, and all recent writers on Crinoidea, to write simply '*Agelacrinus*' just as they would '*Cyathocrinus*.' The rarity of British Agelacrinidæ, while enhancing the interest of the paper, increased the difficulty of determining specific differences. In the type-specimen of *L. Lebouri* the sixth arm was a mere abnormality; the exact position of the anus, especially in so flexible a tegmen, was hardly diagnostic; the plates bordering the ambulacra in *L. Milleri* seemed homologous with the adambulacrals of *L. Lebouri*. He was glad to see that the Authors made *Lepidodiscus* a subgenus of *Agelacrinus*. The slight curvature of the arms in *L. Milleri* made it approach *Hemicystis*; but it seemed probable, from examination of Bohemian and American species, that the varying curvature of the arms and the imbrication or tessellation of the plates were not characters of more than subgeneric importance.

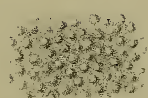
Mr. E. T. Newton, in reply, said that he objected to the principle of altering names originally proposed, and made a point of never doing so unless it was absolutely necessary.

[1] 'Lethæa Geognostica,' tab. iv¹. fig. 6.



2. x 8½.

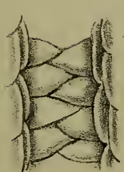
1.



5. x 70.

4. x 28.

3. x 3



E. T. Newton del.
A. Hollick lith.

Mintern Bros. imp.

LEPIDODISCUS MILLERI, *sp. nov.*

14. North Italian Bryozoa.—Part II. Cyclostomata. By Arthur Wm. Waters, Esq., F.L.S., F.G.S. (Read January 27th, 1892.)

[Plate III.]

The Chilostomata from the same localities were dealt with in vol. xlvii. (1891) p. 1 of this Journal. It is always unsatisfactory to describe Cyclostomata, as there are so few characters that can be employed in classification, nor are we yet sure as to the relative importance of those used. The difficulties are much increased by the vast number of named species based upon some slight difference in the mode of growth, and in some cases the individual state of preservation has been the ground of a new species.

I have before me a list of 424 names of Tertiary Cyclostomata,[1] which no doubt could be increased to nearly 600, but we are certainly within the mark when we say that of these more than 200 could not be recognized again, while many are known to be only synonyms.

In the Tertiaries *Hornera*, *Idmonea*, *Filisparsa*, and *Entalophora* are by no means sharply-defined genera, and seem to run into one another.

The most interesting species dealt with is a new one, which I have called *Diastopora brendolensis*. It has a tubule to most zoœcia, but differs from the living species *D. obelia*, which also has tubules; for in the fossil they run up more by the side of the zoœcium, whereas in *D. obelia* they are on the front of the zoœcium, about the middle. The zoarium is usually erect, formed by very compressed branches with zoœcia on both sides; but there are, besides, some incrusting specimens having similar small zoœcia provided with tubules. This would seem to show that those who united under *Diastopora* erect and incrusting forms were right. The genera *Mesenteripora* and *Bidiastopora* are, however, retained by some.

The ovicell by the side of the zoarium of *Hornera serrata* is in a position new for the Cyclostomata.

[1] A similar list of Tertiary Chilostomata comprises about 1400, and I have little doubt that I could bring the list up to 2000. The number of names of Cretaceous species must be as large, and the list of Palæozoic bryozoa also very considerable; from these figures we may see, therefore, that there is an overwhelmingly large field not yet reduced to order.

List of Species.

	Living.	Val di Lonte.	Montecchio Maggiore.	Brendola.	Ferrara di Monte Baldo.	Ronzo.	Crosaro.	Hungary (*Pergens*).	Malo.	Other Localities.
1. Crisia subæqualis, *Reuss*	...	...	...	*	*	...	...	...	...	
2. Diastopora tenuis, *Reuss*	...	* R	*	*	...	...	...	*	*	
3. —— suborbicularis, *Hincks*	*	...	...	*		...	...	...	...	
4. —— brendolensis, sp. nov.	...	*	...	*	*	...	...	...	*	
5. Idmonea concava, *Reuss*	*	*	*	*	*	...	*	...	*	
6. —— reticulata, *Reuss*	...	*	*	*	*	...	*	...	*	
7. Filisparsa varians, *Reuss*	*	*	*	*	...	*	*	*	*	
8. —— astalis, ? *Manzoni*	...	...	*	...	...	...	...	...	*	
9. Entalophora raripora, *d'Orb.*	*	*	*	*	...	*	*	...	*	Cretaceous.
10. —— pulchella, *Reuss*	...	*	*	*	*	...	...	*	*	Priabona.
11. —— tenuissima, *Reuss*	...	...	...	*	...	...	...	...	...	
12. Hornera concatenata, *Reuss*	...	*	*	*	*	*	*	...	*	Cretaceous.
13. —— serrata, *Reuss*	...	*	*	*	*	...	...	...	...	
14. —— asperula, *Reuss*	...	* R	?	*	*	...	...	...	...	Lonigo.
15. —— frondiculata, *Lamouroux*	*	*	*	*	...	*	*	...	*	
16. Crassohornera arbuscula, *Reuss*	...	*	*	*	...	...	...	...	...	Lonigo.
17. Stomatopora major, *Johnston*	...	*	...	...	...	...	...	...	...	
18. Pavotubigera flabellata, *d'Orb.*	...	...	*	*	...	...	...	...	...	
19. Defrancea brendolensis, sp. nov.	...	...	*	*	...	...	...	...	...	
20. Lichenopora hispida, *Fleming*	*	*	*	*	...	...	*	...	...	
21. —— incrustans, sp. nov.	...	...	*	*	...	...	...	...	...	
22. Heteropora subreticulata, *Reuss*	...	* R	...	*	...	...	...	...	*	Cretaceous.

1. Crisia subæqualis (Reuss).

Crisia subæqualis, Reuss, Bry. von Crosaro, p. 279, pl. xxxiv. fig. 8.

This species occurs from Brendola, and also probably another, but it does not seem possible to determine small fragments nor to compare them with living forms. The fresh joint usually grows out above the third zoœcium.

2. Diastopora tenuis (Reuss).

Discosparsa tenuis, Reuss, Bry. von Crosaro, p. 280, pl. xxxiv. figs. 9, 10.

Discosparsa regularis, Reuss, *op. cit.* p. 280, pl. xxxiv. fig. 11.

Lichenopora tenuis, Pergens, Bry. de Kolosvár, p. 6.

There are small zoaria from Brendola, which are flat and thin, with the zoœcia more or less distinctly radial, very little raised, and without interstitial pores, on which account the species is placed under *Diastopora*. This, if not identical with, is closely allied to *Defrancia subdisciformis*, d'Orb. in Reuss, Mitt. u. Ob. Quader, pt. ii. p. 132, pl. xxv. fig. 7.

Loc. Val di Lonte (*Reuss*); Montecchio Maggiore (*P.*); Brendola; Malo (*W.*); Pap-Patak, Pap-Falvi-Patak, Kolos Monostor (*P.*).

3. Diastopora suborbicularis (Hincks).

Diastopora suborbicularis, Hincks Brit. Mar. Poly. p. 464, pl. lxvi.

fig. 11; Waters, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 689; *ibid.* vol. xliii. (1887) p. 342.

A specimen from Brendola has the zoœcial tubes about the same size as the recent and fossil specimens already described, and the ovicell is nearly equal in width and length.

Loc. Living: European Seas. Fossil: Crag; various localities in Australia and New Zealand.

4. Diastopora brendolensis, sp. nov. (Pl. III. fig. 1.)

Zoaria very much compressed, with the zoœcia in more or less regular rows. On many of the zoœcia there is a tubule, which usually terminates near the zoœcial orifice, and runs parallel with the zoœcium, but occasionally it is on the front of the zoœcium and terminates near the middle of it.

These tubules are in a somewhat different position from those of the recent *Diastopora obelia*, and, as far as I am aware, tubules are known only in these two cases.

Until this was cleaned with sulphate of soda, I had not seen the tubules and supposed that it was *Idmonea compressa*, Reuss (Wien. Tert. p. 46, pl. vi. fig. 32; Manzoni, Bri. foss. del Mioc. Austr. ed Ung. p. 6), but in that species no mention is made of tubules.

There are zoœcia on the dorsal surface irregularly placed; on the front the angular sections of the cells resemble Manzoni's figure 17. Zoœcial aperture about 0·06 millim., which is considerably smaller than that of *Diastopora obelia.*

We do not yet understand the function of the tubules, nor do they seem to have received much study, for the only description and figure of their contents is given by Dr. Pergens (Bryozoaires du Crétacé, Bull. Soc. Belg. de Géol. vol. iii. p. 311, fig. 4). Some sections that I have cut correspond fairly with Dr. Pergens's description, and upon examination of my sections I was at once struck with the similarity of the 'fibres allongées' to the various muscles in the zoœcia; but in my specimens they form a club-shaped expansion near the extremity of the tubule, and are not arranged in the definite parallel manner figured by Dr. Pergens, being more or less contorted, and a point of considerable interest, not mentioned by that observer, is that the parenchym cord passes through the centre of this bundle of muscles. There are also sometimes muscles lower down attached to the lower part of the parenchym cord, so that this can no doubt be slightly moved by the muscles.

The internal structure seems to support an idea which I expressed long ago, that these tubules are homologous with the avicularia of the Chilostomata; by this I mean that the function has originally been the same. In the avicularia there is a parenchym body in a sheath, which can be pushed slightly forward when the beak is open; and to me this body has always seemed the important part of the avicularium, while, to my thinking, the prehensile theory never rested upon a sufficient basis.[1]

[1] See my Supplementary Report on the 'Challenger' Polyzoa, p. 27.

The tubules are not to be looked upon as belonging to the zoœcia, but as being of equal individual importance with the zoœcia. My sections of the living *Diastopora obelia* are not sufficient to enable me to give a full description of these tubules, and during a recent short visit to the Zoological Station at Trieste this species was not met with, although the writer was specially on the look-out for it.

There are also from the same localities adnate specimens of fossil *Diastopora*, with similar zoœcia and similar tubules, and seeing that these very exceptional characters are the same in both there seems sufficient reason for considering them as stages of the same thing. Again, from Malo there are a number of specimens without tubules, but in shape and growth exactly resembling the erect *Diastopora brendolensis*. These Malo forms are no doubt the *D. compressa* of Reuss, though the two may have to be united. It may be asked whether the tubules depend on the condition of growth.

Loc. Brendola; Val di Lonte; Novezzina (Ferrara di Monte Baldo); Malo.

5. Idmonea concava (Reuss).

Idmonea concava, Reuss, Bry. von Crosaro, p. 282, pl. xxxv. figs. 3, 4; Olig. von Gaas, p. 478; Waters, Ann. Mag. Nat. Hist. ser. 5, vol. iii. p. 271; Seg. Form. Terz. Reggio, pp. 209, 297, 330, 371; Meunier & Pergens, Bry. du Syst. Mont. p. 13; Pergens, Bry. von Wola Lu'zanska, p. 62.

Idmonea gracillima, Reuss (*non* Busk), Bry. von Crosaro, p. 282; Pergens, Bry. Foss. de Kolosvár, p. 6; Bry. von Wola Lu'zanska, p. 63.

There is sometimes considerable difference in the dorsal surface of a specimen, part being very distinctly concave while the rest is almost flat or even convex, and as *I. concava* and *gracillima* were separated only on account of the characters of the dorsal surface I am convinced that they should be united. I would point out that in almost every locality where one of these forms has been found the other occurs also. Dr. Pergens gives a list of ten Hungarian localities where both occur, and this constant appearance together in beds of various ages, and widely separated, should alone make us suspect their identity.

Loc. Val di Lonte; Montecchio Maggiore; Brendola; Ferrara di Monte Baldo; Crosaro; Malo; Mons (Belgium); Wola Lu'zanska; Hungary (*Perg.*); South Bavarian Eocene, Gaas; Pliocene, Italy. Living: Mediterranean.

6. Idmonea reticulata (Reuss). (Pl. III. fig. 10.)

Idmonea (*Crisina*) *reticulata*, Reuss, Bry. von Crosaro, p. 281, pl. xxxiv. fig. 13.

This is a very interesting species, as showing the *Idmonea* arrangement of the zoœcia on the front, whereas the pitted structure on the dorsal surface is a character frequently occurring in *Hornera*, but not in *Idmonea*. *I. reticulata* is very closely allied to, if not identical with *Crisina triangularis*, d'Orb., Pal. Franç. p. 915.

This would be *Crisidmonea* of Marsson.

Loc. Val di Lonte (*Reuss*); Brendola; Crosaro; Montecchio Maggiore; Ferrara di Monte Baldo; Malo.

7. Filisparsa varians (Reuss).

Filisparsa varians, Reuss, Bry. von Crosaro, p. 286, pl. xxxv. figs. 14, 15; Manzoni, Bri. foss. del Mioc. d'Austr. ed Ung. p. 9, pl. vii. fig. 27; Reuss, Olig. von Gaas, p. 479.

Filisparsa tubulosa, Waters, Ann. Mag. Nat. Hist. ser. 5, vol. iii. p. 275.

Hornera biloba, Reuss, Foss. Pol. Wien. Tert. p. 43, pl. vi. fig. 21; Manzoni, Bri. foss. del Mioc. d'Austr. ed Ung. p. 9, pl. vii. fig. 25.

Filisparsa Delvauxi, Pergens, Plioc. Bry. von Rhodos, p. 6.

In specimens from Montecchio Maggiore there are ovicells at the bifurcation on the anterior surface. The ovicell is of a Tubuliporidan character with the opening wide, either directed straight forwards or slightly downwards. This is but a trifle stouter than *F. tubulosa* of the Mediterranean. The openings of the zoœcial tubes are 0·2 millim. wide.

Loc. Val di Lonte; Montecchio Maggiore; Brendola; Crosaro; Ronzo; Malo; Gaas; Kostel; Baden; Hungary (*Perg. & Hantken*). Pliocene of Rhodes. Living: Mediterranean.

8. Filisparsa astalis (?) (Manzoni).

Filisparsa astalis, Manzoni, Bri. foss. del Mioc. d'Austr. ed Ung. p. 10, pl. viii. fig. 28.

There are some specimens from Montecchio Maggiore which are usually straight, but one colony dichotomizes at a wide angle. The zoarium is about 0·8 mm. wide, and the zoœcia are more or less in series from one side of the zoarium across to the other, with three or four zoœcia in a series. Orifice about 0·11 mm. wide. Anterior and dorsal surfaces dotted, and also faint longitudinal lines on the dorsal surface.

This is much like the description of the living *F. tubigera*, d'Orb., and in size it is about the same as *F. ramosa*, d'Orb., as measured by Pergens (Rev. des Bryoz. du Crét. p. 351).

Manzoni makes some species based upon the presence or nature of the dots; but surely this depends upon the state of preservation, as all *Filisparsa* and *Entalophora* have small tubes through the shell, showing as dots.

Seeing that Manzoni did not give measurements or the magnification, it is impossible to be quite sure about the identification of his species.

Loc. Montecchio Maggiore; Malo.

9. Entalophora raripora (d'Orbigny).

(?) *Entalophora attenuata*, Reuss, Bry. von Crosaro, p. 286, pl. xxxvi. figs. 1, 2.

For other synonyms, see my 'Foss. Cyclost. Bry. from Australia,' Quart. Journ. Geol. Soc. vol. xl. (1884) p. 686; Pergens, 'Rev.

des Bry. du Crét. fig. par d'Orb.' p. 359; and Miss Jelly's 'Synonymic Catalogue.'

There is also, though less common, a more slender *Entalophora* from Brendola and Montecchio Maggiore with much smaller zoœcial tubes (0·09 mm.), and this I am unable to identify with any named species, but am inclined to think that Reuss and Manzoni have caused some confusion between *E. anomale* and *E. attenuata*, and that *E. anomale* should have been the stout *E. raripora*, while *E. attenuata* is the more slender form.

Loc. Cretaceous of Europe (generally distributed); Eocene, Miocene, and Pliocene of Europe. Tertiaries of Australia and New Zealand. Val di Lonte; Montecchio Maggiore; Brendola; Crosaro; Ronzo; Malo. Living: Europe; Australia; Florida; Heard Island.

10. Entalophora pulchella (Reuss). (Pl. III. fig. 12.)

Cricopora pulchella, Reuss, Foss. Polyp. Wien. Tert. p. 40, pl. vi. fig. 10.

Cricopora verticellata, Reuss, *op. cit.* p. 40, pl. vi. fig. 9.

Spiropora pulchella, Reuss, Bry. von Crosaro, p. 287, pl. xxxvi. figs. 4, 5.

Spiropora conferta, Reuss, Bry. von Crosaro, p. 287, pl. xxxvi. fig. 3; Manzoni, Bri. foss. del Mioc. d'Austr. ed Ung. p. 12, pl. x. fig. 39.

Pustulopora pulchella, Stoliczka, Olig. Bry. von Latdorf, p. 77; Manzoni, Bri. foss. del Mioc. d'Austr. ed Ung. p. 11, pl. ix. fig. 35.

Entalophora pulchella, Pergens, Bry. de Kolosvár, p. 6; Bry. von Wola Lu'zanska, p. 65; Revision des Bry. du Crét. p. 358, which see for synonyms of Cretaceous forms; Reuss, Foram. Anth. und Bryoz. des deutsch. Septarienthones, p. 194, pl. ix. fig. 5; Bry. und Foram. des unt. Pläners, p. 116, pl. xxix. fig. 3; Fauna d. Steinsalz von Wieliczka, p. 124.

Entalophora clavula, Reuss, Foram., &c., des deutsch. Septarienth. p. 194, pl. ix. figs. 3, 4 (*non* Reuss, Foss. Polyp. Wien. Tert. p. 41).

The lower part of the zoarium has the zoœcia irregularly placed, that is to say is *E. pulchella* of Reuss, while the upper part has them verticillate and is the *Spiropora conferta* of Reuss. I have never found the irregular growth following the regular. Dr. Pergens agrees with me that in this species part grows as *Spiropora* and part as *Entalophora*; but he thinks, as it is not found in other cases, that we should not on this account unite the two genera. Although we cannot, however, expect hard and fast generic lines, yet it does seem that when the characters of the two genera are found in one stem this is, as I have proposed, sufficient reason for dropping the genus *Spiropora*.

The specimen figured in Pl. III. has three inflations which must be looked upon as ovicellular, and the zoœcia are here more irregular in consequence of the inflations.

Loc. Val di Lonte; Montecchio Maggiore; Brendola; Ferrara di

Monte Baldo; Malo; Priabona; various localities in Hungary (*Pergens & Hantken*); Latdorf; Castelarquato; Eisenstadt, &c. Söllingen; Cenomanian of Saxony (?).

11. Entalophora tenuissima (Reuss).

Spiropora tenuissima, Reuss, Bry. von Crosaro, p. 288, pl. xxxvi. fig. 6.

Specimens from Brendola, with delicate zoarium and narrow zoœcia arranged in verticillate manner, are no doubt what Reuss described, but I am by no means sure that this is a good species.

12. Hornera concatenata (Reuss).

Hornera concatenata, Reuss, Bry. von Crosaro, p. 283, pl. xxxv. figs. 5, 6.

Hornera concatenata, Waters, 'Closure of the Cyclost. Bry.,' Journ. Linn. Soc. vol. xvii. pl. xvii. fig. 2; Pergens, Bry. von Wola Lu'-zanska, p. 63; Bry. Garumniens de Faxe, p. 217.

Hornera subannulata, Phil., Tert. Verstein. N.W. Deutsch. p. 36, pl. i. fig. 9; Stoliczka, Olig. Bry. von Latdorf, p. 79, pl. i. fig. 4; Reuss, Fauna des deutsch. Oberolig. p. 58; Reuss, Foram. Anth. und Bryoz. des deutsch. Septarienth. p. 195, pl. x. figs. 2, 3.

The zoœcia occur in pretty regular series extending nearly across the zoarium. The closure is low down in the zoœcial tube.

Loc. Val di Lonte; Montecchio Maggiore; Brendola; Ferrara di Monte Baldo; Crosaro; Ronzo; Malo; ten localities in Hungary (*Perg.*); Ofener Mergel (*Hantken*); Bavaria; and Upper Cretaceous (*Perg.*).

13. Hornera serrata (Reuss; *non* d'Orb. & *non* Menegh.). (Pl. III. fig. 11.)

Hornera serrata, Reuss, Foss. Bry. von Crosaro, p. 285, pl. xxxv. figs. 10–11.

This very small species, on the anterior surface closely resembling *H. concatenata*, Reuss, is distinguished by the posterior surface on which the zoœcial lines spread out alternately. I have not in my specimens seen any indication of this being the terminal branch of *H. concatenata*; the possibility might, however, be kept in view. The bordering lines on the dorsal surface unite before the median line of the zoarium, but a ridge is continued to each of the two next zoœcia, and it will be seen that in this as well as some of the other *Idmonea* the zoœcia extend far back on the dorsal surface.

In a specimen from Montecchio Maggiore there is an ovicell entirely at the side of the zoarium, and as far as I know this is the first time that an ovicell has been found in this position. It is only indicated by the dotted lines in the figure, as that is drawn from a Brendola specimen.

Loc. Val di Lonte (*Reuss & W.*); Montecchio Maggiore (*G. & W.*); Brendola; Ferrara di Monte Baldo.

14. Hornera asperula (Reuss). (Pl. III. fig. 7.)

Hornera asperula, Reuss, Bry. von Crosaro, p. 284, pl. xxxv. figs. 8, 9.

Hornera d'Achiardi, Reuss, *op. cit.* p. 285, pl. xxxv. fig. 12.

This is a very small species, and in specimens from Brendola numerous short branches grow at right angles to the main branch. There is no serial arrangement of the zoœcia as in *H. concatenata*, and in the younger ends there is a longitudinal ribbing as figured in *H. d'Achiardi*, whereas the older part is plain.

Loc. Val di Lonte (*Reuss*); Brendola; Montecchio Maggiore (*Gott.*): Ferrara di Monte Baldo ; Lonigo.

15. Hornera frondiculata (Lamouroux).

For synonyms, see Jelly, Catal. of Marine Bryozoa, p. 115, and add :

Hornera trabecularis, Reuss, Bry. von Crosaro, p. 284, pl. xxxv. fig. 7.

H. trabecularis of Reuss represents the growing end of *H. frondiculata*, and Pergens has already indicated that they are synonymous. There are also stouter basal portions from Brendola.

Loc. Widely distributed in the Eocene, Miocene, and Pliocene of Europe, and in the Australian Tertiaries ; Wanganui, New Zealand ; Val di Lonte (*Reuss*); Montecchio Maggiore; Brendola; Malo; Crosaro; Ronzo. Living: Mediterranean ; Cape Verd.

16. Crassohornera arbuscula (Reuss). (Pl. III. figs. 5, 6.)

Ceriopora arbusculum, Reuss, Foss. Polyp. Wien. Tert. p. 34, pl. v. figs. 12, 13.

I had not seen this species when I described *Crassohornera waipukerensis* (Quart. Journ. Geol. Soc. vol. xliii. p. 349), but, as I then said, they are very closely allied. In the Montecchio Maggiore specimens the entire surface is covered with shallow pits, with a pore in the centre, those on the dorsal surface being the smaller. The ovicell, which is dorsal, extends over nearly the whole width of the zoarium, and the pits on its surface are more angular than those on the zoœcia.

The zoarium starts with a flat base, and, after growing vertically for a very short distance, grows horizontally, with numerous short branches on each side. The position of the ovicell indicates that we have to do with more than a basal growth, and shows relationship with *Hornera*, nor is it by any means certain that a second genus is required.

Manzoni (Bri. foss. del Mioc. d'Austr. ed Ung. p. 18, pl. xi. fig. 43) says this is probably the same as *Ceriopora globulus*, *C. cylindrica*, &c., but with this opinion I am unable to agree. There is also *Ceriopora arbusculus*, Roemer, from Söllingen, which, though named independently, is very similar.

Loc. Val di Lonte (*Reuss*); Montecchio Maggiore; Brendola; Lonigo.

17. Stomatopora major (Johnston).

For synonyms, see Waters, Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 342.

A specimen from Val di Lonte would seem to be this species, and I believe that the *Diastopora echinata*, Reuss, Foss. Polyp. Wien. Tert. p. 52, pl. vii. figs. 14, 15, and *Alecto echinata*, Manzoni, Bri. foss. del Mioc. d'Austr. ed Ung. p. 16, pl. xiv. fig. 57, are also this species.

The zoœcia have an internal diameter of about 0·15 mm.

18. Pavotubigera flabellata (d'Orbigny).

Pavotubigera flabellata, d'Orb., Pal. Franç. p. 767, pl. 752. figs. 4–8; Waters, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 691.

There are some specimens with the point of origin excentric, just as figured by d'Orbigny, while in some the colonies are almost discoid, and others again are semicircular; this last is probably a younger form and has been described by Reuss as *Defrancia dimidiata*. It would seem that in these various forms we have only stages of growth before us.

Loc. Cretaceous, Meudon; Tertiary of Australia, Aldinga; Brendola; Montecchio Maggiore.

19. Defrancea brendolensis, sp. nov. (Pl. III. figs. 2–4.)

Zoarium stalked, then spreading out and forming a lamina, which has radiate lines underneath. Upper part of the zoarium more or less cup-shaped, with usually 10 to 12 very stout and much raised rays, with the zoœcia opening to the outside of the zoarium. Centre of the cup pitted. In one specimen there is no lamina, and in this case there is a regular increase in size from the base, making the zoarium funnel-shaped, and the under surface has large pits, so that it then does not differ from the Cretaceous *Bicavea urnula*, d'Orb., Pal. Fr. pl. 776, fig. 2.

D. brendolensis is allied to the *Discotubigera insignis*, Manzoni (Bri. foss. del Mioc. d'Austr. ed Ung. p. 17, pl. xvi. fig. 64); to *Defrancia* (*Pelagia*) *Beyrichii*, Reuss (Septar. p. 193); to *Bicavea*, d'Orb., and possibly *Discocytis*, d'Orb.

Loc. Brendola; Montecchio Maggiore.

20. Lichenopora hispida (Fleming).

Tubulipora stelliformis, Reuss, Foss. Polyp. Wien. Tert. p. 49, pl. vii. fig. 4.

Defrancia interrupta, Reuss, Bry. von Crosaro, p. 258, pl. xxxiv. fig. 12, pl. xxxvi. fig. 9.

Loc. Living: European Seas; Australia; Tristan d'Acunha. Fossil: Miocene, Eisenstadt and Mörbisch; Pliocene, Crag, Calabria. Australia; New Zealand. Brendola; Val di Lonte; Crosaro; Montecchio Maggiore.

21. Lichenopora (?) incrustans, sp. nov. (Pl. III. figs. 8, 9.)

Zoarium incrusting as a single layer. Zoœcia opening vertically with strong bars radiating out to the neighbouring zoœcia.

Until this was properly cleaned it looked like *Diastopora*. There are no signs of a radial or discoid growth and the structure reminds us of that of *Heteropora*, so that it is difficult to know where it should be generically placed.

I have not had suitable material for making sections in order to study whether the cross-bars are hollow.

Loc. Brendola and Montecchio Maggiore.

22. Heteropora subreticulata (Reuss).

Heteropora subreticulata, Reuss, Bry. von Crosaro, p. 288, pl. xxxvi. fig. 7; Pergens, Bry. von Wola Lu'zanska, p. 65.

Heteropora reticulata, Marsson (*non* Busk), Bry. Rügen. Kreide, p. 26, pl. ii. fig. 4.

A specimen from Brendola twice dichotomizes. Zoarium about 1 millim. wide. This, I believe, is the same as a specimen I have seen from the Chalk of Gravesend and which was then considered to be *Clausa micropora*. As already remarked by Reuss, the zoœcia are more abundant upon the one side than upon the opposite. The cancelli are situated in deep pits, and in well-preserved specimens are much smaller than the oral apertures. Oral aperture about 0·07 mm. wide.

Loc. Val di Lonte (*Reuss*); Brendola; Malo; Wola Lu'zanska. Cretaceous, Rügen.

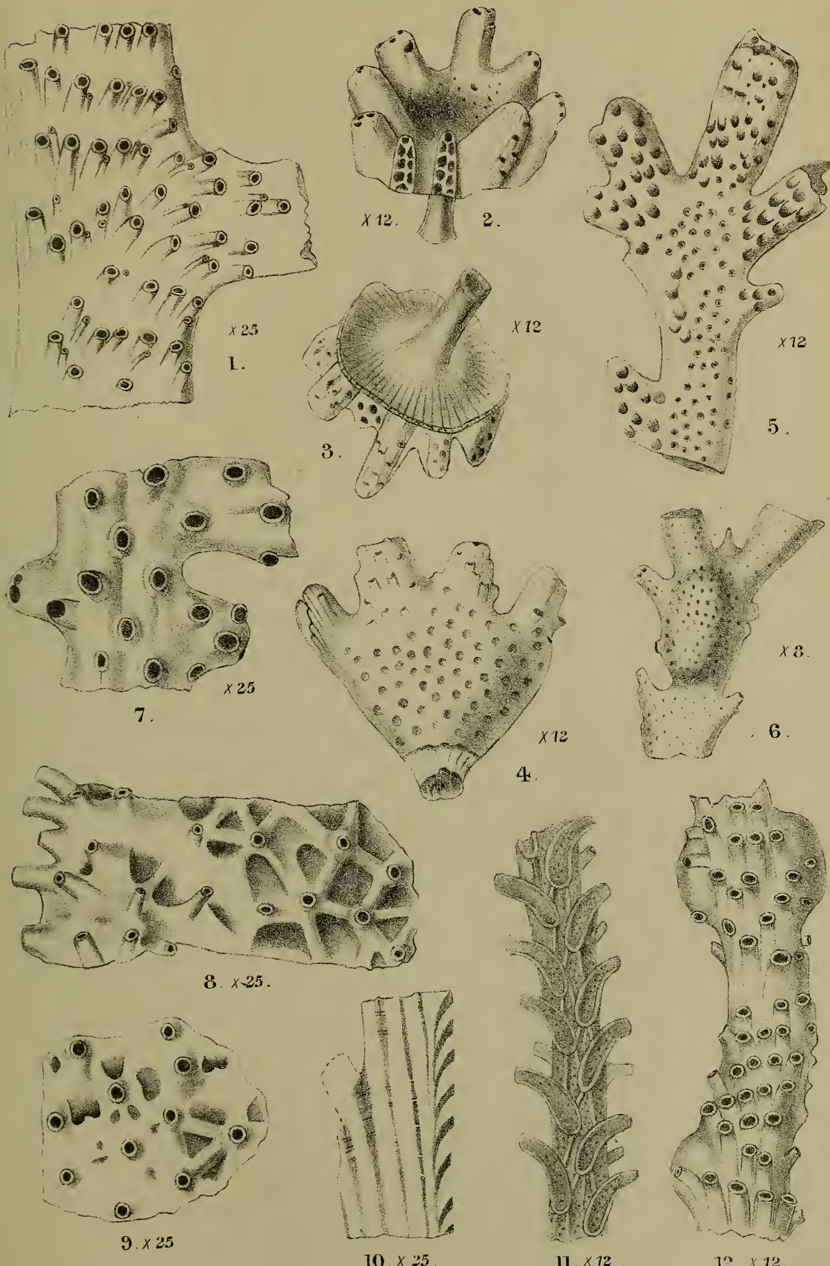
Note.—To the Chilostomatous species mentioned in my previous paper I would add *Microporella distoma*, Busk, from Malo, Novezzina, and Crosaro.

EXPLANATION OF PLATE III.

Fig. 1. *Diastopora brendolensis*, sp. nov., × 25.
Figs. 2–4. *Defrancea brendolensis*, sp. nov., × 12.
Figs. 5, 6. *Crassohornera arbuscula*, Reuss, × 12 & 8.
Fig. 7. *Hornera asperula*, Reuss, × 25.
Figs. 8, 9. *Lichenopora incrustans*, sp. nov., × 25.
Fig. 10. *Idmonea reticulata*, Reuss. Section, × 25.
Fig. 11. *Hornera serrata*, Reuss. Dorsal surface, × 12.
Fig. 12. *Entalophora pulchella*, Reuss, showing ovicellular inflations, × 12.

Discussion.

Dr. G. J. Hinde said that the revision of the characters and classification of the Bryozoa, so carefully carried out by Mr. Waters, was of considerable importance to all students of these forms.



A. W. Waters del.

A. Hollick lith.

NORTH ITALIAN BRYOZOA–CYCLOSTOMATA.

15. Archæopneustes abruptus, *a* New Genus *and* Species *of* Echinoid *from the* Oceanic Series *in* Barbados. By J. W. Gregory, Esq., B.Sc., F.G.S. (Read January 6th, 1892).

[Plate IV.]

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I. Diagnosis of the Echinoid.

Archæopneustes, nov. gen.[1]—Test large, elongate; high and generally conical, with the anterior slope much the steepest. Anterior ambulacrum flush.

Apical system: ethmolysian (in cases which are certainly known; but M. Cotteau's figure leaves the matter doubtful in one species).

Ambulacra: the lateral are subpetaloid, broad and unequal; the petaloid portions extend to the ambitus. The pores are large; in the posterior pair the outer pores are elongate or comma-shaped. The anterior ambulacrum is reduced, and contains only very small, scattered, single pores.

Peristome: very excentric anteriorly. Labiate: in a depression.

Periproct: on the narrow posterior vertical margin.

Fascioles: none, or possibly an imperfectly developed marginal one.

Distribution.—Cainozoic (recent and fossil) in West Indies.

Species 1. (Type of genus) *Archæopneustes hystrix* (A. Agassiz).

Species 2. *Archæopneustes abruptus,*[2] n. sp.

Form: anterior margin well rounded and with no anterior groove; the maximum width, which is greater than the length, is at a little less than a third of the length of the test from the anterior margin; from the widest part the sides taper back by a long curve to the narrow posterior end. Seen from the sides the anterior margin is short and steep; and from the vertex there is a long backward slope which increases in steepness till it reaches the posterior margin.

Apical system: at the apex, very excentric anteriorly; details unknown, but it is probably compact.

Ambulacra: the antero-lateral pair diverge from the apex almost at right angles to the long axis of the test; the postero-lateral are longer and broader. Both pairs are flush; the inner pores are

[1] The name is due to the characters being more archaic than in the case of its nearest ally, *Palæopneustes.*

[2] The specific name refers to the abruptness of the anterior slope.

round; the outer elongate, especially in the postero-lateral ambulacra, in which they become comma-shaped. The petals reach to the ambitus. The interporiferous areas are broad, and taper but slightly at the lower end.

Interradii: The postero-lateral are the broadest. In all the plates are massive, somewhat V-shaped, and imbricate slightly.

Periproct: large and marginal; it is elliptical, with the longer axis vertical.

Peristome: less excentric than in some species. Strongly bilabiate.

Dimensions of type:—

	mm.
Length	87
Height	60
Width	95
Distance of apical system from anterior margin	29
" mouth " " "	27
Antero-lateral ambulacra: length	72
" " width	16
Postero-lateral ambulacra: length	77
" " width	19

Type. Brit. Mus., E 3433. (G. Firth Franks Coll.)

Distribution. Uppermost limestone of the Oceanic Series. Bissex Hill, Barbados.

Affinities and Distinctions. From *A. hystrix* (A. Agassiz) this species differs in the more anterior position of its apical disk, but this may be exaggerated by the slight crushing back of the anterior margin of the specimen; moreover, the plates in the new species are V-shaped, whereas Prof. Agassiz figures the margins in his species as horizontal and nearly straight. From *A. cubensis* (Cott.) it may be distinguished by the fact that, owing to the more central position of the apical system in the Cuban species, the antero-lateral ambulacra run obliquely forward and are not in the same straight line.

From *Palæopneustes cristatus* (A. Ag.) and *P. Jimenoi* (Cott.) it differs in that the petaloid portions of the ambulacra in these are short, and the pores become single and minute at some distance from the ambitus; the shape of these three species is also different.

II. Zoological Affinities.

The irregular toothless Echinoidea are divided into two orders, the Cassiduloidea and Spatangoidea; the former is characterized by the central or subcentral mouth surrounded by the depressed widened 'phyllodes' of the ambulacra, and the raised 'bourrelets' between them, which together form the 'floscelle.' The Spatangoidea on the other hand possess no floscelle, have the mouth generally very excentric anteriorly, and the anterior ambulacrum much reduced. In

1847 L. Agassiz[1] founded a genus *Asterostoma* for a species (of what he regarded as the same as Lamarck's *Clypeaster excentricus*)[2] which combined the reduced anterior ambulacrum of the Spatangoidea with the central mouth of the Cassiduloidea. With the exception of various expressions of opinion as to the proper systematic position of the genus, nothing material was added till in 1871 M. Cotteau described two species of large Echinoidea which he assigned to the same genus, owing to the great resemblance in the structure of the abactinal surface, and the fact that they came from the same locality.[3] Unfortunately no figures were given of the peristome, and some palæontologists subsequently concluded that it was on the same plan as in the typical species, in spite of M. Cotteau's statement that the mouth was bilabiate and anterior. Thus Prof. A. Agassiz[4] seems to have been greatly impressed with the resemblance of M. Cotteau's species to an Echinoid dredged off Barbados, which served as the type of his genus *Palæopneustes*; he remarked that these differ "only in the absence of actinal ambulacral furrows and in having a labiate actinostome instead of the pentagonal sunken mouth represented in the poorly preserved specimens of *Asterostoma*." As in the type of this genus the mouth is central and non-labiate, Prof. A. Agassiz's genus is valid, but he left the two species described by M. Cotteau, to which his own are closely allied, in the old genus.[5] The first recognition of the importance of the difference of the mouth was by P. Martin Duncan[6] in his Revision, where he made a new genus, *Pseudasterostoma*, for the larger of M. Cotteau's species (*A. Jimenoi*); the other species (*A. cubense*) was still left in *Asterostoma*, but as M. Cotteau has kindly given me a sketch of the peristome of that species (reproduced in Pl. IV. fig. 6) it must also be separated from the genus. Both *Asterostoma* and *Pseudasterostoma* were left by Martin Duncan in very close alliance, and associated with some remarkable extinct genera in a new family—the *Plesiospatangidæ*; this was included in the order Cassiduloidea, though forming a connecting link with the *Spatangidæ*; the two genera were thus separated far from *Palæopneustes*. Duncan does not seem to have compared them closely with the living genus.

A short time ago an Echinoid was received from Mr. G. Firth

[1] In Agassiz and Desor, 'Catalogue Raisonné des familles, des genres, et des espèces de la classe des Échinodermes.' Ann. Sci. Nat., Zool. sér. 3, t. vii. p. 168.

[2] 'Histoire naturelle des Animaux sans Vertèbres,' t. iii. (1816) p. 15.

[3] 'Notice sur le genre *Asterostoma*.' Mém. Soc. géol. France, sér. 2, t. ix. (1871) pp. 177–184, pls. xvi. and xvii. For preliminary notice of these, see Bull. Soc. géol. France, sér. 2, t. xxiv. (1867) pp. 826, 827; and also 'Sur le genre *Asterostoma*, de la famille des Échinocorydées,' Compt. Rend. vol. lxx. (1870) pp. 271–273.

[4] 'The Echini collected on the Hassler Expedition,' Bull. Mus. Comp. Zool. vol. iii. no. 8 (1873) pp. 188, 189.

[5] 'Report on the Echini,' Reports, Expedition of the 'Blake,' no. xxiv. pt. 1. Mem. Mus. Comp. Zool. vol. x. no. 1 (1883) p. 91.

[6] 'A Revision of the Genera and great Groups of the Echinoidea,' Journ. Linn. Soc., Zool. vol. xxiii. (1889) pp. 201–204.

Franks, to whom the British Museum is indebted for a valuable collection of fossils and rocks from Barbados. The specimen was collected by Mr. Franks in a bed belonging to the Oceanic Series at Bissex Hill. It was obvious that it belonged to the genus *Palæopneustes*, but the whole appearance of the abactinal surface was so much like that of *A. cubense*, Cott., that I was led to ask M. Cotteau for further information about the peristome of that species. M. Cotteau's sketch shows that it is on the normal spatangoid type, and that it agrees in all essential respects with the new species from Barbados and with *Palæopneustes hystrix*, A. Ag.[1] The new species, the two fossil species from Cuba, and the two recent species also from the West Indies, may all be described as irregular, nodostomatous, adete Echinoids, in which the peristome is anterior and bilabiate, the periproct on the low posterior vertical margin, and the anterior ambulacrum reduced. This definition includes a sufficient series of characters to show that the five species are in very intimate alliance. There are, however, two points of difference: three of the species (*cubensis*, *hystrix*, and *abruptus*) have the petals continued to the margin and the mouth very excentric anteriorly; two others (*cristatus* and *Jimenoi*) have the petals short and closed, and the mouth somewhat more central. This latter point is clearly shown in Prof. A. Agassiz's figures of *P. cristatus*,[2] and it may be inferred from the figure of the abactinal side of *A. Jimenoi* given by M. Cotteau. These characters are associated with a marked difference in the form of the test, which is elliptical and conical in the first group and more evenly rounded in the second. The difference in the structure of the petals seems fully entitled to generic distinction, especially when accompanied by the concomitant variation in form and the position of the mouth. As the petals in the three first species are on the more primitive type, it is proposed to name the genus proposed for them *Archæopneustes*.

Duncan's genus *Pseudasterostoma* has to be abandoned as a synonym of *Palæopneustes*, and one would be glad if it could be retained for the three species for which a name has to be found. But this unfortunately cannot be done, for the following reasons:—(1) *P. Jimenoi* (Cott.) is expressly mentioned as the type; (2) *A. cubense*, Cott., is expressly excluded;[3] (3) the shortness of the petaloid portions of the ambulacra is given as one of the characters of that genus. *Pseudasterostoma* cannot therefore be dissociated from its type species and applied to a form with different characters, which Duncan had rightly excluded from it.

[1] A. Agassiz, 'Reports on the Results of Dredging . . . . by the 'Blake': No. IX. Preliminary Report on the Echini,' Bull. Mus. Comp. Zool. vol. viii. no. 2 (1880), p. 82; also Mem. Mus. Comp. Zool. vol. x. no. 1 (1883) pp. 58–60, pls. xviii., xix. fig. 2.

[2] 'Zoological Results of the Hassler Expedition: Part I. Echini,' Ill. Cat. Mus. Comp. Zool. no. viii. (1874) pl. iv. fig. 3, and especially Mem. Mus. Comp. Zool. vol. x. no. 1 (1883) pl. xxi. fig. 11.

[3] Duncan, *op. supra cit.* p. 204.

The absorption of *Pseudasterostoma* and the removal of M. Cotteau's two species to the adete *Spatangidæ* deprive the *Plesiospatangidæ* of the most important links between the two orders (Spatangoidea and Cassiduloidea), but leave it as a more homogeneous group, though bereft of the particular interest that Duncan had assigned to it.

The following synonymic summary of the genera in question may render the above conclusions less liable to be misunderstood.

Asterostoma, L. Agassiz, 1847, Ann. Sci. Nat., Zool. sér. 3, t. vii. p. 168.

T **excentricum,** L. Agassiz, *op. cit.* p. 168.

cubense, Cotteau, = *Archæopneustes.*

Jimenoi, Cotteau, = *Palæopneustes.*

Palæopneustes, A. Agassiz, 1873, Bull. Mus. Comp. Zool. vol. iii. no. 8, p. 188. (First diagnosed by P. M. Duncan. Journ. Linn. Soc., Zool. vol. xxiii., 1890, pp. 223, 224.

T **cristatus,** A. Agassiz, 1873, Bull. Mus. Comp. Zool. vol. iii. no. 8, p. 189. (Fig^d Ill. Cat. Mus. Comp. Zool. no. viii. p. 14, pl. iv. figs. 1–3; also Mem. Mus. Comp. Zool. vol. x. no. 1, pp. 58–60, pl. xxi.)

Jimenoi (Cotteau).

Syn. *Asterostoma Jimenoi*, Cotteau, 1871, Mém. Soc. géol. France, sér. 2, t. ix. pp. 180, 181, pl. xvi. fig. 1, pl. xvii. fig. 1. Also Ann. Soc. géol. Belge, t. ix. 1882, Mém. pp. 25–27.

Pseudasterostoma Jimenoi (Cotteau). P. M. Duncan, 1890. Revision, Journ. Linn. Soc., Zool. vol. xxiii. pp. 203, 204.

conicus, Dames, 1877, Palæontographica, vol. xxv. p. 47, pl. viii. fig. 1, = *Plesiolampas.* (See Duncan, *op. cit.* pp. 194 & 224.)

Murrayi, A. Agassiz, 1879, Proc. Amer. Acad. vol. xiv. p. 210, = *Linopneustes.*

Antillarum (Cotteau), Duncan, *op. cit.* p. 224, = *Peripneustes.*

Archæopneustes, n. gen.

T **hystrix** (A. Agassiz).

Syn. *Palæopneustes hystrix*, A. Agassiz, 1880. Bull. Mus. Comp. Zool. vol. viii. no. 2, p. 82. (Fig^d 'Blake' Echini, Mem. Mus. Comp. Zool. vol. x. no. 1, pp. 58–60, pls. xviii, xix. fig. 2.)

cubensis (Cotteau).

Syn. *Asterostoma cubense*, Cotteau, 1871. Mém. Soc. géol. France, sér. 2, t. ix. pp. 181, 182, pl. xvi. figs. 2–4, pl. xvii. figs. 2–4. Also Ann. Soc. géol. Belge, ix. 1882, Mém. pp. 27–30.

abruptus, n. sp.

III. Geological Evidence.

But, in addition to the biological value of *Archæopneustes abruptus*, it is of interest as throwing further light on the relations of the Radiolarian Series of Barbados. We have seen that its closest allies are two species now living in the West Indies and two extinct species from Cuba. The last had been assigned to the Cretaceous by MM. d'Orbigny and Cotteau, owing to their resemblance to the common Chalk *Echinocorys*. The discovery, however, of some fragments of one of the species (*A. cubensis*) in some beds in the island of St. Bartholomew referred to the Eocene, led M. Cotteau [1] to regard the Cuban deposits as also of this age. Subsequent authorities have still further raised the horizon in the geological scale. Thus Prof. von Zittel [2] places the genus as Miocene, while Sr. M. F. de Castro [3] puts it as Miocene or Pliocene. But the specimens from St. Bartholomew being mere fragments, perhaps no especial value need be attached to them. As *A. abruptus* and *A. cubensis* are both fairly closely allied to *A. hystrix*, one would be inclined, in the absence of other evidence, to follow Sr. de Castro and simply call them Upper Cainozoic. To whatever age the Radiolarian Series be ultimately referred, the Cuban beds will probably also be found to belong to the same period ; the lithological condition of the Echinoids in the two islands seems identical.

Prof. W. Dames has described an Oligocene (Aquitanian) species which he referred to *Palæopneustes* ; but, as the anterior ambulacrum is well developed, it must belong to another genus, as Duncan had already pointed out.

In regard to the depth of the deposit, *A. hystrix* ranges down to a depth of 208 fathoms; it is thus not a deep-sea species, nor, even in the absence of any such data, would one be likely to regard this thickly plated *A. abruptus* as an abyssal form. The specimen was found on Bissex Hill, towards the top of the Oceanic Series ; it is from the same horizon as some Echinoid spines, fish-teeth, simple corals (as yet undetermined), and a few mollusca : the horizon is towards the top of the series, but, as Bissex Hill is an outlier, its exact position is as yet undetermined.[4] The characters both of the Echinoid and its matrix are quite different from those of the deep-sea *Cystechinus crassus*,[5] Greg., from another part of the series. *Archæopneustes abruptus* seems to have lived after the close of the period of maximum depression, and the band of limestone nodules in which

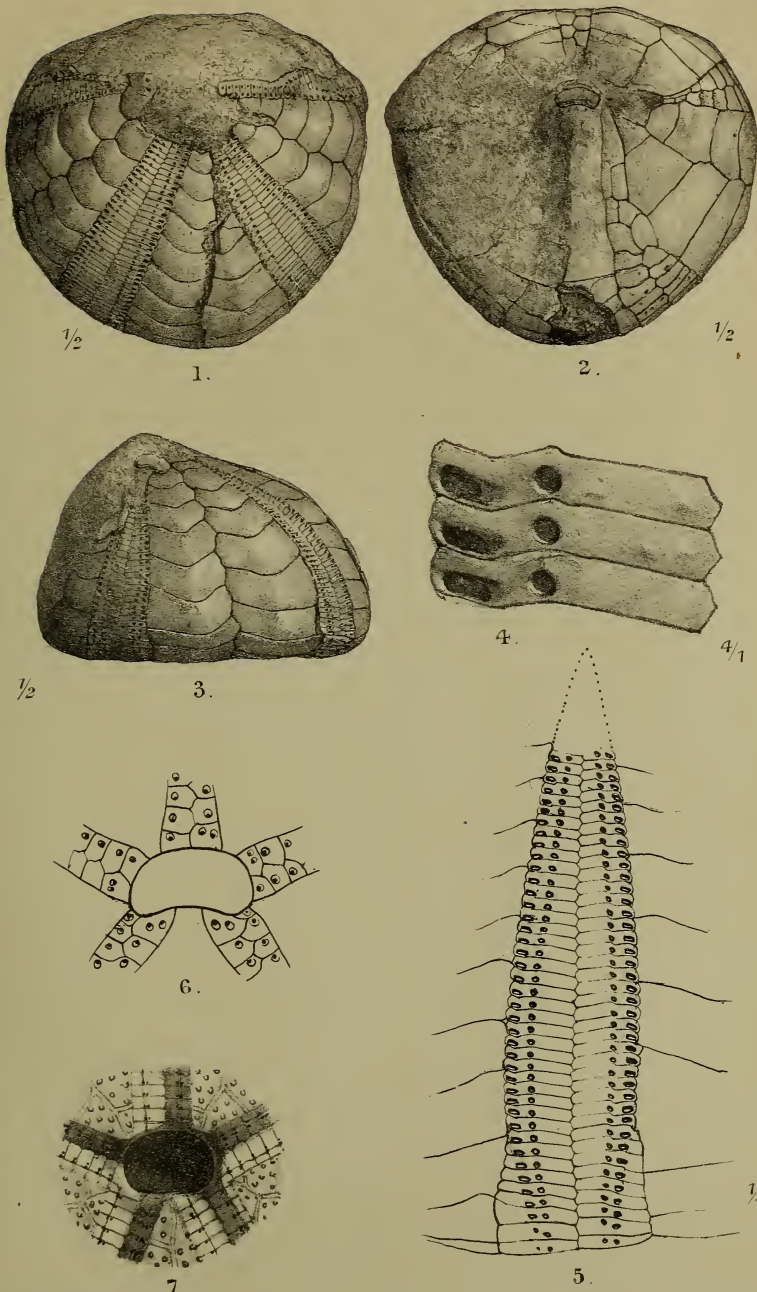
[1] 'Description des Echinides Tertiaires des Iles St. Barthélemy et Anguilla,' Handl. k. Svenska Vetensk. Akad. Bd. xiii. no. 6 (1875), p. 46.

[2] 'Handbuch der Paläontologie,' Bd. i. (München, 1879) p. 536.

[3] 'Pruebas Paleontológicas de que la Isla de Cuba ha estado unida al continente Americano, y breve idea de su constitucion geológica,' Bol. Com. Mapa geol. España, t. viii. (1881) p. 364.

[4] For the geology of the locality, see J. B. Harrison and A. J. Jukes-Browne, 'The Geology of Barbados,' Salisbury (1890), pp. 24, 25.

[5] J. W. Gregory, '*Cystechinus crassus*, a new species from the Radiolarian Marls of Barbados, and the evidence it affords as to the age and origin of those deposits,' Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 640–650.



F. H. Michael del. et lith.

Mintern Bros. imp.

ARCHÆOPNEUSTES AND ASTEROSTOMA.

it occurs may mark the first comparatively shallow-water deposit formed on the rising ocean-floor.[1] This Echinoid, though derived from a bed included in the Oceanic Series, does not itself come from an oceanic Radiolarian marl, and therefore is in no way opposed to the view of the truly abyssal origin of those deposits.

EXPLANATION OF PLATE IV.

Figs. 1, 2, & 3. *Archæopneustes abruptus*, n. sp. $\frac{1}{2}$ nat. size.—Fig. 1. Abactinal view; Fig. 2. Actinal; Fig. 3. Lateral.

Fig. 4. Ambulacral plates from the anterior zone of the left postero-lateral ambulacrum. ×4 diam.

Fig. 5. Left postero-lateral ambulacrum. Nat. size.

Fig. 6. The peristome of *Archæopneustes cubensis* (Cott.), from a sketch by M. Cotteau.

Fig. 7. The peristome of *Asterostoma excentricum*, Ag. (after d'Orbigny).

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[1] [Since this paper was read, Messrs. Jukes-Browne and Harrison have microscopically examined the Bissex Hill limestone, and find it to contain fragments of the lower beds; this is a further proof that this limestone was formed during the rise of the deep-sea deposits into shallower water. They therefore propose to exclude this rock from the Oceanic Series. But as the limestone was formed far below the limit of the growth of reef corals, and as the small fauna from this bed appears to be composed of extinct species, whereas those from the base of the coral reefs are all recent, they are here left in the Oceanic Series.—23rd Feb., 1892.]

16. *The* Geology *of* Barbados. Part II. *The* Oceanic Deposits.

By A. J. Jukes-Browne, Esq., B.A., F.G.S., and Prof. J. B. Harrison, M.A., F.G.S., F.C.S. (Read January 6th, 1892.)

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In a former paper we described the raised coral-reefs of Barbados; we now offer an account of the important series of raised oceanic deposits which form part of the solid framework of the island, beneath its comparatively superficial coating of coral-limestone.

§ 1. General Description of the Deposits.

(a) *Geological Position.*—The Oceanic Deposits form a group or series of beds which is clearly marked off from the Scotland Series below and the Coral Limestones above. They do not, however, appear as a continuous band between the other two formations, because the elevation of the island from oceanic depths was accompanied by a considerable amount of faulting, and tracts of the Oceanic Deposits were dropped down between blocks of the older Scotland Series. Waves and currents then formed a surface of erosion across the faulted mass before the corals began to grow, and consequently the reefs rest, not only on various parts of the Oceanic Series, but in many places directly on the Scotland Beds.

The unconformity between the Oceanic Deposits and the Scotland Series on which they rest is as clear as the lithological contrast between the two formations is great. The older series has been thrown into a succession of folds and flexures which in many places amount to plications and contortions, and all this compression was accomplished before the formation of the Oceanic Deposits, which often rest on the edges of highly-inclined or vertical strata. In respect of colour and lithological composition there could hardly be a greater contrast than that which exists between the two formations. The older series was evidently laid down in shallow water bordering a large land-area; it consists of coarse grits, brownish sandstones (coarse and fine), mottled clays (grey, brown, and yellow), with several hundred feet of dark sandy clays, in places saturated with petroleum. The Oceanic Deposits, on the contrary, consist chiefly of fine white earths, much resembling soft chalk in general appearance, with subordinate beds of pink and yellow clay and occasional layers of grey pumiceous sand or silt.

(b) *General Lithological Characters.*—Considering the small extent of the area over which they are exposed and the moderate thickness which they attain, the Oceanic Deposits are remarkably variable in composition. The series is roughly divisible into five portions or phases, which blend one into another, but are essentially different in lithological character.

The first phase was one of calcareous deposits, and consists mainly of white or cream-coloured earthy limestones, some soft and some hard, which resemble parts of the Lower Chalk of England and France. They break into blocks along joint-planes, which are often coated with black oxide of manganese; they contain from 60 to 80 per cent. of carbonate of lime, are full of *Globigerinæ* and other oceanic foraminifera, and have a fine powdery matrix in which coccoliths and certain curious crystalloid bodies are often abundant.

The central part of the series is essentially siliceous, some beds consisting of 77 per cent. of organic silica with only 0·35 per cent. of calcareous matter. These are the well-known Infusorial or Radiolarian Earths, composed almost entirely of siliceous organisms,—radiolaria, diatoms, and sponge-spicules, the broken débris of these remains forming a matrix in which more perfect specimens are scattered. Associated with these beds are layers of felspathic and pumiceous sand or dust, and some of them are rendered gritty by the intermixture of such material. Other beds are so fine, soft, and slightly consolidated that specimens of them are as light in the hand as lumps of pumice. Their exposed portions are generally white, though below the surface they are often yellowish, drab, pink, or streaked with these colours.

Above these siliceous earths is a second band or zone of calcareous material, the quantity of carbonate of lime varying from 44 to 80 per cent. These beds are generally white and always contain foraminifera in greater or less abundance, but usually mixed with some siliceous organisms. Manganese is often present on the surfaces of the joint-planes.

Above the beds last mentioned there is a rapid change into a mass of very fine argillaceous earth, red, pink, yellow, white, or mottled. This earth seems to be analogous to the so-called 'red clay' of modern oceanic depths, but is remarkable in never containing more than a trace of carbonate of lime. A few fragments of radiolaria and sponge-spicules occur in this earth, and it would appear to have been formed at a depth where no calcareous matter could be accumulated; it often exhibits hollow spaces (up to ½ inch in diameter) which appear to be the casts of small manganese nodules, the manganese having been dissolved away and the space being either left empty or filled with loose powdery earth.

There is only one spot in the island where we can be certain of the occurrence of still higher beds than these red and mottled earths; this locality is Mount Hillaby, where they are overlain by about 25 feet of grey mudstones or felspathic earths, which are mainly composed of fine volcanic dust.

§ 2. The Minute Structure of the Rocks.

Samples of the principal varieties of the Oceanic Deposits of Barbados were sent to Dr. John Murray, F.R.S.E., and to Mr. W. Hill, F.G.S., while samples of those which appeared to contain much inorganic mineral matter were sent to Prof. Bonney, F.R.S.; but, his time being fully occupied, they were handed to Miss C. A. Raisin, B.Sc., who kindly undertook to examine them.

Dr. Murray wrote to us in September 1889 that he had examined the specimens we sent him, and that he believes "they are all deposits formed in deep water. The red earths are very like some of our red clays, and the deposits with radiolaria resemble our radiolarian oozes. In the same way the calcareous deposits resemble our *Globigerina*-oozes;" and in a later letter he says "I think the specimens could be identified as oceanic clays without knowing their association with marls, but it would be difficult to fix a depth."

This is brief but explicit testimony to the close correspondence between the Barbadian deposits and the modern oceanic oozes.[1]

To Mr. Hill and Miss Raisin we are indebted for full reports on the specimens submitted to them. The information contained in these reports is now presented in a combined and condensed form for the convenience of the reader, but the portions furnished by each writer are carefully indicated.

Mr. Hill found that his specimens could be grouped under the following heads: (1) Unmodified earths and marls; (2) Silicified earths; (3) Calcified earths or calcitic limestones. The rest fall under the heads of (4) Pumiceous deposits; (5) Grey mudstones; (6) Fine clays or argillaceous earths.

(1) **Unmodified Earths and Marls.**—Mr. Hill reports as follows:—

These earthy rocks may be divided into calcareous, calcareo-siliceous, siliceo-calcareous, and siliceous, according as the calcareous or the siliceous constituents predominate. There are marked differences between the purely calcareous and the purely siliceous rocks. Most of the former are like our chalks, dull white or greyish pulverulent limestones, readily soiling fingers and clothes with white dust. The siliceous rocks are lighter in weight, and often emit a tinkling sound like coal-cinders when handled, while the finer particles do not readily detach themselves.

The following is a list of the specimens examined. The locality and position of each are given, with a brief account of the leading characteristics of each group as seen in thin sections under the microscope with a $\frac{2}{3}$-inch objective.

[1] A remark to the same effect appears on p. xxix of the Report on the Deep-sea Deposits of the 'Challenger' Expedition, 1891.

(a) *Chalky Earths and Calcareous Marls.*

Near Codrington, basement bed.
Canefield estate, basal chalk.
Cleland Hill, uppermost chalky beds, two samples 5 and 10 feet below the coral-rock.
Olton's Cave, 44 feet below the gully-floor (sent by Mr. E. Easton, C.E.).
Granular marl, from the knoll at the top of Bissex Hill.

All these appear to be nearly pure foraminiferal deposits, though in the first four the area occupied by more or less perfect tests is small compared with that occupied by fine calcareous material. This fine material will be fully described in the sequel; it forms the matrix in which the larger constituents are embedded. In these chalky earths the predominating foraminifer, and the only form visible in thin sections, is a *Globigerina*, but after washing some of the material several other genera and species were found to occur. Radiolaria are rare, but a few sponge-spicules can be seen. All the specimens contain a few mineral grains.

The last on the list presents different characters. It has a granular aspect, is rather light in weight, greyish buff in colour, and having little cohesion the mass breaks down on slight pressure. Examined in thin section it is seen to consist almost entirely of *Globigerinæ*, their tests being closely crowded together, and very few other forms being visible. The matrix which fills the interstices is largely composed of separate calcite-crystals of irregular shape. A few coccoliths are present, and a small quantity of inorganic material, apparently broken felspar-crystals and volcanic glass.

(b) *Calcareo-siliceous Marls.*

Pico Teneriffe, on the north-west coast.
Melvin's Hill (base).
Airy Cot, base of Mount Hillaby.
Mount Hillaby, summit of southern peak, and 10 feet below.
Cleland Hill. No. 2. Hard chalk above basal limestone.
Cluff's estate, on the north coast.

The rocks occurring in these six localities are largely calcareous, but a number of radiolarians are visible in all of them. The Pico Teneriffe specimen is the most calcareous, but appears weathered, and foraminiferal tests are more faintly outlined than usual. In all the specimens the greater part of the calcareous matter is very fine. In Cleland Hill and Cluff's few foraminiferal tests can be seen in section, while it is evident that many forms which show strongly are radiolarians, though their siliceous skeleton is often obliterated and their outline only is preserved.

All contain, especially those from Mount Hillaby, Cluff's, and Melvin's Hill, minute, angular mineral-fragments, the largest of which measure about ·02 mm. in their longest axis.

(c) *Siliceo-calcareous Earths.*

Castle Grant, lowest beds, No. 1.
do. do. No. 2.
do. upper beds.
Joe's River, low level.
Conset Bay gully, near the base, hard chalky bed.
Conset Bay gully, higher beds.
Chimborazo, 3 feet under red clay.
do. middle bed in road-cutting.
Mount Misery.
Mount Hillaby, 20 feet from the top of the southern peak.

In these specimens entire siliceous organisms or their comminuted remains preponderate, so far as one can judge by the eye. There is, however, a considerable variation in the amount of perfect skeletons which can be recognized. This is due in some degree to a difference in the character of the deposit. Thus in the Castle Grant (lowest), Mount Misery, and Joe's River samples few entire radiolarian skeletons can be noticed, but examination of the finer material shows it to be chiefly radiolarian débris, with a small amount of calcareous matter and fine inorganic particles. In the rest, some of which are rather more calcareous, entire radiolarians are abundant and foraminiferal tests few and far between, sponge-spicules occur commonly, and in all there are angular mineral-grains.

(d) *Siliceous Earths.*

Loamfield inlier.
Burnt Hill, Conset Bay.
Springfield.
Chimborazo (brown band).
do. (No. 1).

These are the earths from which the well-known radiolaria of Barbados are extracted. They consist entirely of radiolarians and sponge-spicules with a few diatoms; there are no recognizable calcareous organisms, but a few small calcareous particles can sometimes be detected. The matrix is a felted mass of interlacing fragments of radiolaria and sponge-spicules, and is therefore very different from that of the more calcareous earths.[1]

The rocks which are included in group 1 (*a*, *b*, *c*, and *d*) do not seem to have undergone much change since their deposition, beyond a certain degree of consolidation. This is especially the case with the more purely calcareous (chalky) and the purely siliceous earths. The changes which have taken place are most evident in those which contain both calcareous and siliceous organisms.

When thin sections of these mixed deposits are compared, it is seen that the radiolarian form becomes most easily lost. Radiolarians are not readily seen in chalky sediments, even if perfect, and when the skeleton becomes filled with calcareous material all

[1] [This felted structure is described as conspicuous in deeper layers of the radiolarian ooze brought up from 4475 fathoms in the North Pacific; see 'Report on the Deep-sea Deposits,' Chall. Exp. p. 175. In the interstices of this felted matrix may be seen aggregations of minute granular particles which resemble those shown in plate xxvii., fig. 5, of the same Report.— A. J. J.-B., Feb. 3rd, 1892.]

except a vague outline is obliterated. It is certain also that in these mixed deposits the radiolarian skeleton either enters into solution or into a chemical combination with the surrounding lime, and that the silica, in a form not visibly acted on by hydrochloric acid, is redeposited in the interior both of radiolarians and foraminifera. Thus in the calcareo-siliceous earths it frequently (not always) happens that while the radiolarian is unmistakably outlined in the thin section, the siliceous skeleton has disappeared, its place and the interior of the original test being filled with a clear crystalline material.

Foraminifera, on the other hand, are nearly always well preserved; their tests lose the hyaline appearance of living or recently dead individuals, and become impregnated with crystalline carbonate of lime, but retain the details of their minute structure. It is worth noting that both their outline and structure are clearer in mixed than in purely calcareous deposits.

(2) **Silicified Earths.** *A siliceous limestone from the base of Cleland Hill.*—In hand-specimens this rock looks like a dense hard white limestone. Examined under the microscope by means of thin sections it is seen to be one of the siliceo-calcareous deposits, in which many entire radiolarians can be recognized, and in which foraminifera, chiefly *Globigerinæ*, are not uncommon.

There is also much fine calcareous matter, and to the eye the character of the rock does not seem to differ materially from the softer siliceo-calcareous deposits.

By treating a very thin slice of the rock in a solution of hydrochloric acid, though there was a strong reaction, the slice did not break down. A thin section of the remainder showed that the acid had removed a large part of the calcareous matter, and that the rock was permeated with a glassy material not acted on by the acid, and neutral to polarized light. The tests of the foraminifera are partially replaced by this material, which has also penetrated the foramina and the interior spaces of the cells.

Another part of the slice, previously treated with acid, easily disintegrated in a heated solution of caustic potash.

From its optical and chemical properties it would appear that the cementing material of the rock is of the nature of colloid silica.

Siliceous Concretions.—In the siliceous and calcareo-siliceous rocks there occur nodules, some of which in their general appearance strikingly remind one of the nodules of immature chert found in the Chalk Marl of Wiltshire and in the Malmstone of Hampshire.

The nodules which bear the strongest resemblance to flint in their appearance and fracture are from the Radiolarian Marl of Springfield, a purely siliceous deposit.

These, when examined in section under the microscope, are seen to have been formed by the cementation of radiolarians and other siliceous organisms by glassy silica, the whole being neutral to polarized light. There is no reaction when a thin slice is treated with hydrochloric acid, but the mass disintegrates in a heated solution of caustic potash.

Bluish cherty nodules from the calcareo-siliceous deposit of Castle

Grant give, on the other hand, a decided reaction with acid, and thin sections under the microscope show that foraminifera and calcareous particles constitute a considerable part of their mass.

By treating a thin slice with acid the result was very similar to that obtained in the case of the Cleland Hill rock; the slice did not break down, but much of the calcareous element was removed, and a thin section of the remainder shows a groundmass of minute particles of rather irregular shape. These appear to be fragments of the organic constituents of the rock soldered together by a cement of glassy material which, as before, has penetrated the tubules and the interspaces of the foraminiferal cells. Another part of the slice easily disintegrated in a heated solution of caustic potash.

Thus it would seem that the cementing material of the nodules is of the nature of colloid silica, and that they are essentially siliceous concretions, but there is no globular colloid silica like that which so often accompanies the segregation of silica in the English Cretaceous rocks.

(3) **Calcified Earths.**—A sample of a dull yellowish and rather hard rock ten feet above the base of the series at Bissex Hill was sent to Miss Raisin, who reports as follows:—

This rock is composed partly of siliceous organisms, partly of crystalline calcite, with a very few depolarizing chips of minerals, within an indefinite, amorphous groundmass. The calcite has no connexion that I could observe with organisms, except a chance adhesion to a radiolarian test; and it is almost entirely in the form of rhombohedral crystals.[1] These often enclose darker central rhombohedra which have apparently been formed by a cessation of the crystalline growth and the deposit of a dusty layer or a film of sulphide of iron over the surface before the formation of the calcite recommenced. Occasionally a larger crystal has a small projecting rhomb appearing like an accretion. The forms of the calcite and the indication of its intermittent growth suggest quiet, undisturbed formation *in situ* from independent centres, but it is difficult to say whether they were formed during the deposition or during the subsequent consolidation of the rock. The mineral chips are very few and are all angular (averaging ·02 mm. in diameter); they include a few broken fragments of brownish volcanic glass, some felspar, and probably mica. They give but little clue to the mode of origin of the rock, but on the whole it is most probable that they were transported through the air to a sea on the floor of which radiolarian tests were accumulating.

(1) Bissex Hill, basal bed at the north end of the outlier.
(2) do. do. grey limestone in the road about 60 feet from the top of the hill (S.W. side).
(3) do. do. by the roadside on the N.E. side of the hill.

These were examined by Mr. Hill. They are all hard, bluish-

[1] Compare the structure of the 'Coral (?) Mud, Codrington College,' described by Mr. Hill in his Appendix to our first paper, p. 247, vol. xlvii. of this Journal. Possibly the calcite grains in this mud were derived from the erosion of calcified Oceanic Deposits, and not from the detrition of coral-reefs.

grey crystalline limestones, varying in depth of tint. In thin sections that which may be called the matrix is seen to be granular crystalline calcite; the texture, however, varies, some parts being coarser than others, and in all there are ramifying veins and patches of clear crystalline calcite. These veins not unfrequently contain clearly defined foraminifera and radiolaria, as well as small accumulations of minute, angular mineral chips such as are met with sparingly throughout the rock.

These rocks appear to be earths which have been rendered crystalline by the infiltration of calcite. The two former were originally calcareo-siliceous earths, for both foraminifera and radiolaria are still discernible in the less altered parts. The last must have been almost entirely siliceous, for no foraminifera were noted, and about one third of the slice examined consists of inorganic material. The slide was therefore sent to Miss Raisin, who found the mineral fragments were chiefly pumice and felspar, with a few pieces of brown glass, and one or two grains which might possibly be quartz. There is one piece of vesicular pumice, infiltrated with calcite, which is of unusual size (about 1 mm. in length); also a large clear felspar which has a twinned structure, and contains negative crystals elongated along the planes of the felspar.

The minuter elements of the Barbados Rocks.—Mr. Hill contributes the following remarks:—When the finest material of the Barbados earths is examined under the microscope with high powers, say $\frac{1}{10}$-inch objective, much of it can be recognized as foraminiferal or radiolarian débris, but much also consists of particles derived apparently from neither of these sources, and a proportion is in so fine a state of subdivision that it affords no clue to its derivation.

(a) *Calcareous Earths.*—By breaking up a small fragment of the most calcareous earths, *e. g.* the Canefield Chalk, in water, that which sinks readily to the bottom is chiefly foraminiferal débris, but 50 per cent. of that which remains suspended, after half a minute has elapsed, will be found to consist of bodies which answer to the descriptions given by Prof. Huxley,[1] Dr. Sorby,[2] and others of the coccoliths and crystalloids of the English Chalk and Atlantic oozes, and a large part of the remainder may be referred to fragments of such bodies. There are two types—oval and stellate, with some variety in size and ornamentation.

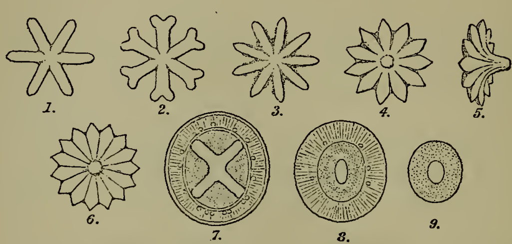
The oval forms (see next page, figs. 7, 8, and 9) are larger, but agree generally with the description given of the coccoliths of the English Chalk and Atlantic ooze. They are usually convex in shape, and many have the duplicate structure described by Prof. Huxley as somewhat like a shirt-stud. They consist of a central disc, which is sometimes granular in appearance and sometimes in the larger forms ornamented by an irregularly shaped cross (fig. 7), but more

[1] Huxley, 'Deep-sea Soundings in the N. Atlantic Ocean made in H.M.S. Cyclops,' Appendix to Admiralty Report, 1858.

[2] Sorby, 'On the Organic Origin of the so-called Crystalloids of the Chalk,' Ann. & Mag. Nat. Hist. vol. viii. (1861) p. 193.

usually by an elongate nuclear spot (fig. 8). Around the disc is a broad marginal rim, in width nearly one third that of the organism, made up of concentric rings. This rim is ornamented in the larger coccoliths by radiating striæ, or ribs, and occasionally around the centre of the rim are minute bead-like elevations (see fig. 7). The smallest (fig. 9) have a more circular outline, and have only a central spot and a rim without ornamentation. The largest oval form measured was ·023 mm. in its longest diameter.

The stellate bodies (figs. 1–6) consist of rays which emanate from a common centre, in number from five (rarely three) to sixteen, and between these extremes every variation occurs, the most common forms being those of eight to twelve rays. In those which



Explanation.

Figs. 1–6. Crystalloids } from the chalky Oceanic Deposits of Barbados.
Figs. 7, 8, 9. Coccoliths }

Fig. 5 illustrates the appearance of (4) and (6) when viewed edgeways.

have the smallest number the rays are shaped like elongated parallelograms (fig. 1) arranged on a common base; they occasionally bifurcate at their summits (fig. 2). This latter peculiarity is rare in the calcareous earths, but occurs commonly in the foraminiferal muds to be hereafter noticed.

With the increase in number the ray becomes more acutely pointed and the interval between each is filled up: the result is a rosette-like disc, with serrated outline and radiate ornamentation corresponding to the number of the rays (figs. 4 and 6). The centre has then on one side a nuclear spot, not seen in those with few rays, and on the other the centre is produced to a kind of stalk, in length about half the diameter of the disc (see fig. 5), the whole when seen edgeways reminding one of a short or broken tintack; the ornamentation of the disc appears to be carried towards the summit of the stalk as ribs or flutings. The largest of these measured ·015 mm. in diameter. These stellate bodies are exceedingly abundant in the calcareous Oceanic Deposits of Barbados, and play almost as important a part in the formation of those deposits as the often-described coccolith.

Although one variety with six rays (fig. 2) certainly occurs in the Atlantic ooze and one very similar in the muds from West Java, they do not appear to have attracted special attention. Dr. Sorby, in his paper on the 'So-called Crystalloids of the Chalk,'[1] describes a form somewhat analogous to those of the Barbados deposits, and Ehrenberg figures as 'Krystaldrusen' from the Chalk of Upper Egypt and Lebanon forms which closely resemble, if they are not identical with, the rosette-shaped discs described above.[2]

These stellate bodies do not appear to retain their individuality so long as the ordinary coccolith, but are apt to become obscured by the deposition of calcite. In those which have but few rays this seems to commence between each ray, giving the edges at first a ragged appearance, and finally, as in the case of the Plumtree Gully specimen (p. 217), obliterating the crystalloid altogether.

Coccoliths also show an augmentation of their mass by the deposition upon them of calcite, but it seems to form along the striæ or ribs which ornament the rim. Then, while coccoliths give a black cross when viewed with polarized light, the stellate bodies vary under its action, in some cases remaining neutral while in others there is a decided reaction, a difference which seems to occur in all forms.

Both are destroyed by treatment with a weak solution of acid.

(b) *Siliceous Rocks.*—Turning now to the siliceous deposits, the finest portion of these may be recognized as the comminuted remains of radiolarians, diatoms, and sponge-spicules. As these remains embrace a vast variety of forms it is impossible to individualize the fragments, though many bear structural evidence of their derivation. It is interesting to note that coccoliths and stellate crystalloids are entirely absent in purely radiolarian deposits.

In those rocks which are partly calcareous and partly siliceous the finest material is a mixture of calcareous forms and particles with the débris of siliceous organisms.

Comparison with the English Chalk.—We specially desired to have Mr. Hill's opinion on this point. He finds that the calcareous and calcareo-siliceous earths of Barbados may be compared with the Grey, Middle, and Upper Chalk of England, which they resemble in having a matrix of very fine calcareous material (many of the minuter particles being of a definite and similar shape), in which are distributed numerous foraminiferal tests and cells. The two deposits are the result of an accumulation of similar organic material and exhibit the same lithological peculiarities, so that the name Chalk is equally applicable to both, but no Barbados Chalk can be said to agree specimen for specimen with that from any particular horizon in England.

Examined and compared by means of thin sections, Barbados Chalk differs from English Chalk as follows:—1, in the entire absence of the shelly fragments of molluscs and echinoderms; 2, in the presence of recognizable radiolarian remains; 3, in the greater thickness of the cell-walls of the foraminiferal tests and in the clearer details of their minute structure; 4, in the greater size and abundance of the coccoliths and crystalloids; 5, in the

[1] Ann. & Mag. Nat. Hist. vol. viii. (1861) p. 197, figs. 3 & 4.
[2] Ehrenberg, 'Mikro-geol.' pl. xxiv. figs. 66, 67 a, pl. xxv. figs. 12–15 B.

presence of angular mineral chips or grains, and of more minute inorganic particles which differ from those usually met with in our Chalk; 6, in the larger proportion of the minuter particles which can be resolved by high powers and are directly suggestive of derivation from foraminifera, siliceous organisms, coccoliths or crystalloids. These particles present a different appearance from that of the minute crystals of calcite which occur in the English Chalk.

As in the English Chalk, the perfect or nearly perfect tests of foraminifera occupy a small area when seen in sections.

Comparison with the White Limestone of Jamaica.—As mentioned in a former report by Mr. Hill, certain parts of the White Limestone of Jamaica appear to be of oceanic origin.

A specimen obtained from Hanover County was kindly sent me by Col. Feilden, and another, already mounted as a microscope slide by Messrs. Watson, has been obtained for comparison.

Both agree very closely with the calcareo-siliceous section of the Barbados Oceanic Deposits. The specimen sent by Col. Feilden is harder and more crystalline than many of the oceanic 'earths,' but will compare in this respect with the siliceous limestone at the base of Cleland Hill. Thick-shelled *Globigerinæ*, similar to those of the Barbados rocks, are conspicuously abundant, and one or two radiolarians can be seen in outline.

(4) **Pumiceous Earths.**—Miss Raisin reports that these contain very few organisms and consist mainly of volcanic materials, the particles of which vary from ·05 to over 1 mm. indiameter.

(1) Castle Grant, middle gritty beds.
(2) Melvin's Hill, a light grey, slightly coherent sand.

In the first specimen the mineral chips are mostly felspar, often in broken crystals and exhibiting multiple twinning, but there are numerous flakes of clear pumiceous glass, and two or three large pieces of mica. The groundmass consists of fine argillaceous material.

The second consists mainly of flakes and splinters of clear colourless pumice, many of these exhibiting the usual vesicular structure with rounded or 'pipy' cavities. There are a few chips which appear to be felspar, occasionally twinned and often broken crystals. Some radiolarian tests also occur.

(5) **Grey Mudstones.**—These were examined by Miss Raisin.

(1) Mount Hillaby, 10 feet from top of northern peak.
(2) do. 5 feet do. do. do.

In the above specimens a gelatinous or argillaceous substance forms the groundmass, in which are scattered small, angular mineral-fragments and a few radiolaria, but there is no calcareous matter. Many of the minerals are broken crystals, and they suggest the characters of fine volcanic dust.

In the first some particles are probably felspar, some may be mica, and there is one rather large grain, somewhat rounded, which is probably quartz (diam. 1 mm.).

In the second the particles are chiefly angular, but include a few pieces of pumice and some brownish spheres, which may have resulted from the alteration of glauconitic casts of foraminifera.

(6) **Fine Clays.**—These are the argillaceous earths mentioned on p. 171 as similar to modern oceanic 'red clays.'

(1) Hillaby estate, a pale yellow earth.
(2) Castle Grant, a pink earth.
(3) Canefield, a red earth.

Miss Raisin reports that these consist mainly of a fine amorphous argillaceous substance, in which are some very minute mineral fragments (·005 to ·030 mm. in diameter); organisms are scarce, but occasionally a spicule, a broken radiolarian test, or a foraminiferal cast (·025 mm. or less) is seen.

The mineral fragments can seldom be identified, but the general form of many is suggestive of felspar. They are mostly angular and often mere crystal-shaped specks. In the Canefield and Hillaby earths are some small particles of an opaque metallic oxide (probably black oxide of iron) with an aggregate and somewhat crystal-like form, as if developed *in situ.*

General Remarks on the Inorganic Constituents of Groups 4, 5, *and* 6.—With reference to the pumiceous earths (4) and the grey mudstones (5), Miss Raisin observes that the general appearance of the mineral fragments in these rocks agrees very well with the idea of a volcanic origin. They are seldom rounded, but generally quite angular, and consist of broken chips of fresh-looking minerals. Except that they are smaller, they are not unlike the particles in the fine felspathic dust erupted from Cotopaxi,[1] and those of the volcanic dust which fell on Barbados in May 1812.[2] The latter, however, includes a fair amount of pale greenish pyroxene. Pumice, too, is much more abundant in some of the Barbados rocks.

It would appear that the falls of felspathic and pumiceous dust sank through the water and mingled with the oozes which were accumulating on the ocean-floor.

The fine-grained coloured clays or argillaceous earths were compared with two samples of 'red clay' from the Atlantic, but unfortunately neither of these were pure 'red clays,' both samples containing much calcareous matter.

One of them (from lat. 24° 20′ N., long 24° 28′ W., 2740 fathoms, supplied by Dr. J. Murray) is very calcareous;[3] fragments of shell, foraminifera, and apparently coccoliths occur, with one or two rhombohedral particles bearing some resemblance to the rhombohedral calcite of Bissex Hill. This deposit has many angular crystalline fragments often too minute to be identified with certainty, but doubtless in many cases felspar; it has also indefinite

[1] Slides of this dust were kindly lent by Prof. Bonney.
[2] A sample of this fall of dust was supplied by Prof. Harrison.
[3] [It appears from the account given of this sample in Dr. Murray's Report on the Deep-sea Deposits that it was one from which all the finest silty part of the material had been previously washed away, leaving a residue which was far richer in carbonate of lime than the original deposit. It was not therefore suitable for our purpose.—A. J. J.-B., March 21st, 1892.]

agglutinations partly argillaceous, with some opaque granules of iron or manganese oxide. Some chips of hornblende or augite can be identified, and occasionally a fragment which may be a greenish glass or possibly a flake of biotite.

The other slide (kindly lent by Prof. Bonney) was from a depth of 2700 fathoms near St. Helena. This material is equally fine, with the same aggregations and the same very minute, angular mineral chips, but coccoliths are certainly present and in large numbers.

It is evident that there is much similarity between these Atlantic 'red clays' and the argillaceous earths of Barbados, the special points of resemblance being the minuteness of the constituents, the angularity of the mineral particles, the presence of many fragments of felspar or of a felspar-like mineral, and the rarity of particles which can be recognized as quartz.

When a marine clay formed in water of less depth, such as the Gault, is compared with these a certain amount of similarity is seen. There are many angular fragments, some very minute, in an argillaceous base; but most of the grains are more rounded and at least subangular, quartz is more abundant, and many of the felspar-fragments are larger and show indications of decomposition.[1]

§ 3. The Chemical Composition of the Rocks.

The samples taken for analysis were in all cases drawn from large quantities of the rocks selected in the field to represent as closely as possible their average composition, so that the analyses indicate the general composition of the local deposits, and not that of small samples which may or may not be truly representative of the beds under examination. We regard this as a matter of great importance, and consequently have spared no pains to effect our object.

In the material of the Oceanic Deposits the main interest lies in the existing proportions of calcium carbonate, of colloid silica, of clay (silicates of alumina and iron not decomposable by cold dilute hydrochloric acid), and of quartz. The following is the method adopted with the view of determining as accurately as possible the colloid silica present as such in the rocks, and of avoiding that decomposition of some of the silicates present which necessarily ensues when clays or marls are treated with hot concentrated mineral acids, a result which leads to an over-estimate of the amount of colloid silica and to an under-estimate of the clay.

The samples were all analysed in the air-dried state, but the results have been calculated so as to show the composition of the rocks free from hygroscopic water. They were reduced to very fine powders in an agate mortar, and two quantities of from four to five grammes each were separately treated with dilute ($2\frac{1}{2}$ %) hydrochloric acid in the cold (30° C.). After the acid in the first

[1] These remarks are confirmed by the descriptions of the mineral particles of 'red clay' and 'blue mud' in Dr. John Murray's 'Report on the Deep-sea Deposits' (see pp. 196 and 231), 1891.

portion (A) ceased to attack the sample it was removed by elutriation and filtration, the insoluble residue heated in a water-bath for several hours with a strong solution of sodium carbonate to which some caustic soda had been added, and washed, with the assistance of a Bunsen's pump, (1) with the same solution, (2) with water, and (3) with dilute hydrochloric acid. The residues obtained were dried, ignited, and weighed, and consisted of the clay and of other siliceous minerals. After weighing, this residue was reduced to an impalpable powder in an agate mortar, and a weighed portion boiled repeatedly with strong sulphuric acid until the clay was completely decomposed. The excess of acid was then driven off and the residue heated with dilute hydrochloric acid to dissolve the basic sulphates of alumina and iron formed, and after removal of the dissolved portions it was heated with a solution of sodium carbonate to dissolve the silica set free. The final residue, after being washed and ignited, consisted only of crystalline siliceous minerals, and in the majority of cases only of quartz.

The solution obtained from the second portion (B) was evaporated to dryness and, as well as the undissolved matters, kept at a temperature of from 120° to 130° C. for an hour or longer to render all the silica insoluble in water. The residue and undissolved matter were treated with warm hydrochloric acid, taken up with water, filtered and washed. The residue from that was dried, ignited, and weighed, and consisted of the colloid silica originally present, of a small quantity of colloid silica arising from the decomposition of certain hydrous silicates present in the rocks in small quantity, and of the clay and other siliceous minerals. The difference between the proportions of this and of the clay and siliceous minerals as determined in sample (A) gave the amount of colloid silica present. The alumina, iron peroxide, &c., were determined in the hydrochloric acid solution from (B) by the usual methods, and the carbonic anhydrides in another portion of the sample. At first, acetic acid was used as the solvent; but doubts arising as to its partially attacking certain zeolitic minerals present, it was decided to use hydrochloric acid and to estimate the small quantity of silica set free from these minerals as colloid silica. As this was probably derived originally from siliceous organisms the method may be considered fairly accurate. Where the colloid silica was principally present in an amorphous form, as in the foraminiferal chalks, it entered into solution with far greater ease and rapidity than when it was in the form of remains of siliceous organisms, when it not unfrequently offered considerable resistance to solution. Is this difference in the solubility of the silica due to differences in its state of hydration or to purely molecular causes?

The samples of argillaceous earths and of volcanic sands and mudstones were examined by the methods of analysis usually employed for clays and for siliceous minerals, the soluble silica present being determined as described. In these samples the alkalies were separately determined, whilst in the other samples, as they were determined by difference, the errors of analysis fall upon them. In the samples of pumiceous material it was of some importance to determine the amounts of quartz present, and as the relatively large quantities of pumiceous and crystalline silicates present could not be completely decomposed by boiling sulphuric acid, this was done by fusing the finely powdered sample with a considerable excess of microcosmic salt, which decomposed the silicates without appreciably attacking the quartz. The fused mass was dissolved in water, and the residue boiled with sodium carbonate solution and with hydrochloric acid, when the portion not dissolved consisted only of the quartz present. This method is easily and rapidly executed, and was found to be an excellent one for the treatment of igneous rocks in which quartz may be present in too small proportion for certain identification by microscopic examination only.

In all cases the final residues of crystalline silica left were examined microscopically, and, if found impure, the treatment with sulphuric acid and alkaline carbonate or with microcosmic salt was repeated.

For purposes of analysis the rocks of the Oceanic Deposits may be conveniently classed as follows:—the lower and upper foraminiferal beds (chalks), the calcareo-siliceous rocks, the pure radiolarian marls, the argillaceous earths, and the layers of volcanic material. These divisions are purely arbitrary, as the various beds pass by imperceptible gradations from one to another. Using Haeckel's classification,[1] we have foraminiferal rocks passing through mixed radiolarian to pure radiolarian rocks, and these again passing through radiolarian clays to red clay. Similar gradual changes in chemical composition, &c., apparently characterized the samples of deep-sea deposits obtained in the 'Challenger' Expedition.

In the tables given the samples are arranged in order of geographical position, proceeding from the south northwards.

(a) *The Lower and Upper Foraminiferal Beds—Chalks and Limestones.*—These beds show a wide range of composition, and are characterized by the colloid silica in them being diffused through the mass, the remains of siliceous organisms seldom occurring. From the analyses it will be noticed that the colloid silica varies in amount from about 1 to 25 per cent.; the clay from 3 to 13 per cent.; and the calcium carbonate from 45 to 88 per cent., being, as might be expected, highest in the crystalline limestones, where it generally occurs as a cementing material of crystalline calcite; but in the case of the Cleland Hill rock the cement is siliceous. Manganese peroxide is present in many of the samples, as black streaks and coatings and as minute spherules. Most of them contain small amounts of zeolitic minerals and only minute amounts of quartz.

[1] 'Challenger' Reports, vol. xviii. part i. Radiolaria, p. clxix.

	Limestones.			Chalks.							
				Lower Beds.					Upper Beds.		
	Bissex Hill, blue limestone at base.	Cleland, white limestone at base.	Bissex Hill, grey limestone 60 feet from summit.	Codrington, reddish chalk.	Melvin's Hill (grey).	Canefield (white).	Mt. Hillaby (grey).	Cleland (grey).	Codrington (yellow).	Cleland (white).
Loss on ignition	1·81	3·02	2·08	2·63	3·09	2·59	2·87	2·41	5·28	1·84
Quartz	·08	·06	·44	·08	·20	·05	·69	·08	·21	·01
Colloid silica	3·67	25·50	5·57	1·34	18·49	5·02	14·56	13·28	25·31	7·36
Clay	2·94	9·22	3·37	9·14	11·30	3·99	13·47	13·49	13·09	5·69
Iron sulphide (FeS)	·35	......	·36							
Iron peroxide and alumina	·40	1·89	1·03	5·78	2·94	1·10	2·47	2·14	4·65	2·99
Manganese peroxide	......	·80	......	·29	·30	1·43	trace	·39	2·22	·91
Calcium phosphate	......	·27	trace	·11	·52	·35	·48	·38	·73	·38
Calcium sulphate	......	·17	......	trace	......	·68	trace	·37	trace	trace
Calcium carbonate	88·28	57·18	86·14	80·36	60·08	83·23	62·45	65·88	44·73	79·84
Lime	......	1·41	......	·06	1·33	......	1·43	·91	2·56	·48
Magnesium carbonate	2·19	......	·34							
Magnesia	......	·22	·16	·41	1·42	1·19	1·33	·55	·78	·49
Alkalies and loss in analysis	·28	·26	·51		·33	·37	·25	·12	·44	·01
	100·00	100·00	100·00	100·20	100·00	100·00	100·00	100·00	100·00	100·00

The analyses of oceanic foraminiferal oozes to which we have access are those on pages 369–381 of the second volume of 'The Voyage of the 'Challenger.'' These, rearranged from the figures there given so as to be more easily comparable with ours, are as follows :—

Number of sample / Depth in fathoms	1 / 1890	2 / 1945	11 / 1950	12 / 2325	19 / 1420
Loss on ignition	7·91	5·02	4·58	4·17	3·80
Clay, quartz, &c.	19·02	12·08	4·60	8·33	3·45
Colloid silica	12·10	9·08	4·60	9·16	4·14
Iron peroxide and alumina	9·21	7·41	3·33	6·25	4·42
Calcium phosphate	trace	trace	1·12	trace	2·41
Calcium sulphate	·44	·69	1·20	1·91	·41
Calcium carbonate	50·00	64·55	79·17	67·60	80·69
Magnesium carbonate	1·32	1·17	1·40	2·58	·68
	100·00	100·00	100·00	100·00	100·00

The variations in composition in these *Globigerina*-oozes are similar to those in the Barbados foraminiferal beds, and whilst there is a general resemblance in composition between them there are certain well-marked differences. These are in the 'Challenger' samples the uniformly larger "loss on ignition," the presence of much larger quantities of calcium sulphate and of iron peroxide and alumina, and the absence of manganese peroxide and of lime and magnesia in the form of hydrous silicates. As only small quantities of the oozes were available for analysis, it is possible that the latter points may not represent real but merely apparent differences in composition, resulting from the methods of analysis used. The differences in " loss on ignition " and in calcium sulphate are what we should expect to be the result of the natural changes incidental to the exposure of the Barbados rocks to the action of water and air, by the removal of the more easily soluble constituents and the oxidation of the organic matter.

(b) *The Foraminiferal-radiolarian Beds.*—These occur above the purely foraminiferal rocks at the base of the Oceanic Beds, and also below the upper chalks. They contain large proportions of calcium carbonate, occasionally as much as some of the purely foraminiferal rocks, from which they are distinguished by having a large proportion of their colloid silica in the form of definite siliceous organisms, such as radiolaria, sponge-spicules, &c. There is a general resemblance in chemical composition between these beds and the more siliceous bands of the purely foraminiferal beds.

We have not access to analyses of modern oozes comparable with this group, but we may quote the following remarks by Prof. Haeckel as showing that such deposits undoubtedly exist among recent oceanic oozes :—" *Mixed radiolarian ooze* is the name given to those deposits in which the radiolaria exceed any of the other organic constituents, although they do not make up half the total mass. To this category belong a large number of the 'Challenger' soundings which are entered in the Station List either as red clay or *Globigerina* ooze . . . . Probably such mixed radiolarian ooze is very widely distributed in the depths of the ocean, as for example (Pacific stations quoted), also in the South Atlantic (Stations 324, 325, 331, 332), and in the tropical Atlantic (Stations 348–352)." [1]

It would seem from this that the classification of the Atlantic Oceanic Deposits requires some revision, and we hope that Dr. John Murray will take some note of this point in his forthcoming Report on Deep-sea Deposits.[2]

Analyses of some of the mixed radiolarian marls of Barbados are given in the following table:—

	Lower Beds.				Upper Beds.	
	Codrington (grey).	Vaughan's (white).	Pico Teneriffe (white).	Cluff's Bay (white).	Chimborazo (white).	Cleland (white).
Loss on ignition	3·21	2·89	2·75	1·72	4·69	3·82
Quartz	·44	·02	·04	·25	·05	·29
Colloid silica	22·22	19·53	13·83	16·73	18·77	17·17
Clay	20·20	15·02	4·29	7·67	21·53	7·47
Iron peroxide and alumina	4·49	3·67	1·44	2·78	3·77	3·70
Manganese peroxide	·35	·06	2·51	·81	·54	·44
Calcium phosphate	·51	·16	·51	·68	·18	·33
Calcium sulphate	......	......	·40	·51	trace	trace
Calcium carbonate	46·25	55·23	73·33	67·15	46·81	63·64
Lime	1·84	1·71	·03	·82	2·04	2·55
Magnesia	·75	1·44	·67	1·01	1·53	·64
Alkalies and loss in analysis	......	·27	·20	......	·09	......
	100·26	100·00	100·00	100·13	100·00	100·05

(c) *The Radiolarian or Siliceous Rocks.*—These, which are of great thickness, occur in the middle portion of the Oceanic Deposits; they contain far less calcium carbonate than the two preceding groups, and, as a rule, much larger quantities of clay. They consist essentially of mixtures of clay and of colloid silica in the form of skeletons of radiolaria, of diatomaceæ, and of sponge-spicules, organisms which in places constitute by far the greater part of the bulk of the rock. Certain of the beds also contain considerable quantities of calcium carbonate, generally present in a

[1] 'Challenger' Reports, vol. xviii. pt. i. p. clvii.

[2] [Dr. Murray informs us that he cannot accept Prof. Haeckel's classification of oozes; but we think the discrepancy between them would be greatly diminished if Dr. Murray had taken account of the fragments of siliceous organisms separately instead of including them under the head of 'fine washings.' We note that the deposits at Stations 270, 271, 246, and 284, described in the 'Challenger' Report as *Globigerina*-ooze, appear to be very similar in character and composition to this group of Barbados rocks, and they all come from about 2000 fathoms.—J. B. H. & A. J. J.-B., Feb. 16th, 1892.]

	Siliceous Beds.			Calcareo-siliceous Beds.			‘Challenger’ Samples.	
	Conset Bay (light red).	Melvin's Hill, middle beds (yellow with red splashes).	Canefield (greenish white) (*a*).	Conset Bay, 80 feet from base, grey.	Mt. Hillaby, greyish, 30 feet from top of S. peak.	Cleland (greyish).	Station 265. 2900 fathoms.	Station 274. 2750 fathoms.
Loss on ignition	3·12	2·85	4·95	6·89	4·34	4·70	4·30	7·41
Quartz	·02	1·85	1·44	·63	·20	2·03	not deter	mined.
Colloid silica	77·84	56·65	29·31	24·68	42·20	32·16	38·75	46·50
Clay	7·80	27·74	51·02	28·39	14·33	18·31	32·49	13·11
Iron peroxide and alumina	4·04	6·06	8·78	8·15	7·89	7·31	17·95	22·56
Manganese peroxide	trace	·20	·63	trace	·24	·48	·57	3·23
Calcium phosphate	·31	·58	·44	·19	·71	·26	·65	1·39
Calcium sulphate	3·46	1·44	·31	·46	trace	trace	·29	·41
Calcium carbonate	·35	......	......	25·47	26·20	31·23	2·54	3·89
Lime	2·43	·57	1·27	2·33	2·48	3·20		
Magnesia	·50	1·97	1·77	2·76	1·17	·08	(carbonate) 2·46	1·50
Alkalies and loss in analysis	·13	·09	·08	·05	·24	·24	not deter	mined.
	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

(*a*) Sample from below layers of volcanic material, showing a large quantity of clay.

finely-divided state. The accompanying analyses (p. 188) illustrate the variations in their composition; analyses of radiolarian oozes from stations 265 and 274 of the 'Challenger' Expedition are given for comparison.[1]

Modern radiolarian oozes are generally of a reddish colour; but Dr. Murray informs us that some of them become grey when dry, and the subsequent leaching out of the oxides of iron and manganese by percolating water might decolourize them altogether.

(d) *The Red and Mottled Argillaceous Earths.*—These beds differ from the rest of the Oceanic Deposits, being somewhat light earths or clays having a peculiarly greasy feel, ranging in colour from a dark chocolate-red through various shades of red and pink to yellow and greyish white, sometimes being mottled. Physically they have a closer resemblance to 'fuller's earth' than to true clays. The colours appear to be due to the state of combination and hydration of the iron peroxide present and to the manganese peroxide which they all contain, partly in the form of coatings upon their joint-planes or of minute spherules. They contain comparatively small amounts of colloid silica in the form of sponge-spicules and an occasional radiolarian, but are in all cases free from calcareous organisms. Out of all the numerous samples examined calcium carbonate or lime was only determined in one, and there amounted to less than 1 per cent. of lime. The following are the compositions of some of the most characteristic samples examined:—

	Castle Grant (bright red).	Castle Grant (mottled pink and cream).	Melvin's Hill (dark chocolate red).	Mount Hillaby (light red).	Mount Hillaby (yellow).	Mount Hillaby (creamy white).
Loss on ignition	8·55	7·46	6·41	7·10	4·72	7·42
Quartz	·41	·23	·52	·76	·73	1·98
Colloid silica	4·98	3·87	4·14	4·85	5·76	5·57
Combined silica (by difference)	47·65	46·17	43·38	51·70	54·50	48·43
Iron peroxide	4·86	4·77	8·32	2·84	6·95	5·09
Alumina	25·20	31·54	31·56	25·48	21·03	26·99
Manganese peroxide	3·05	2·69	1·77	2·71	1·24	2·73
Lime	trace	trace	......	......	......	trace
Magnesia	2·57	1·41	1·44	2·68	2·62	·98
Potash	·18	·10	·17	·10	·50	·07
Soda	2·55	1·76	2·29	1·78	1·95	·74
	100·00	100·00	100·00	100·00	100·00	100·00

We have been favoured by Dr. John Murray with the analyses of the samples of red clay obtained by the 'Challenger' Expedition; they will be found *in extenso* on page 198 of his report on the 'Deep-sea Deposits,' and we find that the majority of them appa-

[1] 'Challenger' Reports, 'Deep-sea Deposits,' pp. 435, 436.

rently exhibit a closer resemblance in composition to certain of the Barbados radiolarian deposits than to the argillaceous earths.[1] All the 'Challenger' samples contained calcium carbonate, many of them in considerable quantity, the range being from ·92 to 22·63 per cent.[2]

Several of the samples (Nos. 8, 10, 15, 16, 17, and 22) contained less than 3 °/₀ of calcium carbonate, and such samples would, upon exposure to the action of percolating water during lengthened periods, assume compositions similar to those of the Barbados argillaceous earths. Apparently also the amounts of calcium and magnesium carbonates assumed to be present in the 'Challenger' samples analysed by the late Dr. Brazier were determined by considering that all the lime and magnesia dissolved from the clays by hydrochloric acid in quantities above those necessary to combine with the sulphuric and phosphoric acids, were in the form of carbonates, and not, as in all probability they must have been, in part as silicates decomposable by acids.

In order to facilitate comparison, we have rearranged as follows the analyses of these samples so as to render them more easily comparable with those of the Barbados rocks:—

Number of sample	8	10	15	16	17	22
Station	19	21	252	253	256	281
Depth in fathoms	3000	3025	2740	3125	2950	2385
Combined water, &c.	7·44	5·92	3·60	4·50	4·50	7·70
Colloid silica	27·68	24·70	24·89	24·70	24·95	32·60
Combined silica and quartz	25·16	30·20	37·70	37·40	34·82	11·27
Iron peroxide soluble in HCl	10·33	12·25	13·14	7·95	9·77	24·60
Iron peroxide not soluble in HCl	1·57	6·73	2·60	3·88	2·00	3·80
Alumina soluble in HCl	12·91	7·04	5·23	8·31	6·00	8·80
Alumina not soluble in HCl	7·81	5·51	7·85	7·75	11·37	1·60
Manganese peroxide	...	...	trace	·55	·68	2·73
Calcium carbonate	1·49	2·44	2·22	·92	1·69	2·50
Calcium sulphate	·96	·51	·51	·37	·42	trace
Calcium phosphate	trace	trace	...	·19	·48	sl. trace
Magnesium carbonate	3·10	3·48	·41	2·70	1·33	3·24
Lime not soluble in HCl	1·03	·81	1·50	·28	1·14	·84
Magnesia not soluble in HCl	·52	·41	·35	·50	·85	·32
	100·00	100·00	100·00	100·00	100·00	100·00

[1] Haeckel remarks that Stations 241 to 245, which are classed in the Station Report as being red clays, 'might have been almost as appropriately termed radiolarian ooze.' 'Challenger' Reports, vol. xviii. pt. i. Radiolaria, p. cxlix.

[2] Samples Nos. 1, 2, 12, and 19 in the table above referred to show amounts of calcium carbonate ranging from 36·80 to 60·29 per cent., but we have been informed by Dr. John Murray that these samples consisted of red clays after the finer portions (*i. e.* the clay) had been washed away. It appears to us to be somewhat misleading to include these samples in a table showing the composition of red clay, without a footnote pointing out their exceptional character.

The most noticeable difference in all the samples is the large quantity, varying from 11·03 to 32·60 per cent., of silica "soluble in HCl" (soluble in alkalies after treatment with hydrochloric acid ?) present in all the 'Challenger' samples as compared with the small proportions (from 3·87 to 5·76 per cent.) found in the Barbados deposits. As, however, Dr. Murray, in his table given on p. 197 of the Report, showing the average composition of the 'Challenger' samples of red clay, places the siliceous organisms present at only 2·39 per cent., and as in addition the amounts of alumina shown in the table of analyses as being "soluble in HCl" are in the majority of cases in very high proportion to the total amounts present in the samples, it is evident that the analyses do not represent with accuracy the original proportions of colloid silica present in the samples. They give instead the amounts originally present, together with those set free from the silicates of the clays by the action of strong and probably boiling hydrochloric acid. Again, whilst in the Barbados argillaceous earths the alkalies potash and soda are present in proportions varying from ·81 to 2·73 per cent., these usual and important constituents of clay have not been estimated in the 'Challenger' samples. We consider that, if the 'Challenger' samples of red clay which contained only small amounts of calcium carbonate and the samples of the Barbados argillaceous earths had been analysed by similar methods, a close resemblance in composition would have been found in them, and that the differences would have been such only as would arise from the action of percolating water containing organic acids upon the Barbados deposits, from which the calcium carbonate and the iron peroxide present in a limonitic form would be leached out.

Seeing that clays similar in character to these argillaceous earths occur as terrigenous deposits, it is necessary to consider certain other points about them in addition to their general resemblance to the 'Challenger' samples. First, therefore, 'clay' present in samples of foraminiferal and radiolarian deposits was separated by elutriation, and, after separation of the colloid silica from it, was found to be similar in nature and in constitution to the argillaceous earths. Again, if the argillaceous earths and the clays present in the other Oceanic Deposits were of terrigenous origin, we should expect them to correspond in composition with the clays of the South American littoral, with those of the underlying Scotland Group which are undoubtedly terrigenous, and with the clay present as an impurity in the coral-rocks of the island. But such is not the case. The clays of the South American littoral, *i. e.* those of British Guiana derived from the waters of the Orinoco and others of the great South American rivers, invariably contain considerable quantities of quartz, never, as far as our experience goes, less than 15 %, and frequently far higher amounts. This quartz is in a state of remarkably fine subdivision, and is not separable from the clay by ordinary processes of elutriation. Similar quartz is present in quantity in the clays derived from the waste of the coral-rocks, and in those of the Scotland Beds; whilst it is present in only minute amounts, which in part are doubtless derived from alteration of colloid silica, in any of the Oceanic Deposits. The clays of the South American littoral moreover contain considerable proportions of potash, not unfrequently amounting to over 2 per cent., and this is also the case, although to a lesser extent, with the clays derived from the coral-rocks and with the Scotland Beds, whilst the argillaceous earths contain but minute amounts of this alkali.

(e) *The Layers of Volcanic Sands or Ashes and Mudstones.*—The following table gives compositions of three of the interbedded layers which consist so largely of volcanic material; that of a sample of the volcanic sand or dust from the Souffrière of St. Vincent, which fell upon Barbados in 1812, and is locally known as May Dust,[1] being included for comparison. The layers from which the samples analysed were taken are, 1st, a bed varying from 7 to 10 inches in thickness, exposed in Conset Gully (see p. 205); this is of a dark brown colour, containing, as do several of the thinner beds of volcanic material, a considerable quantity of petroleum (derived probably from the lower Scotland Beds); 2nd, the bed of pumiceous sand, near Chimborazo, at the top of Melvin's Hill (see pp. 180, 208); and 3rd, the bed of grey mudstone from the summit of Mount Hillaby (see pp. 180, 209).

	Conset Gully (coarse).	Melvin's Hill (rather coarse).	Mount Hillaby (fine mudstone).	May Dust (sandy).
Loss on ignition	11·50	·41	2·23	2·81
Quartz	·65	·12	·04	·26
Colloid silica	18·46	28·50	19·34	12·47
Combined silica	47·31	38·31	44·22	41·52
Alumina	9·39	14·59	16·55	21·85
Iron peroxide	1·55	1·07	trace	1·81
Iron protoxide	3·72	2·15	5·43	6·33
Manganese oxide	3·44	...	·09	·03
Manganese peroxide	...	4·24		
Lime	2·10	2·23	7·59	7·16
Magnesia	·90	1·25	1·57	1·99
Potash	1·25	1·94	·36	1·04
Soda	trace	5·21	2·58	2·99
	100·27	100·02	100·00	100·26

In these layers of volcanic materials soluble or colloid silica is always present in considerable quantity, partly in the form of siliceous organisms, but largely as a cementing material. It is also present, but in much smaller quantity, in the so-called May Dust, in which it occurs in the form of siliceous organisms of freshwater origin, and as finely divided silica. The general resemblance in composition between the sandy dust known to have come from St. Vincent, and the layers occurring in the Oceanic Series, when the increased amount of the colloid silica in the bedded layers is allowed for, points to a similar origin, that is, from a lava containing but little free silica. Two of the samples (those from Conset Gully and

[1] The 'May Dust' is said to have been collected at the time of falling.

from Melvin's Hill) contained considerable proportions of the oxides of manganese, of which only traces were present in the mudstone from Mount Hillaby and in the May Dust. We examined many years ago a sample of May Dust which contained oxides of manganese in considerable quantity, a fact which was noted by Sir Humphry Davy, who examined some of it soon after its falling.

The older layers of volcanic materials contain much less lime than do the Mount Hillaby and May Dust samples.

The occurrence of these layers of volcanic sands and muds in the Oceanic Deposits, the general resemblances in composition between them and the argillaceous earths, and the fact that minute fragments of pumiceous minerals are scattered throughout the beds, point strongly to the conclusion that the clay present in the Oceanic Deposits has been derived from the finest portions of the volcanic materials which fell from time to time upon the surface of the area in which the deposits were forming.

§4. Organic Remains found in the Rocks.

With the exception of radiolaria, which abound in the siliceous earths, and of foraminifera, which are equally abundant in some of the calcareous rocks, fossils are very rare in the Oceanic Deposits of Barbados. The discovery of the *Cystechinus* described by Mr. Gregory shows, however, that larger organisms were not entirely absent; [1] but the very paucity of such remains is another point of resemblance between these deposits and the modern abyssal oozes.

It is, of course, only from a comparison of the constituent and embedded organisms with their living congeners that conclusions can be drawn respecting the age of the deposits and the depth of water in which they were accumulated. In considering the bearing of the fossils on these points, it will be convenient to deal separately with the contents of (1) the siliceous earths, (2) the calcareous earths.

(1) *Fossils from the Siliceous Earths.*—The radiolaria from these deposits have long been known, and it would serve no useful purpose to give a list of them here; but we may note an important observation by Prof. Haeckel to the effect that the fossil radiolaria of Barbados are most nearly allied to those which occur in the deepest parts of modern oceans.[2] Now radiolarian oozes are found in the Pacific and Indian Oceans between depths of 2000 and over 4000 fathoms, and it is a fact significant of the physical changes which have taken place since the formation of radiolarian ooze in the Caribbean region that no such ooze has been found in the modern Atlantic; that is to say, no deposit which contains more than 50 per cent. of radiolarian remains.

Haeckel also compared the species of radiolaria found in the

[1] Another echinoid (*Archæopneustes*, Greg.), with some small turbinate corals, and some other fossils occur in the limestone which caps Bissex Hill, but we do not regard this as, strictly speaking, part of the Oceanic Series (see § 6).

[2] 'Challenger' Reports, vol. xviii. part i. p. clxxv.

Barbadian earths with those obtained from the modern ooze, and found that about 25 per cent. of the Barbadian forms are known from the modern ooze. It is true that, as Mr. Gregory points out, the living radiolaria have not been so well investigated that such a comparison can be taken as having the value that it would have in the case of one of the higher groups; still the fact remains that many of the Barbadian species are absent from the recent deposits, and therefore, so far as the radiolarian evidence goes, it points to a date somewhat older than Pleistocene or post-Tertiary; a Pliocene date would be entirely in accord with this evidence.

[As regards the diatoms, we have not been able to ascertain whether any of them are extinct species or bear in any way on the question of geological age, but in the recently published volume on Deep-sea Deposits ('Challenger' Expedition Series) Dr. J. Murray furnishes us with a strong point of comparison with modern abyssal deposits. Fragments of the frustules of the diatom *Ethmodiscus* are frequently present in the radiolarian earths of Barbados in considerable quantity, and he remarks that this is "quite characteristic of some of the deepest tropical red clays and radiolarian oozes far from land" (*op. cit.* p. 31).—Feb. 16th, 1892.]

The most important fossil which has yet been obtained from the radiolarian beds is the echinoderm which was described by Mr. J. W. Gregory in 1889 under the name of *Cystechinus crassus*.[1] We have ascertained that the well at Haynesfield, from which this fossil was obtained, had a depth of about 168 feet, 140 of this being coral-rock, and the remainder radiolarian earth; the specimen came from near the bottom at a depth of about 166 feet, as stated in Mr. Gregory's paper. The occurrence of this echinoderm is of great importance, inasmuch as it affords valuable evidence both as to depth of water and geological age.

Mr. Gregory remarks that "*Cystechinus* is one of the most typical of deep-sea echinoids; thus, for example, Neumayr quotes it with a few other genera as never found above the 1000-fathom line." Three species of *Cystechinus* were obtained during the 'Challenger' Expedition, all of which came from very deep water. "*C. clypeatus*, the species which is probably the nearest ally of *C. crassus*, was found off Tristan da Cunha at Stations 133 and 334, and in the China Sea at Station 205, at depths of 1900, 1915, and 1050 fathoms respectively."

No fossil form of the genus was known previous to the discovery of *Cystechinus crassus* in Barbados, so that its presence gives little assistance in determining the age of the deposit. Since many of the modern oceanic echinoderms belong to very ancient types, we might expect *Cystechinus* to be present in oceanic deposits belonging to any Tertiary period.

The only other fossil which has been obtained from the radiolarian beds is a shark's tooth of the *Lamna* type; this is in the possession of Mr. Armstrong, of Little Island estate, Barbados, and is embedded in a fragment of the grey limestone of Bissex Hill.

[1] Quart. Journ. Geol. Soc. vol. xlv. p. 640.

(2) *Fossils from the Calcareous Earths.*—The only fossils yet obtained from these earths are foraminifera. Samples of the deposits were sent to the late Dr. H. B. Brady, who kindly undertook to examine and report upon them. He did examine most of these in 1889, and sent us a preliminary report in December of that year, with a list of the species (81 in number) which he had identified up to that date ; at the same time he stated that, owing to its coherence, the material was not easy to manipulate, and if we could send him samples of the looser beds or rainwash from the coherent chalks, he would examine them as soon as he had completed his work on the raised deposits of the Pacific Islands. Samples were obtained and sent to him, but he was unable to finish their examination before his death in January 1891. His courtesy and readiness to impart information were known to all who applied to him, and while especially regretting the loss which has deprived us of further information, we esteem ourselves fortunate in being able to present the Society with a report which contains much of interest and importance.

Report by the late Dr. H. B. Brady.

"I have made a preliminary examination, in respect of the foraminifera they contain, of most of the specimens of earthy deposits from Barbados which you sent to me. The results, though far from complete, possess considerable interest, and as I am unable at present to continue the investigation I send them to you as they stand.

"The physical character of these Barbados rocks is not favourable for the separation of microzoa. With one exception the specimens sent were fine-grained and compact, without being very hard ; easily broken into fragments, but very difficult to disintegrate completely by washing or other mechanical means. Chemical reagents are inadmissible where foraminifera are concerned, and the amount of force needful for the reduction of the rock to its constituent particles is sufficient to break up the more delicate forms ; while the close adherence of portions of the matrix obscures the external characters of the larger specimens. It may be urged that the difficulties are not greater than in the case of common white chalk, which often presents very similar characters ; but chalk is not uniformly so intractable, and, from its abundance, larger quantities can be operated upon at one time. Besides which, we already know what forms to expect from the various Cretaceous beds, and the identification of specimens with some adherent matrix is comparatively easy.

"Nine specimens of the Barbados deposits, weighing from $1\frac{1}{2}$ ounce to 4 ounces, have been washed, and the residues examined. Of these one, presenting altogether different features from the rest, may be set aside and treated separately. Although much labour was expended on the other eight samples, in no case was the washing quite satisfactorily accomplished ; and the residues, which in seven of them only ranged from 1 to 6 per cent. of the original weight, might in every instance have been reduced with advantage, though the foraminifera had already suffered considerably by breakage. The small quantity of washed material thus obtained (5 to 20 or 30 grains from each ounce of rock) is not much to depend upon for the complete presentment of the calcareous rhizopods. Neither are microscopical sections of any great service, except for purposes of comparison, owing to the muddy nature of the deposits and the relative sparseness of recognizable organisms.

"In three out of the eight samples to which I have referred no foraminifera were met with; in a fourth very few, and those only of species common to the others.[1] The results of the examination of the remaining samples are embodied in the first four columns of the annexed table (p. 198).

"There was one specimen, as I have said, which differed from the rest in its physical characters; it was labelled 'rotten earth, Bissex Hill, 50 feet down.' It is a light-brown friable rock which easily disintegrates, leaving 40 per cent. of residue or thereabouts after washing. It is more calcareous than the rest, containing perhaps less than 25 per cent. of siliceous matter. It resembles in many respects some recent specimens of *Globigerina*-ooze.

"There is still much to learn respecting the rhizopod fauna of these deposits before any very satisfactory conclusions can be drawn as to their geological age or the depth of water at which they were formed. The species which have been so far determined are enumerated in the annexed table. This has no pretension to completeness, but it will serve as a basis for future work; the number of species in every column might, without doubt, be largely increased by fresh examination with improved methods of preparing the material.

"The list contains 81 species and well-marked varieties, 5 of which are left for the present undetermined. Of the remaining 76 there are only 2 species of *Nodosaria* and 3 of *Ellipsoidina* that are not well known in the living condition. It may be further remarked with regard to *Ellipsoidina* that our present knowledge of the genus and its distribution is very defective; it appears more than probable that specimens belonging to the group, both recent and fossil, may have been mistaken for isomorphous forms of *Lagena*, *Glandulina*, and *Nodosaria*. The two species of *Nodosaria* referred to are represented by only one or two specimens apiece, and taken by themselves are of little importance.

"We may say with some confidence that of the 81 species of foraminifera enumerated 71 or 72 are certainly recent forms, and half the remainder probably so. An investigation of the microzoa of a large series of soft deposits from various islands of the South Pacific has yielded a very similar result, and I agree entirely with Dr. Guppy, who has assigned to them geologically a post-Tertiary origin.

[1] Eleven specimens had been sent to Dr. Brady, and those which proved of little use must have come from some of the following localities:—Castle Grant, lower beds (3 samples sent); near Bloomsbury; Mount Misery; summit rock of Mount Hillaby.

"Turning to the question of the probable depth at which these beds were deposited, the evidence still leaves a good deal to be desired. It is generally assumed that the presence of skeletons of radiolaria and similar siliceous remains as the chief constituents of a deposit is an indication that it was laid down at a considerable depth, and the 'Challenger' researches give a general support to this view. I have notes of 41 'Challenger' bottom dredgings more or less characterized by abundance of radiolaria, and of these only 7 were taken at a depth less than 1000 fathoms, whilst 25 were from more than 2000 fathoms. On the other hand, the almost complete absence of the pelagic varieties of *Pulvinulina*, and, except in the Bissex Hill material, the poor show of *Globigerinæ*, whilst certain other calcareous forms are well represented, are not what one would expect in a deep oceanic deposit far from land.[1]

"The annexed table (p. 198) furnishes us with ten or eleven salient species, whose known distribution in the living condition is of value as far as it goes.

"*Miliolina venusta* was found at 12 'Challenger' stations, ranging from 1070 to 2750 fathoms, and at only one in shallow water, and though it has since been recorded from some other shallow-water localities it may be considered relatively as one of the deep-water forms of *Miliolidæ*.

"*Verneuilina triquetra*, in 'Challenger' material from 390 fathoms (West Indies), 210 fathoms (Pacific Islands).

"*Pleurostomella subnodosa*, at 1825, 2200, and 2350 fathoms.
,, *brevis*, at 129 and 1950 fathoms.
,, *alternans*, at 129 and 2075 fathoms.

"*Cassidulina subglobosa*, at 50 stations, 6 of which have a depth of more than 2000 fathoms, 17 of more than 1000, 23 of more than 400, while 3 are under 100 fathoms.

"*Allomorphina trigona*, recent at two stations only, 345 and 620 fathoms.

"*Polymorphina angusta*, at 14 stations, 7 of which have a depth of more than 2000 fathoms and only 3 of less than 1000.

"*Rotalia Soldanii*, at 57 stations, of which 41 are from depths of more than 1000 fathoms.

"*Nodosaria hispida*, var. *sublineata*, 435 fathoms (West Indies) and 350 fathoms (Pernambuco).

"As I have already stated, a more complete examination of these rocks and their constituent organisms should throw into much clearer light the points under consideration. The aspect of the rhizopod fauna apart from the species just referred to, without being

[1] We now know that the *Globigerina*-marls and limestones of Bissex Hill are at least 50 feet thick, and that in this locality there is a fine show of *Globigerinæ*. A sample from one of the limestone-blocks was afterwards sent to Dr. Brady, who wrote to us as follows:—'The limestone of which it is a section exactly resembles a modern sea-bottom of, say, perhaps 1000 fathoms (more or less), formed, at any rate, in open ocean, away from land influences. From a section one always has to speak with a margin, as it is next to impossible in many cases to identify species. Still, I do not think at 1000 fathoms you will be very far wrong.'

specially indicative, is not inconsistent with the idea of a sea-bottom of considerable depth, perhaps from 500 to 1000 fathoms, but the impression I have formed on this point must not be taken for more than it is worth."

	Base of Melvin's Hill.	Canefield.	Mount Hillaby, 20 feet from top.	Below Edgecliff.	Bissex Hill, rotten earth.
Miliolina venusta, Karrer	...	*	...	*	...
—— (*Sigmoilina*) *tenuis*, Czjzek	...	...	...	...	*
Textularia agglutinans, d'Orb.	*	*	*	...	...
—— *aspera*, Brady	...	*	...	...	...
—— sp.	*	...	...	...	...
Bigenerina capreolus, d'Orb.	...	...	...	...	*
Spiroplecta annectens, P. & J.	...	...	...	*	...
Verneuilina triquetra, Munst.	...	*	...	...	*
Gaudryina pupoides, d'Orb.	...	*	*	...	...
Bulimina striata, Buch	...	...	*	...	...
—— *elegans*?	...	...	*	...	...
Pleurostomella subnodosa, Reuss	...	*	...	*	...
—— ——, var. *attenuata*, Brady	*	...	*	...	...
—— *alternans*, Schw.	...	...	...	*	*
—— *brevis*, Schw.	...	...	...	*	...
Bolivina robusta, Brady	...	...	...	...	*
Cassidulina crassa, d'Orb.	...	...	*	...	*
—— *subglobosa*, Brady	*	*	*	*	*
Ehrenbergina serrata, Reuss	...	...	...	...	*
Allomorphina trigona, Reuss	*	...	...	...	...
Ellipsoidina ellipsoides, Seg.	*	*	...	...	...
—— *exponens*, Brady MS.	...	*	...	...	...
—— ? *rotundata*, d'Orb.	*	*	*	...	...
Lagena hispida, Reuss	*	*	...	*	...
—— *striata*, d'Orb.	*	*	...	...	...
—— *sulcata*, W. & J.	*	...	...	...	...
—— *striato-punctata*, P. & J.	*	...	...	...	...
—— *fimbriata*, Reuss	*	...	...	...	...
—— *alveolata*, var. *caudigera*, Brady	...	*	...	...	...
—— *lævigata*, Reuss	...	...	*	...	...
—— *marginata*, W. & B.	...	*	*	...	...
—— *lagenoides*, Will.	...	*	...	...	...
—— *pulchella*, Brady	...	...	...	*	...
—— *trigono-marginata*, P. & J.	...	...	*	...	...
Nodosaria communis, d'Orb.	*	...	...	...	...
—— *pauperata*, d'Orb.	*	...	...	...	...
—— *mucronata*, Neugeb.	*	...	...	...	...
—— *longiscata*, d'Orb.	...	*	...	...	...
—— *farcimen*, Sold.	...	*	*	...	...
—— *ovicula*, d'Orb.	...	*	...	...	...
—— *pyrula*, d'Orb.	*	...	...	...	...
—— *hispida*, var. *sublineata*, Brady	...	...	...	...	*

TABLE (*continued*).

	Base of Melvin's Hill.	Canefield.	Mount Hillaby, 20 feet from top.	Below Edgecliff.	Bissex Hill, rotten earth.
Nodosaria plebeia, Reuss	...	...	*	...	*
—— *Raphanus*, Linn.	...	...	...	...	*
—— *obliqua*, Linn.	...	*	...	...	*
Frondicularia Milletii, Brady	...	...	...	...	*
Vaginulina legumen, Linn.	*	...	...	...	...
Rhabdogonium tricarinatum, d'Orb.	...	...	...	...	*
Marginulina glabra, d'Orb.	*	*	...	...	...
Cristellaria tenuis, Bornem.	...	...	...	...	*
—— *crepidula*, F. & M.	*	*	...	*	...
—— *Wetherellii*, Jones	...	...	...	...	*
—— *rotulata*, Lamarck	*	...	...	...	*
—— *cultrata*, Montfort	...	...	...	...	*
Polymorphina angusta, Egger	*	*	*	...	...
Uvigerina pygmæa, d'Orb.	...	...	...	...	*
—— *angulosa*, Williamson	...	...	...	...	*
—— *asperula*, Czjzek	...	...	...	...	*
Sagrina virgula, Brady	*	*	*	*	*
—— *Raphanus*, P. & J.	*	...	...	...	...
—— *nodosa*, P. & J.	...	...	...	...	*
Globigerina bulloides, d'Orb.	*	*	*	*	*
—— *inflata*, d'Orb.	...	*	...	...	...
—— *conglobata*, Brady	?	*	...	...	...
—— *æquilateralis*, Brady	...	...	...	...	*
Spheroidina bulloides, d'Orb.	...	...	...	...	*
Pullenia spheroides, d'Orb.	*	...	...	...	...
—— *quinqueloba*, Reuss	...	*	...	...	...
Truncatulina lobatula, W. & J.	...	...	*	...	*
—— *Akneriana*, d'Orb.	...	*	...	*	...
—— sp.	...	...	*	*	...
Anomalina ariminensis, d'Orb.	...	...	...	...	*
—— *ammonoides*, Reuss	...	...	...	*	...
—— *grosserugosa*, Gümb.	...	...	...	*	*
—— *polymorpha*, Costa	...	*	...	...	...
Carpenteria monticularis, Carter	...	...	...	...	*
Pulvinulina, sp.	*	*	*	*	*
—— *crassa*, d'Orb.	...	*	...	...	...
—— *pauperata*, P. & J.	...	...	...	...	*
Rotalia Soldanii, d'Orb.	*	*	*	*	...
Nonionina umbilicatula, Mont.	...	*	*	...	...

Summary of the evidence from Organic Remains.—First, with respect to the age of the deposits; upon this point the testimony of the foraminifera is very important: the fact that out of 76 determined species 71 (or 93 per cent.) are living species is strong evidence for a very late Tertiary date, either Pleistocene or late Pliocene time.

The occurrence of the genus *Cystechinus* in the siliceous earths is confirmatory of this conclusion. As that genus is known only in a living condition, it might be thought to favour a very recent age, but inasmuch as its representatives are entirely confined to deep water it may be inferred that the genus is a Tertiary form which, like many of its associates, has lived on in the ocean depths. It is therefore just as likely to occur in deep-sea deposits of Pliocene as of Pleistocene age.

We may conclude then that the Oceanic Deposits of Barbados were most probably formed during the period which we call Pliocene; and it is possible that, with the still later deep-water deposits, they cover not only the whole of Pliocene time, but so much of the post-Pliocene as elapsed before the rising island reached the level at which reef corals could build.

Next, with regard to the depth of water which is indicated by the fossil organisms. In an area which has certainly experienced a profound subsidence, followed by an equally great upheaval, the depth of the sea during the accumulation of oceanic oozes may have varied very much, and the great variety of deposits exhibited by the Oceanic Series of Barbados suggests a concomitant variation in depth. It is true that the accumulation of red clay does take place in some areas at the same depths as those in which radiolarian ooze or foraminiferal ooze is being formed elsewhere, and consequently the change from one kind of deposit to another must depend on other conditions besides the single element of depth. Still, we may be prepared to find that the contents of the successive deposits do indicate different depths of water.

With respect to the calcareous earths the evidence of the foraminifera does not seem to be very clear or definite. Of the samples examined by Dr. Brady and mentioned in his list three came from the basal beds, while the other two came from higher horizons. There are 25 species in the latter which were not found in the former, but the fauna of the lower beds is not so uniform as to show that these species are not likely to occur in it, for Canefield alone yielded 16 species which were not found at the other two localities, while some of these 16 also occurred in the higher beds. It is clear that, as Dr. Brady remarks, fuller lists are required, and all that can be said is that the fauna of the beds at both horizons is consistent with a depth of from 500 to 1000 fathoms.

Of the *Globigerina*-rock which occurs on Bissex Hill and belongs to the higher calcareous horizon Dr. Brady speaks more confidently as indicating a depth of about 1000 fathoms, and certainly formed in open ocean far away from land. It is noteworthy too that of the salient species pointed out by him the four species whose range is best known, viz. *Miliolina venusta*, *Cassidulina subglobosa*, *Polymorphina angusta*, and *Rotalia Soldanii*, are all most abundant in depths of more than 1000 fathoms.

The minute, calcareous, stellate particles which occur so abundantly in the more chalky beds, and which appear to be of organic origin (see p. 178), confirm the evidence of the foraminifera, but do not afford any more precise indication of the depth of water, inasmuch as they occur in modern *Globigerina*-ooze at all depths from about 600 to 2000 fathoms.

With respect to the siliceous earths we have Haeckel's testimony that the radiolaria suggest depths comparable to the deepest parts of the modern oceans (3000–4000 fathoms); and we have the evidence of the *Cystechinus* and of the diatom *Ethmodiscus*, both of which are quite compatible with a depth of more than 2000 fathoms.

While, therefore, it is at present impossible to say at what depth the basal chalky earths were formed, we may safely assume that the water became gradually deeper owing to continued subsidence, till during the formation of the purely-siliceous radiolarian earths its depth was between 2000 and 3000 fathoms; that the movement was then reversed, and upheaval brought the sea-floor to within 1000 fathoms of the surface during the formation of the upper calcareous beds. The red clays can hardly have been accumulated in a less depth than 2000 fathoms, and it is possible therefore that they indicate a second subsidence. Finally we have the topmost beds of Mount Hillaby, which may have been accumulated in almost any depth, but still at a distance from land. Such are the conclusions which seem fairly deducible from the evidence.

§ 5. Stratigraphical Description of the Oceanic Deposits.

(a) **Areas of Exposure.**—The chief physical feature of Barbados is the escarpment of coral-rock which was described in the first part of this memoir. This embraces and forms the boundary of the area known as the Scotland district, and it is within this district and its prolongation along the coast to the south-east that the chief exposures of the two older rock-groups are to be found.

At each end of the area above indicated (see Map, facing page 202) the Oceanic Beds are found at the sea-level; toward the centre of the island, between Mount Chimborazo and Mount Hillaby, their base rises to between 800 and 900 feet above the sea.

At the southern end of the narrow strip of ground which lies between the sea and the high plateaux of coral-rock in the parish of St. John's, the lower platforms of coral-rock terminate in a low semicircular escarpment. Beneath this are slopes formed by the outcrop of the white earths of the Oceanic Series, and these slopes enclose a valley which opens north-eastward into Conset Bay and along which the Scotland Beds are exposed.

From Codrington and Conset Bay the Oceanic Deposits occupy most of the ground between the coast and the great escarpment, as far as Congor Rock and Newcastle estate; a powerful fault then brings up the Scotland Series and throws back the base of the white earths to a height of about 200 feet above the sea, where they form a narrow strip of ground beneath the lowest terrace of coral-rock.

This strip has been traced for nearly a mile to Foster's Hall Wood, beyond which it seems to run in under the coral-rock.

The white earths are brought in again by a fault which strikes south-westward from near Bathsheba Station. From this fault they run westward, forming a slope which is nearly half a mile in breadth, with a dip to the south-east. At the same time the base of the Oceanic Series rises rapidly to the west, from a low level near Bathsheba to a height of about 900 feet between Horse Hill and Little Island, where it runs under the coral escarpment. Another fault, however, brings it down again below Little Island and Castle Grant.

By Chimborazo and Maynard's a large tract of these deposits is brought in between two great faults, and another long tract runs from Bloomsbury by Mallard's to Spring Vale, being separated from the Maynard area by a long narrow strip of Scotland Clays, which can be clearly traced when the sugar-canes are off the fields. In both these tracts the prevalent dip is to the south-east.

West of the Caledonia fault there is only a narrow tract of Oceanic Deposits below the coral-rock, and for about half a mile they still dip to the S.E.; on Highland estate a change occurs, and thence by Canefield and Mount Misery the beds dip to the north-east, the outcrop at the same time spreading out till it is three-quarters of a mile wide.

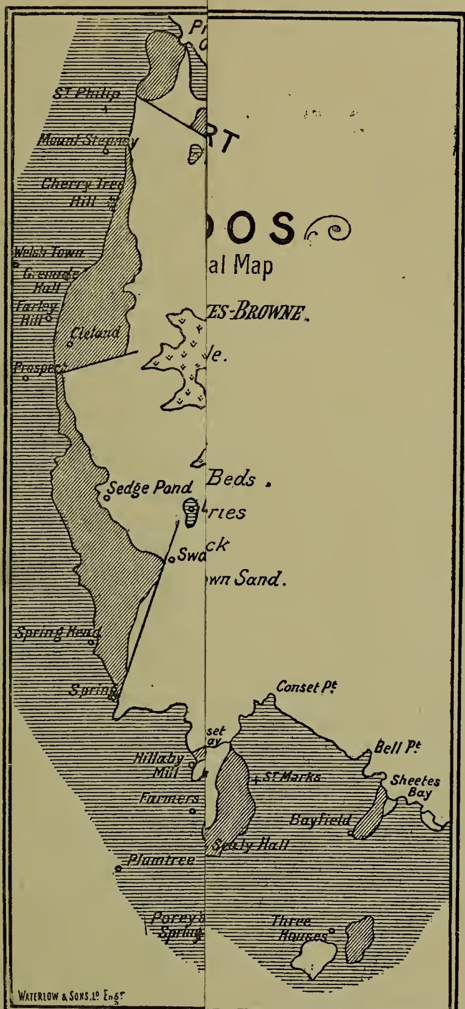
A fault running E.N.E. from Farmer's Gully then throws the beds up to a higher level, and with a N.N.W. dip they spread over the tract east of Farmer's and Hillaby, which extends to Mount Hillaby, the highest point of the island. Here there are cross faults, and the dips on Mount Hillaby are eastward. The tract is bounded on the north by a powerful fault, which completely cuts out the white earths and brings up the Scotland Sandstones.

The next tract of the Oceanic Beds is brought in by a fault which runs from below Spring Mill to Swann's estate in a N.E. direction. This tract is a mile wide along the line of the fault and extends for about 2½ miles to the north, but as the beds dip steadily to the south-east the base rises northward, while the base of the coral-limestones descends, so that eventually the exposure of white earths is reduced to a very narrow strip.

Below Prospect, however, a wider area of them is again brought in by a fault which strikes nearly due east and west, with a downthrow to the north. In this area the dip is also to the south-east, and, like the last, it narrows northward from Cleland and Bredy's till its base finally passes beneath the descending coral-rock escarpment near Mount Stepney.

Once more are the Oceanic Beds brought in by a downthrow about half a mile from Grant's Bay, where they are exposed in the cliffs and pass under the coral-rock by the promontory known as Pico Teneriffe.

(b) **Sublying Areas.**—The tracts which have been mentioned are those which emerge from beneath the escarpment of the coral-rock. They are, of course, portions of larger areas, parts of


St Philip
Mount Stepney
Cherry Tree Hill
Welsh Town
Grenade Hall
Farley Hill
Cleland
Prospect
Sedge Pond
Swa
Spring Head
Spring
Hillaby Mill
Farmers
Plumtree
Porey's Spring
Conset Pt
Bell Pt
Sheetes Bay
St Marks
Bayfield
Sealy Hall
Three Houses
DOS
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Beds.
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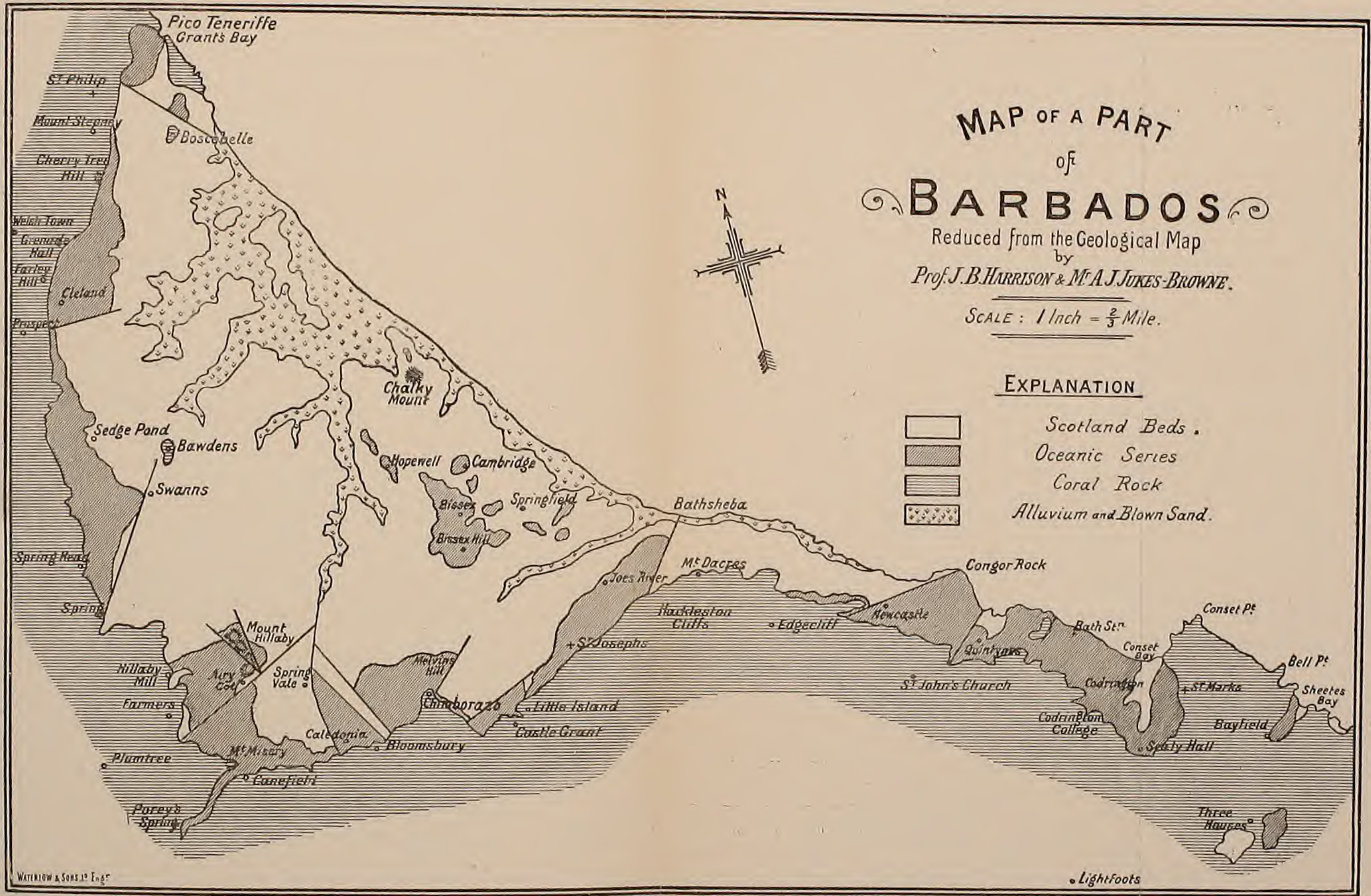

MAP OF A PART of BARBADOS
Reduced from the Geological Map by Prof. J. B. Harrison & Mr A. J. Jukes-Browne.
Scale: 1 Inch = 2/3 Mile.
EXPLANATION
Scotland Beds.
Oceanic Series
Coral Rock
Alluvium and Blown Sand.
N
Pico Teneriffe
Grant's Bay
St Philip
Boscobelle
Chalky Mount
Sedge Pond
Bawdens
Swanns
Hopewell
Cambridge
Springfield
Bissex Hill
Bathsheba
Mt Dacres
Joes River
Congor Rock
Newcastle
Edgecliff
St Josephs
Mount Hillaby
Spring Vale
Melvins Hill
Chimborazo
Little Island
Castle Grant
Caledonia
Bloomsbury
Plumtree
Canefield
Farmers
Hillaby Mill
Cleland
Prospect
Spring Head
Bath Stn
Conset Bay
Conset Pt
Bell Pt
Sheetes Bay
St Marks
Codrington
Codrington College
Bayfield
St John's Church
Quintynes
Three Houses
Lightfoots
Waterlow & Sons Ld Engr

which are concealed beneath the newer limestones. Thus the tract which borders the coral-rock from Sealy Hall to Newcastle doubtless extends a long way westward beneath the coral-limestones. The accuracy of this inference is proved by such well-sections as we were able to obtain information about; at Haynesfield, two miles south-west of Newcastle, the well was carried into radiolarian earth at about 150 feet, and a boring made for the Water Supply Company near Lightfoot's proved 18 feet of the red clays beneath the corals, and radiolarian earth below them. It is probable, therefore, that nearly the whole of the coral-limestone area in St. John's parish is underlain by Oceanic Deposits. They also extend under the lower plateau by St. Mark's Church to Bayfield and Sheete's Bay, where a small tract of them is exposed by erosion. A little south of this there is another inlier by Three Houses; and still farther south, on the borders of Christchurch parish, between Hopefield and Loamfield, there is another inlying area exposed by removal of the coral-rock. The probable structure of the Christchurch ridge was illustrated by fig. 9 of the first part of this memoir.

Passing now to the northern part of the island, the occurrence of radiolarian earths at Porey's Spring, and thence up the gully to Canefield, shows that a considerable mass of these deposits underlies the coral-rock of that district. This mass is probably bounded on the north by the Farmer's Gully fault, and on the east by a continuation of the Caledonia fault.

How far the Spring and Sedge Pond area extends westward we have no evidence, but since there is a westerly slope beneath the coral-rocks and the Oceanic Beds dip to the S.E., the base of the latter would probably be brought up within a short distance. A boring at Rock Dundo, however, proved the existence of another sublying area of Oceanic earths at a level of only 263 feet above the sea (see Part I. fig. 6).

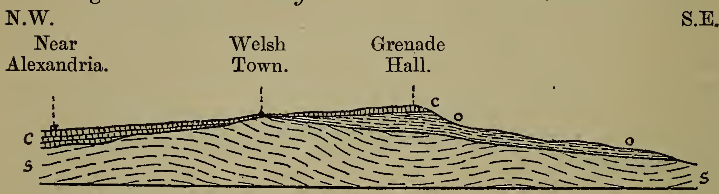
With regard to the westerly extension of the Cleland area, we have interesting evidence from information furnished to us by Mr. E. Easton, C.E., as to borings made through the coral-rock near Welsh Town. These disclosed the existence of a ridge of the Scotland Clays close to the surface by Welsh Town, but sloping steeply to the north-west beneath coral-rock which gets gradually thicker till, near Alexandria, it is 150 feet deep, with the clays still below it. South-eastward the Oceanic Deposits come in between the clays and the coral-rock, as shown in fig. 1 (see next page).

Most of the extreme northern end of the island seems to be underlain by Scotland Clays and Sandstones, for these beds come to the surface in two localities; but along the north-eastern coast there are several exposures of Oceanic Deposits, one round Laycock Bay, two smaller ones near Lowland, another between Islicot and River Bay, and finally a narrow strip on the coast north of Cluff's.[1] It is noteworthy that if the Boscobelle fault were prolonged north-westward to near Cluff's all these exposures would lie

[1] These places lie to the north of the area included in the Map facing p. 202.

on one side of it and all the exposures of Scotland rocks would lie on the other side, making it very probable that the structure of the Boscobelle and Grant's Bay area is continued to the north-west below the covering coral-limestones.

Fig. 1.—*Section through Welsh Town and Grenade Hall.*



[Distance: one mile and a half.]

Vertical scale: 1600 feet = 1 inch.

S. Scotland Beds. O. Oceanic Beds. C. Coral-rock.

(c) **Outliers.**—Besides the tracts which have been indicated, detached and outlying patches of the Oceanic Series cap some of the hills within the Scotland district (see Map, facing p. 202). The largest and most conspicuous of these outliers is that which forms Bissex Hill, its summit rising to 966 feet above the sea. The length of this is about one mile, with an extreme width of three-quarters of a mile; the beds seen everywhere dip to the northward, and their base descends from between 760 and 770 feet at the south-western corner of the hill to about 380 feet at the northern end of the outlier, giving a dip of about 6° to the north.

North-east of Bissex Hill are three smaller outliers, evidently once connected with the larger one; north-west are two others at about 350 feet; and east of its southern border are three others at elevations of between 500 and 600 feet.

The physical conformation of the country makes it clear that this group of outliers was originally connected with the Chimborazo area, for the distance between them is only a mile and there is still a complete connecting ridge from Melvin's Hill (below Chimborazo) to the foot of Bissex Hill. The road from one place to the other is carried along this ridge, and the traveller looks down on either side into valleys that are 300 to 400 feet deep; consequently no geologist can doubt that the isolation of Bissex Hill is due to the removal of material from this watershed by the action of rain.

Chalky Mount, to the north of Bissex and only half a mile from the coast, consists mainly of hard Scotland Sandstones, but the central hill (551 feet) has a capping of white Oceanic earth and there are still smaller patches on the two minor peaks to the northward.

The only other outlier that came under our notice is near Boscobelle, and is brought in by the same fault as that which carries the Oceanic Beds down to the sea-level at Grant's Bay, but it is separated from that area by a deep valley cut in the Scotland Sandstones.

(d) **Description of Beds at certain Localities.**—*Codrington.*—One of the most accessible localities from Bridgetown is the neighbourhood of Codrington College and Conset Bay, along the coast of which the railway is carried. In the siding which leads to the sugar-mill on the College estate, the basal beds of the Oceanic Series, heavy greyish-white chalky limestones, are seen resting upon the dark sandy clays of the Scotland Series, and dipping at about 8° W.N.W. The same beds are visible on the slope of the valley below the mill, and can be traced for about a quarter of a mile up the valley towards the College. The slope above consists of calcareous and siliceous earths, the latter pure white and of small specific gravity; while just below the College garden is an outcrop of a mottled yellowish-white marl, chalky, and containing foraminifera in fair abundance. There are also traces of soft reddish clay just below the coral-rock, by the College itself. The difference of level between the base and the College is probably 150 feet and the distance about 1000 feet, which, with a dip of 6°, will bring in 105 feet, so that the total thickness here may be 250 feet.

The railway-cutting which extends from the end of the Codrington siding to the northward shows a curious section; at its southern end there are beds of siliceous earth like those seen in the Codrington valley, dipping W.N.W. at 8°, and these continue for about a quarter of a mile, when at a place known as 'Burnt Hill' the dip suddenly increases to about 20°, and the white earth passes into a broken mass of black rocks saturated with petroleum. These broken beds continue for about 100 yards, when the petroleum disappears and the radiolarian beds resume their natural hue, dipping W.N.W. steeply at first, but gradually decreasing to an angle of 10°. Burnt Hill is evidently on a line of fault and fracture, for the Scotland Beds can be seen here and there at the base of the broken mass, and it is doubtless along the fault that the petroleum has risen to the surface. The tradition that this hill was once on fire is confirmed by the red and cindery look of the radiolarian rock at the top of the hill, some portions of it being actually vitrified.

About 150 yards north of Burnt Hill is a deep gully running in from the shore to the south-west, with very steep sides, which expose an excellent section of the Oceanic Deposits and show a thickness of about 70 feet. The beds are markedly stratified, and in the lower part consist of alternating soft and hard layers, the latter being 4 to 6 inches thick and occurring at intervals of 4 or 5 feet. The base is not seen, but the lowest beds are greyish white and calcareous, containing about 46 per cent. of calcium carbonate, and these are succeeded by less calcareous beds for about 20 feet; lying on these is a layer of hard, dark-brown, gritty marl, consisting largely of angular crystalline grains of felspar;[1] the next 10 feet consist of white siliceous radiolarian earth; and then comes a thin layer (3 to 4 inches) of grey sand, consisting entirely of broken crystals of felspar and powdered fragments of pumice. Many of the same broken crystals are scattered through the beds above and below these two

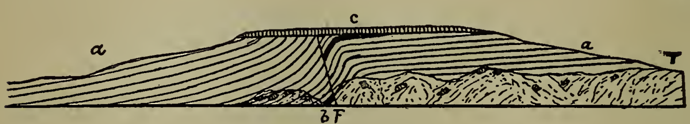
[1] This horizon is probably 70 or 80 feet above the base of the series.

gritty layers, imparting a gritty character to them. The beds dip uniformly W.N.W., the average inclination being 25°, though the angle seems to vary somewhat and there are a few small faults. Above the bed of grey sand there are white siliceous earths exposed for 30 or 35 feet.

Bath and Quintynes.—From this gully to the 16th milestone on the railway the exposures of the white earths are similar to the above, but the dip is less, about 8° or 10° W.N.W. At the 16th milestone the railway cuts through the side of a hill and shows a section of about 70 feet of radiolarian earths, capped by an outlying patch of coral-rock. At the southern end of this section the beds dip S.E. about 10°, but in a little distance this dip suddenly increases to 80° and the beds are cut off by a fault.

Fig. 2.—*Section along Railway near Bath.*

S.E. N.W.



[Distance: 145 yards.]

Horizontal scale: 40 yards = 1 inch. Vertical scale: 200 feet = 1 inch.

a. Siliceous earths. *b.* Brown layer. *c.* Coral-rock. T. Talus. F. Fault.

A brown gritty layer, like that in Conset Gully, is seen on both sides of the fault and proves its throw to be between 60 and 70 feet (see fig. 2). The Scotland Beds must be near the level of the line on the north-west side of the fault, but are concealed by the talus. They are, however, exposed over a small area of ground east of Quintynes.

The same portion of the Oceanic Series, including the brown layer, is exposed in the cutting north of this tract, where the beds dip at about 30° N.W.; and a little farther on is another cutting which shows an anticlinal curve in the same beds, with dips of 40° to S.E. and 30° to N.W.

Castle Grant and Chimborazo.—The Oceanic Deposits form a steep slope below the coral cliffs on Little Island and Castle Grant estates. At the opening of the deep gully which separates these two estates the coral-rock rests upon a soft, soapy, yellowish earth which looks like a marl, but is purely siliceous and entirely free from lime, whether combined as a carbonate or a silicate. A little lower down red, pink, and yellow earths, of a similar nature, can be seen in a pathway, and still lower a steep slope on Castle Grant estate shows the following succession :—

	feet
White siliceous radiolarian earth, with large globular concretions of bluish chert from 6 to 12 inches in diameter, about	20
Gritty beds, consisting of radiolarian débris mixed with mineral grains ; these beds include a layer of grey sand and one of brown marl..	10
Firm white calcareo-siliceous earth................. .... about	40

The base is not seen, for the boundary appears to be a fault, but a strong spring issues at or near their junction with the black bituminous clays of the Scotland Series. There have been many slips down the slope, but the true dip seems to be a fairly steep one, 12° or 15° to the south-east. The lowest beds seen yielded on analysis 57 per cent. of carbonate of lime, and are therefore more calcareous than the greyish beds near the base of the series by Conset Bay, though not so chalky as the basement-bed there ; we infer that they are about 20 or 25 feet from the base.

West of Castle Grant the cliff of coral-rock ends suddenly, the border of the coral retreating to the gully below Nicolls, and from beneath it rises a mass of red, pink, and yellow, soft argillaceous earth, which is purely siliceous though almost destitute of radiolaria.

Fig. 3.—*Section from Chimborazo to Castle Grant.*

[Distance one mile.]

a. Scotland Beds. *c.* Coloured clays.
b. White earths. *d.* Coral-rock.

These clays appear to have a thickness of about 40 feet, and are succeeded to the westward by the dark, sandy, bituminous clays of the Scotland Series, which thus rise to the top of the slope about 3 furlongs north-west of Castle Grant.

The yellow earths have the appearance of overlying the Scotland Clays by the road, but we believe they are faulted against one another (see fig. 3), for otherwise we cannot account for the white earths which underlie the coloured group everywhere else. The level of the outcrop of these red clays west of Castle Grant is about 1050 feet.

From this point the Scotland Beds form the whole of the main ridge and slope as far as Chimborazo Mill, the outcrops of the Oceanic Deposits being thrown back to the southward and forming a second escarpment of moderate height, capped by a low cliff of coral-rock.

Below Chimborazo House another fault brings in a greater thickness of the series, the base of the Oceanic Deposits lying some way down the northern and western slopes of the hill. The result of this and the Castle Grant fault has been to lift a block of the Scotland rocks to a high level between the two tracts of Oceanic Deposits (as shown in fig. 3). In the hollow where the fault runs there are red and yellow clays probably faulted in, but their occurrence shows that the total throw is about 240 feet.

The dwelling-house at Chimborazo stands on a small outlier of coral-rock, the surface of which is just 1100 feet above the sea; another knoll to the north of this, and only a few feet less in elevation, consists of dark red and yellow earths belonging to the argillaceous group of the Oceanic Series (20 or 30 feet thick) resting on white siliceo-calcareous earth, below which is purely-siliceous radiolarian earth.

The ridge connecting these knolls is traversed by a road, the cutting for which shows the following beds:—

	feet.
Whitish radiolarian earth, of small specific gravity	5
Bedded yellowish-white marl	4
Hard brown marl, slightly gritty	0½
Firm yellowish marl, with patches of small brownish particles	1½

All these beds contain radiolaria, and dip at 2° or 3° to the south-east.

The road on which this section is seen joins the main road that runs northward down the slope of the escarpment, and the cuttings for this show the middle and lower beds of the Oceanic Series down to the very base, the total thickness, including the Chimborazo section, being apparently about 250 feet.

In the highest part of the road-cutting there is greyish gritty earth, including a layer of bluish-grey sand about 5 feet thick, which examination has shown to be mainly pumiceous. Below this is whitish siliceous earth of small specific gravity, with some concentric ferruginous stainings and occasional pipings of a buff-coloured material; these beds include a thin layer of grey marl. The road then crosses a combe and passes by cottages where no section is visible, probably hiding the Castle Grant gritty beds. Opposite the Schoolhouse a cutting in the lower spur of the hill shows whitish and somewhat calcareous earth; just below this, where a road branches off, the basal beds, white, chalky, and heavy, are seen resting on dark sandy clay. This place is known as Melvin's Hill.

Canefield and Porey's Spring.—On the Canefield estate the basal beds are very chalky, containing 83 per cent. of calcium carbonate; they are quarried and are used by the coopers on this and other estates instead of imported English chalk. The higher slopes consist of siliceous earths, and the highest ridge on the neighbouring estate of Highland is capped by a mass of chocolate-red argillaceous earth. The Oceanic Deposits are exposed along the floor of the deep gully which cuts through the escarpment of the coral-rock between Canefield and Mount Misery, and can be seen at intervals as far as Porey's Spring, a distance of about a mile. Their continuity, however, appears to be broken by faults; the basal chalky beds are exposed by the side of a cross-road about a quarter of a mile from the top of the gully, but a little farther there is siliceous earth dipping to the N.N.W.

In the main road south of Porey's Spring there is white siliceous earth dipping to the N.N.W. at 4° or 5°, covered by coral-rock, and farther up the hill a little of the fine soft red clay comes in between the white earth and the coral, showing these to be the highest white earths, though they are here 300 feet lower than their level at Canefield.

Mount Hillaby.—As already stated on p. 202, the greater part of the Hillaby area lies between two nearly parallel faults with upthrows to the north, the beds themselves dipping to the N.N.W.; but the highest part of Mount Hillaby seems to be a faulted trough, which not only forms the highest ridge in Barbados, but contains a greater thickness of the Oceanic Series than is elsewhere preserved.

We found that an ascent from near Airy Cot, on the south side of the hill, gave us the best clue to its structure. Just north of the Schoolhouse, on the road to Airy Cot, a fault brings up the Scotland Sandstones, and Airy Cot Mill stands on them. North of and close by the Mill the chalky basal beds of the Oceanic Series come in at a level of about 905 feet, and they extend up the slope to about 940 feet; then come white siliceous earths with a moderate proportion of carbonates, passing up into purer siliceous earths which reach to about 1040 feet, with a N.N.W. dip; they must be over 100 feet in thickness. Above are siliceous beds with some calcareous matter reaching to 1070 feet, at which height an exposure shows four layers of grey felspathic and pumiceous grit alternating with layers of white radiolarian earth; the gritty layers vary from 6 inches to $2\frac{1}{2}$ feet in thickness, and the depth of the exposure is about 9 feet, while the dip is about 8° N.N.W.

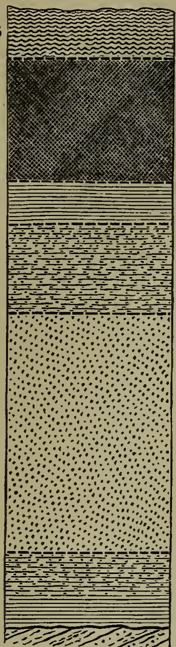
Above these come thick blocky beds of tough calcareous earth having the aspect of chalk, and these continue to the top of the southern peak at a height of 1095 feet. We took samples from this summit and from points at 5, 10, 20, and 30 feet below it. In some of these buff-coloured pipings occur, and small lumps of limonitic oxide of iron are not unfrequent here and elsewhere.

On the next peak to the north-east these chalky beds are covered by red and pink soft argillaceous earths like those of Castle Grant, and these also dip to the N.N.W. A sudden change of dip then takes place, owing doubtless to a fault, and the beds north-east of its course dip eastward. The northern parts of the hill show red earths dipping first E.S.E. and then east, and the path up to the highest peak (1104 feet) shows the top of these red clays dipping S.S.E. at about 60° and succeeded by some 25 feet of grey siliceous volcanic muds, the lower beds being finely laminated in dark and light grey layers, and including a layer of fine whitish clay about a foot thick. The highest beds are firm and blocky.

The same volcanic muds are found on the north-eastern peak, dipping E.S.E. at about 15°. The material of these beds is fine and firm, and sufficiently hard to be used locally for walling purposes, but near the top there is a thin layer ($1\frac{1}{2}$ inch) of coarse felspathic grit.

Passing westward and recrossing the line of fault, we came upon a mass of coloured clays, red, pink, yellow, and white, dipping as before to the N.N.W., but at a higher angle (about 40°), and a thickness of at least 50 feet of them could be measured.

The complete succession on Mount Hillaby we estimate as follows:—



		feet
6	Grey volcanic mudstones	25
5	Very fine-grained argillaceous earths, red, pink, and yellowish, often mottled	60
4	Chalky earths and marls	25
3	Calcareo-siliceous earths, with layers of pumiceous sand....................................	45
2	Pure siliceous radiolarian earths....................................	130
1	Calcareo-siliceous earths, passing down into chalky earths	40
	Scotland Beds.	325

Checking this by the dip and linear distance, we find the horizontal distance between the base and the south-western peak to be about 800 feet, and taking the average dip to be 6° this would bring in 84 feet, while the difference of level is 190 feet—the total amounting to 274 feet, compared with our estimate of 235 feet. The total thickness would in this way be increased to 359 feet, and may safely be considered as between 320 and 350 feet.

On the published map only one fault is drawn through Mount Hillaby, for the eastern slope is so obscured by slips and broken débris that its structure is uncertain. The base or limit of the white earths is fairly clear on the road to Mount All, but on the south-eastern slope it seems to run a long way towards Groves. At the time, we took the material seen near Groves to be the result of landslips ; but we are now inclined to think that much of it is in place, and that it lies outside a second fault which curves round to form the boundary-line along the north-eastern side of the hill (see Map, facing p. 202). It is difficult to understand the high dips of the central part of the hill without such a troughed piece as is shown in the sketch-section, fig. 4, p. 211.

In such a faulted trough, narrowing southwards, the strata at the narrow end are likely to be pinched and tilted, which will account for the much higher dips found at the south than at the north end of the hill, and it is very probable that the axis of the trough is inclined southward, which will explain the southerning in the E.S.E. and S.S.E. dips.

Fig. 4.—*Section through Mount Hillaby.*

S.W. N.E.

[Distance: one mile.]

a. Seotland Beds. *c.* Coral-rock.
b. Oceanic Beds. F. Faults.

Cleland and Farley Hill.—We did not find any good sections in the district below Spring Head or near Sedge Pond; but an excellent section is exposed in the next area, along the road which leads by Cleland to Farley Hill. South of Cleland, and at a place known as Cockcrow Rock, the base of the Oceanic Deposits can be seen resting on the Scotland Sandstones and consisting of a hard, splintery white limestone with a roughly conchoidal fracture; this bed is 12 to 15 inches thick, and is succeeded by a hard white chalky rock, which is about 5 feet thick and contains nearly 66 per cent. of carbonate of lime. Above this are 20 to 30 feet of calcareo-siliceous earth, and then thick beds of siliceous radiolarian earth. Near the top of the hill calcareous beds come in again, as at Mount Hillaby, the highest 10 feet consisting of some of the purest chalk in the island, samples of white chalk from here containing about 80 per cent. of carbonate of lime and enclosing many foraminifera. These beds are found just below the coral-rock. The total thickness is probably over 200 feet.

The dip near Cleland and Bredy's seems to be to the S.E., and consequently the base or boundary-line rises northward from Bredy's estate, where it is at about 300 feet, to a high level under Cherry Tree Hill. At the latter place the lower calcareous beds can be seen resting on Scotland Beds and dipping to the north-east; from the base of these to that of the coral-rock above the total thickness is not more than 40 feet, and a little farther north the Oceanic Beds disappear entirely beneath the coral escarpment, which then rests on Scotland Beds.

Grant's Bay.—North-east of St. Philip's Church the Oceanic Beds are brought in again by a fault, and extend thence to Grant's Bay, on the coast just south of the point called Pico Teneriffe. Schomburgk correctly states that this promontory consists of the 'Infusorial Earth,' but he does not mention its highly calcareous and chalky nature, the proportion of calcium carbonate in the lower beds being 73 per cent. These pass up into more siliceous earths, and about

100 feet are cut through in the valley south of the bay, exposures occurring at intervals. In the cliff at Pico Teneriffe about 50 feet are seen, the beds dipping at a low angle to the N.N.E., and underlying a plateau of coral-rock, the base of which gradually slopes northward till it reaches the sea in Gay's Cove.

Bissex Hill.—The deposits which form this outlier present some interesting local peculiarities. A good section is afforded by the cutting for the road that is carried up the southern face of the hill. On this the usual chalky basement-beds occur at a level of 765 feet, passing up into greyish-buff calcareo-siliceous beds in alternating hard and soft courses. The beds dip into the hill at an angle of 5° or 6°; and the brown gritty layer, which occurs about 80 feet up in the series, crosses the roadway about 30 feet vertically above the level of the base. Above this, white siliceous beds continue for some distance, but about 140 feet (vertically) above the base a hard bluish-grey limestone more than a foot thick occurs in the bank and weathers out in large blocks, some of which have been carried up to the hill-top and used both for building and for road-metal. Above this again siliceous earths can be seen for about 10 feet; but the higher part of the hill is covered with a yellowish granular marl, with layers and concretionary lumps of harder yellowish granular marlstone, which prove to consist entirely of foraminifera and chiefly of *Globigerinæ* loosely compacted by a calcareous cement.

The highest knoll or summit,[1] on which the flagstaff is placed, consists of firm foraminiferal marl, or what might be called a soft marlstone, and the surface of this is covered with blocks of hard yellowish fossiliferous limestone. These blocks are of all lengths up to about $2\frac{1}{2}$ feet, and as they were found to consist chiefly of foraminifera we supposed that they had been originally embedded in foraminiferal marl of a similar character to that which forms the base of the knoll.

Subsequently, however, we felt some doubt about this point, and asked Mr. G. F. Franks, F.G.S., to obtain further information for us. This he kindly did, sending us a fresh set of specimens, and in one of these we detected what appeared to be fragments or pebbles of a previously consolidated rock. This specimen was sent to Mr. W. Hill, F.G.S., who reports that our surmise is correct, the included fragments consisting of an indurated foraminiferal marl or chalk, like those which occur so generally in the Oceanic Series.

The mass of the rock consists of the tests of foraminifera embedded in crystalline calcite, and consequently when a small slice is seen under the microscope it much resembles the *Globigerina* marlstone above mentioned, but there is a greater variety of foraminifera, and fragments of the plates and spines of echinoderms are seen here and there. These differences are more conspicuous in a hand-specimen, the shining surfaces of the broken echinoid

[1] [The remainder of this description of Bissex Hill has been re-written.—Feb. 16th, 1892.]

plates and spines giving it a different aspect, while in some of the blocks casts of turbinate corals are abundant.[1]

It would appear, therefore, that these blocks are the broken remnants of a stratum which once capped the hill, and that the rock is of later date than any part of the Oceanic Series. The limestone blocks are partially embedded in a loose crumbling marl, but a sample of this received from Mr. Franks proves to be a material quite different from that *in situ* below and similar to that of the limestone, for it contains a variety of organic fragments such as small joints of *Pentacrinus*, echinoderm spines, and broken (? pteropod) shells, all more or less worn and rolled, while *Globigerinæ*, though abundant, do not make up more than 20 or 25 per cent. of the mass.

This crumbling marl may have resulted from the disintegration of the limestone, but, however this may be, it certainly is not a true Oceanic Deposit. We regard it and the associated limestone as equivalents of the foraminiferal muds hereafter described (p. 215), which occur at several localities between the Oceanic Series and the coral-rocks; for if this capping of Bissex Hill does not belong to the Oceanic Marls on which it rests it must be unconformable to them, all the red-earth group and the volcanic muds of Mount Hillaby being absent on Bissex Hill.

The summit of the hill is 190 feet above the point where the base of the Oceanic Series occurs, and about 700 yards in horizontal distance from it; in this distance a dip of 5° would bring in a thickness of about 60 feet which, added to the 190 feet of vertical difference, gives a total thickness of 250 feet for the portion of the series here preserved.

Mr. Franks also writes to us that he has found the hard grey siliceous limestone exposed in two places, by the road which runs along the north-eastern slope of the hill towards Bissex Estate House. Here there are several layers of it alternating with greyish white earth, and near one exposure a bed of fine, dark grey sandstone appeared, probably the representative of the pumiceous sand at Chimborazo.

On the extreme northern spur of Bissex Hill, half a mile beyond the Estate House, another limestone occurs, apparently at the very base of the Oceanic Series. This is a hard, compact blue limestone, smoother and bluer than the upper one, and forms a continuous bed some 3 or 4 feet thick, which weathers to a yellowish buff where exposed to the air. This bed can be traced for a little distance, dipping N.E. by N., and it appears to rest on the Scotland rocks.

Small outliers of siliceous earth occur at Cambridge to the E. and near Hopewell to the N.W., but do not present any features of special interest.

Comparing the sections we have now described with one another,

[1] We understand from Mr. Franks that it was from this limestone that the echinoderm described by Mr. Gregory as *Archæopneustes abruptus* was obtained. The *Scalaria* figured by Sir R. Schomburgk probably came from the same rock.

we consider that the foraminiferal marl at Codrington, the calcareous foraminiferal beds at the top of Bissex Hill, the calcareo-siliceous marl at Chimborazo which contains some foraminifera, the similar beds below the red clays on Mount Hillaby, and the highly calcareous marl of Farley Hill above Cleland, are all on the same horizon. If this is so, the white-earth group everywhere shows the same gradual passage upwards from chalky foraminiferal beds at the base to siliceous radiolarian earth, and again from this back to chalky foraminiferal marl or limestone. Above these last are the red and mottled clays, and finally the highest grey earths and volcanic muds of Mount Hillaby.

We also recognize two horizons of brown gritty marl: one between 70 and 80 feet from the base, seen at Conset Bay and in cuttings on the railway, at Bissex Hill and at Castle Grant; the other at a much higher horizon, as exposed in the road-cutting by Chimborazo. There are moreover two bands of grey pumiceous sand, one between 80 and 90 feet from the base, seen at Conset Gully and Castle Grant, and another near Chimborazo and Mount Hillaby, nearly 100 feet higher up in the series.

There is another conclusion which may be fairly deduced from the preceding stratigraphical observations, and that is with respect to the layers of hard limestone which occur in certain localities at the bottom of the Oceanic Series. We think the facts clearly show that these are portions of the chalky earths, which have been locally converted into limestone through the infiltration of calcite by water that has percolated through some length and depth of the calcareous earths.

Our observations on the beds *in situ* and our analyses of them in the laboratory induce the belief that some of them have been largely altered by the action of water, and that some of the more siliceous varieties of the deposit have had their silica percentage increased by the abstraction of the carbonate of lime which was originally present. At Springfield, for instance, there is a small outlier which consists wholly of siliceous earth, although the horizon is that of the lower calcareo-siliceous earths. Wherever also the Oceanic earths have been reached below the coral-rock, they are always found to be more or less altered by the passage of water. There are only three localities where solution and re deposition of the organic silica seem to have taken place to any extent, viz. Springfield, Cleland Hill, and Castle Grant, at all of which a free passage of water takes place.

§ 6. Detrital Deposits of intermediate date between the Oceanic Series and the Coral-rocks.

In 1890 Mr. E. Easton, C.E., sent us a set of specimens which had been obtained from beneath the coral-rock area, some from shafts and borings, and some from subterranean watercourses. Most of them are earthy marls composed chiefly of inorganic materials; but three of them are foraminiferal muds, and one is a foraminiferal limestone.

We did not recognize the existence of such intermediate deposits when we were in Barbados, and we do not think that they anywhere attain a thickness of more than 10 or 12 feet. From the facts now known to us we believe that they rest on different parts of the Oceanic Series, and probably in some places on the Scotland Beds.

We consider them to have been formed by the action of currents gently washing over the surface of the earlier deposits, when a general upheaval of the area had brought this surface to within a depth of 400 fathoms. They may have been formed in any depth between this and 50 fathoms, but they afford no evidence that any part of the bank was within the limit of coral-growth. The following descriptions are condensed from reports by Mr. W. Hill and Miss Raisin.

(1) **Foraminiferal Muds.**

Bath, 130 *feet.*—A yellowish clay. This clay appears to consist of fine felspathic material and minute crystals of calcite ; the whole is in a state of very fine subdivision. A good many *Globigerinæ* are to be seen in the thin section.

Bath, 132 *feet.*—From a boring on the Bath estate, S.W. of the Mill. A greenish clay. This is practically a foraminiferal deposit in which *Globigerina* is the predominating form. There is, however, a large amount of inorganic material. Miss Raisin says of this specimen : "The calcite is in very minute crystals ; felspathic material is largely present, but a few distinct fragments of larger felspar (and also what is probably quartz) can be recognized."

Cole's Cave, 60 ft. below the gully-floor.—A greenish earthy marl similar to the last, but with fewer foraminifera. Of the inorganic material Miss Raisin remarks : "The rather larger mineral chips are more numerous, and can be recognized as broken crystals and fragments of clear felspar."

Several examples of foraminiferal volcanic muds from the west coast of Java and from the Solomon Islands were kindly supplied by Dr. H. B. Guppy and compared with the Barbados deposits. None agree in character with the Oceanic foraminiferal or radiolarian earths.

But one of them from "4 miles inland on the W. coast of Java" compares to a certain extent with the foraminiferal mud of Cole's Cave. Both consist largely of inorganic material, which for the most part is probably felspathic, and in both there are many *Globigerinæ*. But in the Java specimen the inorganic matter is coarser ; there occur pumice and volcanic glass, neither of which can be recognized in the greenish earth of Cole's Cave ; nor is there in either of these specimens a preponderance of the minute calcite-crystals which is a feature in the two other foraminiferal muds of Barbados. It is singular that in two deposits which have much in common there should occur a stellate form of crystalloid somewhat similar in appearance to fig. 2 (p. 178), but differing from this in having the bifid extremities of the rays acutely pointed.

One other mud from "Sirwana, Bantam Coast," bears some resemblance to the Cole's Cave deposit, in the character of the inorganic material, which, as before, is coarser. Foraminifera, of which *Globigerina* is the preponderating form, are more abundant; but there are several other species, and the aspect of the whole suggests that it is a shallow-water deposit.

(2) **Foraminiferal Limestone.**

Rock Dundo.—From 44 feet below the floor of the gully, in a shaft made for the Water Supply Company. This is a semi-crystalline foraminiferal rock, white, but not very hard. When examined under the microscope it appears to combine some of the characters of a chalky Oceanic earth and a granular *Globigerina*-marl with others which seem to indicate much shallower water. *Globigerinæ* are abundant, but other forms, including *Amphistegina*, which abounds in the coral-reef rocks, are present. There is, however, an entire absence of the other organic fragments which distinguish coral-reef rocks.

We consider this to be one of the detrital earths, and the probability is increased by the existence of a green clay which came from the same shaft and which we examined in Barbados; its organic contents appeared to be chiefly radiolaria encrusted with crystalline growths of quartz or calcite.

The base of the coral-rock in this shaft is between 38 and 40 feet below the gully-floor; the green clay came from about 40 feet, at 41 feet there was white earth, and the limestone above described at 44 feet.

(3) **Calcareous Earths and Marls.**

From a boring at Lightfoot's; depth from surface, 130 feet.
From Harrison's Cave, 25 feet below the gully-floor.
From a boring at Cane Garden in St. Thomas, depth 110 feet.
From a boring in the gully north-east of Plumtree, three specimens from depths of 69, 70, and 80 feet.

The samples from the first three localities and that from 80 feet down at Plumtree are of a similar nature, being all fine greenish earths consisting mainly of minute calcite-crystals and fine felspathic material. Calcite predominates at Lightfoot's and at Harrison's Cave, felspathic material in the other two. Miss Raisin remarks that "the calcite is in minute rhombohedra; rather large angular fragments of felspar (up to 4 mm.) occur in two of them, and in one slide (Cane Garden) a few very small chips of brown glass. A black opaque mineral, apparently iron-pyrites, occurs abundantly in scattered spots all over the slides, sometimes in perfect cubes, sometimes in the form of granules or minute nodular clusters."

As regards organic remains, Mr. Hill found a few radiolaria in the slide from the Lightfoot's sample, but no foraminifera in any of them. In the Plumtree Gully sample (80 feet) there are many coccoliths and stellate crystalloids like those described on p. 178. Around some of the latter calcite has crystallized in such a manner as to obliterate the original form. Many are quite free from this peculiarity, but it is quite easy to trace in a number of examples the gradual growth of calcite until an irregularly-shaped minute calcite-crystal is produced. On the coccoliths also a deposition of calcite has taken place.

The specimen from Plumtree Gully at 69 feet appeared to be a concretionary nodule of exceedingly fine, white calcareous earth, exhibiting concentric rings of dark brown colour. That from 70 feet is a white marly clay, consisting largely of minute calcite-crystals with very fine, probably felspathic material.

§ 7. Notes on the existence of similar Deposits in other West Indian Islands.

(a) *Trinidad.*—Beds of white radiolarian earth occur in the Naparima district, near San Fernando, on the western side of Trinidad. Their existence has been known for some time, but little information with respect to their geological position and relations has been forthcoming.

Messrs. Wall and Sawkins made a geological reconnoissance of Trinidad in 1860, and the results were published in a Geological Report with map and sections. They describe the Tertiary strata which occupy a large part of the island under the name of the 'Newer Parian Formation,' and distinguish five groups to which they give special names, lettering them A, B, C, D, E, as if they were successive stages in this formation. It appears, however, from the map and from their general section through the island (plate i.) that the 'Older Parian' (Cretaceous) Series forms an anticlinal ridge, crossing the island from west to east, and having an area of Tertiary rocks both on the south and on the north side, and further that the first two groups occur only on the north side and the other three groups only on the south side of the central ridge.

On the section the beds on the north side are underwritten 'first (upper) member of the Tertiaries (*Caroni* formation)' and 'second member of the Tertiaries (*Tamana* formation);' while on the south side the *Naparima* formation is marked as 'corresponding to the second member of the Tertiaries,' and the *Moruga* formation as 'corresponding to the upper member of the Tertiaries.' The *Nariva* formation is called 'the third member of the Tertiaries,' and it would appear therefore that they regarded it as older than the Tamana Group, but they remark that its relation to the 'Older Parian' was not ascertained and that it was not recognized on the north side of the anticline.

From the above statements it is clear that the rock-groups described and named by Messrs. Wall and Sawkins were mainly geographical, and that they were uncertain about their equivalency.

In 1866 Mr. Lechmere Guppy described the coast-section at San Fernando [1] as consisting chiefly of asphaltic clays, shales, and marls inclined at a high angle to the south; he regards them as belonging to the same group as the Tamana and Manzanilla Beds on the north of the Cretaceous 'divide,' referring them all on general grounds to the Lower Miocene, and regarding the Caroni and Moruga Series as Upper Miocene.

In a later paper Mr. Guppy writes:—"The late discoveries (of bitumen, &c.) added to my own observations make it seem probable that the Nariva Series of the Government geologists is the equivalent, on the south side of the central range, of the Caroni carbonaceous series on the north." [2] This paper is accompanied by a diagram to show the general succession of the Trinidad strata, in which the Tamana and San Fernando Beds are referred to the Eocene, the Caroni, Nariva, and Naparima Beds to the Miocene, and the Moruga Series to the Pliocene. He does not, however, specially deal with the relations of the Naparima Marls, and on our applying to him in 1889 he was unable to give us any further information about them, except that they are not exposed in the coast-section at San Fernando.

Prior to this, one of us had been over part of the Naparima district and had seen the white radiolarian marls exposed in road-cuttings. They appeared to succeed and overlie a great series of clays and sandstones which much resembled the Scotland rocks of Barbados, and as the dip of the marls in the sections seen was very slight, and much less than that of the clays and sandstones, we conclude that the former rest unconformably upon the latter. More recently our friend Mr. G. F. Franks, F.G.S., visited the same district and obtained for us samples of the marls from several localities; he also is of opinion that they rest unconformably on the older deposits, though whether these belong to the Nariva Series or to the San Fernando Beds he could not ascertain.

We think, therefore, that the line between the so-called Miocene and Pliocene of Trinidad will in all probability have to be drawn at the base of the Naparima Marls, and that when the real succession and the exact relative age of the Trinidad Tertiaries are ascertained the age of the Oceanic Deposits of Barbados will thereby be determined.[3]

Examination of the samples obtained from the Naparima district showed them to be similar in every respect to the Barbados earths. Analysis proved some to be mainly siliceous, with only 30 per cent., while others are calcareo-siliceous, with 40 per cent. of calcium carbonate. Slides prepared from them showed that these earths contain radiolaria and diatoms in abundance, the number of the latter being greater than is usual in the Barbadian earths.

[1] Quart. Journ. Geol. Soc. vol. xxii. p. 571.

[2] Proc. Scient. Assoc. Trinidad, 1877, part xi. p. 113.

[3] The discovery of *Nucula Schomburgki* in the San Fernando Beds by Mr. Guppy naturally suggested the probability of their being of the same age as the Scotland rocks of Barbados. He therefore refers the latter to the Eocene.

The following are analyses of three of the Trinidad samples:—

	Philippine Estate.	Hermitage.	Cedar Grove.
Combined water	2·38	4·62	2·11
Crystalline silica, &c.	1·38	4·05	1·47
Colloid silica	19·66	41·15	41·56
Clay	26 38	15·36	15·16
Iron peroxide and alumina	5·64	3·31	4·10
Manganese peroxide	·32	·44	·82
Calcium carbonate	40·50	29·46	31·82
Calcium sulphate	·18	·09	·28
Calcium phosphate	trace	trace	trace
Lime	1·22	1·11	1·50
Magnesia	2·34	·41	1·18
Alkalies	traces	traces	traces
	100·00	100·00	100·00

(b) *Hayti.*—Slides of washed radiolarian earth purporting to come from Port Jérémie in Hayti are on sale by European dealers. We have procured (and examined) several such slides from different persons, and find them all similar to one another and much resembling similarly prepared material from Barbados, but we cannot obtain information regarding the deposit from which they have been procured.

(c) *Jamaica.*—The White Limestone of Jamaica has been mentioned in the first part of this memoir, and some reasons were given for thinking that it is not a single formation as represented in the Reports of the Geological Surveyors (1869),[1] but comprises at least two limestones of different origin and age.

The descriptions of the Surveyors generally recognize two divisions in the White Limestone: a lower portion consisting of bedded limestones interstratified with marls, and an upper series of more massive limestones. The lower beds often contain nodules of flint, while the upper do not; on the other hand remains of mollusca, corals, and echinoderms appear to be more abundant in the upper beds. It should have been stated that the specimens of limestone from the counties of Manchester and St. Elizabeth which were examined by Mr. W. Hill and found to resemble coral-limestones were from the upper beds; while the rock obtained by Col. Feilden from Hanover County was almost certainly from the lower beds, inasmuch as he informs us that flints were abundant in it. This rock is identified by Mr. Hill as an oceanic limestone similar to the calcareous earths of Barbados, but altered and indurated by calcification. The flints are said to resemble those from the English Chalk.

With respect to the age of the White Limestone the reports of the Surveyors are inconsistent with one another; in some (as on pp. 23 and 149) it is spoken of as Miocene, in others as Pliocene (pp. 129, 301), and in the Tabular View at the end of the volume it

[1] 'Report on the Geology of Jamaica,' by Messrs. Sawkins, Barrett, and others, Mem. Geol. Survey, 1869.

is labelled 'Post-Pliocene.' Mr. Barrington Brown, however, to whom we wrote on the subject, informs us that this last reference was a mistake; that during the course of the Survey and before the fossils were examined there was naturally much uncertainty with respect to its age, but it was finally intended to class it as Pliocene, because it was found to rest on a fossiliferous yellow limestone which was considered by Mr. R. Etheridge to be of Miocene age, and probably late Miocene.

An observation of Prof. Gabb's[1] has an indirect bearing on this point: after stating that the Miocene strata of San Domingo have yielded over 300 species of fossils, including nearly all that have been found in Jamaica, thereby establishing the identity of the formation in the two islands, he says "the present collections have so materially changed the correlation between the fossil and living faunæ that it is necessary to do the greater part of the work over again." He finds there are 217 extinct and 97 living species, the proportion of living forms being between 30 and 33 per cent., which is higher than Lyell's estimate of the proportion in the Miocene of the Loire. He was therefore inclined to regard the beds as Pliocene, but the presence of several antique types prevented him from taking this step; and he agrees with Mr. R. Etheridge in placing the Jamaica and San Domingo beds, together with the Caroni formation of Trinidad, in the upper or later division of the Miocene.

This is doubtless the true place of the Jamaica yellow limestone, for Lyell's estimate is now known to be too low, and recent researches make it probable that the proportion of living species in the Faluns of the Loire is from 30 to 40 per cent. This being so, it is clear that the overlying White Limestone Series cannot be older than early Pliocene.

Besides the White Limestone there are in Jamaica deposits of raised pteropod ooze which are thus described by Mr. Lucas Barrett ('Geology of Jamaica,' p. 82):—"A remarkable fossiliferous marl occurs on the south coast of St. Thomas-in-the-East, on the east coast by Manchioneal, and on the north coast of Portland near Port Antonio, often forming elevations 300 feet high. It is characterized by a peculiar assemblage of organic remains, consisting of pteropoda, a few bivalve and univalve mollusca, with some gigantic foraminifera. It is evident that the deposition of this marl took place at a considerable depth . . . this is confirmed by the result of some dredging I had on the north coast, where from the depth of 150 to 200 fathoms the dredge brought up the whole of the mollusca and foraminifera I had before collected from this marl. This shows that since the deposition of this stratum, which is of Pliocene age (for deep-water mollusca have a greater range in time than shallow-water species), the coast has been elevated at least 1200 feet . . . It was this elevation that impressed the physical features, the coast-lines, littoral mountain-ridges, and parallel fissures on the east coast of Jamaica, modifying the effect of previous disturbances and illustrated by

[1] Trans. Amer. Phil. Soc. 1881, n.s. vol. xv. p. 99.

subsequent elevations occurring along the same great physical lines; for marine strata more recent than the Pteropod marl are inclined at a high angle, and overlain unconformably by still newer marine strata."

The marine strata referred to in the last sentence are in all probability the lower beds of the White Limestone Series, and it would appear that Mr. Barrett thought these were newer than the pteropod marls, but no proof of superposition is given. The same is the case with some extensive deposits of white chalky marl which occupy low ground, and often abut against the White Limestone; but the final opinion of the Surveyors with respect to both these and the pteropod marls seems to have been that they are post-Pliocene, or in other words Pleistocene. Clearly there are many interesting questions in the geology of Jamaica which are awaiting further investigation, and the mutual relations of these white marls and limestones is not the least important of them.

[(d) *Cuba.*—When this paper was read, Mr. J. W. Gregory was able to announce, from the examination of rocks he had obtained from Baraçoa in Cuba, that radiolarian earths existed in that island; he finds them to be similar in structure and mode of occurrence, and also in their calcareo-siliceous varieties, to those of Barbados.—Feb. 16th, 1892.]

§ 8. Changes in the Physical Geography of the Caribbean Region during Tertiary time.

In Part I. of this memoir we made some remarks on the physical geography of the Caribbean region during the formation of the raised coral-reefs, and we expressed our opinion that the period of upheaval indicated by these reefs was preceded by a time when there was free communication between the Atlantic and Pacific Oceans. It would doubtless have been better if we could have presented our evidence of a great submergence first and dealt with that of a subsequent elevation in the second place, but circumstances obliged us to reverse the natural order of things and to treat of the coral-reefs first.

Now, however, that we have given the evidence for our statement that the final upheaval of the region was preceded by a profound submergence, we are in a position to urge our views still more strongly, and we can at the same time support them with some futher collateral evidence.

In considering the general question of the physical history of the region during Tertiary time we are quite aware that the data at present available are insufficient for anything more than an indication of the greater physical changes which took place in that time. We are also aware that the Barbadian sequence is incomplete and must be supplemented by evidence from other islands. If the Scotland Beds are the equivalents of the San Fernando Beds of Trinidad and if the Oceanic Series is of Pliocene age, there is an unrepresented interval filled in other islands by the important group of deposits which is referred to the Miocene.

The Barbadian sequence, however, taken by itself furnishes us with valuable historical material. It is not like that of certain Pacific islands where Oceanic Deposits are the oldest stratified rocks and no base other than volcanic rocks has yet been found. Barbados has a history that is anterior to the Oceanic episode ; its great series of sandstones and clays testify to the close proximity of a large land-area in early Tertiary time, and the existence of similar terrigenous deposits in Trinidad, Hayti, Cuba, and Jamaica may be taken as strong evidence that there was at that time continental land in the Caribbean region. In Jamaica the Eocene Series alone is estimated at 2500 feet, and it consists of shales, sandstones, and trappean conglomerates which show that a large area of land was undergoing detrition.

Our view of Caribbean geography therefore starts with a period of shallow water and with conditions that appear to have been continental, but we do not think that the present hydrographic contours of the Caribbean Sea afford any clue to the trend or outline of this early Tertiary land.

In Trinidad and San Domingo these conditions seem to have been maintained during Mid-Tertiary time, but in Jamaica there was submergence allowing a large area and a considerable thickness of yellow limestone and marl to be accumulated. This subsidence was certainly continued during the formation of the succeeding White Limestones, which in many places overlap and extend beyond the yellow limestones. Some of these Pliocene white limestones are of oceanic origin, though their extent and thickness are at present unknown. The white foraminiferal limestone of San Domingo which caps the highest Miocene beds [1] may possibly be of the same age, and we have already stated that we regard the Oceanic Deposits of Barbados and Trinidad as belonging to the same period of geological time.

It is therefore in the Pliocene period that we find proofs of a very deep submergence of the whole Caribbean region ; for it will be borne in mind that Jamaica is 1100 miles west of Barbados, that Jamaica itself is 150 miles long, and that its western end is only 400 miles from the nearest point of Central America, while the western end of Cuba is only 130 miles from Yucatan ; hence it is very probable that the submergence which produced oceanic conditions in Jamaica extended also to Central America, and we shall be surprised if deep-water marls and limestones of Pliocene age are not eventually found in that region.

It is known that both in Panama and Nicaragua there are Tertiary marine deposits of various dates. Prof. Agassiz informs us that the fossils obtained by Dr. Maack at heights between 300 and 763 feet on the Isthmus of Darien are of Miocene age, and that he mentions *limestones* near Empire Station on the Panama Railroad which are filled with such fossils ; [2] but he also obtained post-

[1] Gabb, in Trans. Amer. Phil. Soc. 1881, n.s. vol. xv. p. 103.
[2] Pub. Doc. Navy Dept. U.S.A. 1144, vol. v. pp. 155–175.

Pliocene fossils at a height of 150 feet along the line of rail from Panama. In Nicaragua there seems to be a nearly complete series of Tertiary deposits flanking the central range of highlands,[1] including beds which are referred to the Pliocene.

[We are informed by Mr. John Hughes, F.C.S., that deposits of white siliceous and calcareous earth occupy considerable areas in Guatemala. He has given us a sample of the former which proves to consist entirely of diatoms and sponge-spicules.

Extensive deposits of diatomaceous earth have recently been discovered in South California. They are described by Dr. A. M. Edwards,[2] of Newark, U.S.A., who informs us that they extend from Monterey, south of San Francisco, where they are associated with foraminiferal marls, to beyond San Pedro. The diatoms in them are similar to those in the celebrated Richmond earth, and it is quite possible that they are of Pliocene age, though hitherto referred to the Miocene.]

Although more evidence is required, all that is known favours the conclusion that Central America is now a very much higher and more connected tract of land than it was at any period of Tertiary time and that there has been upheaval during Pleistocene time.

It is satisfactory to find that on this point we are really in accord with Prof. A. Agassiz. In Part I. of this memoir we quoted certain passages from 'The Three Cruises of the Blake,' the meaning of which we took to be that in Prof. Agassiz's opinion the complete separation of the Atlantic and Pacific Oceans by the elevation of the Isthmus took place at the close of Cretaceous time. From a letter with which he has recently favoured us we find that we misunderstood him, and what he meant to convey was that a freer communication between the two oceans had existed in Cretaceous than in early Tertiary time, and that the ridging up of the sea-floor which eventually led to their separation *began* in Eocene time. Mentioning the Cretaceous deposits of the southern part of the Isthmus, he writes : "I merely assumed that this connection was quite extensive and must have continued from that time more or less uninterruptedly nearly to the present time, and that during that time the Gulf Stream must have passed over the Isthmus of Panama, or a great part of it, into the Pacific......I concluded in a general way that the separation of Atlantic and Pacific commenced at some time late in Cretaceous or early in Tertiary time, and was absolute only in the latest Tertiary or comparatively recently. The district affected extended from the Isthmus of Tchuantepec to and including the northern part of South America (Colombia), but I had no intention of stating that the separation was complete at first."

We have quoted Prof. Agassiz's letter because on re-perusing the passages referred to we still think they seem to bear the construction we put upon them, and it is therefore the more needful that the author's meaning should be explained.

The opinion has been expressed that unless the Isthmus was very

[1] J. Crawford, Brit. Assoc. Rep. 1890, p. 812.
[2] Am. Journ. Sci. vol. xlii. (1891) p. 369.

deeply submerged the bulk of the Gulf Stream water would still be deflected instead of passing through the opening. As the Gulf Stream is a surface-current, and its depth where crossed by the 'Challenger' in May 1873 was ascertained to be 100 fathoms, it seems safe to conclude that a fairly wide gap 600 feet deep in the centre would be sufficient to give it passage. But we think it highly probable that the depth of water over parts of Panama, Costa Rica, and Nicaragua was much more than 100 fathoms. Some of the Pliocene limestones of Jamaica may well have been formed in 400 to 500 fathoms, and as they have been raised to levels of between 2000 and 3000 feet above the sea they may be taken to indicate an upheaval of from 4800 to 6000 feet (800 to 1000 fathoms). If anything like this change occurred also in Central America very little of it could have been above the sea-level in Pliocene time, for very little of it is now 1000 feet above that level.

Our belief that there was free communication between the Atlantic and Pacific at a late period in Tertiary time is strengthened by the very nature and contents of the raised Oceanic Deposits. Radiolarian ooze is at the present time specially characteristic of the tropical parts of the Pacific Ocean. It occurs chiefly between the depths of 2300 and 2900 fathoms, but as both red clay and *Globigerina*-ooze occur at the same depths its formation is clearly dependent on other conditions besides those of depth and surface-temperature. The fact that these three different kinds of oceanic ooze all occur in the Pacific and replace one another at these depths suggests that the Oceanic Deposits of Barbados which include the same three varieties were formed in water of about the same depth (2000 to 3000 fathoms), and strongly supports the view that the Caribbean Sea was then as much a part of the Pacific as of the Atlantic Ocean.

It may fairly be asked, however, how this could be if at that time the Atlantic Equatorial current traversed the Caribbean Sea and set into the Pacific. Would not the organic deposits of this sea be still likely to have an Atlantic aspect? To this it may be replied that the Equatorial current would doubtless pass over the southern part of Central America, south of the high plateau of Guatemala, and that there would probably be an incurrent stream from the Pacific over the Isthmus of Tehuantepec bringing Pacific water into the Gulf of Mexico and the Antillean area. This would introduce the radiolaria which now swarm in the Pacific, and they would doubtless flourish in the warm waters of the intra-American Seas.

At the present time, though the greater part of the Caribbean Sea is over 2000 fathoms deep, no radiolarian ooze is found upon its floor. The deposit now accumulating in this sea is a *Globigerina*-ooze of a reddish-brown tint, while in the shallower waters around the Caribbean islands a white pteropod ooze is the usual deposit. Both often contain radiolaria, but never in any considerable quantity.

These facts show how great a change has taken place in the physical conditions of the region, and they are in accord with all the other available evidence. When the upheaval which set in during Pleistocene time had finally shut out the Pacific waters, Atlantic types gained the mastery in the Caribbean Sea and have to a large extent replaced the older Antilleo-Pacific fauna.[1]

Discussion.

The Chairman said that, since the late Dr. Brady wrote on the "so-called Soapstone of Fiji," there had been no communication on the subject of oceanic deposits of such importance as Mr. Jukes-Browne and Prof. Harrison's paper, which dealt with them from a physical, chemical, and biological point of view. In both cases the deposits were held to be of late Tertiary age, and this conclusion made the excessive depths at which the Barbados earths were supposed to have been deposited all the more startling. Possibly the species of *Archæopneustes* described by Mr. Gregory might point to shallower waters.

Dr. Blanford regretted that a diagram-map of the West Indies had not been hung in the meeting-room. He asked for further evidence as to the red clay being a deep-sea deposit. The mammalian fauna of South America, as he had pointed out on a previous occasion, could not be explained unless North and South America had been united at times during the Tertiary era. Turning from these minor points he congratulated the Authors on having conclusively answered the challenge thrown down to geologists some years ago, to produce true deep-sea deposits that had been raised above the sea-level. If it was urged that Barbados was on the edge of the oceanic area, the same remark would assuredly not apply to Jamaica. The discovery in Barbados of both *Globigerina*- and radiolarian ooze intercalated between shallow-water deposits was clear evidence that portions of the continental area might be depressed to oceanic depths and re-elevated.

Prof. Sollas congratulated the Authors on the strength of their case. It could no longer be put forward as an assured fact that deep-sea deposits never enter into the constitution of land-masses. Still, the evidence of the excessive depths claimed by the Authors did not amount to demonstration; it was of the nature of analogy, which was sometimes misleading. It was to be hoped that additional fossils of the Metazoa would be discovered in the chalky beds. A vastly larger number of observations are required to define the bathymetrical limits of a species or group than in many cases we at present possess. Striking exceptions to general rules are numerous enough to give us pause; even so characteristically a deep-water

[1] For confirmation of the extent to which the faunæ of the Pacific and Caribbean waters still resemble one another, see, as regards mollusca, P. P. Carpenter, Brit. Assoc. Rept. for 1856, p. 363: as regards echinoderms, Verrill and A. Agassiz, quoted by Sir Wyville Thomson, 'Depths of the Sea,' p. 13; and as regards deep-water animals, letters on 'Dredging Operations off the West Coast of Central America,' Bull. Mus. Comp. Zool. vol. xxi., Cambridge, U.S., reprinted in 'Nature,' Jan. 21st, 1892.

group as the Hexactinellida has afforded one instance of a comparatively shallow-water species, *Cystispongia superstes* having been dredged from 18 fathoms off Yucatan.

Prof. HARRISON pointed out, in answer to Dr. Blanford's remarks, that the evidence upon which the red and mottled argillaceous earths of the Oceanic Series were considered by Mr. Jukes-Browne and himself to be deep-sea deposits was the close resemblance in physical properties and chemical composition which they present to certain of the modern deep-sea oozes which have been termed 'red clays,' and that the only organisms found in them were purely siliceous, being principally the remains of radiolaria with a few sponge-spicules. The 'clay' occurring in the pure radiolarian marls was also separated, and upon comparison was found to be similar to the argillaceous earths. The term 'red clay' appears to have been used in the 'Challenger' Expedition Reports in a very comprehensive manner, as under it are included not only argillaceous deposits containing but few organisms, but also deposits consisting in some cases of radiolarian, and in others of foraminiferal organisms.

Mr. J. W. GREGORY remarked that, as the new echinoid occurred in a limestone at the extreme top of the Oceanic Series, it in no way disproved the deep-sea origin of the radiolarian marls. He fully agreed with Dr. Blanford in doubting any considerable submergence of the Isthmus of Panama in Upper Cainozoic time; Dr. Maack's collection proved only an Eocene or Miocene submergence, and the surveys of Lieut. Wyse and the French engineers of the Canal had not revealed any considerable elevation of the recent marine deposits. He exhibited specimens of radiolarian marls from Cuba, which were identical in characters, variation, and mode of occurrence with those of Barbados, and he maintained that this completed tho Authors' case, and disproved the objection that had been advanced that these deep-sea deposits only occurred on the margin of a volcanic area.

Mr. W. HILL drew attention to the contents of the calcareous earths and their resemblance to modern chalky oozes.

17. *The* Olenellus Zone *in the* North-west Highlands of Scotland.

By B. N. Peach, Esq., F.R.S.E., F.G.S., and J. Horne, Esq., F.R.S.E., F.G.S. (Read February 10th, 1892.)

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[Plate V.]

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While tracing the various subdivisions of the Durness Series of quartzites and limestones from Sutherland southwards into Ross-shire, careful attention has been paid to any indications of fossiliferous zones which might throw additional light on the age of the strata. During last season's campaign, certain sections in the Dundonnell Forest happily furnished the evidence which has been eagerly sought after.

§ 1. Physical Features of the Dundonnell Forest.

Between Little Loch Broom and Loch Maree the members of this series traverse one of the wildest tracts in the west of Ross-shire. The Dundonnell Forest lies mainly to the south of the head of Little Loch Broom, stretching southwards by An Teallach (3483 ft.) to Loch an Nid and Creag Rainich (2646 ft.). The southern portion of the Forest is drained by the Loch an Nid river, which, finding its source in the loch of that name, flows northwards for about three miles towards the shooting-lodge of Achneigie. The river is bounded on the east for part of this distance by a precipitous crag (1000 ft. high), and on the west by the long dip-slopes of quartzite and Torridon Sandstone of Sgurr Ban (3194 ft.) and Ben a Chlaidheimh. Near Achneigie the river bends towards the north-west, soon pouring its waters into Loch na Sheallag. From this loch issues the Gruinard river, discharging into Gruinard Bay.

The sections from which the fragments of *Olenellus* were obtained occur along the eastern slope of the valley drained by the Loch an Nid river, between Loch an Nid and Achneigie. Though there is here conclusive evidence of the continuation of those terrestrial displacements described in a former communication to this Society,[1] the area is comparatively free from those extreme complications

[1] 'Report on the Recent Work of the Geological Survey,' &c., Quart. Journn. Geol. Soc. vol. xliv. (1888) p. 378.

so characteristic of the region between Assynt and Loch Eriboll. Owing to the admirable exposures on the mountain-slopes and to the well-nigh continuous sections in some of the streams the relations of the strata are clearly displayed.

§ 2. General Geological Features.

In this portion of the Dundonnell Forest the basal quartzites rest with a marked unconformability on the Torridon Sandstone, which is admirably defined on the dip-slopes of Sgurr Ban and Ben a Chlaidheimh. Bed after bed of the underlying Torridon Sandstone is transgressed by the pebbly grit at the base of the quartzites. Here, as elsewhere, the evidence plainly demonstrates that, prior to the deposition of the quartzites, the older rocks were elevated, gently inclined, and subsequently worn down to a great plane of marine denudation (see fig. 2, p. 233).

From the base of the quartzites there is an unbroken sequence, in certain sections, either to the 'Serpulite Grit' or to the basal bands of the Durness Limestone. At these horizons the fossiliferous strata are truncated by a powerful thrust, which, at Loch an Nid, brings forward a slice of Archæan rocks with the Torridon Sandstone and basal quartzites, forming one of the striking geological features of the district. The fragments of *Olenellus* were discovered in the undisturbed area to the west of this important structural line.

§ 3. Allt Righ Ian Section.

The locality where the fossiliferous dark blue shales in the 'Fucoid Beds' were first observed while mapping this part of the Forest, and where portions of *Olenellus* were first found by Mr. Macconochie, occurs in a small stream on the eastern side of the valley, joining the Loch an Nid river about half a mile to the east of Achneigie. Rising in the drift-clad plateau formed by the eastern schists, the Allt Righ Ian furnishes, in the lower part of its course, a continuous section of certain members of the Durness Series. From the materials brought down during heavy floods a great cone has been formed at the mouth of this burn on the right bank of the river.

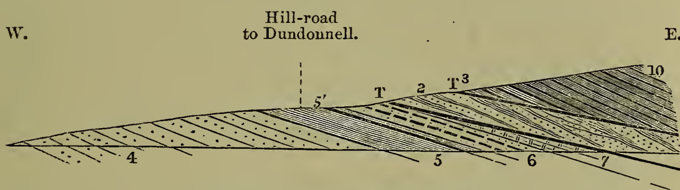
Joining the burn at the head of this cone, the passage-beds between the basal quartzites and the overlying 'Pipe-Rock' are exposed. Ascending the section, all the various sub-zones of the 'Pipe-Rock'[1] are met with, followed in regular order by the 'Fucoid Beds.' Here the burn has cut a small gorge in the brown dolomitic shales and bands of rusty dolomite forming the lower part of this zone. Just above the point where the burn is crossed by the hill-road between Dundonnell and Achneigie, the upper portion of the 'Fucoid Beds' is seen. Owing to a slight fall in the slope of the ground, the stream has carved for a short distance above the

[1] See Vertical Section II. of Durness Series, Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 406.

mountain-path a broader channel, which is partly filled with gravel, particularly after a heavy rainfall. For this reason the higher members of the zone are not so well exposed.

At this part of the section the attention of the observer is at once arrested by two prominent bands of dark blue shale, intercalated in the normal dolomitic beds of the zone. The upper band is about 3 feet and the lower one about 9 feet from the top of the 'Fucoid Beds.' Some of these dark blue shales are slightly calcareous and are traversed by small worm-casts. The fragments of *Olenellus* were found in the lower band, the best specimens being confined to a seam less than an inch thick.

Fig. 1.—*Section in Allt Righ Ian, from the base of the 'Pipe-Rock' to the Moine thrust-plane.*



[Length of section=400 yards.]

2. Thrust Torridon Sandstone.
4. 'Pipe-Rock.'
5. 'Fucoid Beds.'
5'. *Olenellus* Zone in 'Fucoid Beds.'
6. 'Serpulite Grit.'
7. Basal Bands of Durness Limestone.
10. Eastern schists.

T. Glen Logan Thrust. T^3. Moine Thrust.

The upper limit of the 'Fucoid Beds' is well defined, the base of the 'Serpulite Grit' forming a small cascade over which the stream leaps on to the softer beds below. Along certain lines, the higher zone, which here consists of a massive grit, is crowded with *Serpulites Maccullochii* (*Salterella*) in splendid preservation.

From the base of the 'Pipe-Rock' to the highest visible portion of the 'Serpulite Grit,' the strata have a persistent dip to the south of east at an average angle of 16°; the total thickness of beds amounting to 400 feet.

The normal sequence of the Durness Series is here interrupted by a powerful thrust, already referred to as one of the striking geological features of the district, which brings forward a thin wedge of Torridon Sandstone, through which the stream has cut a small gorge. Though changed in tint and considerably crushed, this mass can be readily identified after a careful study of the geological structure of the region. When traced southwards in the direction of Loch an Nid, this slice of Torridon Sandstone increases in thickness and is seen to rest unconformably on undoubted Archæan rocks. Within a short distance to the east, in Allt Righ Ian, the crushed Torridon

Sandstone is truncated by the Moine Thrust which ushers in the Eastern Schists.

§ 4. Sections north of Allt Righ Ian.

Immediately to the north of Allt Righ Ian the strata between the higher zones of the 'Pipe-Rock' and the basal bands of the Durness Limestone are admirably displayed in several important stream-sections. They are of special interest from the excellent exposures of the *Olenellus* shales and from the organisms found in the dolomitic bands associated with the dark blue shales. No fragments of trilobites have as yet been found in these sections, partly owing to the difficulty of following the fossiliferous layer along the line of outcrop.

One of these streams (unnamed on the six-inch map) rises on the moory watershed between Allt Coire Chaorachain (draining into Strath Beg) and Strath na Sheallag. About a mile to the north of Allt Righ Ian it is crossed by the hill-road leading to Dundonnell, whence it flows southwards for ⅔ mile, where it is joined by a small tributary (Allt a Chip). Here the main stream is deflected to the south-west, joining the Loch an Nid river near the mouth of Allt Righ Ian.

Ascending Allt a Chip from the point of junction with the main stream, where the lowest sub-zone of the 'Pipe-Rock' is seen resting on the basal quartzites, an excellent section is exposed in the sides of a small gorge. The various sub-zones of the 'Pipe-Rock' are overlain by the 'Fucoid Beds,' the two bands of dark blue shale occupying their respective horizons near the top of the zone and separated by the normal dolomitic beds. Here their thickness can be accurately measured on the sides of the chasm; that of the upper being 3 feet and the lower 19 inches. A layer of rusty dolomite about a foot thick, overlying the lower band of dark blue shale, was found to be crowded with excellent specimens of *Hyolithes*, sp.

Returning to the main stream of which Allt a Chip is an affluent, the observer crosses a similar succession of strata as he follows the section towards the watershed. Here again both layers of dark blue shales are visible near the top of the 'Fucoid Beds,' the upper one cropping out at the base of a small waterfall formed by the overlying 'Serpulite Grit.' A few yards below this latter locality numerous serpulites (*Salterella*) were observed in a brown dolomitic band associated with the *Olenellus* shales. Crossing the 'Serpulite Grit' there is an excellent exposure of the basal bands of the overlying Durness Limestone, forming a prominent cliff on the east bank of the stream about 300 yards to the south of the point where it is traversed by the hill-road leading to Dundonnell. Here the top of the 'Serpulite Grit' passes below black shaly limestone, 4 feet in thickness, succeeded by 15 feet of dark mottled limestone. The black limestone-shales, weathering with a brown tint, are slightly cleaved, but they are crowded with splendidly-preserved specimens of *Serpulites Maccullochii* (*Salterella*) which are readily seen on the weathered surfaces. These beds forming the base of Group I. of the Durness Limestone Series[1] are truncated by the thrust traversing Allt Righ Ian, bringing forward a wedge of Torridon Sandstone which is here only 15 feet thick.

§ 5. Sections near Loch an Nid.

The locality where the trilobites were found in the zone of the 'Serpulite Grit' is near Loch an Nid, about eight miles to the N.N.E. of Loch Maree.

For nearly two miles to the north of Loch an Nid, the quartzites form prominent escarpments on the eastern side of the valley and rise to a height of several hundred feet above the level of the stream. Ascending the rocky slope to the horizon of the highest zones of the 'Pipe-Rock' the observer finds a narrow belt of bright-green grassy ground, formed by the surface-soil of the décomposing 'Fucoid Beds' and partly covered with morainic matter. The overlying 'Serpulite Grit' gives rise to a more or less continuous escarpment, disappearing at intervals underneath a thin coating of drift or surface-soil. At this level the attention is at once arrested by a conspicuous geological feature, forming one of the great structural lines on the eastern side of the valley. By means of a powerful thrust a slice of Archæan rocks, covered unconformably by the Torridon Sandstone and basal quartzites, is made to overlie the members of the Durness Series. This line of disruption, which is the northern continuation of the well-known thrust-plane in Glen Logan near Kinlochewe, can be traced with remarkable precision along the mountain-slope east of the Loch an Nid river. The materials immediately overlying the thrust-plane form a prominent cliff, over which, after a heavy rainfall, numerous rivulets leap on to the members of the Durness Series. Many of these streamlets are not indicated on the six-inch Ordnance map, but they are of especial importance, on account of the excellent sections of the strata close to the line of displacement.

Immediately to the north of Loch an Nid there are three small streams traversing this escarpment of disrupted gneiss. The first of these is about 250 yards distant from the northern shore of Loch an Nid; after crossing the Glen Logan thrust-plane it descends a grassy slope to the underlying quartzites, joining the river below a fine waterfall near the mouth of the loch. As this stream is indicated on the six-inch Ordnance map, it forms a base-line for measuring the distance to the section which now falls to be described.

About 200 yards north of the above-mentioned rivulet there is a small section of especial interest at the base of the escarpment of displaced Archæan gneiss. It traverses the 'Serpulite Grit' and the top of the 'Fucoid Beds,' the underlying strata being concealed

[1] See our Report on the Geology of the North-west of Sutherland, 'Nature,' vol. xxxi. p. 31.

by materials carried down during heavy floods and by morainic matter. The following vertical section, measured with an Abney level, is exposed in the small escarpment cut by this streamlet.

		feet.	inches.
Zone of 'Serpulite Grit.'	Grey quartzose grit	18	—
	Flaggy grits, with intercalated shales	7	—
	Grey shales	1	—
	Dark blue shales containing *Olenellus*	0	8
	Grey grit	2	—
	Dark grey shales	1	6
	Grey quartzite	7	3
Top of 'Fucoid Beds.'	Brown dolomitic shales, with bands of dark shales	5	3

In the dark-blue fossiliferous shales we obtained a head-shield and other fragments of *Olenellus* in fine preservation. These shales are underlain by grey grits and quartzites forming the lower portion of the escarpment of the 'Serpulite Grit.' When traced southwards along the hill-slope, the upper and lower ledges of quartzose grit coalesce and form a prominent escarpment overlying the 'Fucoid Beds.'

About 100 yards to the south of the foregoing section, a fragment of *Olenellus* was found by Mr. Macconochie in a dark shale in the 'Fucoid Beds,' exposed in a streamlet not far below the cliff of disrupted gneiss.

For nearly ½ mile to the north of Loch an Nid, the 'Serpulite Grit' is overlain by a few feet of the basal bands of the Durness Limestone, forming the lower plane or 'sole' of the Glen Logan thrust. The limestone is not visible in all the streamlets within the foregoing limits, but where it is exposed and not much altered by the displacement of the overlying materials, serpulites (*Salterella*) occur in fine preservation.

The geological structure of the disrupted masses overlying the Glen Logan thrust-plane along this portion of the Loch an Nid Craig is of absorbing interest. But the description of these complications is foreign to the main object of this paper. It is sufficient for our present purpose to state that these displaced masses are abruptly truncated at a higher level by the Moine thrust, which forms the second great structural feature of this magnificent crag.

§ 6. Comparison of the Zones of the Durness Series, exposed in the Dundonnell Forest, with their Prolongations to the North and South of that Region.

The discovery of *Olenellus* in the 'Fucoid Beds' and 'Serpulite Grit' suggests certain interesting questions regarding the probable variation of the subdivisions of the Durness Series along the belt between Loch Eriboll and Strome Ferry. One striking result of the tracing of the various zones from Sutherland southwards into Ross-shire is the remarkable persistence of the sub-zones identified in Assynt and at Loch Eriboll.

Beginning with the basal quartzites (from 200 to 300 feet in thickness) they preserve the same character along the whole line. They consist of flaggy false-bedded grits and quartzites, with occasional

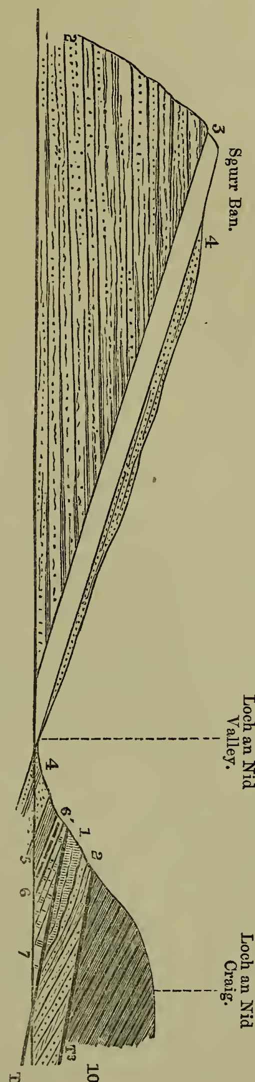


Fig. 2.—*Generalized Section from Sgurr Ban to Loch an Nid Craig.*
[The complications between the Glen Logan and Moine thrust-planes are omitted.]

[Length of section = about 3 miles.]

1. Archæan Gneiss.
2. Torridon Sandstone.
3. Basal Quartzite.
4. 'Pipe-Rock.'
5. 'Fucoid Beds.'
6. 'Serpulite Grit.'
6'. *Olenellus* Zone in 'Serpulite Grit.'
7. Basal bands of Durness Limestone.
10. Eastern schists.
T. Glen Logan thrust-plane.
T^3. Moine thrust-plane.

partings of shale, which are destitute of those worm-casts so characteristic of the overlying zone. One exception seems to have been found to this apparent absence of organic life. In the course of last season one of us observed along the crest of the ridge between Sgurr Ban and Ben a Chlaidheimh, on the west side of the Loch an Nid valley, vertical worm-casts in a band of quartzite belonging to this zone. In the Ben Eay Forest, south of Loch Maree, certain dark grey shales, which may probably yield organic remains at some future time, occur near the base of the series.

The overlying zone of 'Pipe-Rock,' from 250 to 300 feet thick, displays in the Dundonnell Forest the five sub-zones so typical of this subdivision in Assynt and the regions northwards to Loch Eriboll.[1] They have been traced southwards through the mountainous region south of Loch Maree towards Loch Kishorn. The sub-zones are based on the peculiar features of the vertical burrows in the quartzite, which are probably due to different species of errant annelids.

At the top of the third sub-zone on Ben Arkle, Sutherlandshire, numerous examples of *Serpulites Maccullochii* (*Salterella*) were observed in massive quartzite free from the vertical worm-burrows. A band possessing the same lithological characters, and occupying the same relative position, has been noted in certain sections in Assynt and to the south of Loch Maree, but hitherto it has yielded no serpulites.

The 'Fucoid Beds,' varying from 50 to 80 feet in thickness, are remarkably uniform in character when traced along the belt southwards from Loch Eriboll. Consisting mainly of brown dolomitic shales with bands of rusty dolomite, they are traversed by numerous worm-casts, usually flattened and resembling fucoidal impressions, a resemblance which misled the older observers. But between Little Loch Broom and Loch Kishorn dark blue shales near the top of the zone have been observed at various localities evidently occupying the same horizon as the *Olenellus* Shales in the Dundonnell Forest. Our colleague, Mr. Gunn, has traced these dark blue shales across the *col* from Strath na Sheallag into Allt Gleann Chaorachain, towards Strath Beg. They have been observed in Glen Logan, near Kinlochewe, and on Meall Giubhais to the south of Loch Maree. Another officer of the Geological Survey, Mr. Lionel Hinxman, has also detected them at the top of the 'Fucoid Beds,' in the thrust-area that occupies the pass between Glen Kishorn and Tulloch in Strath Carron. It is not improbable that the *Olenellus* Shales may yet be traced continuously through a great part of Ross-shire.

Of special interest is the occurrence of *Serpulites Maccullochii* (*Salterella*) and *Hyolithes*, in fine preservation, in brown dolomitic bands associated with the *Olenellus* Shales near the top of this zone.

Along the boundary-line between the 'Fucoid Beds' and the overlying zone of 'Serpulite Grit,' from 25 to 40 feet thick, there is frequently an alternation of false-bedded grits and shales, evidently the passage-beds from the one horizon to the other. This intermediate series is conspicuously developed in the Loch Eriboll region, and it has been observed to a more limited extent in Ross-shire. Near the crest of the zone the quartzites merge into carious dolomitic grit

[1] See Quart. Journ. Geol. Soc. vol. xliv. (1888), p. 406.

crowded with *Serpulites Maccullochii* (*Salterella*) and traversed by vertical worm-burrows, projecting as long pipes, several inches in length, on weathered surfaces.

The small development of the Durness Limestone represented in the Dundonnell Forest belongs to the base of the Ghrudaidh Group. The bands immediately overlying the 'Serpulite Grit,' are richly charged with serpulites like the corresponding beds in the Eriboll sections, a sub-zone which has been recognized along the whole line from Eriboll to Loch Kishorn.

The appearance of serpulites (*Salterella*) on these various horizons ranging from the 'Pipe-Rock' to the basal limestone, and their association with *Olenellus* in the 'Fucoid Beds' and 'Serpulite Grit' lead us to cherish the hope that portions of *Olenellus* may yet be found in certain shales in the quartzites and probably in the lowest group of limestone.

§ 7. Conclusions drawn from the Discovery of *Olenellus*.

The evidence now adduced proves (1) that the 'Fucoid Beds' and 'Serpulite Grit' are of Lower Cambrian age, the quartzites forming the sandy base of the system; (2) that the Torridon Sandstone, which is everywhere separated from the overlying quartzites by a marked unconformability, is pre-Cambrian.

§ 8. Description of Fossil Remains.

Of the organic remains obtained from the dark shale-bands mentioned in the former part of this paper, fragments of trilobites are the most abundant, and the portions most commonly met with are their carapaces.[1]

From a collection of over fifty specimens there are only three that show any other recognizable part of the animal. One is a body-segment, either the first or second; another, from its greatly developed recurved pleural spine, may be referred to the third segment; while the remaining one appears to be a portion of a styliform telson.

The form of the carapaces, the arrangement of the glabella, the palpebral lobes and eye-slits, the cheek-spines, and the absence of any true facial suture, indicate that these remains are referable to the genus *Olenellus* and to that section of it characterized by *O. Thompsoni* of Hall.

With the exception of a few portions of a large species too fragmentary for description all the remains may be ranked under one species, which however shows a considerable range of individual variation.

The fragments of body-rings and telson above alluded to appear to belong to different individuals and cannot be referred to any one

[1] [In the present paper I use the term 'carapace' for that portion of the test of the trilobite which is homologous with the shield bearing the eyes and covering the six pairs of limbs in *Limulus, Scorpio, Slimonia, Eurypterus,* and *Pterygotus*.—B. N. P., Feb. 26th, 1892.]

of the numerous carapaces found, yet all the fragments are marked with a similar surface-ornamentation. This consists of a network of finely-raised lines enclosing polygonal flat-bottomed depressions. Further, the collection affords carapaces of the dominant species of the proper size to fit these other fragments. The presumption therefore is in favour of the opinion that all these remains belong to members of one species. It is to be hoped that a further search will yield us sufficient material to clear up this point and will also afford us the means of describing the larger species, the remains of which at present in our possession seem to indicate that its carapace sometimes attained a breadth of six inches. The thanks of the Authors are due to Mr. Charles D. Walcott, Prof. Brögger, and Prof. Lapworth for valuable assistance in directing them to the literature bearing upon the subject of *Olenellus*.

Genus Olenellus, Hall, 1862.

Before entering on the detailed description of the fossils, it may be fitting to state the view as to the subdivision of the genus adopted in this paper; it is practically identical with that of Walcott as given in his 'Fauna of the Lower Cambrian or *Olenellus* Zone,'[1] which is as follows:

I. *Olenellus* to be restricted to such forms as have the character istic Olenellid carapace and styliform telson, the type of which is *O. Thompsoni*, Hall, and including the species *O. Gilberti*, Meek, *O. Iddingsi*, Walcott, and *O. Walcotti*, Schaler and Foerste.

II. *Mesonacis*.[2] To include those forms with Olenellid carapace, Paradoxidean pygidium, and with greatly produced spines upon the central lobes of one or more of the body- or abdominal segments. Type:—*Mesonacis vermontana*, Hall, including *M. asaphoides*, Emmons, and *M. Mickwitzi*, Schmidt.

III. *Holmia*.[3] To include those forms that have the Olenellid carapace with Paradoxidean pygidium, and a row of spines down the centre of the axis of the body-rings and the occiput, the occipital spine being often greatly elongated. Type:—*Holmia Kjerulfi*, Holm, including *H. Bröggeri*, Walcott, and *H. Callavei*, Lapworth.

It is in this restricted sense that the generic term *Olenellus* is here used.

Olenellus Lapworthi, nov. spec. Pl. V. figs. 1–11.

Carapace in a general way semicircular, but varying in different individuals, from the length being sometimes more and sometimes less than half the breadth. On the dorsal aspect it is

[1] Tenth Annual Report U.S. Geol. Survey, 1888–1889, pp. 633–635.
[2] Walcott, Am. Journ. Sci. vol. xxix. (1885) p. 328, figs. 1 & 2.
[3] Matthew, Trans. Roy. Soc. Canada, vol. vii. sec. 4 (1889), pp. 135–162.

margined on the front and sides by a raised border, rounded off outside and separated from the cheeks and frontal area by a depression. This border is narrow, but varies in breadth in different individuals, being nearly twice as wide in some as it is in others. In all it is widest nearest the postero-lateral angles and gradually diminishes in front towards the middle line, being about one third narrower in front than behind. At each of the postero-lateral angles the carapace is continued into a long strong spine, directed backwards and slightly outwards. The spine also varies in different individuals, being longest and strongest in the most elongated forms. On an average the spine measures about two thirds of the length of the carapace.

The posterior margin is concave and divided into three areas, viz. a central one coinciding with the boundary of the occiput, and two side wings. Each of these latter has a thickened border, which begins narrow at the edge of the occipital ring, widens out gradually for $\frac{3}{4}$ of its extent, and then suddenly tapers off just before reaching the cheek-spine, from which it is cut off by a wide and shallow notch. No tubercle or rudiment of a spine is observable at the angle where the band bends into the notch.

The cheeks and the frontal area are continuous, rising gently and evenly from the depression bordering the marginal fold; but since the fossils are preserved in shale and are in consequence somewhat compressed, there is no means of finding out from them the amount of original convexity. The glabella and eye-lobes rise steeply out of the combined genal and frontal area, the external or visual wall of the eye-lobes being almost vertical.

The glabella is club-shaped, rounded in front, and widest where the eye-lobes merge into it just in front of the foremost furrow. From this point it tapers very gradually backwards; it is crossed by three furrows, each of which begins at the outer margins, passes forward, and suddenly bending round upon itself, passes inwards and backwards to meet its other half in the middle line. Each furrow is deepest at the two angles and shallowest at the middle line. A fourth, the occipital furrow, crosses from side to side with a straighter course than the others, though it is still bent backwards a little in the middle line. As a consequence of this arrangement of furrows the anterior portion of the carapace is cordate; the three succeeding lobes are M-shaped, and the occipital ring, which is large, is deeper at the sides than in the middle line. The occipital ring bears a short rudimentary spine or tubercle in the middle line, near its posterior margin.

The eye-lobes are crescent-shaped and are more than $\frac{1}{3}$ the length of the carapace. Anteriorly they merge with the glabella just in front of its first furrow. Thence they extend backwards and slightly outwards, and end at a point a little behind the occipital furrow and a considerable distance from the edges of the occipital ring.

The exterior margin of the orbit is steep, and from its crest the test sinks more gently inwards to the general level of the head.

The visual portion of the eye occupies the greater part of the steep outer edge of the crescent, and though no actual remnant of the visual membrane has been preserved, the place it once occupied is represented by a narrow crescent-shaped slit with rounded extremities, which describes a curve of about one third of a circle. This is margined by a thickened ridge or pseudo-palpebra. The inner or anterior canthus of the eye is a little wider and more rounded than the outer or posterior. The eye-lobe and the edge of the glabella almost enclose a portion of the test which stands up in the form of a gently-swelling elongated boss. No trace of a facial suture is observable on the dorsal aspect of any carapace that we have studied.

On the underside of some specimens the *doublure* is shown and is always a little wider than the dorsal marginal ridge. The suture along the external edge of the *doublure* has not been observed, but this may be because the specimens are not sufficiently well preserved to show it. No trace of the facial suture has been found where it cuts the posterior margin in *Paradoxides*, though the specimens were favourable for its observation. The hypostome has not been observed.

A table of measurements of several carapaces of O. Lapworthi *is here given to show the amount of variation in form:—*

	M 2473d, fig. 1.	M 2468d, fig. 2.	Sg. 1. fig. 3.	M 2472d, fig. 4.	M 2476d, fig. 7.	M 2502d.
	mm.	mm.	mm.	mm.	mm.	mm.
Length along middle line .	16	16·5	18	15	9	8
Breadth just in front of genal spines	28	35	40	25	18	14
Distance between inner canthus of eyes............	8	10	11	5		
Distance between outer canthus of eyes............	11	14	12	8		
Length of genal spine......	...	10	...	8		
Breadth of margin in front of genal spine	1·25	1·5	3	2		
Breadth of margin near middle line	·45	1	1	1·5		

The figures at the top of the columns in the above table apply to the numbers of the specimens in the books of the Geological Survey of Scotland.

Though no body-segment has been found attached to any one of the numerous carapaces, yet the presumption is in favour of the opinion that the remains of segments and the telson already mentioned belong to this species.

The first or second body-segment (Pl. V. fig. 9) consists of a central lobe 7 mm. wide by 1·5 mm. deep. The left pleuron is best preserved, and is 8 mm. by 1·5 mm. deep. It is continued in the same straight line as the axis of the central lobe, and is strengthened on both margins by a thickening, the anterior one being the stronger; it ends in a short pleural spine bent backwards at nearly a right angle to the pleuron. A groove passes obliquely from the angle made by the anterior margin with the edge of the middle lobe to the postero-lateral angle. No tubercle is seen on the middle lobe.

A body-segment with central lobe, 7 mm. long by 3 mm. deep, with left pleuron attached 7 mm. long (Pl. V. fig. 10), curves off into a greatly elongated pleural spine 15 mm. in length. A similar groove to that already described crosses the pleuron obliquely and is continued into the spine. From the great length of the spine it is probable that this is part of the third body-segment. No other segment has been observed.

Telson.—A portion of a styliform telson 12 mm. long, with an articular surface 5 mm. wide at the anterior end and 4 mm. wide at the broken extremity, is preserved as an isolated fragment on a slab with the remains of this species (Pl. V. figs. 11 & 11 *a*).

On every portion of the upper surface the test is ornamented by a network of raised lines which enclose polygonal spaces (Pl. V. fig. 2 *b*). The nature of this ornament is the same throughout, but the pattern is varied according to position—the spaces becoming more elongated towards the lateral margins. In the present species it is most pronounced upon the medial lobes of the glabella, where it can be seen by the use of a strong lens. On an average three of these spaces measure about one millimetre.[1]

The above description shows that the present species is very near to *Olenellus Thompsoni* of Hall. It differs from that species in being smaller, in the glabellar furrows crossing the glabella, in their general arrangement, and in the presence of a rudimentary mesial spine on the occipital ring.

From *O. Gilberti* it differs in the posterior angle of the palpebral lobes being removed from the edge of the glabella, and from *O. Iddingsi* and *O. Walcotti* in the form of the carapace.

It is named after Prof. Chas. Lapworth, F.R.S., who has done so much towards the elucidation of our older Palæozoic rocks and who was the first to prove the existence of *Olenellus* in our own country.

Among the *disjecta membra* of Olenellid trilobites from the dark shales above described are certain portions of the carapaces of a much larger species than that described. Two of these fragments allow of the part of the animal to which they belong being made out. The first, represented in Pl. V. fig. 12, natural size, is part of the left angle of a carapace with the genal spine. It bears a broad marginal band, and the genal spine is short and broad. The width of *doublure* is also indicated by the bulge its inner margin causes by being com-

[1] An ornamentation similar to this has been described by Walcott as occurring in *O.* (*Mesonacis*) *asaphoides*, Emmons, and also in *O.* (*Holmia*) *Bröggeri*, and by Schmidt in *O.* (*Mesonacis*) *Mickwitzi.*—Dr. Hicks, in his article on 'The Fauna of the *Olenellus* Zone in Wales' in Geol. Mag. for 1892, p. 21, mentions the occurrence in the St. David's rocks of fragments of a trilobite which 'show a reticulated ornamentation.' These fragments he ascribes to *Olenellus.*

pressed against the carapace, and shows that it is wider than the dorsal marginal band. No trace of an 'interocular' spine of Foord is seen on the posterior margin. The chief value of this fragment is to show that the characteristic ornamentation is on so large a scale as to be apparent to the naked eye. The elongation of the pattern on the marginal rim is also very distinctly shown (Pl. V. fig. 12 *b*), and reminds one very much of the characteristic markings of the *Asaphidæ*.

Portions of test with this characteristic ornamentation, which must have belonged to even larger individuals, occur in the collection; but they are too fragmentary to allow of their being located with accuracy.

The fossils, other than trilobites, that have as yet been obtained from these dark shales are chiefly remains of pteropods, among which a *Salterella* like *S. pulchella* occurs. Several species of *Hyolithes* also occur, together with a flattened curved tube resembling the *Helenia bella* described by Walcott. One specimen of a large Entomostracan, near to *Aristozoe rotundata*, is also found in the collection.

We may be allowed to suggest that the elongated pleural spines, together with the enlarged third segment so pronounced in some species of *Olenellus* and *Paradoxides*, are in some way connected with the genital apparatus, and they may be sexual. This may account for their being sometimes present and sometimes absent in the same species.

One word of speculation as to the systematic position of the Olenellids may be admissible here. The absence of facial sutures suggests that it is from this group that the Limuloids branch off. The ornamentation, the styliform telson, and the small number of body-segments in *Olenellus* proper appear to indicate a close relationship to the Merostomata through such forms as *Stylonurus* and *Eurypterus*. *Olenellus* therefore seems to form a central point upon which the more modern trilobites, the Limuloids, and the Merostomata converge.

EXPLANATION OF PLATE V.

Fig. 1. *Olenellus Lapworthi.*—Carapace, nat. size. From 'Fucoid Beds,' Allt Righ Ian, Dundonnell, Ross-shire. M 2473^d.

Fig. 2. *O. Lapworthi.*—Carapace, nat. size. M 2468^d.

Fig. 2 *a*. *O. Lapworthi.*—Counterpart, nat. size, of fig. 2. Allt Righ Ian.

Fig. 2 *b*. *O. Lapworthi.*—Ornamentation of surface of carapace, enlarged.

Fig. 3. *O. Lapworthi*, nat. size, from 'Serpulite Grit' near Loch an Nid, Ross-shire.

Fig. 4. *O. Lapworthi.*—Carapace showing underside, nat. size. 'Fucoid Beds,' Allt Righ Ian. M 2472^d.

Fig. 5. *O. Lapworthi.*—Carapace, nat. size. M 2482^d.

Fig. 5 *a*. *O. Lapworthi.*—Carapace enlarged, shows glabellar furrows and surface ornamentation. 'Fucoid Beds,' Allt Righ Ian.

Fig. 6. *O. Lapworthi.*—Portion of carapace, nat. size. 'Fucoid Beds,' Allt Righ Ian. M 2479^d.

Fig. 7. *O. Lapworthi.*—Portion of carapace, nat. size. 'Fucoid Beds,' Allt Righ Ian. M 2476^d.

Fig. 8. *O. Lapworthi.*—Portion of carapace, nat. size. 'Fucoid Beds,' near Loch an Nid. M 2517^d.

Fig. 9. *O. Lapworthi.*—? First or second body-segment, nat. size. 'Fucoid Beds,' Allt Righ Ian.
Fig. 10. *O. Lapworthi.*—? Third body-segment, nat. size. 'Serpulite Grit,' near Loch an Nid.
Fig. 11. *O. Lapworthi.*—Fragment of telson, nat. size. 'Fucoid Beds,' Allt Righ Ian. M 2479[d].
Fig. 11 *a.* Counterpart of fig. 11.
Fig. 12. *Olenellus,* sp.—Fragment of carapace, nat. size. 'Fucoid Beds,' Allt Righ Ian.
Fig. 12 *a.* Counterpart of fig. 12.
Fig. 12 *b.* Ornamentation from margin of fig. 12, magnified.
Fig. 13. *Olenellus,* sp.—Fragment of carapace, nat. size. Conjectural restored outline to show probable position of part preserved. 'Fucoid Beds,' Allt Righ Ian.

The numbers M 2473[d], etc., refer to the List-books of the Geological Survey of Scotland.

Discussion.

Dr. Hicks was much pleased to find that the interpretation of the succession in the older rocks of Scotland now given by the Authors agreed entirely with the views which he had advocated for so many years, not only as applicable to Wales, but generally to the British Isles, and to most of the continent of Europe. In a map of Europe published in the Quart. Journ. Geol. Soc. in 1875, he indicated by sections the varying thicknesses of the deposits in the different countries, and the order of the succession of the faunas, and he pointed out that wherever the base-line of the Cambrian rocks was seen, it was found to rest unconformably on pre-Cambrian rocks. He had found fragments of *Olenellus* at St. David's in the year 1868, but had only recently recognized that they were portions of the carapace of that genus. Along with the *Olenellus* at St. David's there appears to be a species of *Conocoryphe.* The latter genus as now defined has, like *Olenellus,* no true facial sutures, but it ranges also into the Middle Cambrian, and is there associated with the genus *Paradoxides.* Now that the Torridon Sandstone is recognized to be of pre-Cambrian age, it is a matter of much importance to find out the nature of the fragments contained in it, as by that means it may be possible to arrive at some idea as to the composition of the still earlier pre-Cambrian formations. He had already tabulated a considerable number; but doubtless there were many others which he had not met with. He congratulated the Authors and the officers of the Survey associated with them on the important results of their labours, and he hoped they would soon be able to add to their discoveries by finding other faunas.

Dr. Woodward congratulated the Authors on their admirable paper. The discovery of *Olenellus* in Scotland fixed with certainty the Lower Cambrian age of the 'Serpulite Grits' and 'Fucoid Beds.' He pointed out that Mr. Walcott denies the presence of *Olenellus* in Australia, but in 1886 Mr. Hardman had sent home the head and spine of a trilobite, and numerous pteropods, from Kimberley, Western Australia; these had been identified by Messrs. R. Etheridge, Jr., A. H. Foord, and Dr. Woodward as *Olenellus* (?)

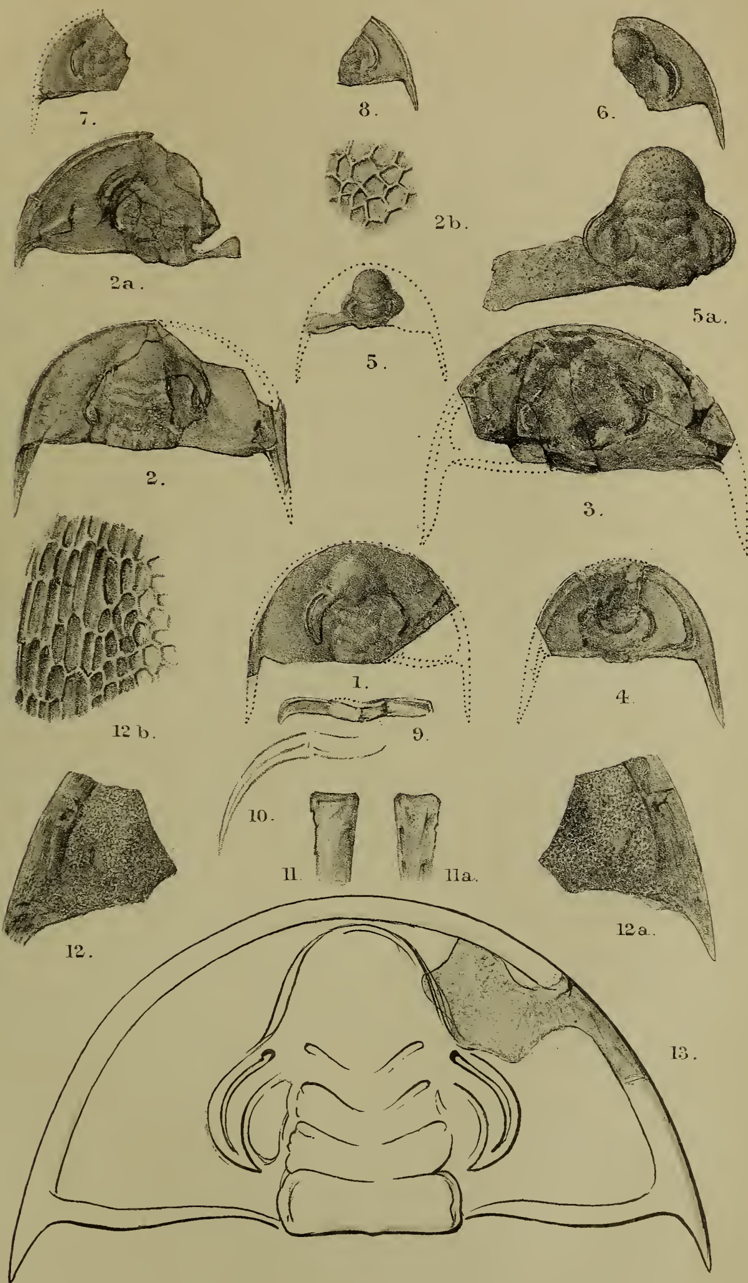
and *Salterella*, and their associated occurrence seemed to prove most conclusively the Lower Cambrian age of these rocks. Great stress had been laid by Mr. Peach on the non-detection of the facial suture in *Olenellus*, as proving that the *Olenelli* had *no free-cheeks*, and should therefore be separated from the Trilobita. But in *Conocoryphe* and many other trilobites the facial suture was often obscure, nevertheless he saw no reason to doubt its existence in all the group—only in some trilobites it was more visible than in others; nor did he see any grounds whatever for separating the *Olenelli* from the Trilobita, as ancestral forms of *Limuli*, more than any other members of the order, with which they certainly agreed in all their general characters.

The President spoke of the detailed and accurate field-work on which the paper was based. There could now no longer be any question as to the pre-Cambrian age of the Torridon Sandstone, which might for the sake of brevity be termed Torridonian, until its true place in the geological record was fixed. He objected to the Torridon Sandstone being classed as Archæan, and remarked that already the officers of the Geological Survey had detected traces of organic remains in it, and by further investigation other and better-preserved forms might be obtained. With regard to the discovery of the *Olenellus*-zone, he believed that we were only at the threshold of what was yet to be found. It was intended to prosecute a vigorous search along the outcrops of the strata this summer, and he hoped that before long they would have further results to communicate to the Society regarding these early portions of the Palæozoic rocks.

Prof. Lapworth also spoke.

Mr. Peach replied to the remarks made by previous speakers.

Quart. Journ. Geol. Soc. Vol. XLVIII. Pl. V.



B. N. Peach del.
F. H. Michael lith.

Mintern Bros. imp.

OLENELLUS

18. *On the* ROCKS MAPPED *as* CAMBRIAN *in* CAERNARVONSHIRE. By the Rev. J. F. BLAKE, M.A., F.G.S. (Read December 9th, 1891.)

[PLATE VI.]

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§ 1. INTRODUCTION.

IN a previous communication[1] devoted to a consideration of the question whether certain rocks in North-west Caernarvonshire, which had been considered pre-Cambrian, were really of that age, I arrived at the conclusion that they were not, mainly on three grounds: (1) that the pre-Arenig rocks of Bangor form one indivisible series whose general features attach them to the Cambrian; (2) that the felsite at Bryn Efail appeared to have altered the sedimentary rocks with which it is in contact; and (3) that the series on the west of Bryn Efail is essentially different from the series on the east. At the time of writing the paper now alluded to I was perfectly aware that the proper elucidation of the question required more than this. The only thoroughly satisfactory way of proving that a set of rocks are not pre-Cambrian is to show what they are, that is, to trace out their relations with the other rocks of the district and to show, if possible, that they are part and parcel of the Cambrian succession. But the Cambrian succession had never been made out. Sir Andrew Ramsay in his Memoir describes, of course, the Purple Slates, and makes mention of various grits and conglomerates; but he arranges the members of the series in no definite order, and supplies no detailed description of their characteristic features. Hence, to determine this succession requires the detailed survey of all the rocks which are mapped as Cambrian in the district. This was a task from which I shrank, having at the time no further interest in the rocks if they were not pre-Cambrian.

Recently, however, my conclusions have been attacked, and the grounds for them called in question. One of these grounds—the section at Bryn Efail—has been stated to be founded on erroneous

[1] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 271.

observation [1]—and after a re-examination of it, I have to confess that this is true. I *have* been deceived by the slaty aspect of the marginal remnants of the squeezed and altered greenstone—and the section has no bearing on the question in hand—thus illustrating my remark that "it is ill founding a determination on one section." The other two grounds, however, remain intact, and the conclusions on further examination are found to be amply justified.

It seemed to me, however, that having been thus led into error I could best atone for it by undertaking the work from which I had previously shrunk. It has been a hard and laborious task, but the results will be found, I trust, to amply repay the labour.

The Cambrian succession as I make it out is, in descending order, as follows:—

1. Pale Slates.
2. Upper Purple Slates.
3. St. Ann's Grit.
4. Lower Purple Slates.
5. Rhiw-wen Grit.
6. Hard banded Pale Slates and Hälleflintas.
7. Bangor Conglomerate.
8. Hard banded Pale Slates and Hälleflintas.
9. Bangor Breccia.
10. Blue banded Laminated Grits.
11. Tairffynnon Conglomerate.
12. Blue banded Laminated Grits.
13. Brithdir Quartz-felspar Grit.

As will be seen in the sequel, all these members are not invariably present. Thus, when the St. Ann's Grit dies out, the Upper and Lower Purple Slates run into a single mass. The Rhiw-wen Grit is often wanting. The Bangor Conglomerate does not appear to occupy a definite horizon and when it is absent the rocks above and below can scarcely be distinguished, while the same may be said of the conglomerates in the Blue Laminated Grits. Thus the complete series reduces to three main subdivisions:—1. The Purple Slate series. 2. Pale banded Slates and Hälleflintas. 3. Laminated Grits and Conglomerates.

§ 2. The Upper Limit of the Series considered.

Before commencing the description of these various members or tracing their range and relations, I must give reasons for excluding from the series the grit which has been hitherto taken to be the top and which is known (amongst other names) as the Bronllwyd Grit. Doubtless, the justification for including it in the Cambrian has been its great resemblance in some places to the St. Ann's Grit, particularly when they both contain small quartz-pebbles. But it cannot be denied that the Cambrian strata below present throughout well-marked peculiarities, and the line of subdivision between these and the Bronllwyd Grit is easily traced. On the other hand, the Silurian strata above, as mapped by the officers of the Geological Survey,

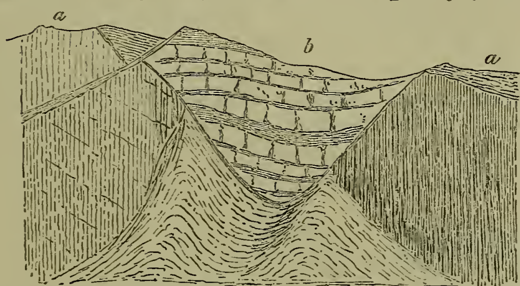
[1] Miss C. A. Raisin, Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 329.

present equally well-marked characters. They are never purple, but always brown or grey, and they have a habit of becoming alternations of thin beds of grit and slate, which elsewhere shade into each other, and hence a line of separation from the Bronllwyd Grit cannot be drawn with accuracy. Moreover a bed of grit, often attaining an immense thickness, particularly if we are justified in correlating this with the Harlech Grits, is the more natural commencement of a new series of rocks, in which similar grits recur, than a band of slate intervening between two such grits would be. These reasons alone appear to me sufficient for classing the Bronllwyd Grit with the overlying rather than with the underlying series—supposing that we have to do with a conformable series of rocks.

But on examining the junction, I think we have evidence of something of the nature of an unconformity. This junction, however, is not often seen, since a great part of the boundary is a fault. As this statement is not in accordance with the Survey mapping, I proceed to prove it.

The boundary on the extreme north is a curved east-and-west

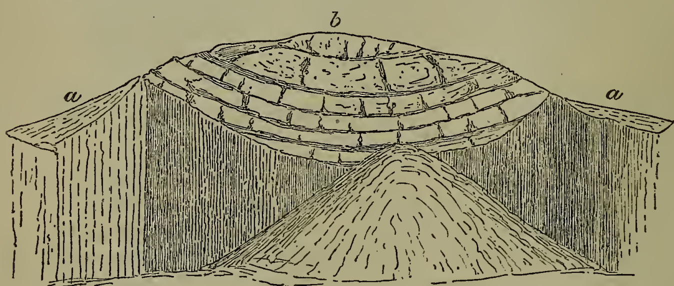
Fig. 1.—*Fault in Bryn Hafod-y-Wern slate quarry (looking East).*



a. Purple slates. *b.* Bedded grits and brown slates.

line, which is not a line of fault, but so soon as it begins to run approximately north and south, we actually *see* the fault in Bryn Hafod-y-Wern slate quarry (fig. 1). The fault-plane forms a vertical boundary to the quarry on its eastern side; and on the west of the fault-plane are the massive Purple Slates, on the east the bedded grits and intervening brown slates in undulating curves, which are truncated abruptly at the fault-plane. A mile farther to the south, in an unnamed quarry to the south-east of Achub, the faulted junction is shown as a convex curved surface with the massive Purple Slates on one side, and on the other bands of pebbles in the grit, undulating horizontally and terminating abruptly at the nearly vertical face in contact with the slate. Again, in the town of Bethesda the Bronllwyd Grit is seen dipping north-east. Due north of the exposures the surface of the slate is more than 100 feet higher—indicating a fault between the two. South-east of Bethesda the junction becomes for some distance a natural one; but on descending into the valley of Llanberis we find the immense masses of grit which overlook Marchlyn Bach are suddenly reduced to a breadth of outcrop of less than 150 feet, while on the opposite side of the valley at least 600 feet are seen in continuous sequence on the precipitous face of Clogwyn Mawr (=Pen Careg-y-Fran). It is true that Sir A. Ramsay says "it requires much dissection of the strata to make out that the crags of Pen-Careg-y-Fran . . . are all represented by the narrow strip of grit that crosses east of the slate quarries,"[1] but no amount of dissection can make a *continuous sequence* of 600 feet reduce to an outcrop of 150 feet in a quarter of a mile. A great fault down the Lake of Llanberis now throws the junction $1\frac{1}{4}$ mile to the west. From Llanberis town in a south-east direction the evidence for a fault is more theoretical, but the line of junction is a very straight one, and as it rises nearly 1000 feet in less than a mile, the plane of separation must be nearly vertical; yet the dip of such grits as are seen is only 20° to the E. The beds on the east of the line, by Bettws Garmon, have quite a different aspect from the Bronllwyd Grit, and brown slates are close at hand. All along the east side of Moel Tryfaen the smooth and marshy ground seems to show the absence of any grit, and on descending the valley leading to Nantlle one sees that the rocks nearest the slate quarries are black Silurian shales. South of Nantlle Lake the line of junction, which continues remarkably straight—though passing over hill and dale, while the Silurian beds have no higher dip than 60°—intersects two quarries. In the first (fig. 2) massive grits are in contact with

Fig. 2.—*Fault in Quarry, S. of Nantlle (looking S.S.E.).*



a. Purple slates. *b.* Massive grits.

the Purple Slates; in the adjoining quarry dark slates, while in both the fault is seen, for the beds are truncated at the surface of junction. The massive grit which crops out on the hillside soon disappears, having been brought in by a synclinal; and dark shales continue on the Silurian side. Finally, continuing for little more than half a mile the line which now runs nearly west, we reach the great

[1] Mem. Geol. Surv. vol. iii. 2nd ed. (1881) p. 174.

Silurian slate-quarries of Clynnog, which are dug to 100 feet below the level of the nearest Cambrian slate.

Such is the evidence on which it is inferred that the boundary is for the most part a fault, whose throw increases continually towards the south, and which thus accounts for the non-occurrence of the Cambrian slates to the south of Clynnog. Thus the only locality where we can find a natural boundary is in the neighbourhood and to the south-east of Bethesda.

The best place to see the junction is on the slopes of Braich Melyn overlooking Bryn Ogwen, where it can be traced step by step. It occurs in several places in one crag of rock, the lower part of which is Pale Slate, the upper grit (fig. 3). The line of junction makes an angle of about 65° with the horizon, and the cleavage of the slate is nearly parallel to it. The base of the grit encloses large fragments of the same slate (fig. 4), sometimes only a few inches across, but in places becoming huge blocks some feet in diameter. It seems impossible to avoid the conclusion that the Pale Slates had been indurated before the deposit of the grit—in fact that they formed the shore-line on which the grit was deposited. These blocks are confined to the base and are quite angular, and they are not produced by fault-brecciation, for they are irregularly dispersed amongst the quartzose materials of the uncleaved grit. They do not appear to have been noticed, unless they are the 'mud pans' referred to by Prof. Hughes[1] and considered to be due to deformation in a massive grit and shale. This, however, is certainly not their character on Braich Melyn. This breccia is also exceedingly well seen at Glan-y-gors, south of Bethesda town, where the

Fig. 3.—*Junction of Bronllwyd Grit and Pale Slate, Braich Melyn.*

a. Pale Slate.
b. Bronllwyd Grit.

Fig. 4.—*Block of Bronllwyd Grit, enclosing large fragments of Pale Slate.*

[From Braich Melyn. ⅛ natural size.]

[1] Geol. Mag. for 1889, p. 10.

beds have been let down to a lower level by the fault marked on the Geological Survey map. The same is well seen also where the lowest grit bed is exposed on Bronllwyd itself, just at the turn of the highest slate-railway. Here the lumps of included slate are darker than usual, but they are still angular. The same breccia is also seen on the slopes of Ffridd-y-Fedw in the extreme north, and is there an admirable guide to the junction-line. Nowhere along the line that I have shown to be a fault has this breccia been met with.

As to whether the Bronllwyd Grit lies upon different portions of the Purple Slate series or not is by no means clear. There are signs that it does overlap, which might be accepted as corroborative evidence, but which alone could not be expected to carry conviction to a doubter. Thus, at Braich Melyn and Bronllwyd the bed immediately below is the Pale Slate, but at Glan-y-gors the grit lies directly on Purple Slate. This latter is called the 'slate of the Tramway cutting' by Prof. Hughes (*op. cit.*), and is placed by him below the whole of the Penrhyn Quarry slates. If this determination of their position were correct, it would prove an unconformity, but a fault, of which there is ample evidence, is inserted on the Survey map between this spot and the Penrhyn Quarries. Farther north the rocks, as will be seen by the map, run in a circle, and at different distances along the radii in different directions are found varieties of slate which we may fancy we recognize as corresponding in due order to those of the Penrhyn Quarries—and in particular the exposures at the greatest distance are of Pale Slate. Yet the overlying grit rests indiscriminately on these various members. There is nothing to show, however, that these varieties are constant in position and may not come on in different localities on the same horizon. In any case the grit is never seen to lie on anything but some part of the Upper Purple Slates, so that the unconformity, if existing, is not demonstrated to be a large one in this locality.

In studying the distribution of the remaining rocks referred to the Cambrian, it was natural to take in the first instance the Geological Survey map as a guide. On this map numerous bands of grit are marked and their distribution traced, but though in the sections they are numbered they are not distinguished in mapping, and numerous faults are inserted, so that the map is exceedingly complicated. Indeed, I have found it unintelligible on the ground. With some of the main features my own observations agree, but after a sincere attempt to verify the details, and the demonstration therein that as tested by the six-inch map many of them were indubitably erroneous, I have had at last to commence with a *tabula rasa*, and the result is that my map in almost all its minor details differs from that of the Geological Survey (see Pl. VI.). I do not for a moment suppose that my map is absolutely correct; but I have examined the rocks at every discoverable exposure in the whole area, though I may have wrongly identified some of them. So far as the observations are correct, the map is drawn so as to be consistent with them all—but other connexions, and, in the complicated districts, other faults, might possibly be as consistent with the same necessarily imperfect data as those that are drawn. My own is only one possible solution, but the Geological Survey map is in many cases an impossible one. These doubts, however, affect only the surface-distribution. Of the vertical succession there can be no doubt whatever.

§ 3. The Pale Slates.

These, which are also called Green Slates, have attracted attention as lying at the top of the series in the great quarries of Penrhyn and Llanberis, and are of particular interest in the former, as having yielded the only recognizable fossil in the series. I do not think, however, that their colour has any special geological significance. As Prof. Hughes remarks, they are not cut off by a sharp line from the Purple Slates, and as far as I can judge they are merely a discoloured portion of the latter. For in the Llanberis quarries we see similar slates in the neighbourhood of the greenstone dykes, and when these latter do not reach the surface the paleness of the slate is often a guide to where they occur towards the bottom of the workings. In accordance with this we find bands of pale slate distributed sporadically amongst the purple, as at Llanllechid and Nantlle. Their occurrence in certain places at the top, though in greater quantities than usual elsewhere, may therefore be merely an accident, due possibly to their exposure to weathering before the deposition of the Bronllwyd Grit.

§ 4. The Purple Slates and the St. Ann's Grit.

The great mass of this slate is divisible into several portions, which have been dwelt upon by Sir A. Ramsay, and more recently have been described by Prof. Hughes (*op. cit.*). In particular there is a band of reddish grit about the middle and a thin band of green grit nearer the bottom, but still above the St. Ann's Grit. These, however, are too impersistent or too easily misplaced to be appreciable on a map, and for geological purposes the whole must be taken together. It is known to be much broken, contorted, and faulted, but these accidents have only an economical importance, and need not be further noticed.

The St. Ann's Grit is a more important mass which, when present, is not easily missed, and thus it serves as a guide to the stratigraphy. It receives its name from its occurrence on the hill on which St. Ann's Church, Bethesda, stands. It is sometimes very fine-grained and compact, and sometimes coarser; in the latter case it contains small quartz-pebbles which, as noted by Prof. Hughes, in certain localities are rosy, but as a whole the grit is characteristically green. At St. Ann's it is thrown into a sharp anticlinal fold whose axis runs N.N.E., and in the centre of which the Lower Purple Slates come up in a long tongue, while to the north-west the corresponding broader synclinal on the hill-slopes below Sling

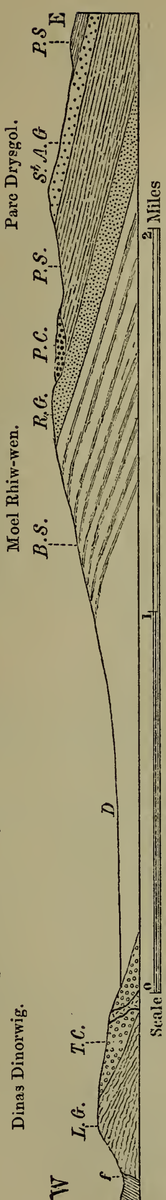


Fig. 5.—*Section from Dinas Dinorwig to Moel Rhiw-wen and Parc Drysgol.*

f. Fault. T.C. Tairffynnon Conglomerate. P.C. Post-Cambrian.
D. Drift. B.S. Banded Slates. P.S. Purple Slates.
L.G. Laminated Grits. R.G. Rhiw-wen Grit. St. A.G. St. Ann's Grit.

lets in the Upper Slates. The same grit is met with on the west side of the Penrhyn Quarries, where it forms a ridge which appears to die out at the north-eastern end and to be cut off at the other by the great fault that shifts the Bronllwyd Grit. The greater part of the slates to the west are a repetition of the Upper Slates, as is shown by the Bronllwyd Grit overlying them at Glan-y-gors and by the occurrence in them of the upper thin band of grit at Felin Fawr slate-works, which is followed below by the St. Ann's Grit.

We cannot be sure that all the other grits referred to the St. Ann's Grit are exactly on the same horizon: all we know of them is that they have approximately the same character, are very massive, and lie in the midst of the Purple Slates. Such a mass covers the eastern slope of Parc Drysgol, and, having very much the same dip (see fig. 5) as the fall of the ground, appears to be more important than it probably is. Nothing but grit, however, can be found on this slope, so that there are not two or three bands, as marked on the Survey map. To the west of it comes the Lower Purple Slate. All this lies on the western side of the above-mentioned fault, so that the Drysgol grit is the continuation of the St. Ann's. On the eastern side of the same fault we find the Careg Ludan grit, which occupies approximately the same horizon, but has a more bedded character and is not quite so green. It is thrown into a sharp synclinal at the slate quarry called Chwarel Fawr, Dinorwig, where the Lower Slates have been worked and the grit is seen forming an arch above them. The northern limb of this arch is found between this quarry and the felsite of Moel Gronw, while the southern spreads out on the broad slopes of Careg Ludan, which, coinciding somewhat with the surface of the fold, give the grit an unmerited importance. The Allt Ddu slates lie below it again, so there must be some faults in the slate itself, as, indeed, Sir A. Ramsay's careful investigation of the details of the quarries has already shown. The same grit when seen on edge, descending to the Llanberis Lake, seems less important. The last of these green grits in the middle of the slates is seen on either side of Llyn Padarn, that on the southern side soon dying out, as noted by Sir A. Ramsay.

South of this point I have nowhere seen a green grit of any importance, though some bands occur in quarries south of Nantlle. But this is no proof that the St. Ann's Grit does not or did not exist. Within two miles of where it is last seen the whole breadth of the visible outcrop of Cambrian strata is reduced by the uprising of the felsite mass on either side of the Bettws Garmon valley to 900 feet, so that there is no room for more than part of the Upper Slates, and though this breadth expands between Moel Tryfaen and Tal-y-Sarn to three-quarters of a mile, yet in the Nantlle slate-quarries one dip of 45° to the east and another of 70° to the west are observable, so that the slates are undulating and are doubtless cut off on the west (as on the east) by a fault.

Moreover, it is certain that in this southern portion we do not see the whole of the Cambrian series, but only the uppermost portion. What may lie to the west of the felsite masses is practically unknown, all being covered by Drift, or rarely exposing rocks which cannot be paralleled with the known lower part of the succession as subsequently described. Only in one spot on the west have I seen any purple slate, viz., by the side of the River Rothell, and even here the exposure is so small that the relations are quite obscure and hard to interpret.

Returning now to the complicated region in the north, we find that no purple slate occurs west of a line drawn from Coch-winllan near Halfway Bridge to the base of Parc Bwlch on Moel-y-Ci. As, however, the general trend of the strata south of this line is to the north-east, its occurrence so far west even as this is due to dislocations. The line above indicated is the western boundary of a broken band, the separate pieces of which present no contradiction to the order of succession elsewhere, but the determination of whose position depends upon a knowledge of that succession. The northern patch of Purple Slate included here runs north and south. It belongs to the Upper Slates and is apparently overlain by what seems to be Silurian, but of this I cannot be quite certain. The southern is of Lower Slates and occurs in a faulted wedge. On the eastern side of this broken band the strata are bent into a curve, as indicated in the Geological Survey map, so that the St. Ann's Grit and the slates above and below dip first east, then north, and finally north-west, till they meet the boundary again, and are finally cut off by the Aber fault.

In a general way, these slates are thus striking towards Bangor, though the strata there are assuredly neither the actual continuation of the arch nor of the broken strip. Now, at the northern end of the hill overlooking the town on its south-eastern side, we find the Purple Slate in characteristic form. The boundary between it and the Hälleflinta runs near the top of the Recreation Ground and cuts off the north-eastern corner, descending to the road-level just south of the Mountain Square Slateworks. These are of course the Lower Purple Slates, and show the usual character of that portion in being more massive and bedded, more sandy and less cleaved. They have a high dip of about 70° to the east, and are overlain by the Silurian grits and micaceous slates, with a dip of about 30° to S.S.E. along an irregular line, which end by overlapping them and coming into contact with the 'Hälleflinta.'[1]

§ 5. The Rhiw-wen Grit.

That there is a grit at the base of all the Purple Slates, and thereby distinct from the St. Ann's Grit, is very evident on Moel Rhiw-wen (fig. 6). The summit of this enclosed hill is crossed in a N.N.E. direction by a band of green grit with quartz-pebbles, which occasionally weathers brown here. On the western side it is seen lying on Pale Banded Slate, particularly at a quarry at Rhiw-wen, while on the east—after passing a conglomerate, which is believed to be unconformable—we come to old quarries of Purple Slate on the rise to Drysgol: and the same relations of strata are seen at the northern end. By the aid of this observation we are able to recognize the true position of the grit on Moel-y-Ci (fig. 6). It is seen rising from beneath the Purple Slate on the eastern side by Bron-y-foel, and is succeeded on the upper slopes by Pale Banded Slate. This last occupies most of the hill, but capping the western slopes we find crags of grit again. Here it dips slightly into the hill, but soon turns up again and forms the summit. The grit on this hill also weathers brown and is rather coarse, and I take all the masses to be the same grit, forming part of a partially denuded semi-anticlinal, and corresponding with that on Moel Rhiw-wen.

We cannot, however, always recognize a grit as a distinct bed in this position. The base of the Purple Slates gets gritty, and so does the top of the Pale Slate series, but often no line can be drawn. In the broken ground south of Tregarth we can, by selecting the proper direction, pass over in downward succession purple slate, grit (St. Ann's), purple slate, grit (Rhiw-wen), and pale slate. The

[1] I have previously shown (Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 271) that rocks of this age lie unconformably on all the members of the Cambrian or older series from Bangor to Caernarvon, and this disposition of them I have again confirmed by a careful examination of (I believe) *all* the exposures near the former town. Sir A. Geikie, in his Presidential Address for 1891, states that neither he nor Mr. Peach, after 'numerous' observations, could find 'any discordance in strike or dip between the flinty tuffs and the overlying shales and grits,' and accepts what to me appears a *reductio ad absurdum* in consequence. The fact, however, of the unconformity throughout is, to my mind, so abundantly clear that I am sure a further examination would convince Sir Archibald; and I will not therefore crowd this paper by adducing further proofs.

Fig. 6.—*Section across Moel-y-Ci.*

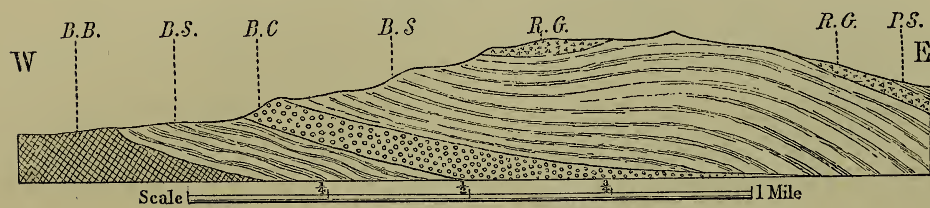
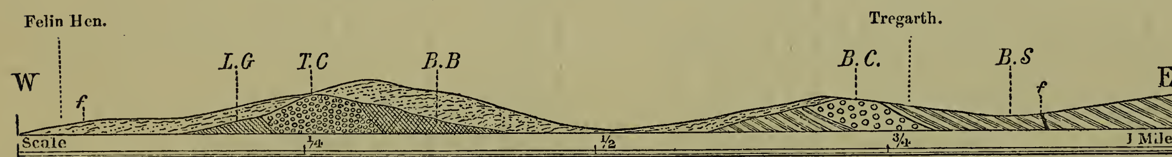


Fig. 7.—*Section in the cutting between Felin Hen and Tregarth.*



B.B. Bangor Breccia.
B.S. Banded Slates.
B.C. Bangor Conglomerate.
R.G. Rhiw-wen Grit.
P.S. Purple Slates.
L.G. Laminated Grits.
T.C. Tairffynnon Conglomerate.
f. Faults.

dips, however, are so irregular, and the variations of one grit might so easily be extended to include those of the other, that it is only the most probable supposition, from various stratigraphical considerations too numerous to mention, that the grit next the pale slate is really Rhiw-wen Grit in its proper place. On the opposite side of the Ogwen Valley fault (where the beds run in circles), though the beds below the Purple Slate are often gritty near the top, no distinct band can be made out, especially as the clearest line of junction is certainly faulted, and it is the same at Bangor. The 'Hälleflinta' is there immediately followed by the gritty Purple Slate.

On the south side of Llyn Padarn there is a green grit occupying this position, west of the Glyn Peris Hotel, that is to say, it is seen to rise from beneath the Purple Slate in the quarries and is seen also to overlie Pale Banded Slate in the cliff at the bend of the Cwm-y-glo road. There is also a grit of similar character in a corresponding position on the opposite or northern side of the lake. Hereabouts, however, there is a complication in relation to the felsite, so that some of the rocks in this position have a very remarkable character, the description of which must be left till the felsites are dealt with.

On the south side of the Rothell, at Pontrhythallt, a reddish grit crosses the stream, causing rapids, and this occupies the position of the Rhiw-wen Grit—if the beds above are true Purple Slate, but nothing more is seen of any such rock to the south of this spot.

§ 6. The Pale Banded Slates and Hälleflintas.

This is a very important group of rocks, requiring to be carefully distinguished from the Purple Slates. Here and there perhaps the Banded Slates may put on a slightly purple hue, but this is very rare. The Purple Slates are characteristically massive, while these, especially when most slaty or gritty, have invariably a well-marked banded structure. When they put on the 'hälleflintoid' form these bands reduce to fine laminæ, which, though often much contorted, are still recognizable. The series is well seen over all the ground that lies to the north of the felsite masses. Thus on Moel Rhiw-wen (see fig. 5, p. 250) hard Pale Banded Slates occupy the western half of the summit and all the western slopes, where they bend over slightly, so as to have a small westerly dip, as is roughly shown in Sir A. Ramsay's section. We here get a good idea of their importance, for they occupy ground differing in elevation by 600 feet from the top to the bottom, in which the eastern and western dips may nearly compensate each other. On Moel-y-Ci (see fig. 6, p. 253), with the exception of the summit-capping of grit and the conglomerates on the west, the Pale Banded Slates occupy the whole of the ground from a height of 1344 feet down to about 500 feet, with very little on the whole to be allowed for dip. North of this they occupy a broad band of country, throughout which they have an easterly dip, from the high ground at Sling down to the crossing of the river near the Aber fault. In this region they appear to be confounded on the Geological Survey map with the Bronllwyd Grit, from which they are absolutely distinct. They also occupy a large area between Tregarth and the River Ogwen, where they also in parts have an easterly dip, as is well seen in the mineral-railway cutting and in the crags above it, but this area is supposed to be cut off from the last by a fault (see fig. 7, p. 253). They are also brought up in a wedge at Parc Bryniau, where they have a northerly dip. On the east side of the River Ogwen they occupy a semicircular area, where they are seen by their dips to form one half of a dome, of which we do not see the base, the lowest beds exposed being the great conglomerate to be presently mentioned.

It is these same rocks, of a somewhat more hälleflintoid character than usual, yet always either banded or laminated, which occupy the heights of Bryniau Bangor, extending from Minffordd northward to the end of the Recreation Ground.

When we have gained some familiarity with the rocks of this portion of the series in those localities where they are characteristically developed and where there can be no doubt of their position, we are better fitted to examine them in the areas where more doubt may be felt or has been expressed. One of these is the country north-west of Bryn Efail to beyond Dinas Mawr. In several spots at Llys Dinorwig and Bryn Derw, and in the cutting near Coed Madog figured by Miss Raisin,[1] exposures may be seen. Miss Raisin calls the rocks 'argillites,' a term which fairly expresses their general character. There is, however, some grit amongst them; but the main point is that they are essentially banded and grey, and of one thing we may be certain, that no such rocks are met with above the Rhiw-wen Grit. The section in the cutting is very instructive in relation to controverted points. The rocks are more or less contorted, as in many other places, and the result is that they dip in different directions in different parts. This accounts for our finding other spots where the dip is reversed; but as, on the whole, the beds descend towards the east in the cutting, so the majority of the dips (in fact all but one) are to the east in the isolated exposures. At Bryn Derw there is a small patch of an earthy conglomerate, in which felsite-pebbles must be very scarce, if any are present, for I could find none. There is also a crag of grit, and by the side of the main road to the west is a boss of purple-banded grit. In the light of later knowledge I am not prepared to say what these are; if they belong to the series they may represent the bottom of the Rhiw-wen Grit.

Beyond Dinas Mawr the rocks, though banded, are more purple and gritty than in any other area of rocks referred to the same portion of the series, and in one place there appears to be some felsite. Yet the base of Dinas Mawr itself is fairly characteristic hard Pale Banded Slate, with a dip of 50° or more to the east. In

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 335.

spite, therefore, of their somewhat abnormal character, I can only regard these rocks as belonging to this part of the series.

On the eastern side of the Llyn Padarn felsite characteristic Banded Slate is again seen, but the consideration of its relations must be postponed till the conglomerate of this district is dealt with.

On the south-east side of the lake we find similar Pale Banded Slates beautifully exposed in the crag at the bend of the road, west of the Glyn Peris Hotel. Here they certainly come below the Rhiw-wen Grit. Finally, by the side of the River Rothell, at the previously-mentioned locality, we find below the hard red grit some very typical hälleflinta with curious lines of lamination.

§ 7. The Bangor Conglomerate.

This is the well-known band to which attention has been drawn by Prof. Hughes, which is considered by him to form the base of the Cambrian as distinguished from pre-Cambrian rocks, but which I have shown in a previous paper to lie in the midst of the mass of the banded hälleflintas alike above and below it, and not to be continuous, but to die out in their midst. The great mass of similar conglomerate, full of huge felsite-pebbles, which crosses the Bangor and Bethesda road $3\frac{1}{2}$ miles from Bangor, occupies the same position, and it comes up from beneath the mass of the hard Banded Slates already referred to, which in places may well be called hälleflinta. But we do not here see below it, as it is the centre of an anticlinal and is cut off by a fault along the river, on the opposite side of which it is not continued.

In the strip of country to the west of this, however, beyond the fault which bounds the broken area, we get another exposure of conglomerate in the same position. It is well seen in a small crag by the wayside where the road crosses the railway to the N.W. of Tregarth (fig. 7, p. 253). It here consists of bands of purple grit and conglomerate, capped by a very coarse bed of the latter with 2- to 3-inch pebbles of red and white felsite and fragments of purple slate, the whole dipping eastward at 20°. It is seen also in the railway-cutting, where it is followed on the dip by the banded grits; while on the other side, at Gelli, there is a quarry in banded hälleflinta also with an easterly dip, which must therefore lie below it. It thus appears to lie in the midst of the banded series. It may be traced thence in a northerly direction to Bryn Cûl, where the overlying banded rocks are also gritty, and farther on into a crag by the river-side below Coch Winllan, where it is followed above by green finely-banded hälleflinta, all dipping E., and all the exposures of the hälleflinta to the west have a similar dip. In the other direction it rises into the great crags of Pandy, where the felsite-pebbles are huge and well rounded, though showing no dip; but both to the east and the west are crags of banded hälleflinta, or hard slate, dipping uniformly east. A similar crag, similarly related, is found at Fronheulog on the same strike; there cannot, therefore, be the slightest doubt that there is here a coarse felsitic conglomerate in the *midst* of the banded series.

Farther south, on the western slopes of Moel-y-Ci (see fig. 6, p. 253), we find again huge crags of very coarse felsitic conglomerate, coming up from below the hard Banded Slates of the mountain as observed by the dip of the latter, and this may be traced on the same S.W. strike as far as the crag called Careg-y-gath. Below this conglomerate, between it and Waen Pentir, there are numerous exposures of the hard banded gritty slates, which, however, become horizontal and almost bend over at the Waen, but are 100 feet in level below the conglomerate crag.

The fault that has let down the rocks of Moel Rhiw-wen, as determined by other observations, prevents anything of the conglomerate being seen on its western side, but we pick it up again at Bryn Madog and Dinas Mawr, the conglomerates of which are well known. These, like the mass near Tregarth, are associated with reddish purple grits, but have large felsite-pebbles and lie in the midst of the banded series, the dips wheresoever observed being to the east. They correspond, therefore, in position as well as in character with the conglomerate at Bangor, and by so doing assist in the correlation of their associated banded beds.

The rocks which lie below the banded series are distinguished by their more gritty character, and by the greater proportion of conglomerate and breccia-bands which they contain. The more compact forms are sometimes banded, and very generally show an irregular lamination, but they may occasionally become slaty. This description shows how difficult it may be at times to distinguish them from the rocks at a higher level. It would, in fact, have been natural to class them all together, had it not been that there is a band of rock of a remarkable kind which may be taken as characterizing a definite horizon, and by means of which we can separate off the lower portion of the series.

§ 8. The Bangor Breccias.

These are composed of so peculiar a rock that there is no mistaking it wherever it occurs. It is never found amongst any of the beds hitherto described, but is more or less repeated at a lower level. Of its nature I need say little, as it has been so well described by Prof. Bonney.[1] Sometimes it is almost a grit, sometimes almost a conglomerate, but it always contains small angular fragments of slate in considerable abundance; if these are bluish the rock is bluish, but if they are red the rock also looks red.

The detailed stratigraphy of the rocks south of Bangor is not of immediate consequence, but I have done the best I can with the six-inch Ordnance map to trace the most probable arrangement, from which it appears that there must be two bands of such breccia, one curving round from Cae Seri to Brynllwyd, and the other from

[1] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 317; vol. xxxix. (1883) p. 480 (C).

Minffordd to the Poorhouse, forming a synclinal with the axis along the high ground. This is consonant with the apparent running of the Tairffynnon Conglomerate below, but it requires a fault to run from the east side of Minffordd to the station, an arrangement which a reversed dip in the road north of Minffordd renders probable. If this be correct, then both Prof. Bonney's map and my own previous map must be wrong in this respect, as neither recognizes more than one breccia. But, however they run, there they are with associated Laminated Grits and hard slates. There is indeed a breccia at a higher level at Bangor which has been noticed by previous authors, though it is of a different character, being more earthy, and in any case is quite exceptional, so that we may say that this type of breccia is characteristic of the lower part of the series.

Crossing the faulted Silurians, we find this breccia well shown in the cutting half-way between Felin Hen and Tregarth (fig. 7, p. 253), with a well-marked easterly dip. Following the strike thus indicated we find it again in numerous exposures leading by Waen-hir to Craig-llwyd on the 6-inch Ordnance map, where it meets a fault, on the other side of which is Purple Slate dipping towards it. It occupies, therefore, in this locality exactly the same position as at Bangor. Farther south, below Moel-y-Ci, there are numerous crags ranged in a N.E. and S.W. direction consonant with the bedding of the overlying banded series, which show this peculiar breccia to perfection, here again in its expected place (see fig. 6, p. 253). Finally, to the west of Dinas Mawr we find identical rock crossing the road in many spots round Pen Isa'r Waen as we should now expect if the overlying beds have been rightly interpreted. The fragments of slate are here rather more rounded than usual.

In the case of grits, banded slates, and conglomerates, we are always liable to confusion between one example of the kind and another, though we may keep ourselves fairly straight by attention to stratigraphy. But with a rock like this a mistake seems scarcely possible; thus we have at least one fixed point, in a correlation of the beds above and below in the different areas. The fixed point is the *top* of these Bangor Breccias, for they may be repeated below, and the interval which separates them from other noted beds may vary considerably.

§ 9. The Blue Laminated Grits and Tairffynnon Conglomerate.

The typical Bangor Breccias are separated in the Bangor district by a considerable mass of Laminated Grits from the Tairffynnon Conglomerate, below which somewhat similar rocks come on in force and in places become more irregular and compact, like one of the Anglesey pelites. These rocks are well known from Prof. Bonney's description,[1] so they need not be dwelt upon here, yet these Blue Laminated Grits are exceedingly characteristic and merit special

[1] Quart. Journ. Geol. Soc. vol. xxxv. (1879) pp. 317 & 319 (2).

attention. We get them, in perhaps not their most characteristic form, in several exposures round Caerhûn, where they may be either above or below the conglomerate, which is here lost sight of. South of this a wide area is probably occupied by them, but nothing is seen till we come to the quarries at Fachell which I have already described, one of which has this well-marked type and another the muddy conglomerate at the base.

Now, at this spot there cannot be any doubt as to where we are in the series, and we are thus prepared to examine Dinas Dinorwig over the other side of the Silurian strip. All the north-western slopes of the hill down to the fault are occupied by this Laminated Grit (see fig. 5, p. 250), which, now we know it, is perfectly unmistakable. It is on the south-eastern slopes and a little over the crest on the sides that we find the conglomerate referred to by Dr. Hicks,[1] not only in irregular crags which might be loose blocks, but also striking solidly across the road on either side of the hill. This, then, is the equivalent of the Tairffynnon Conglomerate, and does not lie at the base of the series. In one part towards the east it partakes somewhat of the character of the Bangor Breccia, and in another there is a band of felsite with conglomerate overlying it. Between here and Pontrhythallt the exposures seen are mostly of the same blue grit, though one quarry shows a conglomerate, as noted by Dr. Hicks. As a whole, however, the general stratigraphy, and the dying off of the Dinas conglomerate on its strike at Nant Efa, indicate a fault, with the beds above the conglomerate undulating as far as seen.

The only other locality where these lower beds are seen is in the Felin Hen cutting and to the south of it (see fig. 7, p. 253). The Tairffynnon Conglomerate is here magnificently exposed; in fact, it is better shown than anywhere else. The pebbles are large and in great quantity. It is curious, however, that there seems here to be little or no interval between these beds and the Bangor Breccia, which is the converse of what we last noticed near Pontrhythallt. The dip of the beds is to the east, as in all the other rocks of the section, and we accordingly find masses of the same rock at the farms of Moel-y-Ci and Ty'n-y-Clau on the south, after which it appears to die out. Below this conglomerate in the Felin Hen cutting comes the Blue Laminated Grit, in quite a typical form, with the same dip as the rest, and this again may be traced southwards if we go as far as the rising ground at Careg-y-Fedwen, though the mapping here is rather doubtful in detail.

§ 10. The Brithdir Grit.

This lies immediately on the felsite near Brithdir and round its edge to the Caernarvon road; it is therefore the lowest of all the Cambrian series in this locality, and its character is already well known. A similar small-grained quartz-felspar grit is seen at

[1] Quart. Journ. Geol. Soc. vol. xl. (1884) p. 197.

Fachell occupying the same position, below the curious muddy conglomerate with red pebbles, and it is here only, if ever, that we can reach the base of the Cambrian in Caernarvonshire. There is indeed a small-pebbled conglomerate in the Felin Hen area to the west of the Laminated Grits, which *might* be the same, but it might also be some other conglomerate developed in the mass. There is certainly no evidence that it lies here upon felsite; it probably does not.

Such is the Cambrian succession in Caernarvonshire as I read it. It is interesting to trace how the early volcanic outbursts of the period which gave rise to the felsites of Dinorwig were followed by the deposits of rough and rapid waters capable of rounding the hard rocks, and of carrying them miles from their source; how the alternations of condition, tidal or otherwise, gave rise first to the Laminated, then to the Banded Slates and Grits; how some new outburst provided so many fragments of the Monian slates that the waters nearest Bangor could scarcely round or disintegrate them, soft as they may have been; how a still later lava-outburst provided a fresh source of huge pebbles and gave apparently fresh powers to the waters to roll and remove them; and how finally tranquillity set in, and except for the occasional intrusion of grit-bearing rivers the sea set steadily to work to disintegrate, transport, and deposit the materials for the vast masses of our fine-grained roofing slates.

Apart from the idea thus afforded us of the conditions that prevailed during the Cambrian period—which is after all the main object of our researches—the description just given shows as plainly as possible that there is nothing in the least peculiar about the Bangor district: the rocks are not altered there more than anywhere else, and they correspond bed for bed with the rest of the Cambrian series. Indeed, with the exception of the upper parts of the Purple Slate and the associated grits, they show as complete a sequence as any other locality that may be pointed out. There is, therefore, not the slightest ground for seeing anything pre-Cambrian there, and even my own supposition that they were the lower parts of the Cambrian series, *elsewhere unseen*, is proved to be erroneous.

But a question naturally arises from our review of the conditions of sedimentation, namely as to where was the centre of the volcanic eruptions whose products we find embedded in the slate. With regard to the Tairffynnon Conglomerate, we may imagine that the old Dinorwig centres were not yet exhausted, though we cannot point very definitely to any fresh evidence of eruption there.

The Bangor Breccias must have had their origin in an explosion unaccompanied by lavas, and hence we should scarcely expect to find any relics of the orifice. But in the case of the Bangor Conglomerates and their equivalents to the south, lying as they do in the midst of the banded series, we ought to be able to point to some fresh source of the felsite-pebbles. One such source is ready to our hand,—the Llyn Padarn felsite, which we might thus expect *a priori* to be a mid-Cambrian outburst, and as such, independently of controversy, to be worthy of particular study.

§ 11. Conclusions.

The above observations prove that there is a definite succession in the Cambrian series, which is the same in the isolated portion east and south of Bangor as in the main mass. Whether we see the base or not depends on the age assigned to the Dinorwig felsite. If that be Cambrian there might be beds of the same system below it, but there probably are none, since we certainly see the base at Beaumaris. Whether we see the top or not depends on whether the Bronllwyd Grit, which belongs to the overlying group, is conformable or not, and there is no evidence that it is. In any case, no intervening beds above the Purple and Pale Slates are known in North Wales.

It is also proved that the rocks to the west of the felsite belong to the lower part of the series, and those to the east to the upper, both being determined in areas where the felsite is absent, and hence it appears probable that the felsite mass is a volcanic complex belonging to the middle of the Cambrian period.

Thus my former conclusions, though somewhat modified, are shown to be substantially correct.

Part II. (Abstract).

It is further argued that a study of the Llyn Padarn felsite proves it independently to be as above supposed, and a post-Cambrian age is assigned to the conglomerates of Moel Tryfaen and Llyn Padarn.

PLATE VI.

Map showing the sequence of the rocks called 'Cambrian' in Caernarvonshire.

Fig. 1 represents the northern part of the area, and Fig. 2 is its continuation to the south. Scale: 1 inch = 1 mile.

Discussion.

Dr. Hicks said it was evident that the Author had on some very important points greatly modified the views advanced by him in his former paper. Mr. Blake now admitted that Miss Raisin had proved conclusively that he had been greatly deceived by the Bryn Efail section, which he had referred to as the crucial spot to prove that the quartz-felsite was intrusive in Cambrian slates. What he had supposed to be baked Cambrian slate had been shown by Miss Raisin to be diabase intrusive in pre-Cambrian quartz-felsite. Dr. Hicks maintained that there was abundant evidence to show that the Llyn Padarn quartz-felsite is of pre-Cambrian age, and also that Mr. Blake had included many pre-Cambrian rocks in his so-called Cambrian succession. It would appear also, from some of the specimens on the table, that the Author had mistaken some crushed and cleaved pre-Cambrian felsites for Cambrian purple slates. The speaker referred to the fact that he had, in the report of the excursion of the Geologists' Association to Caernarvonshire in 1883, indicated the position of each of the zones in the Cambrian, in the section from the Penrhyn slate-quarry to the Nant Ffrancon Valley, and that since then some of the zones had been worked out with much success. In his recent memoir on the *Olenellus*-fauna, Mr. Walcott says that the *Conocoryphe-viola* zone above the Penrhyn quarry must be included in the Lowest Cambrian; therefore it is clear that the lowest beds of the Cambrian occur in the succession on the east side of the quartz-felsite axis. The conglomerate which rests on this axis and underlies the beds which contain the earliest known Cambrian fauna must be considered to mark the base-line of the Cambrian in this area.

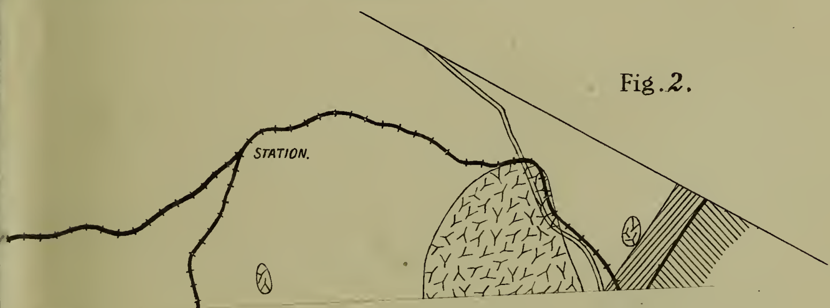
Mr. Marr thought that the distribution of the conglomerate seen at Llanberis and on Moel Tryfaen was difficult to account for if the rock was post-Cambrian. He had noticed blocks of a breccia resembling the conglomerate on the summit of Moel Tryfaen amongst the talus thrown out at the mouth of the adit on the hillside.

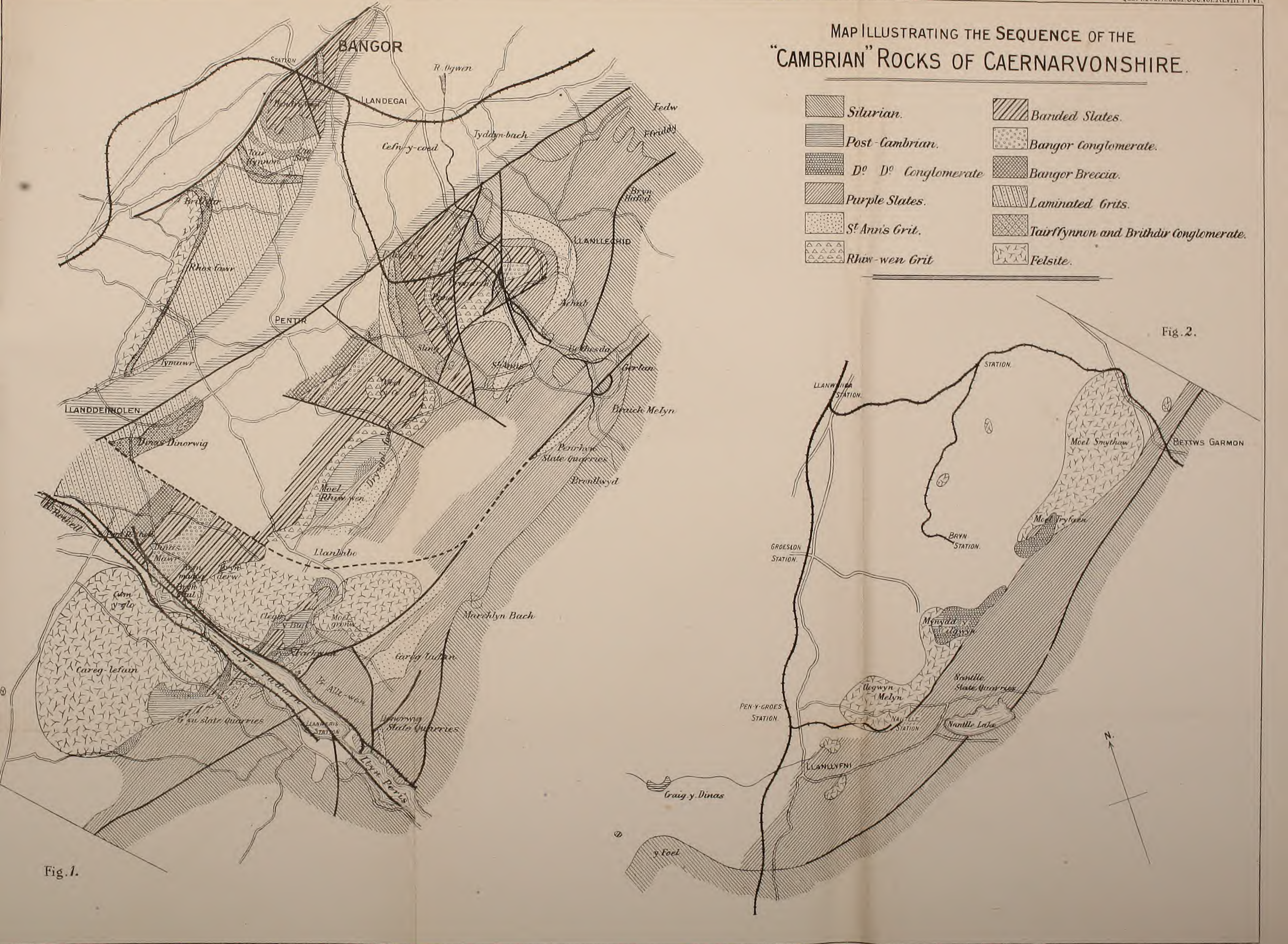
Prof. Blake replied that something that might be called a conglomerate often followed the felsite anywhere; but where he had drawn the latter as intrusive, the stratigraphical evidence seemed to point to its being so, whatever the 'purple slate' might be. As to the *Paradoxides*, &c., they could be discussed when they had been seen. His conclusions depended very much upon details of mapping, and the criticisms of those who were not acquainted with these details were apt to be somewhat wide of the mark, but he believed that some truth would be found in his paper.

LLUSTRATING THE SEQUENCE OF THE
" ROCKS OF CAERNARVONSHIRE.

urian.	*Banded Slates.*
st-Cambrian.	*Bangor Conglomerate.*
Do Conglomerate	*Bangor Breccia.*
ple Slates.	*Laminated Grits.*
nn's Grit.	*Tairffynnon and Brithdir Conglomerate.*
w-wen Grit	*Felsite.*

Fig. 2.




MAP ILLUSTRATING THE SEQUENCE OF THE
"CAMBRIAN" ROCKS OF CAERNARVONSHIRE.
Silurian.
Post-Cambrian.
Do Do Conglomerate
Purple Slates.
St Ann's Grit.
Rhiw-wen Grit
Banded Slates.
Bangor Conglomerate.
Bangor Breccia.
Laminated Grits.
Tairffynnon and Brithdir Conglomerate.
Felsite.
BANGOR
STATION
R. Ogwen
LLANDEGAI
Fedw
Tyddyn-bach
Cefn-y-coed
Tair Ffynnon
Rhos-fawr
PENTIR
LLANLLECHID
Bethesda
Gerlan
Braich Melyn
Penrhyn Slate Quarries
Bronllwyd
LLANDDEINIOLEN
Dinas Dinorwig
Moel Rhiw-wen
Llanddeiniolen
Marchlyn Bach
Careg-lefain
Llyn Padarn
Yr Allt-wen
Dinorwig Slate Quarries
LLANBERIS STATION
Llyn Peris
Carreg Lefain
Fig. 1.
Fig. 2.
STATION.
LLANWNDA STATION.
BETTWS GARMON
Moel Smytho
Moel Tryfaen
BRYN STATION.
GROESLON STATION.
Mynydd y Cilgwyn
Clegwyn Melyn
Nantlle Slate Quarries
NANTLLE STATION
Nantlle Lake
PEN-Y-GROES STATION.
LLANLLYFNI
Graig-y-Dinas
y Foel
N.

19. *The* Raised Beaches, *and* 'Head' *or* Rubble-drift, *of the* South *of* England: *their* Relation *to the* Valley Drifts *and to the* Glacial Period; *and on a* late post-Glacial Submergence.

By Joseph Prestwich, D.C.L., F.R.S., F.G.S.

[Plates VII. & VIII.]

Part I. (Read February 10th, 1892.)

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§ 1. Objects of the Paper.

I have been led of late years to conclude that, besides the subaerial, marine, and river-valley drifts of Glacial and post-Glacial age, there is another which cannot be referred to any of the causes to which those drifts owe their origin. Nevertheless this drift is not only of common occurrence, but it is found in positions and with characters at one time simulating the Valley Gravels, and at another presenting features more analogous to those due to Glacial or to Subaerial action. It is therefore desirable, in order to prevent confusion, that the place of this Drift should be defined before proceeding, as I had intended, with the other Quaternary series in their due order.

I described long ago one phase of the Rubble-drift—as I propose for the present to term this drift—in the Sangatte Cliff,[1] namely that long known as the 'Head,' which is associated with all our Raised Beaches; and more recently I have briefly discussed some of the theoretical questions connected with its origin.[2] Since then I have, however, materially enlarged the scope of the enquiry and arrived at more definite conclusions.

I purpose, therefore, in this paper—1stly, to give the range of the Raised Beaches and Head in the South of England and South Wales; 2ndly, to show their relation to the Valley Drifts; 3rdly, to define the characters and position of the Head or Rubble-drift, and to determine its several phases inland; and, 4thly, to enquire into the origin and age of this special drift.

As the Raised Beaches have a general uniformity of structure, and have been often described, I may pass over them rapidly, and omit details except where there are new points to notice or where, in a few cases, no description has been previously given. With the

[1] Quart. Journ. Geol. Soc. vol. vii. (1851) p. 274, and vol. xxi. (1865) p. 440.
[2] Brit. Assoc. Rep. for 1880 (Swansea Meeting), p. 581; and Bull. Soc. géol. France, 3me sér. vol. viii. (1880) p. 547.

overlying Rubble-drift the case is different; for the deposit varies in composition, not only according to the locality, but also according to the distance from its source—variations often so great as to have given rise to wide differences of opinion as to its origin.

The first distinctive but purely local name applied to this drift was given at Brighton by Mantell, who termed it the 'Elephant Bed,' as it contained the remains of the Mammoth.[1] De la Beche applied the term 'Head' to a similar angular detritus overlying the Raised Beaches of Devon and Cornwall.[2] Godwin-Austen adopted the same term, but gave it an extension inland beyond the limits of the Beaches.[3] Murchison looked upon the Head as merely one form of a drift which he took to be general over the whole of the South of England, and in which he included other so-called post-Glacial Drifts.[4] To this he gave the name of 'the angular Flint-drift.' For convenience' sake I shall, in speaking of this drift, use the term Head or Rubble-drift, meaning both that portion lodged on the Raised Beaches and that which exists independently in other areas.

§ 2. Range of the Raised Beaches and 'Head,' or Rubble-drift, on the Coast. (See Map, Pl. VIII.)

The encroachment of the sea in recent times on the south-eastern coast of the Channel has been so great that only a few remnants of the Raised Beaches, which we have reason to believe extended all round the South Coast of England, now remain; but of the Head, with which they are commonly associated, frequent traces are to be met with apart from the Beach.

(1) *The Isle of Thanet.*—Small sections of the Rubble-drift are to be seen at the Margate (South Eastern) Railway-station; again, on either side of the North Foreland, in the gaps at Joss Stairs and Stone Stairs, and in the cliffs west of Ramsgate. In all these places it consists merely of chalk-and-flint rubble, mixed with Tertiary flint-pebbles, green-coated flints from the base of the Thanet Sands (which once spread over that island), and with occasional patches of brick-earth. This rubble exists also on the slope of the cliff of the South Foreland adjacent to Kingsdown, near Walmer. I am not aware that any organic remains have been found at these places.

(2) *Dover and Folkestone.*—A more important mass of Head lies at the base of the West Cliff of Dover, just behind the South Eastern Railway-station. It consists of chalk-and-flint rubble of local origin, containing some remains of the Mammoth. It attains a thickness of 40 feet or more; and, as it descends to the level of the shore, it is possible that a Raised Beach may be hidden under it or may have existed at a short distance in front of it.

[1] 'Geology of the South-east of England' (1833), p. 32.

[2] 'Report on the Geology of Cornwall, Devon, &c.' (1839) p. 432.

[3] 'On the Superficial Accumulations of the Coasts of the English Channel, and the Changes they indicate,' Quart. Journ. Geol. Soc. vol. vii. (1851) p. 118.

[4] 'On the Distribution of the Flint-Drift of the South-east of England, on the Flanks of the Weald, and over the Surface of the North and South Downs,' Quart. Journ. Geol. Soc. vol. vii. (1851) p. 349.

At Folkestone a bed of white marl (chalk-rubble), loam, angular flints and Tertiary flint-pebbles, 8 to 10 feet thick, lies on the top of the cliff of Lower Greensand, under the Battery, at a height of about 80 feet above the sea. Mr. Mackie,[1] who obtained from this bed a large collection of mammalian remains (with *Helix concinna* and *H. nemoralis*), considered it to be a fluviatile or lacustrine deposit formed by the small stream which flows through the town—a view adopted by most later writers; but I look upon it, as did Murchison, to be a form of Head. The drift no doubt extended originally down to the sea-level, at a distance probably of $\frac{1}{4}$ to $\frac{1}{3}$ mile beyond the present beach, to which extent the sea has gained on the land since the Rubble-drift accumulated. The rubble *does not* follow the course of the small valley along which flows the present rivulet, but passes across it on to the slopes of the Chalk escarpment, where a section of it was exposed a few years ago at the Cement-works near the upper railway-station, at a height of about 200 feet above the sea. The deposit there varies in thickness, and rests on an uneven surface of Gault and Lower Chalk. The section showed—

1. Brown surface-soil	6 inches.
2. White Marl (Chalk-rubble), with land-shells	3 feet.
3. Angular débris of flints, Chalk, Tertiary flint-pebbles and ironstone (some pieces 2 feet in length)	2 feet.

The shells, which were determined by the late Dr. Gwyn Jeffreys, are more numerous than at the Battery, and consist of—

Helix nemoralis.
—— *concinna.*
—— *pulchella.*
—— *rufescens* (?).
Succinea putris.
Cyclostoma (*operculum*).
Bythinia tentaculata (elongated var.).
Pupa marginata.

The mammalian remains in the Battery section, which have been determined by Sir R. Owen[2] and by Dr. Hugh Falconer,[3] belong to—

Elephas primigenius.
—— *antiquus.*
Hippopotamus major.
Rhinoceros tichorhinus.
—— *megarhinus.*
Cervus megaceros.
—— *tarandus.*
Cervus elaphus.
Bos priscus.
Equus.
Sus sp.
Hyæna spelæa.
Ursus (?)

(3) *The Wealden Coast.*—There is no appearance of a Head or of a Raised Beach between Folkestone and Hythe, unless the patch of Lower Greensand and flint-rubble with land-shells, noticed by Mr. H. B. Mackeson, lying near the top of the cliff at the back of Hythe, should belong to the former. The Beach probably followed the line of the low, ruined, and grass-covered clay cliffs which extend in crescent shape from Hythe to Rye, and formed the shore of an old bay now the site of Romney Marshes and Dungeness. The cliffs

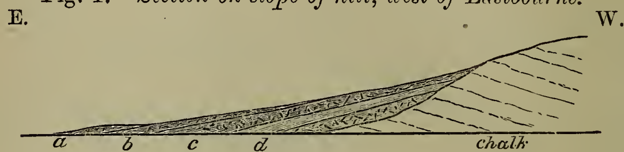
[1] Quart. Journ. Geol. Soc. vol. vii. (1851) p. 257.
[2] Quoted by Mackie, *op. cit.* p. 261.
[3] 'Palæontological Memoirs,' vol. ii. pp. 353, 564.

which project on the coast thence to Hastings and Pevensey are equally without evidence of the Beach or Head.

(4) *Eastbourne.*—The town stands upon a bed of drift, composed of chalk-, clay-, and flint-rubble, from 10 to 12 feet thick, rising only a few feet above the sea-level, and resting upon a floor of Chalk and Upper Greensand. There are no open sections, but in digging the foundations of houses and making the sewers mammalian remains have been found from time to time. They consist of *Elephas primigenius*, *Rhinoceros tichorhinus*, *Hippopotamus major*, *Bos*, and *Equus*.

Although different in aspect and level from the Folkestone and Brighton beds, this deposit cannot be assigned to any river-drift, whereas from position and physical characters it agrees, as Murchison supposed, with the Head or Elephant Bed of Brighton. Traces of the chalk-and-flint rubble from 1 to 5 feet thick were formerly to be seen west of the town on the lower part of the chalk cliff (fig. 1). In this I found a few land-shells, and 1 foot of a hard breccia like Brighton Coombe Rock. As it descends to the sea-level and passes

Fig. 1.—*Section on slope of hill, west of Eastbourne.*



a. Rubble and loam, with a few land-shells ....
b. Coarse chalk-and-flint rubble ....
c. Rubble of red clay-with-flints and chalk ....
d. Alternate fine and coarse rubble, with a few Tertiary flint-pebbles ....

} Rubble-drift, with some concreted portions.

[In order to show the different layers, the deposit is made thicker than it should be.]

under the town, it changes from a chalk-rubble into a rubbly clay-gravel, which extends eastward for a distance of $2\frac{1}{2}$ miles or more on the Pevensey Road. Teeth of the Mammoth have been found about 1 mile east of Eastbourne in a loamy gravel; and the workmen at a neighbouring brick-pit informed me that beneath the bone-bed they came, at a depth of 15 to 16 feet, upon a bed of sand with sea-shells. This would tend to show that the Pevensey Marshes were a sea-bed of the time of the Raised Beaches.

(5) *Birling Gap.*—Three miles westward of Eastbourne is the deep and narrow Chalk valley of East Dean, which terminates on the coast at Birling Gap. The low cliff, 20 to 30 feet high and about 400 feet in length, through which the Gap is cut, consists in its lower part of disturbed and shattered Chalk-with-flints and chalk-rubble, passing up into an angular flint Rubble-drift, which tails out on either side on the slopes of the encircling hills. This drift contains also some Tertiary flint-pebbles and a few subangular flints from an older drift. It is spread out in very irregular sheets of coarse and fine materials, with some seams of a finely laminated, white chalky marl.

I could find no fossil remains of any sort in this rubble; but a few hundred yards distant, up the valley, several Palæolithic implements have been found on the surface of this drift, with which they are not improbably connected, as they are elsewhere.

The cliffs between Birling Gap and the Cuckmere River exhibit several other small dry valleys cut off by the coast cliff. Most of these show traces at their base of the same drift (Head), but they present no new features. The Cuckmere Valley itself is fringed in places by low hills of sand and flint-rubble with large blocks of Tertiary sandstone.[1]

Fig. 2.—*Section of the Rubble-drift at Birling Gap.*

a. Flint-and-chalk rubble, passing down into *b.* Chalk-rubble and disturbed chalk, with layers of shattered flints. *c.* Chalk-with-flints.

(6) At *Newhaven* the sea probably penetrated some distance up the Ouse Valley; for at a pit on the hill-slopes near Heighton, 2 miles inland, to which my attention was directed last year by Mr. H. Willett, there is a well-marked exhibition of Head resting on a floor of chalk which has been levelled by water-action. This floor is about 50 feet above the Ouse, and although no Raised Beach is at present to be seen there are rolled pebbles strewn about, with worn masses of ironstone at the base of the Head indicative of shore- or river-action. The Head extends farther in, and seems to abut against a Chalk cliff, as the Chalk comes to the surface on the top of the hill. This Head is from 10 to 15 feet thick, and consists as usual of roughly-bedded local rubble of chalk and angular flints, with some Tertiary débris, alternating with beds of finely-laminated marl and dense masses of angular flint-rubble (often concreted into solid blocks), together with some very large entire flints and a few brown-stained much-worn flints from an older drift. We found one fragment of an Elephant's tusk and one tooth of *Rhinoceros tichorhinus*, but no shells. This deposit is identical with the Elephant Bed of Brighton.

There is a small exhibition of Head and Coombe Rock at Rottingdean, but no Raised Beach, as the sea has encroached too far on the old line of cliffs.

(7) *Brighton.*—We here have the typical Head of the South Coast, overlying a well-marked Raised Beach. The overlying mass of rubble or the Elephant Bed attains, according to Mantell, a thickness of 60 feet.

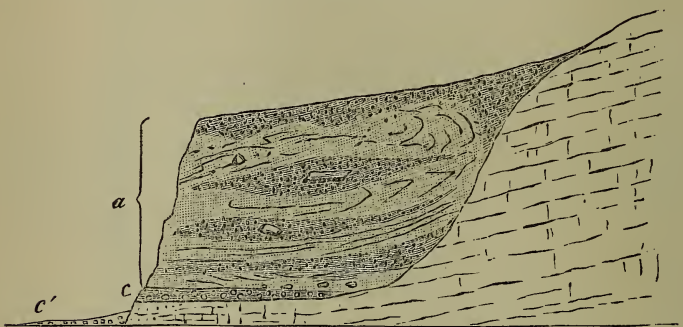
[1] Murchison, Quart. Journ. Geol. Soc. vol. vii. (1851) p. 360.

To the concreted portions Mantell gave the name of 'Coombe Rock.' This rubble is largely developed, and extends under a great part of East Brighton and to the end of Kemp Town. The mammalian remains found in it belong to *Elephas primigenius*, *Rhinoceros tichorhinus*, *Cervus elaphus*, *Hippopotamus major*, *Equus caballus*, *Sus scrofa*, and *Bos*. Mantell remarks on the perfect state of the Mammoth teeth, showing that they could not have been transported from a distance. Murchison applies the same remark to the bones in general, which show fracture but not wear.

Mantell describes the Head as a confused heap of alluvial materials, having a layer of broken sea-shells at its junction with the underlying Raised Beach.[1]

I have often visited the Kemp Town cliff, and as the hypothesis which I shall propose hinges largely on the condition and structure of this section, it will be necessary to describe it at greater length. Murchison's section is a very good one, but I have failed to notice the pipes that he figures.

Fig. 3.—*Section east of Kemp Town, at right angles to the line of old cliffs.*



a. Chalk-and-flint rubble, or Head. *c*. Raised beach. *c′*. Present beach.
[The cliff here is about 80 feet high.]

The upper part of the Head consists of an unstratified mass of sharp angular flints and chalk fragments, overlying a series of irregular lenticular masses of the same character, alternating with others composed chiefly of chalk-rubble and marl with but few flints. Some of the seams are coloured yellow by the admixture of sand (Tertiary), and others consist of a pure chalk-paste or marl, finely laminated. A few much-worn dark brown flints, Tertiary flint-pebbles, and fragments of iron-sandstone, derived from an older drift or from Tertiary strata on the Downs above, occasionally occur; while, projecting from the face of the cliff, large blocks of Tertiary sandstone, angular, or with the angles but slightly worn, may often be seen. One of these measured 8 × 2 × 2 feet. The several layers composing the Head vary extremely in thickness and in horizontal

[1] 'Geology of the South-east of England,' p. 32.

dimensions, but a general similarity and a sort of rude bedding are maintained throughout, with a slight slope upward towards the face of the old cliff.

An appearance of contortion is produced in places by the excess of rubble shot down at particular spots, chiefly about the centre of the cliff, and encircled by layers of a different composition. As the chalk-and-flint rubble approaches the top of the cliff, it is generally bent back and carried down the slope already formed by the previously deposited rubble. The flint-rubble, looked at alone, shows rapid and tumultuous accumulation, while the finer layers of the chalk-rubble or marl often have the fine lamination produced by tranquil water-action and deposition. But there is an entire absence of any of the effects produced by continuously running water, nor is the angle of bedding of the mass such as would be formed under subaerial conditions by rubble falling over the top of the cliff, which would lie at a much greater and more uniform angle.

I have not found any land-shells in the Brighton Head, though from its identity with the Head at Sangatte, where they are common in some of the marly beds,[1] as they are also at Folkestone, they may be expected to occur here.

The old beach consists of a well-worn and rounded flint-shingle, mixed with some sand and a few Tertiary flint-pebbles, together with pebbles and worn blocks (mostly small) of older rocks. On one occasion Mr. James Howell showed me, at the base of the old beach, a thin bed of fine pinkish marl, with indistinct vegetable impressions, having much the character of seaweeds, but I have not been successful in finding this bed again. The upper part of the shingle-beach contains numerous large subangular fragments of chalk, while in the lower part are some much-worn blocks of sandstone and chalk, the latter often drilled by annelids. The shells are few, and mostly in fragments: *Cardium edule*, *Mytilus edulis*, *Littorina littorea*, and *Purpura lapillus* predominate. Mantell mentions that, at the base of the shingle, there is in places a bed of sand 1 to 2 feet thick, in which he found the jawbone of a whale (*Balæna mysticetus*).

The rock-specimens, which are generally small and much worn,[2] other than those of local origin, that I have found in the Brighton Raised Beach are 22 in number, and consist of:—

Light grey and red Granites.
Light red Syenite.
Red Porphyry (decomposed).
Dark grey Felstone.
Greenstone (decomposed).
Mica-schist.
White, grey, and red Quartz.
Olive-green slaty rock.
White and grey Quartzite-pebbles.
Dark and light green Sandstones.
Red and grey calcareous Sandstones.
Compact brown Sandstone.
Fissile micaceous Sandstone.
Light-coloured Limestone.
Brown Shale.
An Oolitic Rock.
An earthy yellow Lime-rock.
Chloritic Chalk.
Dark yellow Chert (in one specimen I noticed the impression of an *Echinus*).
Black Chert.
Ragstone (Lower Greensand).
Jasperoid Flint.

[1] Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 440.

[2] Mr. W. J. L. Abbott, F.G.S., informs me that some of the quartzite and quartz-specimens found by him were distinctly ice-scratched (January 7th, 1892).

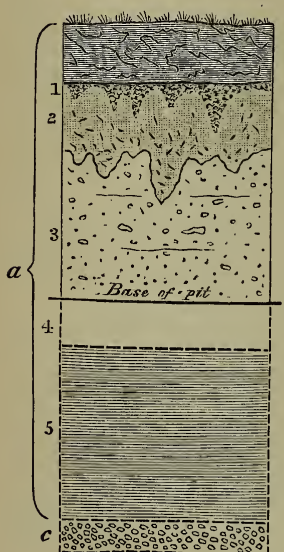
The origin of these foreign rocks, which are more numerous and larger at Pagham and Hayling Island, will be discussed farther on.

(8) *Hove and Portslade.*—West of Brighton, the Raised Beach falls nearly to the sea-level at Hove, and the Head passes into an ordinary ochreous flint-gravel with brick-earth, overlying a shell-bed.[1] In making the main sewer on the road between Brighton and Hove, a section 15 feet deep was exposed, showing:—

	feet
Brick-earth with a few flints	3
Unstratified flint-gravel and brown clay	9
Light coloured sand (irregular)	1
Black carbonaceous clay with indistinct vegetable remains, large worn flints, and fragments of shells (*Tellina, Mytilus*, &c.)	2

The gravel lies in rough furrows running nearly due N. and S., or from the foot of the hills towards the sea. This plain of gravel extends westward for some miles, and sometimes forms a low cliff, a section of which near Southwick shows a mass of chalk-and-flint rubble overlying a thin bed of sand with fragments of shells. Half a mile to the north of this, at the foot of the chalk hills near Portslade, is a pit of considerable interest. When I saw it in 1879, it presented the following section:—

Fig. 4.—*Section of Brick-pit near the Portslade Station.*



		feet
a.	Light brown brick-earth with few flints	4
	1. Angular flint-and-chalk rubble: indents into 2	1 to 3
	2. Chalk-and-flint rubble—ochreous sand and flints uneven at base	4 to 6
	3. Unstratified chalk-and-flint rubble, with numerous large unworn flints: remains of Mammoth and Tichorhine Rhinoceros occur in the lower part of this bed	8 to 10
	The section ends here a little above the base of 3; *the underlying beds are drawn from the foreman's description.*	
	4. White clay (bed 3 continued)..	2
	5. Brown clay	12
c.	Shingle and large flints with *Pecten* and *Cardium*. (Raised Beach) ...	3
	Chalk.	

At a depth in the chalk-rubble, according to the foreman of about

[1] This was described by Sir R. Murchison, Quart. Journ. Geol. Soc. vol. vii. 1851) p. 367.

5 feet, but of 15 feet according to the label on the specimen in the Brighton Museum, a well-shaped pointed flint implement, weathered white and slightly patinated, had been found shortly before my visit. The brown clay, 5, may have been derived from adjacent Tertiary strata.

(9) *The Sussex Coast Plain.*—This plain is covered by a thin bed of drift-clay and flint-gravel, which it is not possible to connect with the action of the two small rivers (Adur and Arun) that traverse the eastern half of the plain, while the western half is not traversed by any river. Nor can it be ascribed to marine action, although it overlies a marine bed—the equivalent of the Raised Beach of Brighton.[1] But it may be, and I believe is, an extension at a lower level of the Rubble-drift or Head swept down from the slopes of the neighbouring Chalk hills, which in transit has lost (except in a few places near the Chalk hills) its calcareous matter, together with the bulk of the heavier load of flints, so that on the coast it is represented merely by a thin bed of gravelly clay and brick-earth. This also was the opinion of Murchison and of Godwin-Austen.

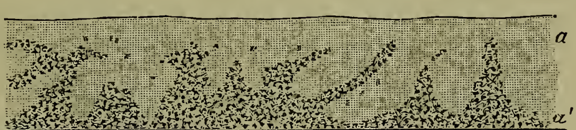
At Waterbeach and Lavant, a few miles to the north of Chichester, we find thick beds of mixed chalk-and-flint rubble or of flint-rubble with enclosed masses of chalk-rubble. At Broil Common, nearer to Chichester, this has passed into a mass of unstratified, coarse flint-gravel 8 feet thick. At the Portfield the rubble-gravel is intercalated with thin lenticular seams of sand and loam, in which the late Mr. Hill, Curator of the Chichester Museum, found:—

Helix nemoralis.	*Pupa marginata.*
—— *concinna.*	*Succinea putris.*
—— *pulchella* (?).	*Zua lubrica.*

Nearer the coast the bed becomes thinner and consists merely of brick-earth with a bed of flints at its base, but without stratification.

Occasionally the deposit shows disturbance and distortion, the flints (a') being pushed up into the brick-earth (a), as in fig. 5, below.

Fig. 5.—*Section in the cliff near Pagham.*



a. Brick-earth .... } 4 to 6 feet.
a'. Irregular seams of flint-gravel .... }

Sometimes the base-line is level, at other times it rests on an irregular and eroded surface.

Mammalian remains, similar to those of the Elephant Bed of Brighton, are occasionally found in this drift. The fine lower jaw

[1] The inland range of this beach I have before described, Quart. Journ. Geol. Soc. vol. xv. (1859) p. 215.

of Mammoth, with the teeth complete, from Worthing, mentioned by Mr. Dixon,[1] and the greater part of the Mammoth's skeleton, from Peppering, near Arundel, described by Dr. Mantell, belong to beds of this age. But the largest and best known collection of mammalian remains comes from Selsey or Bracklesham. There is, however, a difference of opinion as to the position of this bed. Some geologists have considered it to be of older date than the Brighton Head, although I see no reason for doing so. The sections are certainly obscure, but the remains, with the exception of the *Elephas antiquus* (which does not occur at Brighton, though it does at Folkestone), are all of the same ordinary species, namely :—

Elephas antiquus.	*Bison priscus.*
—— *primigenius.*	*Bos longifrons.*
Rhinoceros tichorhinus.	*Cervus elaphus.*
Equus caballus.	*Canis lupus.*

Elsewhere under the rubble, remains of the old Beach are often met with—sometimes with, and at other times without shells. Mr. Dixon records its occurrence at Broadwater and Sompting near Worthing, with *Littorina littorea*, *L. rudis*, and *Purpura lapillus*. At Oving, near Chichester, it contains *Tellina balthica*, and in the Chichester Museum there are specimens of *Cardium edule* and *Mytilus edulis* from the same place.[2] This Beach attains its highest level of 130 feet above O.D. at Waterbeach, near Chichester, 7 miles inland. To the shells already recorded I may add *Nassa incrassata*. Under the gravelly clay on the coast near Pagham, a thin bed with *Littorina*, *Cardium*, and *Mytilus* is occasionally met with, and fragments of the same have sometimes become incorporated in the overlying drift. An ear-bone of a whale was found at Bracklesham.

Over the plain between Worthing and Pagham, in addition to the pebbles of foreign rocks commonly found as far as Brighton, large boulders of similar rocks are met with in considerable numbers. Near Barnham Farm, there was a few years ago a block of fine-grained red granite, measuring $2\frac{1}{2}$ feet by $1\frac{1}{2}$ foot. Occasional blocks occur in the direction of Chichester. At Waterbeach I found small boulders of chalk, but none of foreign rocks, in the sand of the old sea-bed. But it is at and around Pagham Harbour that the foreign boulders are found in greatest number and of largest size. Godwin-Austen mentions[3] :—

Grey porphyritic Granites.	Masses of Vein-quartz.
Compact red Granites.	Siliceous Sandstones.
Syenite.	Conglomerates.
Hornblendic Greenstone.	Micaceous Sandstones with *Orthidæ*.
Mica-schist.	Black micaceous shaly Sandstones.
Green fissile slates, and	Compact Limestones.
Fibrous chloritic semicrystalline rocks.	

[1] 'The Geology of Sussex,' 2nd ed. revised by Prof. T. Rupert Jones (1878), p. 21.

[2] This bed is distinct from the remarkable shell-bed with its large *Pholades* at Bracklesham, to which I purposely omit reference owing to the uncertainty of the sections hitherto given.

[3] 'On the Newer Tertiary Deposits of the Sussex Coast,' Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 56.

One block of porphyritic red granite, which had fallen out of the low cliff, we found to be 27½ feet in circumference.

(10) *Hayling Island*.—The surface of this island is flat, and its structure is very similar to that of the plain just described—namely a covering of gravelly clay, a few feet thick, resting on the London Clay, with boulders occasionally projecting above its surface. Large boulders are common on the coast, and many are to be seen in the farmsteads and at the cross-roads. I spent a week in the island in 1875, and made a tolerably complete collection of these rocks, which I had hoped to examine later on at leisure. To my regret, the box containing the specimens was lost, so that I can only give a list from the notes I made on the spot. (A short notice of them will be found in the Reports of the British Association Meeting at Southampton in 1882, p. 529.)

Fine-grained white Granite.
Red Granite.
Syenite.
Porphyry.
Diorite.
White Quartz-rock.
Light-coloured micaceous Sandstones.
Light Red Sandstones.
Hard Chalk (drilled by annelids).
Freshwater Limestone (Upper Tertiary).
Fossil Wood (Portland Beds).

Most of the blocks are angular or subangular. Some few are smooth and look ice-worn, but I saw no definite markings. They are often met with in trenching and draining, at a depth of from 1 to 4 feet. They may vary in weight from ½ to 6 tons.

The two largest blocks I saw were of sandstone, and measured respectively 6 ft. 10 in. × 5 ft. × 2 ft. 4 in., and 5 ft. × 5 ft. 2 in. × 2 ft. 7 in. (this last was very angular). On one mile of shore I counted as many as 30 blocks of various sizes and materials. They must originally have been even more numerous, for of late years a large number have been gathered together in the grounds of Westfield House, whilst many have been broken up. I was much interested in a specimen of fossil wood, like that of Portland, 26 inches long by 14 in width, which was shown me at the Vicarage; it seemed to me at the time almost conclusive evidence of the direction from which the boulders came. I was moreover informed that smaller pieces had been found. A similar discovery at Selsey had been recorded by the Rev. O. Fisher.[1]

The boulders in this island might appear to form part of the clay-and-gravel drift, and Godwin-Austen noticed them in the same position in the Pagham district, but I think it more probable that these were stranded on the old Beach-shore, and not until later on were they covered up by the Rubble-drift. These shores may have then presented very much the same aspect that some parts of the West Coast of Scotland now present: a strand dotted over with boulders of all sizes. I was also told that at the depth of a few feet beneath the surface, and under the drift and boulders, marine shells (*Ostrea*, *Cardium*, and *Littorina*) were sometimes met with, but I had no opportunity of verifying the statement.

[1] Geol. Mag. for 1871, p. 524.

(11) *Portsea.*—This is the farthest point westward to which these boulders have been traced, though pebbles of the old and crystalline rocks are to be found beyond, but these are such as could have been drifted by tidal action along a shore-line, whereas the boulders are evidently ice-borne. Mr. Codrington describes the boulders at Portsea as "rounded and smoothed," "from 1 to 2 cubic feet in size," and consisting of "granite, syenite, and greenstone, as well as of sarsenstone."[1] When I visited the pits none were visible. No mention is made of beach-shells.

(12) *The Isle of Wight.*—There is a Raised Beach, thick, but of small extent, at Bembridge Point, whence it extends at intervals[2] to near Ryde. It consists of a mass of rolled chalk-flints, some Tertiary flints, and white quartz-pebbles, rounded fragments of ironstone, cherty ragstone, and sarsenstone, with a few large pebbles of light-coloured and red quartzite, and small pebbles of lydianstone and slaty hornstone, in a matrix of quartzose sand roughly bedded. No large boulders and no shells have been found. The beach is overlain by 20 to 30 feet of Head, composed of brick-earth with a small proportion of angular débris. In this Rubble-drift Mr. Codrington found an ovoid flint-implement perfectly sharp at the edges.[3]

With the exception of this bed at Bembridge, the fragment at Portsdown Hill,[4] and uncertain indications near Pool, the Beach is now lost sight of for the remainder of the Hampshire coast, and is not met with again until the Isle of Portland is reached. (In my former estimate of the altitude of Portsdown Beach an observation by aneroid barometer led me to fix it at 125 feet above sea-level, but the Ordnance Survey shows that it is under 100 feet.)

Nevertheless, it is probable that the Beach passed round the back of the island, at no great distance from the present shore. The extensive landslips at the extreme southern points have obliterated all the older coast features, but between Blackgang Chine and Freshwater Gate they remain intact. Along this line a continuous low cliff (80 to 150 feet) fronts south, while at a short distance northward the central Chalk range of the island runs east and west. On the top of this cliff is a bed of gravel (and brick-earth) from 5 to 10 feet thick. In the absence of any rivers flowing off or through the Chalk range on this part of the coast, this gravel was referred by Mr. Codrington to a river which is supposed to have flowed at the back of the island between the present shore and a land to the southward, now removed, and then to have passed through Freshwater Gate[5] northward into an old Solent river. This supposition, however, involves difficulties similar to those which attend the Solent-river hypothesis. The gravel is wanting in the essential characters of a fluviatile gravel, the gradients are incompatible

[1] Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 535.
[2] Bristow, Mem. Geol. Surv. 'Isle of Wight,' p. 102.
[3] Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 542.
[4] *Ibid.* vol. xxviii. (1872) p. 38.
[5] *Ibid.* vol. xxvi. (1870) p. 540.

with the course and fall of a river, the wear of the materials is too small, and there is an entire absence of fluviatile remains.

The gravel, though unstratified, has in places a roughly bedded structure, owing to intercalated lenticular seams of sand and brick-earth or loam, which latter generally forms a separate bed 4 to 10 feet thick, overlying a gravel consisting of

1. Angular chalk-flints.
2. Subangular, and much-worn brown-stained flints.
3. Angular, or but little worn pieces of chert and ragstone.
4. Subangular pieces of iron-sandstone.
5. A few small pebbles of white quartz and lydianstone.

The chalk-flints come from the Chalk hills which rise to the height of 600 to 700 feet immediately behind the plain. The brown flints are from the clay-gravel on the top of those hills; and the chert, ragstone, and iron-sandstone, together with the small pebbles, come from the Lower Greensand on the middle slopes; while the Gault furnishes the argillaceous portion of the drift. The whole, therefore, is strictly of local origin, and from the range of hills immediately north of where it now lies.

Mr. Codrington mentions that the remains of *Elephas primigenius* have been found in the gravel near Grange Chine, and also half a mile east of Brook Chine. Webster states that numerous trunks of trees, many of them 10 to 12 feet in length, and mixed with nuts, were found under 8 or 10 feet of sand and gravel on the top of Brook Cliff[1]; and Dr. Mantell picked up near the same spot teeth of *Equus* and *Cervus*, which he thought came out of the same peaty bed.[2] Mr. Codrington, on the contrary, found the remains of wood and hazel-nuts "in a hollow in the gravel which was 2 ft. 6 inches thick *beneath* them." Both observers are, however, correct. When I first visited the section in 1856 it exhibited:—

	feet
Angular flint-gravel, sand, and peaty matter	2
Ochreous sandy loam, with an inch or two of peaty matter, with twigs and leaves at its base	4
Coarse ferruginous flint-gravel, concreted in places	3
Stems and twigs of trees	1
Resting on Wealden Clay.	

Visiting the cliffs again a few years since, I met with the following section, in which the plant-remains were above the gravel:—

1. Brick-earth, with stem of tree at base.
2. Ferruginous gravel.
3. Coarse sand.
4. Ochreous gravel, with trunk of tree and branches of wood and nuts.

As the brick-earth approaches the hills it becomes divisible

[1] Sir H. Englefield's 'Isle of Wight,' p. 153; Forbes's 'Isle of Wight,' Mem. Geol. Survey (1856), pp. 7, 104.
[2] 'Geology of the Isle of Wight' (1851), p. 273.

into two parts—an upper one composed essentially of ferruginous sandy débris from the Lower Greensand, and a lower one consisting of a clay similar in colour and substance to the Gault which crops out just above.

At Freshwater Gate there is a well-marked deposit of Head, descending on both sides of the valley to the water-level. It is possible, by drawing a vertical line at any part of the section, to divide the deposit into beds, as was done by E. Forbes,[1] but they are rather lenticular masses than true beds, and such sections would vary with the ever-varying face of the cliff.

On the eastern side of the Bay the deposit is more chalky, with more brick-earth and less gravel than on the western side, where the Chalk hill behind rises higher and the drift goes higher up the slopes—to a height of 60 ft. according to Mr. Codrington.[2] The great mass of the gravel on this side is very coarse and consists approximately of

	Per cent.
Angular flints, with some others stained light brown and more worn	63
Pebbles of hard chalk and chalk-marl	6
Subangular and worn fragments of iron-sandstone and ironstone (Lower Greensand and Wealden)	26
Slightly subangular fragments of chert and ragstone	5

Looking at the angle at which the Cretaceous strata lie, all this débris may have come from high ground a few hundred feet south of the Bay, now removed by the wear of the cliff, and not from any distant point. It presents no appearance of river-action, and the only shells found are land-shells. The few chalk-pebbles would require but little wear to produce them, or they may have lost their angles and become rounded merely by the percolation of water. Most of the chalk-flints retain their sharp angles, and the beds on either side of the Bay follow the steep slopes of the hills and not the horizontal lines of a river-deposit.

Allowing for the differences of the substrata, these drifts on the south-western coast of the Isle of Wight have all the characters of the Elephant Bed of the Brighton district, only on this coast the encroachment of the sea has removed the Raised Beach and the old cliff. In both cases the débris is local and unstratified, has undergone comparatively no wear, and contains land-remains only.

The second edition of the Survey Memoir on the Isle of Wight,[3] which describes more fully the Pleistocene beds, contains several notices of a drift which may possibly be referred to the Rubble-drift, such, for example, as the gravel capping the cliffs between Blackgang and Shepherd's Chine (pp. 230–234), including the sections in Shippard's Chine, in which, besides wood and nutshells, the remains of beetles are recorded (p. 232). The Chalk talus in

[1] 'Geology of the Isle of Wight' (1856), pp. 2–5, 103.

[2] The manner in which this deposit follows the slope of the hill is shown in E. Forbes's sketch of Freshwater Bay, *op. cit.* p. 5.

[3] Revised by Messrs. Clement Reid and Aubrey Strahan, 1889.

Compton Bay (p. 237), which is 20 feet thick, that above Brixton, and perhaps that on Gore Cliff [in which land-shells occur] (p. 238), as well as some other beds, may likewise belong to the Rubble-drift, but I have not had an opportunity of visiting the island since the publication of that Memoir.

(13) *Isle of Purbeck.*—In the same way it is probable that the Raised Beach passed at a short distance from the present shore, at the back of the Isle of Purbeck. Here again with the wear of the coast, all traces of it and of the greater part of the Head have been lost. In Encombe Park there is a trail of mixed gravel and brick-earth, descending in a small shallow gully from the higher ground above, and not connected with any river or valley-course; like the bed at Folkestone Battery, it most probably belongs to this drift. At a height of about 240 feet, and half a mile from the edge of the cliff, remains of the under-mentioned animals, which I saw in the collection of the late Lord Eldon, were found :—*Elephas primigenius*, *Rhinoceros tichorhinus*, *Cervus tarandus* (?), *Equus*, and *Bos.*

At Lulworth and Arrish a Head of local drift descends to near the shore-level, but the Beach is still absent.

(14) *The Isle of Portland.*—The beach on the top of Portland Bill is in an admirable state of preservation. The details of it will be found in a former paper by the present writer,[1] and the shells, which are numerous, are tabulated with others at p. 300. The relation of the Head to the Beach, and the very significant features of the former, are best seen in a section near the top of the cliff west of the lighthouses, at the southern end of the long inclined plane forming the surface of the island.

Fig. 6.—*Section on the western side of Portland Bill.*

a. Rubble of angular fragments of Purbeck Beds.
a'. Rubble (much contorted) of sand and marl, with numerous patches of land-shells and several large angular blocks of Purbeck strata.
c. Raised Beach (no shells in this part)—disturbed at its junction with the overlying Rubble.
1. Purbeck strata.
2. Portland rock.

The Rubble-drift, *a*, *a'*, which is here only from 5 to 15 feet thick, is bent back, as it were, on itself, doubling over the Beach (fig. 6).

[1] Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 29.

At the northern end of the island, where the Rubble rests against the slope of the scarped edges of Portland strata (400 feet high), it forms a mass of unstratified rubble some 60 feet thick or more. At both places it consists entirely of local, angular and subangular débris and blocks, some of large size, derived from the Purbeck and Portland strata; and in both cases it contains land-shells,—with some marsh-shells at Chesilton, where the rubble contained also *Cypris Browniana* and *Candona candida*. There may have been a piece of marshy ground or a pond in the Kimmeridge Clay here, previously to the impact of the Head.

●○ *Pupa marginata*, Drap.
○ *Succinea oblonga*, Drap.
○ *Helix virgata*, Da Costa.
○ *Limax agrestis*, Linn. (the shield).
●○ *Limnæa peregra*, Müll.
○ *Limnæa truncatula*, Müll. (opercula).
● *Bythinia tentaculata*, Müll.
● *Planorbis glaber*, Jeffr.

○ Found at Portland Bill. ● Found at Chesilton.

I note particularly these structural conditions of the Head, on account of their bearing on the theoretical questions that will afterwards arise.

Between Portland and the Exe the sea has cut back the Jurassic and Cretaceous strata of the Dorset coast, and formed the deep bay of Lyme Regis, in which there are no traces of the old Beach. It no doubt took a more direct course across the bay than the present beach. The remains of it are, however, to be found in the present beach and in the Chesil Bank,[1] both of which are in great part reconstructed out of its materials.

The valley of the Exe would seem at this time to have formed an estuary. Mr. W. Vicary pointed out to me a slight terrace on either side of the valley, corresponding with what probably would have been the beach-level, about 15 feet above O.D.; and Godwin-Austen mentions the occurrence of marine shells at a depth of a few feet from the surface of the valley near Exeter.

(15) *The South Devon and Cornish Coasts.*—The cliffs of hard Palæozoic rocks of these counties have undergone comparatively slight wear since the Raised Beach period. Consequently, remnants of that Beach are common along these coasts, nestling in many nooks and sheltered places. They are most of them well known, having been described by the early Cornish and other geologists.[2] A very complete account of them, with additions, has also lately been given by Mr. W. A. E. Ussher.[3] I may therefore confine myself to brief notices, except in those cases where there are special points to remark upon.

[1] 'On the Origin of the Chesil Bank,' Proc. Inst. Civ. Eng. vol. xl. (1874–5) part ii. p. 61.

[2] Trans. Roy. Geol. Soc. Cornwall, vols. i. to x. See also De la Beche's 'Report on the Geology of Cornwall, Devon, &c.,' and Mr. Pengelly's several papers in Trans. Devon Assoc. I have visited the principal of these Beaches.

[3] Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 449, and Geol. Mag. for 1879, p. 27; see also his 'Post-Tertiary Geology of Cornwall.'

The Beach and Head reappear in the cliff to the east of Dawlish, where they consist of a mass of angular local débris (including some large flints) from 7 to 15 feet thick, overlying beds of sand and shingle (the pebbles generally larger than in the present beach) which attain in places a thickness of 24 feet, and rest on the New Red Sandstone. I was informed that shells are occasionally met with in the Beach. Traces of the Beach and Head are also to be seen on the banks of the Teign, on the road to Bovey Tracey.

The well-known Beach at Hope's Nose, originally described by Godwin-Austen,[1] caps the headland a short distance east of Torquay, where, in consequence of its being concreted by a cement of carbonate of lime, it forms a projecting cornice about 31 feet above high-water mark. It is overlain by 3 feet of sand and then by a few feet of angular local rubble (Head), in which I found a tooth of Horse. Many of the shells are entire, but they are mixed with a large proportion of comminuted shells. They comprise—

Patella vulgata.
Littorina littorea.
—— *rudis.*
Murex erinaceus.
Purpura lapillus.
Turritella terebra.
Cardium edule.
Cyprina islandica.
Mytilus edulis.
Ostrea edulis.
Pecten varius.
Burrows of *Saxicava.*
„ of Annelids.

Mr. A. R. Hunt has, however, given a much fuller description of the Raised Beach shells from the Thatcher Rock, a small island facing the headland and about 300 yards distant from the shore[2] (for this list, see p. 300). It is about 25 feet above sea-level.

In Torbay there are small portions of a Raised Beach near Paignton, and another to the south of Brixham. They are about 30 feet above sea-level, and present no new features. The shells in the latter are chiefly *Ostrea edulis* and *Littorina littorea* (many young specimens). Again, at Start Point and two or three other places between Torbay and Plymouth, fragments of the old Beach are to be met with, following closely the line of the present shore. This is still more marked at Plymouth, where the Beach follows the sinuosities of the Sound.

The original section of the Beach at Plymouth—since removed in quarrying—was at the west end of the Hoe, and about 35 feet above the present beach. In another section, more recently exposed, and described by Mr. R. N. Worth,[3] the beach was 8 feet thick, and consisted of alternating layers of sand and pebbles—some large, but mostly small—with big blocks, chiefly of limestone, waterworn at the edges. The coast there consists entirely of limestone, but in the upper part of this Beach pebbles of red and grey grit, of slate, and of the felspathic traps found in association with the Triassic conglomerate in Cawsand Bay, predominate. Cawsand Bay is two miles to the westward of the Hoe,

[1] Trans. Geol. Soc. 2nd ser. vol. vi. (1842) p. 441.
[2] Trans. Devon Assoc. for 1888, vol. xx. p. 227.
[3] Trans. Roy. Geol. Soc. Cornwall, vol. x. p. 204.

and as a deep (above 100 feet) and, in all probability, old channel intervenes, the Triassic materials in the Beach could have been carried there only by floating ice. One boulder of a species of trap rock derived from this source, and weighing upwards of 2 cwt., was found with others in the lower part of the Beach. The shells belonged to the common varieties of *Purpura, Patella, Buccinum*, and *Ostrea*. Bones and teeth of Ox were found in the overlying Head. At another spot, remains of the Mammoth and Hyæna were found between the Head and the Beach. Traces of the Beach, covered by a Head of angular local débris, are to be seen both on the western and eastern sides of Plymouth Sound.

Between Plymouth and Falmouth a Raised Beach exists at Looe Island, Polkerris, Polmere Head, Spit Point, Pendower, Porthscatho, and Porth (see Map, Pl. VIII.).

There is a large amount of angular slate-débris, in places 30 to 40 feet thick, at the entrance to Falmouth Harbour and west of Pendennis Castle. Mr. Whitley informs me that with it there are intercalated "5 beds of impalpable sand mixed with crushed stones." In the lower part are some large blocks of the local Killas. The Head extends a considerable distance seaward from its base on the shore. The following section in descending order was taken some years ago :—

a. Angular débris of slate, with blocks of the same and veins of quartz, in a matrix of fine sand and loam.
b. Quartzose sand, with worn flat pieces or cakes of slate.
c. Sand, with white quartz and slate-pebbles.
d. Raised Beach.

As the Beach trends westward it is reduced to little more than a bank of white quartz-pebbles, while with the decrease in height of the shore the Head diminishes in thickness and passes into an ordinary thin surface-drift, covering both the Beach and the low intervening ridges of slate. In Swanpool Bay the Beach is from 6 to 8 feet above sea-level, and is apparently without shells.

Thence to Penzance, portions of the Beach and Head are to be seen near Rosemullion Head, at Ligwrath, Coverack Bay, Porthbeer, Loo Pool, Pra Sands, and on the cliffs on the eastern side of Marazion Bay. The noticeable points on this coast are the large proportion of loam or earth in the Head, the large blocks of slate and Killas that often occur in it, and the confused heaping of the fragments ; also the large size of some of the slate- and granite-pebbles in the Beach, which vary from the size of a hazel-nut to a foot in diameter ; and the presence of chalk-flints. The Beach is not unfrequently concreted by iron peroxide or carbonate of lime into a solid mass, often overhanging.[1]

From Penzance the Beach hugs the coast round the Land's End to St. Ives, showing that, notwithstanding the force of the Atlantic waves, this promontory has undergone but little change of form since the Raised Beach period. Portions of the Beach and Head

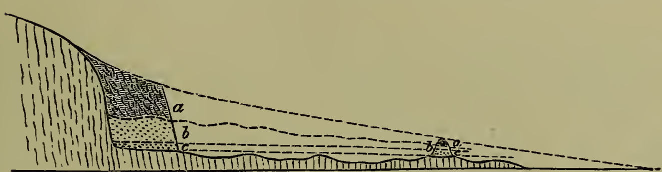
[1] Ussher, Geol. Mag. for 1879, pp. 167–69.

exist at Mousehole, St. Loy Cove, Whitesand Bay, Pornarvon Cove, Porth Just, Priest's Cove, Cape Cornwall, Porth Ledden Cove, Greeb Tor, Pendeen Cove, Carrack Olu Point, Treen Cove, and Porthywidden Cove, St. Ives (see Map, Pl. VIII.).

The Raised Beaches round the Land's End vary from 4 to 15 feet in thickness, and are from 5 to 15 feet above high-water mark. They consist of pebbles of quartz, granite, slate, and greenstone in a granitic sand, together with round and subangular boulders of the same local rocks—some being as much as 2 feet in diameter,—and a few small, subangular chalk-flints.[1] Shells are rare, except in a comminuted state. The overlying Head is from 10 to 60 feet thick, and consists of angular fragments of the adjacent granite, slate, greenstone, and hornblende-rocks, with angular blocks of the same (of considerable size) embedded in a light brown loam. Mr. N. Whitley gives the thickness of the Head between Newlyn and Mousehole at 40 feet. The slope of it is so gradual, in comparison with the slope of the hill, that it would have originally extended 300 feet beyond its present base.

(16) *The North Coast of Cornwall and Devon.*—On the east of St. Ives Bay a Raised Beach extends from Gwythian to Godrevy. The beds vary much in thickness, the Head being in some places 15 feet thick, and the Beach is about 5 feet above high-water mark. A sketch of Mr. Ussher's, from which the following diagram (fig. 7) is reduced, shows that the Head here reached to a rock, 210 feet distant from the shore.

Fig. 7.—*Diagram of Godrevy Beach* ('Godfrey' in map).



		feet
a.	Head of angular fragments	5 to 10
b.	Grey and brown (blown?) sands, dipping inwards	10 to 16
c.	Beach, with slate fragments	1 to 5

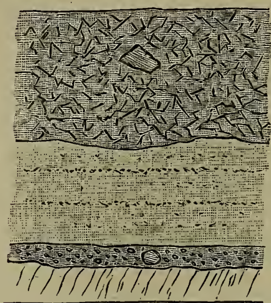
There is a fine example of a Raised Beach in Fistral Bay, near New Quay. It extends along the bottom of the Bay, where it is only a few feet (6 to 10) above the level of the present beach, to the headland at the southern end, where it rises to a height of between 20 and 25 feet. Fig. 8 (p. 282) is a section taken near the centre of the Bay.

[1] Mr. N. Whitley estimates the relative proportions of the pebbles in the Raised Beach near St. Ives at:—

Hornblende-rock	20
Granite	15
Quartz	6
Chalk-flints	2

Mr. S. R. Pattison, on the authority of Prof. Morris, records in this Beach *Modiola vulgaris* (*Mytilus modiolus*), *Cytherea chione*, *Ostrea*, and *Patella*.[1] The thickness of the Blown Sands or old Dunes which lie between the Head and the Beach, and their marked subaerial characters, are here very noticeable.

Fig. 8.—*Section of Cliff, Fistral Bay.*



	feet
a. Head composed of sharply angular débris of slate, with some large angular blocks of white quartz-rock, embedded in brown earth or loam	4 to 20
b. Coarse greyish sand, with some seams of white quartz-pebbles, and some of angular fragments of slate	3 to 12
c. Raised Beach: a shingle consisting chiefly of white quartz-pebbles, in quartzose sand, with large subangular blocks of quartz. Few shells—mostly in fragments—some young shells of *Mya truncata* (?)	2 to 3

I found several specimens of weathered *Patellæ* (*P. vulgata*) in the lower beds of sand, and Mr. Ussher mentions the occurrence of "a few shells of *Helix*." It is said that bones of Ox have also been met with.[2] In places the Sands are consolidated, often false-bedded, and frequently contain minute fragments of the littoral shells. Mr. Whitley described some circular pipes in the Sands and Beach like those in Chalk districts, but at the time of my visit none were visible. Mr. Pengelly has noticed similar conical shafts in the old Blown Sands of Barnstaple Bay.

From New Quay to the coast of Devonshire there are but few traces remaining of the Raised Beach. Some unimportant portions exist near St. Colomb Minor and in Constantine and Perleze Bays. In Daymer Bay there is a beach-reef on the shore, which Mr. Ussher says is the only example known to him in Devon and Cornwall of an old beach below high-water mark. In this are fragments of slate and vegetable remains, with the roots of trees (oak and hazel). The beach indicates a depression of 5 to 10 feet below high-water mark. The exposed coast between Pentine Point and Hartland Point has no Raised Beaches, but after turning

[1] Trans. Roy. Geol. Soc. Cornwall, vol. vii. p. 50.

[2] 'Report on the Geology of Cornwall, &c.,' p. 428; De la Beche has noticed these Blown Sands in several places.

that Point we come to the sheltered estuary of the Taw, which is nearly encircled by them.

A little to the west of Westward Ho is a very massive Raised Beach.[1] It is 15 feet above the level of the present beach, and consists almost entirely of pebbles, in size like large cannon-balls (many of them 1½ feet in longest diameter), of a very hard, compact, greenish-grey sandstone from the Carboniferous rocks a short distance westward, mixed with very little sand. This Beach contains no shells, and is from 5 to 10 feet thick. It is covered immediately by a Head of angular slaty débris 5 to 8 feet thick. A similar Beach with the same massive pebbles is again seen on the top of the cliff at Cornborough Common, but it is there separated from the Head of angular débris by 2 to 3 feet of sand. It thins off inland, but may be traced at intervals as far as Appledore.

At Instow, opposite Appledore, the Raised Beach with shells rests on a platform of rock, a few feet above the level of the river. It has no overlying Head, and has been largely worked for gravel.

Between this place and Fremington the railway passes through a cutting, about 25 feet deep (Pl. VII. fig. 5), of Devonian rocks, flanked at one end by a small quantity of Rubble-drift and at the other by a Raised Beach with a covering of Rubble-drift, of which the section is as under:—

	feet
a. Angular slaty débris embedded in a reddish sandy clay	2 to 6
b. Shingle of large rolled fragments of slate (of less size than at Westward Ho), with some quartzite-pebbles from the New Red Sandstone, small white quartz-pebbles, and a few subangular chalk-flints, in a sandy matrix. There was one boulder of a white, fine-grained granite, measuring $2\frac{1}{2} \times 1\frac{1}{2} \times 1\frac{1}{4}$ ft., but no shells	1 to 12

The Beach abuts against a low cliff, above which the hill rises slightly with a bare surface, while seaward the angular débris (Head) which overlies the Beach irregularly mingles with it, and the line of separation is lost.

South of the line of railway is a thick deposit of clay, which has been referred to by Mr. Maw as possibly Boulder Clay.[2] It is underlain by a thin bed of gravel, at about the same elevation as the Raised Beach in the adjoining Bay, with which Mr. Maw correlates it, and in which I found a few fragments of the ordinary Raised Beach shells. The clay is of an uniformly fine, smooth texture, brown in colour, and attains on the summit of the hill a thickness of 78 feet. Mr. Maw states that a large boulder of 'basaltic Trap' was found in it at a depth of 12 feet. I met with a smaller, somewhat angular boulder of a light-coloured decomposing granite, and one of a light-green felspathic sandstone; but I could not say whether they belonged to the clay-bed or to the

[1] A view of the Raised Beach is given by the Author in his 'Geology' &c., vol. ii. p. 517. It is from this Beach that the Boulder-ridge beach of Appledore is no doubt derived. See also Mr. Pengelly's paper in Trans. Devon Assoc. for 1867, vol. ii. p. 43.

[2] Quart. Journ. Geol. Soc. vol. xx. (1864) p. 445.

overlying irregular gravel. Mr. Maw found no shells in the clay, but only some "blackened pieces of driftwood."

There is not, however, sufficient evidence to connect this deposit with the true Boulder Clay. It is covered by an irregular bed of angular gravel 3 to 8 feet thick, composed chiefly of fragments of grey limestone, and apparently contemporaneous with the Head over the Raised Beach of Barnstaple Bay. This clay would therefore seem to be on the same horizon as the Caves and Blown Sands, and it may be a lake-deposit of that period. It must have had a larger extension than at present, but suffered erosion at the time it was covered by the Head. It requires, however, further examination.

The well-known Raised Beach of Barnstaple Bay extends, with few interruptions, from Croyde Bay by Baggy Point to Morthoe. There is little to add to the description of it by Murchison and Sedgwick and other geologists,[1] except to notice that the sands underlying the Head, which they associated with the Beach, are blown sands or old dunes driven in from the shore after the uplift of the old Beach. The list of shells in the Beach has also been considerably enlarged. The cliff-section may be divided into three parts.—The upper one consists of the usual local angular rubble, composed of small and large fragments of slaty Devonian rocks in a brown earth, without apparent bedding, and varies from 10 to 50 feet or more in thickness (*a*, fig. 9, p. 285). It is cemented in places by a calcareous infiltration, forming a dark compact breccia. The Head rests on an irregular indented surface of the Sands, *b*, which vary in thickness from 5 to 30 feet, and contain occasional thin layers of small subangular fragments of slate. The bedding is horizontal, with frequent oblique lamination. Sometimes the Sands are partly, and at other times nearly wholly concreted, as at Baggy Point, where they form a solid overhanging mass. A section of them, under the Head *a* (fig. 9), there gave:—

		feet
b	1. Loose sand, without shells	2
	2. Concreted sand	$0\frac{1}{2}$
	3. Loose sands, with land-shells	2
	4. Concreted sand, with land-shells	12
	5. Loose sands, with an occasional weathered valve of *Mytilus* and *Cardium*	8

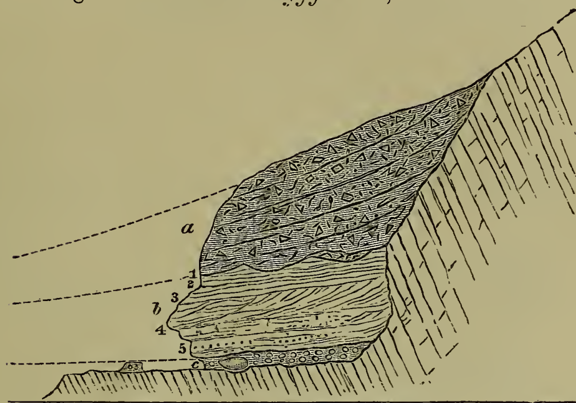
The land-shells were numerous in places and were found by Gwyn Jeffreys to belong to *Helix virgata*, Da Costa, *H. cantiana*, Mont., and *Bulimus ventricosus*, Drap. The *Bulimus* is a South European species, its most northern habitat being the south-west coast of France. The *Helices* are species still living in the district. On the adjacent recent dunes, *Helix virgata*, *H. cantiana*, and *Bulimus acutus* are common.

These Sands overlie a Beach (*c*, fig. 9) which consists of worn and rounded fragments of slate, hard grey and micaceous sandstones, chalk-flints, and pebbles of white quartz and reddish quartzite, in a

[1] Trans. Geol. Soc. 2nd ser. vol. v. (1837) p. 279. Pengelly, Trans. Devon Assoc. for 1867, vol. ii. p. 43.

matrix of sand with a large proportion of comminuted shells, which is often concreted. *Balani* (*B. crenatus*, Darw.?) are attached thickly to the raised rock up to a height of from 10 to 12 feet above high-water mark. Entire shells are not common; the most abundant species are *Purpura lapillus*, *Littorina littorea*, *Patella vulgata*, *Cardium edule*, *Mytilus edulis*, *Mya truncata*, and *Ostrea edulis*. Foraminifera are numerous. The complete list of the shells

Fig. 9.—*Section at Baggy Point, North Devon.*



will be found on p. 300. Amongst them is *Cardium papillosum*, not now known to range farther north than Falmouth. The block of red granite in the beach at Baggy Point measured $7 \times 5 \times 2$ feet. I found also a smaller block of a fine-grained white granite, and one of hornblendic granite in another part of the cliff.

A special feature to notice in connexion with the Raised Beaches from the Land's End to North Devon is the frequent occurrence of Blown Sands or Dunes, *b*, over the Beach and under the Head. These sands show bedding and false-bedding, and are very commonly concreted, owing to the presence of shell-sand which has furnished the cementing carbonate of lime. They attain in places a thickness of from 20 to 30 feet or more, though they have frequently been denuded and deeply indented by the superimposed Head. These prove that, after the formation of the Beach, the coast must have undergone sufficient elevation to raise the Beach above wave-action, and also, if we are to judge by the depth of the old river-channels on the Cornish coast, many feet above the level that the Beaches now have. From the size of the pebbles in the Beaches and the extent of the old Dunes, we may conclude that this coast was exposed to even wilder gales from the westward than at the present day. Large portions of the dunes now forming on these coasts are derived from these old Blown Sands, for which they may often be easily mistaken.

There are no Raised Beaches between Ilfracombe and Lynton, but in places there is an accumulation of local rubble or Head. At Porlock Bay, where it has been described by Godwin-Austen, the Head extends for some distance out to sea and forms the substratum on which the Submarine Forest grew. This therefore fixes a limit to the age of the Submarine Forests on this coast.

(17) *The Somersetshire Coast.*—The principal Raised Beach on this coast is that at Weston-super-Mare, and though, owing to the lowness of the land between Bridgwater and Weston, the sea would seem at one time to have extended inland to the foot of the Mendips, no traces of the Beach are recorded on the surrounding hill-slopes. Within this area, however, as at Chilton Trinity, near Bridgwater, there are several banks of shingle, which may have been shallows in the sea-bed of the period; and Mr. H. B. Woodward records the occurrence of marine shells at Middlezoy and Sutton Door, near Glastonbury.[1]

The section which I saw at Chilton Trinity was only 7 feet deep and exposed:—

	feet
1. Brown loam and a little gravel	$2\frac{1}{2}$
2. Concreted sand, forming thin tabular slabs	$0\frac{1}{2}$
3. Shingle of quartz, quartzite, flints (subangular and stained —from an older gravel), and other pebbles in a matrix of sand with numerous entire shells (chiefly *Mytilus edulis* and *Cardium edule*)	4

Mr. W. Baker, of Bridgwater, made a collection of these shells, of which a list will be found on p. 300 of the present paper.

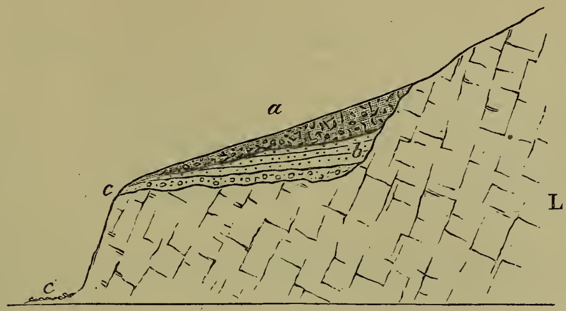
The limestone promontory of Anchor Head Hill, just north of Weston-super-Mare, terminates in a double cliff—the lower one due to present sea-action, while the other, which stands above it and a few feet back, is of the date of the Raised Beach. At the foot of the upper cliff were the remains of a concreted beach about 25 feet above the present shore. But it has, since I first saw it, in great part been quarried away in making new roads and terraces. The only shells I obtained were *Tellina balthica*, *Littorina littorea*, *L. rudis*, *Patella vulgata*, and *Trophon* (?).

Mr. E. C. H. Day[2] mentions that he found bones and teeth of a small species of Horse, and one tooth of *Hyæna spelæa* and of *Canis vulpes* respectively, in the concreted Beach; as this was in a block that had fallen down on the present shore, it may be doubtful whether it was not a portion of the Head, which is also partly concreted. I found no bones.

At Woodspring Hill, two miles north of Weston, there are the remains of another Beach, 20 to 30 feet above high-water, in which *Tellina balthica*, *Littorina littorea*, *L. rudis*, *Patella vulgata*, *Murex*, *Nassa*, *Purpura*, *Cardium*, and *Ostrea* have been found.[3]

1 'Geology of East Somerset,' Mem. Geol. Survey (1876), p. 163.
2 Geol. Mag. for 1866, p. 115.
3 W. Sanders, Rep. Brit. Assoc. for 1840 (Glasgow Meeting), p. 102.

Fig. 10.—*Section at Anchor Head Hill, Weston-super-Mare.*



	feet
a. Angular limestone-rubble (Head) mixed with red clay and sand (this is overlain by 2 feet of *modern talus* formed of loose limestone-fragments)	5 to 12
b. Sand—the lower 2 feet concreted	2 to 10
c. Old Beach, consisting chiefly of rounded pebbles of limestone, with a few scattered subangular blocks of the same, and a few shells—the whole concreted into a solid mass	4
c'. Present Beach.	
L. Carboniferous Limestone.	

(18) *The Lower Severn.*—No traces of the Beach have yet been discovered on the coast farther northward, unless some indications of it occur at Clevedon. At the foot of the hills at the back of that place there is a large accumulation of angular débris (Head).

There can be little doubt that the sea of the Raised Beach period stretched northward up the Valley of the Severn, but whether it formed a deep bay or estuary, or whether at that time it was prolonged through to the Irish Channel, forming the 'Severn Straits' of Murchison, seems uncertain. It is probable that the marine beds at the higher levels should be referred to an earlier stage of the Glacial period. This point, however, is beyond the present enquiry, and one on which Murchison's writings should be consulted.[1]

To the south of Gloucester no marine beds have been described, but the fluviatile and mammaliferous beds of the Stroud Valley form, at their junction with the Severn Valley at Stonehouse, a terrace about 50 feet above the level of the Severn, which indicates possibly the near level of the adjacent sea or estuary at the Beach time. Above Gloucester, there are two instances of the occurrence of marine beds at levels approximating to that of the Raised Beaches. The Rev. W. S. Symonds has recorded the occurrence of worn specimens of *Anomia*, *Turritella*, and *Cyprina* in the railway-cutting at Upton,[2] and Mr. W. C. Lucy that of *Purpura lapillus*

[1] 'The Silurian System,' pp. 533–557, and various papers in Quart. Journ. Geol. Soc.

[2] 'The Severn Straits' (1883), p. 34. These may, however, be merely shells washed out of the Boulder Clay.

in a pit near the workhouse,[1] at a level higher than 47 feet above O.D. The other locality is that mentioned by Murchison [2] at Kempsey, 4 miles S. of Worcester, where the following shells were found in a bed of sand at the base of a bed of gravel:—

Anomia ephippium.	*Cypræa pediculus.*
Cardium tuberculatum.	*Littorina littorea.*
Cyprina islandica.	*Murex erinaceus.*
Ostrea edulis.	*Purpura lapillus.*
Tellina balthica.	*Trochus cinerarius.*
Buccinum undatum.	*Turritella terebra.*
Dentalium entale.	

Bulla and *Oliva* are also mentioned, but some doubt seems to attach to these. The gravel consists of débris from the New Red Sandstone and Silurian rocks, with seams of sand showing false bedding, 14 feet thick. No shells were to be seen at the time of my visit. The gravel forms a low terrace above the Severn, and the shell-bed may have been about 50 to 60 feet above O.D.[3]

The fluviatile beds of Cropthorne, described by Mr. Hugh Strickland, and those of Defford, correspond approximately in level with the above-named marine beds, and, like the fluviatile deposit of the Stroud Valley, in all probability represent, as Strickland and Murchison supposed, the river-drift of the Avon when that river debouched into the adjacent Severn estuary.

The "local drift" of Mr. Strickland, "which lies at the foot of the Oolite hills of Worcestershire,"[4] the angular débris of the high-level Valley Drifts of the Rev. W. S. Symonds, which lies on the slopes of the Malverns, on the other side of the Severn Valley,[5] and part of the Oolitic gravel of Mr. Lucy, "lying near and flanking the Cotteswold range," including some beds of Oolitic débris near the summit of the Cotteswolds,[6] are probably the equivalents of the Rubble-drift or Head, described in connexion with the Raised Beaches.

Passing across the Severn, we find little to record. There is an appearance of a line of old cliffs, a short distance inland between Newport and Cardiff, while the low-lying district between the hills and the coast is covered by a shingle which may represent an old shore, but all this requires further examination.

(19) *Swansea and Gower.*—A remarkable series of Caves and Beaches commences on the coast, where the Carboniferous Limestone comes down to the shore and forms the fine cliffs which

[1] 'On the Gravels of the Severn, Avon, &c.' Proc. Cottesw. Nat. Field Club, vol. v. p. 83, a paper containing much information on the drift-beds of Gloucestershire.

[2] 'The Silurian System,' p. 533.

[3] Murchison said about 100 feet, but, judging by the 'Abstracts of Levelling,' I think that too high.

[4] 'Geology of the Vale of Evesham,' Strickland's Memoirs, pt. ii. p. 103.

[5] 'The Severn Straits,' p. 31.

[6] Proc. Cottesw. Nat. Field Club, vol. v. p. 77.

extend to the westward of Swansea, through Gower to the Worm's Head.

In noticing the Gower Caves, our object will be to show the relation between them and the Raised Beaches and Head. The Caves themselves were admirably described by Dr. Falconer.[1]

Between the Mumbles and the Worm's Head, a distance of 15 miles, ten ossiferous Caves are known to exist, besides two which have been destroyed by the encroachment of the sea. These are situated in the face of precipitous or highly-sloping cliffs, and many of them are accessible only at low tide. They are from 20 to 40 feet above sea-level, and are the result of fissures combined with rain- and wave-action. In some of the Caves a bed of marine sand, of which Bacon Hole affords a good example, underlies the bone-bed.

According to Mr. Benson, the deposits in that cavern consist of:—

	feet
Earth with recent remains of Deer, Fox, &c.	1
Stalagmite	1½
Limestone breccia with bones of Bear, Deer, &c..........	2
Stalagmite (irregular)	0¼ ?
Red Cave-earth breccia with bones of Mammoth, Rhinoceros, Hyæna, &c............	2
Blackish sand with Elephant bones	1½
An irregular seam of stalagmite	0¼ ?
Yellow sand with *Littorina littorea* and *L. rudis* in all stages of growth, and a few individuals of *Clausilia nigricans*............	0½ ?

The floor is of solid limestone.

The shelly sand is about 20 feet above the level of the present beach. At the entrance to this Cave there is a massive fragment of Raised Beach, composed of large well-rounded pebbles attached to the rocks; and Dr. Falconer states that the Cave opens below, but a little more to the eastward of "an enormous accumulation of cemented angular breccia."[2]

In Minchin Hole Cave, a few hundred yards to the west of the last, the Cave-deposits consist of a very similar series of beds, with a thicker bed of shelly sand at the base, and at about the same hieght above sea-level. Shells of *Helix hispida* were found in a dark sand with the bones, lying above the marine bed. Near the entrance, the ossiferous Cave-earth with angular fragments of limestone seemed about 9 feet thick; the layer of stalagmite above this was covered by 12 feet of rubble limestone (Head ?).

Traces of marine sands were likewise found by Col. Wood and Dr. Falconer under the Cave-deposits, at Bosco's Den and Devil's Hole Cave, but the sections are incomplete, and the heights above

[1] 'Palæontological Memoirs,' vol. ii. pp. 498–535. See also Buckland's 'Reliquiæ Diluvianæ,' pp. 80–98; Benson's 'Account of Bacon Hole,' Report for 1852 of the Swansea Lit. & Sc. Society; Dr. W. Taylor, 'The Gower and Doward Bone Caves,' Trans. Cardiff Nat. Hist. Soc. vol. viii. (1876) p. 79.

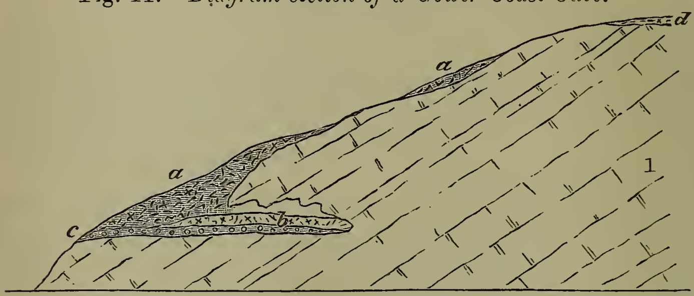
[2] 'Palæont. Memoirs,' vol. ii. p. 502.

the present shore are not given. I should judge them to be from 15 to 20 feet.

Patches also of the concreted sand, and pebbles of an old beach, are attached to the rocks about 12 to 15 feet above the present beach, just outside Bosco's Den, Paviland Cave, and Long Hole Cave; at the last-named place the deposit contained *Littorina littorea*, *L. rudis*, and *Purpura lapillus*. Allowing for the slope outwards from the interior of the Caves, where Col. Wood's sections were taken, this corresponds pretty accurately with the other levels of the Raised Beach on this coast, which, between the Mumbles and Mewslade Bay, may be taken at from 12 to 20 feet above sea-level. The rise has not been uniform.

Not only does this marine basement-bed of the Cave-deposits correspond with the Raised Beach, but the limestone-rubble which overlies the Caves, and in many cases has overspread them, likewise corresponds in character with the Head of the South Coast Beaches. The position of the ossiferous beds in the Caves is therefore intermediate between the Beach and the Head. While, however, the Beach has been in most places worn away by the encroachment of the sea, the Head—being at a higher level—has remained attached to the face of the cliff, wherever the slope has been sufficient to give it support. At Bosco's Den, the rubble fills the fissures above the Cave, masks the entrance to it, covers the Raised Beach, and extends 20 to 30 feet seaward. At Raven's Hole and Bacon Hole similar conditions obtain. Dr. Falconer remarked, in speaking of Bacon Hole and

Fig. 11.—*Diagram-section of a Gower Coast Cave.*



a. Rubble-drift or Head, made up of angular fragments of limestone and pebbles from the drift capping the hill. (This should be carried rather lower down.)
b. Cave-deposits.
c. Raised Beach.
d. Plateau and glacial drift.
1. Carboniferous Limestone.

Crow Hole, that this "breccia corresponds in the character of the materials with the angular brecciated débris which overlies the Raised Beach in the Mewslade section given by Mr. Prestwich" (*op. cit.* p. 518). The diagram, fig. 11, shows the position of these several deposits and their relation to the Caves.

(20) *Mewslade and Rhos Sili.*—These Beaches are amongst the finest examples in the country, but they have not yet been described except in a slight notice of the former that I gave to Dr. Falconer.[1] The Mewslade Beach extends for a distance of nearly half a mile along the coast, and exhibits the old submerged cliff, the Beach, and the Head in a manner analogous to the Brighton and Sangatte sections (see Pl. VII. fig. 6).

The Beach, which maintains a thickness of from 2 to 4 feet throughout, consists of well-rounded pebbles, chiefly of limestone, with a few subangular chalk-flints in a matrix of sand and comminuted shells, and is often concreted. Perfect shells are scarce. The common species are:—*Littorina littorea*, *L. rudis*, *Patella vulgata*, *Purpura lapillus*, *Cardium edule*, *Tellina balthica*, and *Cyprina* (?), with *Balanus*.

The red sand overlying the Beach is in places 4 feet thick, but is very irregular. The Head, which consists of an unstratified mass of angular limestone-fragments in a matrix of red clay and sand, with some rolled fragments and pebbles of grey and red sandstone, quartz-grit, white quartz, &c., is 27 feet thick at the eastern end, becoming gradually thinner westward. The rubble is flush with the top of the submerged cliff, which runs a short distance at the back of the Beach, and behind it the limestone rises to the surface.

Between Mewslade and the Worm's Head is another similar section, but of less height. The only point to note is that there are some large rounded blocks of limestone in the Beach, and that the rubble is composed of larger fragments than at Mewslade. The shells are the same.

The cliffs on the southern coast of Gower range east and west. At their western extremity they are only separated by the bold promontory of the Worm's Head from the fine bay of Rhos Sili, which extends from south to north, or at right angles to Mewslade Bay, for a distance of three miles. In the near background of this bay is a range of high grassy hills, or downs, running parallel with the shore, from which they are separated by a narrow terrace, not more than a furlong in width, sloping from the base of the hills and ending in a line of low cliffs.

The hills are formed of Old Red Sandstone with a thin scattering of Glacial drift spread over the surface, and the terrace is composed of a vast mass of angular rubble or Head derived from these rocks and the overlying drift. Under this Head is a shell-bed resting on a mass of rubble of Old Red Sandstone, very similar in appearance to the upper bed, and beneath which the Red Sandstone shows in places.

The shell-bed may be a beach or a shallow sea-bed, and differs from the littoral Beaches we have been examining. The whole group has at first sight very much the look of a cliff of the Boulder Clay gravels. At the Rhos Sili end the cliff is about 30 feet high, the Head being 10 to 12 feet thick, the shell-bed 2 to 4 feet, and the underlying mass of red rubble 8 feet.

[1] 'Palæont. Memoirs,' vol. ii. p. 536.

The lower angular rubble, which looks like an ordinary talus, maintains for some distance a thickness of from 8 to 12 feet, but at the northern end of the Bay it suddenly expands in the shape of a boss or ridge rising to the top of the cliff and attaining a thickness of about 60 feet, while the shell-bed on both sides thins out against it (see Pl. VII. fig. 7).

The lower rubble there contains some large worn blocks of a quartz conglomerate, and the shell-bed, which has swelled out to a thickness of 20 to 25 feet, consists of large pebbles of limestone, red sandstone of local origin, with others of porphyry, jasper, Coal Measure rocks, conglomerates, &c., derived from the adjacent Boulder Clay Series, in a matrix of greyish sand. The only shells I found in this bed on my two visits were—*Mya* (in fragments), *Turritella terebra*, *Nassa reticulata*, and *N. incrassata* (?). They are numerous in places and in a good state of preservation.

The red rubble which overlies the shingle is from 10 to 30 feet thick, and is spread out in great sheets or lenticular masses, alternately fine and coarse, but without regular stratification. I saw no fossils either in the upper or lower bed of rubble.

The points in which this shell-bed and overlying rubble resemble, and those in which they differ from, the Beaches on the southern coast of Gower are so evenly balanced that it is difficult to say whether the Beaches are synchronous or not. Their close proximity, separated only by the ridge of the Worm's Head promontory, ¼ mile wide, combined with the facts that they are on the same level, and are both covered by a like local Head, leads to the presumption of their synchronism. But the shells are different. None of the ordinary Raised Beach species occur in the Rhos Sili shingle, whereas *Turritella terebra* and *Nassa reticulata* are amongst the most common shells of the Boulder Clay Series, but very rare in the Beaches.

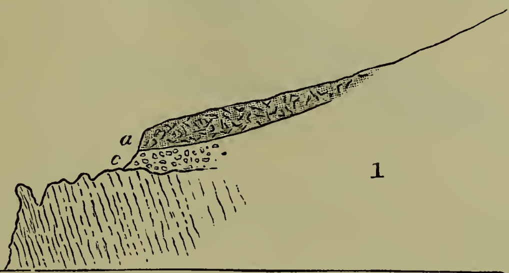
Either the beds are synchronous, the difference in their fauna being due to the circumstance that the one lived on exposed rocky coasts and the other off the shore in a sheltered bay; or the shingle-bed of Rhos Sili belongs to the Boulder Clay Series, and is older than the Raised Beaches. The presence alone of old-rock pebbles in the shingle is not decisive, for they may have come from the Glacial gravels, which are spread over the adjacent district. Nor is the presence of boulders conclusive, for transported boulders occur in both, although they are rare in the Beaches of the Bristol Channel.

On the whole, I am disposed to think that, though the lower rubble-bed may be Glacial—possibly an old talus carried down from the adjacent high range of Old Red Sandstone,—the overlying shell-bed is synchronous with the Beaches of the Gower coast. At the same time this shell-bed, especially where most largely developed, is so singularly like many of the ordinary sections of the shelly shingle-beds of the Boulder Clay that it is impossible to avoid the suggestion that in these sections we may have an instance of the synchronism of the Raised Beaches of the south with the later Glacial beds of the more northerly counties.

(21) *Pembrokeshire.*—At Tenby a much obscured Raised Beach and Head, about 12 feet above sea-level, underlie the esplanade. They are better seen at Penally Head. The so-called Bone-Caves of Caldy Island, described by the Rev. G. N. Smith,[1] will be treated of later (*postea*, p. 320). The Hoyle Cave, which is also near Tenby, is a true cave, but some distance inland. When I saw it the ground had been much disturbed, and part of the roof having fallen in, the order of superposition was rendered very obscure. It appeared to me that the Cave had been occupied by Man after Pleistocene times. I found only Neolithic flints or flakes. I must refer, however, to the Rev. H. H. Winwood's account,[2] as he visited it at an earlier date and when it was more entire.

Thence to Pembroke there are no Beaches, though in Manorbeer Bay there are rolled fragments of conglomerate, the remnants of a destroyed Beach. I am unacquainted with the coast between Milford Haven and St. Bride's Bay, but I am not aware that any Raised Beaches have there been recorded. At a short distance west of Porth Claus Harbour, and 2 miles south of St. David's, occur a somewhat obscured Head and Beach, but without shells. They rest on the upturned edges of the Cambrian rocks, and fronting the present cliff, as shown below :—

Fig. 12.—*Raised Beach, west of Porth Claus Harbour.*



a. Head, consisting chiefly of angular fragments of purple sandstone (Cambrian) in a light brown loam .... 3 ft. (?)
c. Beach, consisting of subangular fragments of Cambrian and pre-Cambrian rocks, granite, veinstone, porphyry, white quartz-pebbles, and a few chalk-flints—no shells. The divisional line between *a* and 1 is not clear .... 5 ft. (?)
1. Cambrian rocks.

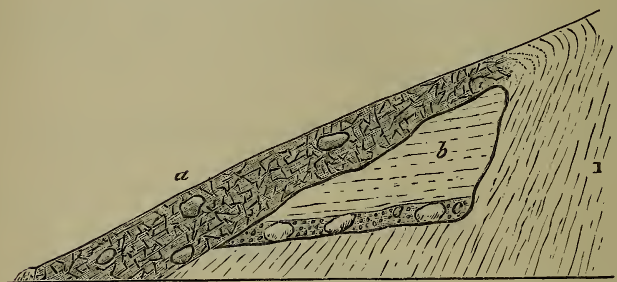
Another better-marked Beach, 8 feet thick, and covered by 15 feet of Head, was pointed out to me by Dr. H. Hicks, at the base of the hills half a mile W. of Porth Claus Harbour.

The last Beach I had occasion to notice on this coast was in Whitesand Bay, 2½ miles N.W. of St. David's, where the remains of it, though extremely fragmentary, are of considerable interest.

[1] Rep. Brit. Assoc. for 1860 (Oxford Meeting), p. 101.
[2] Geol. Mag. for 1865, p. 471.

At the northern end of the Bay, a remnant of Boulder Clay with some large blocks rests on a striated surface of the Cambrian rocks. This is in places immediately overlain by a local Head of angular rock-fragments and Boulder Clay débris. A little to the south of this an irregular Head rests on 15 to 20 feet of Blown Sands. At the southern end of the Bay there are several imperfect sections, one of which shows traces of a Beach consisting of large rounded blocks and a few pebbles, resting on a ledge of nearly vertical strata 8 feet above the present beach. Again, at a short distance from this, a Head, 15 feet thick, extends over and beyond some Blown Sands. In another small section traces of a Beach also appear at the base of these sands. Putting these sections together, I imagine that the following diagram would represent the original order of succession:—

Fig. 13.—*Diagram representing a restored section of the cliff at the southern end of Whitesand Bay.*



a. Head of angular fragments of the local rocks, including some large blocks of granite derived from the Boulder Clay .... 15 ft.
b. Light-coloured sands, with small angular and subangular fragments of slate .... 0 to 20 ft.
c. Beach, mainly represented by large worn and rounded blocks of various rocks, probably in part derived from the adjacent Boulder Clay beds.
1. Lower Cambrian rocks.

There seemed to me to be a close connexion between the incline of the Head and the curvature of the edges of the fissile rocks over which it passed, but on this point I could not feel quite sure. The recent blown sands or dunes which occupy the shore in the centre of the Bay are, no doubt, like those at Croyde in Barnstaple Bay, largely reconstructed from the old dunes.

At the northern end of Abereidy Bay a Head forms a terrace 15 to 20 feet high, and at Dinas Bay there seems to have been an old strait of the Raised Beach period. Beyond this, my visit to the Welsh coast had not the present special object in view, but I am not aware that any Raised Beaches exist along that part of the coast.

§ 3. Origin of the Foreign Boulders in the Raised Beaches.

It was at first supposed that the eastward set of the tide and wind had, in former times as now, carried the shingle from the older rocks of Devon and Cornwall towards the Sussex coast, and that the boulders of crystalline and Palæozoic rocks found on this coast had come from that source.

Godwin-Austen, however, pointed out that there were objections to this conclusion, and considered that the presence of chalk-flints in the Raised Beaches of Devon indicated that the marginal movement of the materials was from east to west, or the reverse of what takes place at present.[1] At the same time he held that the large old-rock boulders must have been carried by ice independently of the coast-line, and could not be referred to any rocks on the English coast. He believed that many of them might be compared with a series from the rocks composing the Cotentin, the Channel Islands, or Britanny, the agreement in many cases being close and striking. There were, however, instances in which the boulders could not be referred to any of the French rocks, and this led him to suggest that an old coast-line, composed partly of Palæozoic and crystalline rocks, extended across the area of the English Channel between Normandy and Sussex before the opening of the Straits of Dover,[2] and that it was from rocks on that ancient coast-line, brought up by the east-and-west anticlinal axis passing south of the Isle of Wight, that the Sussex boulders were derived. He instanced as evidence of their existence in the Channel the fact that in depths of 45 to 50 fathoms he had there found pebbles of granite and of Silurian rocks, and he inferred these pebbles to have belonged to rock-masses composing the ancient coast.[3]

Mr. Codrington thought that the foreign-rock boulders of the Hampshire and Sussex coasts were derived from rocks on the French side of the Channel.[4] Sir Charles Lyell, speaking of the Pagham boulders, observed that they are not of northern origin, but must have been drifted by coast-ice from the coast of Normandy or Britanny, or from land which may once have existed to the south-west, in what is now the English Channel, at a period when the cold must have been at its height.[5]

There is, however, no reason to believe that the Straits of Dover were closed at the time of the Raised Beaches, as, besides the old Beach at Sangatte, the marine bed at the base of the valley-deposits in the old estuary of the Somme is, no doubt, synchronous with the Beaches in the open, thus establishing an almost continuous coast-line on that side of the Straits. On our

[1] Quart. Journ. Geol. Soc. vol. vi. (1850) p. 88.
[2] *Ibid.* vol. xiii. (1857) p 59.
[3] *Ibid.* pp. 61 & 71.
[4] *Ibid.* vol. xxvi. (1870) p. 535.
[5] 'The Antiquity of Man,' 4th ed. p. 330.

side of the Channel I have shown that the Brighton Beach extends to Eastbourne, and there is reason to believe that it was not far in advance of the present coast-line at Folkestone and Dover, while traces of a contemporaneous (but not marine) deposit at the same level exist near the Isle of Thanet. The only indication of a submerged land in the Channel is that afforded by the Varne and Ridge shoals, which at low water are covered to the depth of only 2 fathoms, but these banks consist of Portland and Purbeck strata, and no Palæozoic rocks were found there by M. de Gamond, nor do any exist on the French coast opposite. These shoals may represent a small island with deep water on either side, but not a barrier across the Channel. That the Straits were open, and a drift from the northward then existed, is on the other hand indicated, not only by the presence of granite-pebbles in the Sangatte Raised Beach, but also by a circumstance mentioned by Capt. T. B. Martin, formerly Harbour-Master at Ramsgate, who says that the fishermen employed there in trawling are "occasionally impeded by masses of granite, serpentine, sandstone, slate, and various other stones, which are scattered indiscriminately over the bed of the ocean."[1] The granite, Palæozoic, and other pebbles which were found by Godwin-Austen in the Channel between the Calvados and Sussex coasts may, as well as these off Ramsgate, therefore be due to an ice-bearing current from the North Sea, and this is confirmed by various other facts.

The ice-floes and bergs, with their detrital loads, would as a rule keep in deep water at a distance from the shore, unless other conditions, as those on the coast of West Sussex, favoured their nearer approach. The great bay which there extended at the time of the Raised Beach from Waterbeach, near Chichester, to Bembridge, with a width of about 15 miles and a depth, from Pagham to Portsea, of 10 miles, presented such conditions; for, taking the level of the old beach near Chichester at about 100 feet, and at Bembridge at 30 feet, the water over the Pagham and adjoining flats must have been from 50 to 80 feet deep. In this gulf ice-floes from the eastward would become embayed and stranded, and there no doubt they dropped the blocks of granite and other rocks now found scattered over all that area.

One circumstance which for a time seemed to offer an insurmountable objection to a drift from this direction was the presence, with the foreign-rock boulders at Hayling Island and Bracklesham, of pieces of silicified wood identical with the fossil wood of Portland. For this wood, which is of a marked character, is peculiar to that part of our coast; and it might have been concluded that the drift had been from Portland westward, and not from the eastward and northward, had not another explanation suggested itself. I had seen similar wood in the Boulonnais, though not on the coast; but in Dr. Fitton's description of that district I find the following remark:—"The line of the cliffs from Equihen on the south of Boulogne to Cape Grisnez on the north of that place is capped at intervals with a

[1] Trans. Geol. Soc. 2nd ser. vol. vi. (1841) p. 161.

thin crust of the Purbeck strata, resting upon those of Portland, and consisting of slaty beds of limestone which contain freshwater shells, and include a bed of tough dark-coloured clay in which are numerous fragments of *silicified coniferous trunks not distinguishable from those of the Isle of Portland*."[1] The Sussex fragments may therefore have been derived from the Boulogne coast, or from the island which then probably existed on the site of the Varne and Ridge shoals.

Between this and the western portion of the Channel no special examination of the sea-bed for erratic blocks has been made. We only know that it is strewn over in places with banks of flint shingle. Mr. A. R. Hunt has, however, by the use of a trawl, recently collected a considerable number of foreign blocks from the Salcombe fishing-grounds,[2] some 20 to 30 miles off the coast of Devonshire. He informs me that they were found over an area extending from east to west for a distance of 62 miles, and from north to south for a distance of 20 miles. The blocks varied from $\frac{1}{4}$ cwt. to 16 cwt. in weight, and some of them measured 2 to $3\frac{1}{2}$ feet in length.

The 40 blocks described by Mr. Hunt consist of the following rocks:—

Fine-grained grey Granite.
Coarse-grained pinkish Granite.
Hornblendic Granite.
Microgranulite.
Syenite (dark green).
Serpentine.
Gabbro (mottled purplish green).
Diabase (dark green).
Diorite.
Basalt.
Trachyte.
Archæan Gneiss.
A Metamorphic Rock.
Quartz Grit.
Conglomerate Grit.
Reddish-brown Sandstone.
Sandstone (Neocomian?).
Chalk-flints in considerable number, and unrolled,—many of large size.

Several of the blocks were much rounded, while others were subangular, the igneous rocks being often a good deal altered.

Mr. Hunt dismisses the hypothesis of adjacent land-ice, owing to the absence of similar blocks between Dartmoor and the sea, and concludes that they were brought there by floating ice. But whence? Mr. E. B. Tawney, who examined the blocks microscopically to see whether they could be referred to either side of the Channel, remarks of the granites that he knew of no locality in Britain from which they could be derived, and that in all the specimens there was an absence of schorl, which is so abundant in some of the Dartmoor granites. The serpentine he pronounced to be precisely like some of the Cornish varieties. Again, in comparing them with specimens of the Channel Island rocks, he could not find any of the characteristic Guernsey rocks among those dredged.

Prof. Bonney found only a general resemblance in some of the granites (block No. 35 of Mr. Hunt) and in the diabase (No. 37)

[1] Trans. Geol. Soc. 2nd ser. vol. iv. (1836) p. 326. The italics are mine.
[2] 'On the Submarine Geology of the English Channel off the coast of South Devon,' Trans. Devon Assoc. 1880, 1881, 1883, & 1885.

x 2

with those that occur in Cornwall; another specimen (No. 38) had a certain resemblance to some of the gabbros from Guernsey; while one specimen (No. 28) "had the aspect of a very ancient Archæan gneiss" resembling the Hebridean gneiss of Scotland.

It would appear therefore that none of the boulders of igneous and crystalline rocks can be referred with certainty to any of the rocks on the English or French coasts, with the exception possibly of the serpentine, which is not a very characteristic rock. Mr. Hunt thinks that a few specimens may be derived from the Eddystone and Shovel rocks, and from Triassic strata at the sea-bottom; but this seems uncertain, especially with reference to the Red Sandstone which was found 20 miles south of the Eddystone, and far from the main body of Triassic strata.

We must consequently look to other areas for the origin of the blocks found off the Devonshire coast. The presence of large unrolled chalk-flints, and of the block (No. 23) described by Mr. Hunt as having "all the appearance of Neocomian sandstone," together with the close analogy of the Salcombe group of boulders with those of Hayling Island and Pagham, points to their having, like these others, come from the eastward.

Upon the whole, it seems to me most probable that this important group of foreign boulders is derived from the crystalline, metamorphic, and Palæozoic rocks of Norway, though some of them, together with the boulders of igneous rocks, may have come down the Rhine and Elbe from Central Germany, or from the Ardennes by way of the Meuse. Beneath the alluvial beds of Holland there are sands and gravels with boulders which in all probability had that source of origin. The reddish sandstone-blocks so common in Hayling Island, and now recorded by Mr. Hunt off the Devonshire coast, may have come from the shores of Denmark, North Germany, or Heligoland. But further investigation and a comparison with the rocks of those countries—which I am unable now to undertake—are necessary.

In any case the evidence, so far as it goes, accords best with the supposition that the blocks were carried on ice-floes and bergs from the North Sea westward, through the Straits of Dover and down the English Channel, dropping their larger blocks in mid-channel or in the deep water of bays. It yet remains to be seen how much farther westward they may have passed.

§ 4. The Mollusca of the Raised Beaches.

As a rule the shells are limited to very few species, and consist of the most common littoral forms of our present coasts. In many places none are found, and it is only at Portland, the Thatcher Rock, Barnstaple Bay, and Chilton Trinity, near Bridgwater, that they occur in any numbers.

But although the species were few, it is evident that the individuals were often numerous, for shell-sand and finely comminuted shells form in places a large proportion of the matrix in which the shells and pebbles are embedded. At Portland I found 24 species,[1] and to these Mr. A. Bell has since added 3 others, making a total of 27 species. The richest locality is, however, the Thatcher Rock, Torbay, where Mr. A. R. Hunt has made a collection of as many as 43 species.[2] There were 24 specimens in the collection from Chilton Trinity formed by the late Mr. W. Baker, of Bridgwater, whose names in the following list are altered in accordance with recent synonyms. The collection is, I believe, lost.

All the Portland shells are of littoral species, and almost all such as are now living in the British area. Gwyn Jeffreys remarked of them:—"The shells are rather northern than southern; but I have not detected any peculiarly Arctic species, and certainly none of a Mediterranean or Lusitanian type. All the species inhabit the British coasts from Shetland to Yorkshire, except one, which I consider undescribed, and propose to name *Rissoa subcylindrata*. . . . . . Another species (*Trochus helicinus*) has not, so far as I am aware, been found south of Yorkshire and Dublin Bay. The most northern known locality for another species (*Trochus umbilicatus*) is Stornoway in the Outer Hebrides; and it occurs in a raised beach at Portrush."[3]

The shells at the Thatcher Rock indicate, according to Mr. Hunt, a greater range of depth, as well as a greater variety of sea-bottom. He considers that many must have come from depths of 10 to 20 fathoms, and that while a large number are of species inhabiting rocky coasts, there are others which now live only in sandy bays. These shells are also, like those at Portland, of northern rather than southern species.

The *Cyamium minutum* is now rare in the South of England, but common on the coasts of Scotland and Greenland; the *Nucula nucleus*, *Tellina balthica*, *Lacuna puteolus*, *Littorina rudis*, *Fusus gracilis*, *Pleurotoma turricula*, *Purpura lapillus*, and *Trophon truncatum* are also essentially northern species, but it is rather the absence of southern forms than the presence of distinctly Arctic forms that denotes colder waters—though there are no indications of any extreme cold. It is a molluscan fauna such as might now exist on the shores of the North of Scotland or of Norway, as well as on the South Coast of England, but not south of the English Channel.

Although the number of species is limited, it must be remembered that we are dealing with a littoral fauna, and that we are ignorant of the deep-water fauna of the Channel at that period. At the present day, according to Mr. Damon, the number of species living at all depths in the sea around Portland is not less than 281.

The total number of the Raised Beach shells amounts to 64 species, forming a not inconsiderable proportion of the existing littoral fauna.

The Portland shells and the greater part of the Barnstaple Bay

[1] Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 33.
[2] Trans. Devon Assoc. vol. xx. (1888) p. 225.
[3] Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 52.

shells were determined by Gwyn Jeffreys. Those of the Thatcher Rock were identified for Mr. Hunt by Dr. Jeffreys or by Mr. D. Pidgeon and Mr. J. T. Marshall.

List of the Mollusca of the Raised Beaches.

	Portland (Gwyn Jeffreys).	Torquay (A. R. Hunt).	Bridg-water (W. Baker).	Barnstaple Bay (G. Jeffreys).
1. Bivalves.				
Anomia ephippium, L.	*	...	...	...
Arca lactea, L.	...	...	*	*
Astarte sulcata, Da Costa	...	*	...	...
Cardium edule, L.	...	*	*	*
—— *echinatum*, L.	...	*	*	...
—— *papillosum*, Poli	...	...	...	*
—— *norvegicum*, Spengl.	...	*	...	...
Cytherea chione, F. & H.[2]	...	...	...	...
Cyprina islandica, L.	...	*	...	...
Cyamium minutum, Fabr.	*	...	...	...
Lutraria elliptica, Lam.	...	*	...	...
Mactra subtruncata, Da C.	...	*	*?	*
Mya arenaria, L.	...	*	...	...
—— *truncata*, L.	...	...	*	*
Mytilus edulis, L.	*	*	*	*
—— *modiolus*, L.[2]	...	...	...	...
Modiola marmorata, Forbes	*	...	...	...
Nucula nucleus, L.	...	*	*	*
Ostrea edulis, L.	*	*	*	*[1]
Pecten varius, L.	*[1]	...	...	*
Pinna rudis, L.	...	*	...	...
Solen vagina, L.	...	*	...	...
Tellina balthica, L.	*	*	*	...
—— *fabula*, Gron.	...	...	...	*
Venus exoleta, L.	...	*	...	...
—— *fasciata*, Da Costa	...	*	...	...
—— *gallina*, L.	...	*	...	...
Saxicava rugosa, Lam.	*	*	*	...
Ceratisolen legumen (?), L.	...	...	...	*
2. Univalves.				
Adeorbis subcarinatus, Mont.	...	*	...	...
Aporrhais pes-pelicani, L.	...	*	...	...
Buccinum undatum, L.	*	*	*	*
Cerithium reticulatum, Da C.	...	*	*	...
Cylichna cylindracea, Penn.	...	*	*	...
Lacuna puteolus, Turt.	*	*	*	...
Littorina littorea, L.	*	*	*	*
—— *obtusata*, L.	*	*	...	...
—— *rudis*, Maton	*	*	*	*
Fusus gracilis, Da Costa	...	*	...	...
—— *Jeffreysianus*, Fisch.	...	*	...	...
Murex erinaceus, L.	*[1]	*	*	*

[1] These are given on the authority of Mr. A. Bell.
[2] Found at New Quay.

TABLE (*continued*).

	Portland (Gwyn Jeffreys).	Torquay (A. R. Hunt).	Bridg-water (W. Baker).	Barnstaple Bay (G. Jeffreys).
UNIVALVES (*continued*).				
Nassa reticulata, Flem.......	...	*	...	*
—— *incrassata*, Müll.	*	*	...	*
Natica Alderi, Forbes	...	*	*?	*
Patella vulgata, L.............	*	*	*	*
Pleurotoma striolata, Phil.	...	*	...	...
—— *brachystoma*, Phil. ...	...	*	...	...
—— *turricula*, Mont.	...	*	*	...
Purpura lapillus, L.	*	*	*	*
Rissoa parva, Da Costa ...	*	...	...	...
—— *striata*, Phil.............	*	...	...	...
—— *subcylindrata*, Jeff. ...	*	...	...	...
Scalaria Turtonæ, Turt. ...	...	*	...	...
Skenea planorbis, Fabr. ...	*	...	...	...
Tectura virginea, Müll. ...	*	...	*	*?
Trochus zizyphinus, L.......	...	*	*	...
—— *lineatus*, De Blainv....	...	...	...	*
—— *cinerarius*, L.	*	...	...	...
—— *helicinus*, Gml.	*	...	...	...
—— *umbilicatus*, L.	*	...	*	*
Trophon truncatum, Ström.	...	*	...	...
Turritella terebra, L.	...	*	...	...
Utriculus truncatulus, Brug.	*	*	...	...
3. OTHER FORMS.				
Serpula	...	...	...	*
Balanus crenatus	...	...	...	*
Miliola seminulum	*	...	...	...
Cythere, sp.	*	...	...	...

Of the total of 64 species, only 39 are common to the Glacial drifts of the North of England and Wales. Of these, 27 are found at Moel Tryfaen, 31 in the lower Macclesfield beds, and 28 in the Upper Boulder Clay of Newton.

The total number of species of the Glacial drifts in the districts above-named amounts, according to the lists of Mr. De Rance[1] and Mr. W. Shone,[2] to 98. Allowing for the circumstance that in the one case the shells are almost entirely those of the littoral zone, whilst in the other we have the product of various zones of depth (still the littoral zone is represented in the Glacial Series), it is obvious that a marked difference in the temperature of the seas is indicated by the difference in the mollusca. There is the absence also in the Raised Beaches of such northern shells as *Astarte borealis*, *Leda pernula*, *Fusus islandicus*, *Natica grœnlandica*, and

[1] 'The Superficial Geology of Lancashire,' Mem. Geol. Survey (1877), p. 128.
[2] 'On the Glacial Deposits of West Cheshire,' Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 394.

others common in the Glacial drifts. The Raised Beach mollusca agree therefore pretty closely with the molluscan fauna now living in the British seas, and this accords with the stratigraphical evidence which leads us to place the Beaches with the latest of the River-valley Deposits as described in the next section of this paper.

§ 5. The Relation of the Raised Beaches to the Valley Drifts.

The evidence on this point, though not so definite as could be wished, is still sufficient to prove with tolerable certainty that the Beaches are contemporary with the lowest and therefore the newest of the fluviatile drifts of the valleys, and consequently that the high-level valley gravels are older than the Beaches, though these higher river-drifts rarely extend to the coast. For example, the low-level fossiliferous drifts of the Thames at Grays and Crayford, and the high-level drift gravels of Purfleet, Chadwell, and Dartford, are represented at the mouth of the Thames only by the small bed at Chislet, and by the circumscribed bed of gravel which caps the cliffs between Herne Bay and the Reculvers, at a level about 100 feet higher than the Chislet deposit.[1] In this latter we meet with indications of the proximity of a coast-line, in the presence of *Balanus* and a species of *Globulina*, with which are associated the *Cyrena fluminalis* and a few freshwater shells such as are found at Crayford and Grays. Over these are 3 to 8 feet of Rubble-drift or Head, derived from the gravel and clay of the adjacent range of hills. This shell-bed is, like the Beaches on the coast, at a height of about 15 to 20 feet above sea-level. The Chalk on which it rests is in one part festooned, in the manner I found the Chalk to be at Dartford before the deposition of the Crayford low-level drift.[2]

But in order to obtain better evidence of the relation between the Raised Beaches and the Valley Drifts, we must step for a time beyond our assigned limits, and cross to the valley of the Somme. The estuary of that river, which now does not extend beyond St. Valery, formerly extended to Abbeville, where a number of marine shells are met with at the base of the fluviatile beds of Menchecourt.[3] This estuarine bed is 24 feet above the mean level of the sea, or approximately on the same level as the Raised Beach at Sangatte, and contains the *Buccinum undatum*, *Littorina littorea*, *Nassa reticulata*, *Purpura lapillus*, *Cardium edule*, *Ostrea edulis*, and *Tellina balthica* of our Raised Beaches, together with a large proportion of the fluviatile shells and the *Cyrena fluminalis* of the low-level fluviatile drifts of Grays and Crayford. There are high-level gravels on both sides of the valley at Abbeville, at a height of 98 feet above the marine shell-bed at Menchecourt, and again at the

[1] Quart. Journ. Geol. Soc. vol. xi. (1855) p. 110.
[2] *Ibid.* vol. xlvii. (1891) p. 153, fig. 11.
[3] Phil. Trans. Roy. Soc. vol. cl. (1860) p. 286.

mouth of the Somme at St. Valery, at which place this gravel is about 105 feet above sea-level. The absence of large rivers, the encroachment of the sea, and other circumstances to be hereafter mentioned, have interfered with the exhibition of any equally illustrative case on our own south coast.

At the Isle of Thanet the sea has encroached so much that if there had been any Raised Beaches they must have been destroyed. It is so also along the Walmer and Dover coasts, though at both places there are remains of a Head of rubbly chalk at a level which would indicate that the shore-line was not far distant. The Wealden rivers are obscured at their embouchure by the large accumulation of recent shingle. On the Sussex coast, the flat ground through which the rivers pass conceals their relation with the coast-sections, and on the Hampshire coast the distinctive levels of the valley-beds, well exhibited in the Avon Valley at and around Salisbury, are lost after passing Ringwood. The streams which flow into the Southampton Water have equally indefinite banks.

On the coast of Devon and Cornwall, the Valley Drifts have not yet been well-defined, but we shall have other evidence to offer respecting the age of the Raised Beaches there. In the valley of the Severn, there are too many links wanting to establish with sufficient certainty the relation of the Raised Beaches of Weston-super-Mare and Woodspring with the Pleistocene fluviatile beds of the valley of the Severn and its tributaries. In the absence of marine terraces in the main valley, we may, however, take the fluviatile beds of the tributary valleys as guides to the then sea-levels. Thus, as before mentioned, the low-level fossiliferous drift of the Stroud Valley where it debouches into the valley of the Severn corresponds very well with what should have been the level of the old estuary, as does the level of the Cropthorne bed at the junction of the Avon with the Severn Valley,[1] while the marine beds at Kempsey and Upton would tally with the Raised Beaches of Weston and Woodspring.

On the Welsh coast, the absence of broad valleys with fluviatile deposits leaves a blank in the terms of comparison.

On the whole, especially looking at the Menchecourt section, we may conclude that the Raised Beaches of the English and Bristol Channels are on the same geological horizon as the lower old river-drifts of the Thames and Somme Valleys, and belong to one of the latest phases of the post-Glacial, or, more properly, of the later Glacial period.

Discussion.

The President thought the Fellows were to be congratulated that the father of the Society should still continue to furnish them with such papers as that to which they had listened—so full of careful observation, ranging over so wide an area, and raising so many

[1] Strickland's Memoirs, 'Geology of the Vale of Evesham,' p. 96.

questions of the greatest interest. They would regret that the Author was prevented by illness from being present that evening, but he hoped that he would be able to attend when the second part of the paper was read and when the full discussion of this wide subject could be entered upon.

Dr. Evans concurred in the advisability of postponing the discussion of the paper until the second part had been read.

Part II. (Read February 24th, 1892.)

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§ 6. The Coast Caves and their Fauna; the Zone of Raised Dunes or Blown Sands.

The long rest indicated by the maintained level of the Raised Beaches, and the wear of the cliffs against which they abut, was brought to an end by a rise of the land which placed the Beach above the level of tidal action. It has been suggested that the Raised Beaches do not indicate any alteration of level, being merely the remaining portions of the upper part of the inclined planes up which the shingle was driven by storm-waves; but, amongst other reasons, besides the considerable and varying heights (10 to 50 feet) of the Beaches on the coast, the double cliffs (Weston, fig. 10, and Porthclaus, fig. 12), the presence of *Balani* attached to the upraised rocks (Barnstaple Bay), at or above that at which they could possibly have lived, and the many uninjured shells (Hope's Nose, Portland), clearly show that there has been a change of level. Besides, it must be remembered that the present level of the Beaches has nothing to do with the levels which prevailed at the time of their formation. The present level is the result, not of one upheaval, but of the several upheavals and subsidences which have taken place since that time. It merely represents the difference between the several movements. I need not, however, dwell on this subject as Mr. Pengelly has already proved that the Beaches could not have been formed at the level at which they now stand.[1]

[1] Trans. Devon Assoc. for 1867, p. 1.

It has also been suggested that after the Beach formation the land was elevated to the extent of 2000 feet or more, and in accordance with that supposition it has been concluded that the whole area of the Bristol and English Channels was then transformed into dry land which afforded pasture-grounds for the large mammalian fauna of this late Cave period. The submarine forests so common on our coasts have been adduced as proofs of that elevation. But these sunken forests are not contemporary with the Caves. They belong, as I have shown in another part of this paper, to a subsequent period, and they are moreover limited to moderate depths. There is no well-recorded instance of any submarine forests occurring at a greater depth than about 100 feet, so that on these grounds alone there is no reason to believe that the sea-bed much beyond that depth was raised, or that the *whole* of the area of the English and Bristol Channels was transformed into dry land. On the contrary, such evidence as we have—namely, that afforded by the Blown Sands—would lead us to limit the level of the land after the elevation of the Raised Beaches to a height not exceeding 120 feet or so; for these sands could scarcely have attained the dimensions they have—and it must be remembered that they have undergone considerable denudation—had they been blown to greater heights. It is true that shore sands may be blown inland over hills higher than this,[1] but they then occur merely as a thin covering. Even, however, such an elevation as 120 feet would convert a great part of the Bristol Channel into dry land, and would give a broad fringe of land to the English Channel. (See Map, Pl. VIII.)

What is needed for the massing of blown sands is a wide strand left dry at low water and exposed to the action of strong winds. This must have been for a considerable time the condition of the coasts of Cornwall and Devon after the first uplift of the Beaches, while on the coast of South Wales the cliffs may have stood farther inland and been less exposed to the drifting sands. As these sands lie, on the one side of the Channel, between the Raised Beaches and the Head, whilst on the other side the Cave-deposits occupy the same position, it follows that these two deposits are synchronous; and further, as the Head forms the closing chapter of Palæolithic and post-Glacial times, this group of Cave animals is the last one of the Pleistocene fauna, with the exception of that of the Rubble-drift.

Dr. Falconer therefore was right in his conclusion "that the Gower caves have probably been filled up with their mammalian remains since the deposition of the Boulder Clay," but whether there are no "mammalian remains found elsewhere in the ossiferous caves of Britain referable to a fauna of a more ancient geological date"[2] may admit of a doubt. Dr. Falconer's list (with some

[1] In the Boulonnais they are found on a hill 400 feet high, but only as a thin sprinkling; see my 'Geology,' vol. i. p. 146.

[2] 'Palæont. Memoirs,' vol. ii. p. 535.

corrections) of this Cave fauna will serve the purpose of comparison with that from the Rubble-drift besides, and also as defining this particular zone.[1]

Ursus spelæus.
†—— *arctos.*
†*Meles taxus.*
†*Mustela putorius.*
†—— *erminea.*
†*Lutra vulgaris.*
†*Canis lupus.*
†—— *vulpes.*
Hyæna crocuta (*spelæa*).
Felis leo (*F. spelæa*).
†—— *catus.*
†*Arvicola amphibius.*
†*Lepus cuniculus.*
†—— *timidus.*

Elephas antiquus.
—— *primigenius.*
Rhinoceros leptorhinus, Owen (*hemitœchus*, Falc.).
—— *tichorhinus.*
†*Equus caballus.*
Hippopotamus major.
†*Sus scrofa.*
†*Cervus tarandus.*
—— *megaceros.*
†—— *elaphus.*
†—— *capreolus.*
†*Bison priscus.*

† Survivals in the British Islands from Glacial to Prehistoric or Recent times.

With the exception of *Meles taxus*, *Mustela putorius*, *M. erminea*, and *Lepus cuniculus*, which hitherto have been found only in Caves, the above are all common low-level Valley Drift species.

§ 7. Inland Range of the Rubble-drift or Head: Stream-tin Detritus: Ossiferous Fissures.

Besides the drift-gravels and loams of our valleys due to fluviatile action, and the sands and gravels at various heights due to marine, glacial, and meteorological agencies, the existence in the South of England of other drift-beds which could not be accounted for by any of these causes, and for which some other explanation was needed, has long been suspected. De la Beche, speaking of the drift-beds of Devonshire and Somerset, remarks that north and north-east of the Black Downs there is much flint- and chert-gravel over the New Red Sandstone and Lias, mingled with débris from the Quantock Hills, the transport of which can hardly be explained by means of river-drainages such as we now see: the Chalk and Lower Cretaceous strata may have extended over this area, but he points to difficulties on that view.[2]

Godwin-Austen was of opinion that much of the angular gravel covering the hill-slopes and valleys in the West of England was not referable to fluviatile action, but was due to some widespread general cause.[3]

The main object of Murchison's paper[4] on the Wealden area was to show that the flint-drift of the South of England must be attributed to some other cause than river or glacial action.

[1] 'Palæont. Memoirs,' vol. ii. p. 525, and Prof. Boyd Dawkins's 'Cave Hunting,' chap. xii. See also his 'Classification of the Pleistocene Strata of Britain and the Continent by means of the Mammalia,' Quart. Journ. Geol. Soc. vol. xxviii. (1872) p. 410.

[2] 'Report on the Geology of Cornwall, Devon, &c.' p. 409.

[3] Quart. Journ. Geol. Soc. vol. vii. (1851) p. 118, and vol. xxii. (1866) p. 1.

[4] *Ibid.* vol. vii. (1851) p. 349.

Mr. Topley refers to several instances in Kent and Sussex where the gravel cannot be accounted for by river action,[1] and these he refers generally to subaerial action or to the recession of the Escarpment.

Mr. Whitaker places certain drifts in the London Basin amongst those 'Doubtful Deposits' which generally "have the appearance of a local wash."[2]

My object will be to show that these various drifts are probably referable to the one and the same cause as that to which the Head owes its origin.

The intimate connexion of the Head with the Raised Beaches is merely accidental, owing to the circumstance that the angle between the cliff and the beach formed a trough in which any débris carried down from the hills above would necessarily lodge, just as it would fill up any other indent on the surface over which it had to pass. Godwin-Austen has remarked that "these beds (the Head over the Raised Beach) everywhere range inland, above and beyond the level of the sea-beds on which they rest in the coast sections,"[3] but without specifying localities.

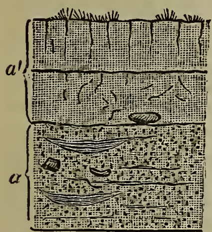
We may take it as established that in every instance the character of the rubble forming the Head depends entirely upon the character of the local strata; that, in the sense used when speaking of sedimentary strata, it is always unstratified, and composed of *sharp angular fragments* of the harder strata, and that it follows the slopes of the hills, often furrowing the surface of, and extending for a certain distance over, the adjacent valleys. As it recedes from its base, however, it becomes subangular, and loses its calcareous matter; so that, as it ranges from the Chalk hills, the chalky element gradually disappears, the flints lose their sharp angles, and the insoluble loam or brick-earth, derived from outliers of Tertiary beds, alone remains. It is on these characters, and on the fact that it contains *only land-shells and the remains of land-animals*, that we have to depend for tracing its range inland. To give all the details of this drift in its many locations and phases would fill a volume. I must therefore confine myself to a few illustrative instances; but it must be understood that there are few districts in the South of England where traces of it are not to be found.

(1) *Upchurch.*—I would refer to this drift the plots of low-lying gravel and brick-earth which lie in places at the base of the Chalk hills, between Faversham and Chatham. Each of them has come down one of the dry Chalk valleys which run up towards the escarpment of the North Downs nearly to their summit, and debouch into the plain at their base, where they are independent of and subsequent to the terraces of river-gravels. One of these narrow dry valleys commences at Queen Down Warren, at an altitude of above 400 feet, and passes near Hartlip to the flat tract between the mainland and the Isle of Sheppey, where its height is from 10 to 50 feet above

[1] 'Geology of the Weald,' pp. 168, 179, 183, 185, 201, 202.
[2] 'Geology of London,' vol. i. 3rd ed. p. 298.
[3] Quart. Journ. Geol. Soc. vol. vii. (1851) p. 123.

sea-level. The narrow bed of coarse flint-gravel which runs down the Chalk valley expands around Upchurch from a width of a few hundred feet to rather more than a mile, and is there associated with thick beds of loam or brick-earth, occasionally containing blocks of Tertiary sandstone.

Fig. 14.—*Section in Upchurch Brick-pit.*



a'. Brick-earth, without shells.
a. Slightly subangular, ochreous flint-gravel and loam, with a few white, red, and black seams (Elephant's tusk in one). Here and there is a lenticular layer of grey laminated clay, with land-shells.

One block of sandstone at the top of the gravel measured $11\frac{1}{4}$ feet long by 4 feet broad and $1\frac{1}{2}$ feet deep. None of the blocks showed glacial striæ. The gravel is all of local (Chalk and Tertiary) origin, and there is an entire absence of the pebbles from the Boulder Clay Series which mark the Thames Valley river-gravels. The bulk of the flints are not discoloured, and the few brown, worn flints are derived from the older plateau-gravel. The beds are of very variable dimensions, the brick-earth attaining in some places a thickness of 20 feet. I found in these pits *Elephas primigenius*, *E. antiquus* (?), *Rhinoceros tichorhinus*, with *Pupa marginata* and *Succinea oblonga*.

A section on the L. C. & D. Railway, at right angles to the direction of the Hartlip Valley, shows how the drift drapes the slopes of the lower hills before it spreads out in the lower ground to the north of this line.

(2) *Sittingbourne.*—In the same way the long, narrow, dry valleys with their central trail of flint-gravel, which debouch at Milton and Sittingbourne, run back to near the summit of the Chalk Escarpment, or to from 400 to 500 feet above O.D. At the lower levels of from 10 to 40 feet around Sittingbourne this drift expands into extensive beds of brick-earth and gravel, of the same character as at Upchurch, but fossils seem scarcer.

(3) *Faversham.*—Again, around Oare and Faversham, at a height of from 20 to 60 feet above the Thames, great deposits of brick-earth and gravel of the same local character have been brought down along two dry valleys which, starting from near the summit of the Chalk Escarpment, pass—one by Stalisfield and the other by Newnham—and meet at Faversham. The brick-earth and gravel contain as usual blocks of Tertiary sandstone; and mammalian remains—chiefly of the Mammoth—are so numerous that, on one occasion alone, a visitor carried away 30 teeth of Mammoth.

It is also possible that the dry valley which descends from near Bredhurst, and passing by Luton joins the Medway Valley at Chatham, may have contributed to the low-level drift around Strood and Rochester. Those near Frindsbury are rich in mammalian remains. In the Luton Valley the brick-earth ascends farther from its river-base, owing possibly to the check received by the flood-waters at its junction with the Medway Valley.

(4) *The Cray and other Valleys.*—Amongst others of these dry valleys in the Chalk hills is the long narrow vale of Longfield which, commencing in the hills above Wrotham, winds its course of 10 miles by Ridley to its junction with the Darent Valley a short distance above Dartford. A long narrow trail of flint-gravel from 3 to 5 feet deep lies along its whole length, but although it is worked in many places I cannot learn that any organic remains have been found in it.

The thin trail of flint-gravel in the upper dry valley of the Cray is also probably connected with this drift. At Green Street Green, where a tributary valley joins the Cray Valley, the gravel swells to a thickness of from 20 to 30 feet, and is confusedly heaped together without a trace of stratification. The gravel consists of a mass of broken and sharply angular chalk-flints, of flint-pebbles derived from Tertiary beds on the adjacent hills, and of large, much rolled and worn flints, derived probably from an older gravel, of which an outlier caps Well Hill. It rests upon a very uneven and broken surface of Chalk, and a good deal of chalk-rubble is mixed up with the lower portion of the gravel, or forms irregular beds or masses in a manner much resembling the deposit of rubble in the cliff at Birling Gap. Remains of the Mammoth, Rhinoceros, Horse, and Ox are occasionally met with, and with these has been found part of the skull of the Musk Ox. In a smaller adjacent pit I found a few specimens of *Pupa marginata* in a thin intercalated seam of loam. A very few rolled and much-worn Palæolithic flint-implements have also been found there by Mr. de B. Crawshay, and one was got in a small shallow pit near the Orpington pumping station, lower down the valley, by Mr. I. Allen. The drift in the upper dry valley of the Ravensbourne is of similar origin.

In speaking of these dry valleys with their trail of angular flints as belonging to this drift, I do not mean to imply that streams have had nothing to do with their denudation at a former period. Their early erosion was probably due to that agency, but the deposits formed by the streams have been destroyed and lost in the intrusion of the later rubble-drift.

(5) *Folkestone.*—On the scarped or steep face of the Downs the accumulation of this drift is less. We have before noticed the Folkestone rubble-bed at the Battery, and to this we may perhaps add the brick-earth (with similar mammalian remains and land-shells) north of the town as a different manifestation of the same drift. At Charing it consists of a great mass of chalk-rubble at the base of the Chalk Escarpment, and at Maidstone of a chalky rubble with a capping of brick-earth and flints, extending down the slope of the

hills to near Cob Tree[1] and Aylesford, where it lies against the base of the hill capped by a bed of high-level mammaliferous river-drift.

How far the brick-earths around Maidstone are connected with drift, and how far with river-floods, I am not prepared to say. I have, however, a growing conviction that large sections of the brick-earths in the South of England are connected with this drift. I would, for example, place with it the high-level (290 feet) brick-earth south of East Malling, that at Crown Point (490 feet) near Ightham, and of Seal Chart Common (529 feet), as also that described by Mr. Topley north-west of Sevenoaks.

(6) *Sevenoaks, &c.*—In the Sevenoaks district it is probable that some of the drifts I termed 'hill-gravels' are of this date.[2] The mass of Lower Greensand débris covering the slope of Sheet Hill near Ightham is certainly a débâcle from the high Greensand range immediately behind. The slopes of Oldbury Hill are covered with débris and blocks from its summit, and on the northern side large blocks lying in a loamy or clayey bed follow the course of the valley for some distance northward. The angular chert-rubble on the slope of the hills by Seal Chart, and the thick bed of the same in the valley between Bessel's Green and Sundridge, may be of the same age, while to the south of the Greensand Escarpment the traces of it are fewer, and include probably those high patches north of Tunbridge mentioned by Mr. Topley,[3] and composed of angular fragments of chert. Of these he remarks that they are "apparently not all true river-gravel, but merely subaerial deposits left by the recession of the Lower Greensand escarpment." Again, speaking of the Ouse basin, he says, "Flints are occasionally found lying over the surface of the Weald Clay in this district. These are not connected with river-gravel, but are probably the remains of the Chalk which once covered the whole area."[4]

(7) *Guildford.*—Another remarkable exhibition of this drift in the adjacent county is that described by Col. Godwin-Austen in a section of the railway on the London road east of Guildford,[5] which I had the advantage of visiting with him. The railway has cut through a high-level terrace of the old river Wey, consisting of stratified sands and gravels, resting at one end on Woolwich and Reading Beds, and at the other on Chalk. The section is nearly half a mile long, 20 feet deep, and its base is 64 feet above the level of the Wey. The fluviatile drift consists mainly of Lower Greensand débris, which was evidently carried from the south through the gorge of the Chalk hills at Guildford. About midway in the cutting a coarse unstratified drift of Chalk and angular flints sets in over

[1] It there contained the plate of an Elephant's tooth, which may, however, have been derived from the adjacent high-level gravel.

[2] Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 275.

[3] 'Geology of the Weald,' p. 185.

[4] *Ibid.* p. 202. I have before given my objections to this view; see Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 158.

[5] *Ibid.* vol. xl. (1884) p. 599.

the river-gravels and finally replaces them. Full details of the section will be found in the paper referred to. The general section, as I would interpret it, is given in Pl. VII. fig. 3, and shows:—

a. Rubble of unrolled and broken flints and chalk, with a few Tertiary pebbles, red clay, and seams of sand. It contains land-shells (*Pupa marginata, Helix*) with bones of the Mammoth, &c., resting on an uneven surface of—
c. River-gravel with mammalian remains (*Elephas, Equus, Bos*).
d. Flint gravel in red clay.

The rubble (*a*) is in places roughly bedded, like the Brighton Elephant Bed, in alternate seams of flints and rubble, while in other places it is much disturbed and twisted, indicating great and lateral thrust combined with a semi-fluid state. It contains no Lower Greensand débris, and could not, therefore, as Col. Godwin-Austen observes, have come through the gorge of the Wey, as the river-drift has clearly done, but came, under glacial conditions, from the Chalk Downs above and immediately south of the cutting. Thence, also, it is evident the chalk and flints, with the red clay and Tertiary pebbles, have been derived.

At Peasemarsh, to the south of Guildford, another form of this drift was described by R. A. C. Godwin-Austen[1] as "an old terrestrial surface indicated by peat, trees, and sedimentary deposits." A nearly perfect skeleton of a Mammoth was found there beneath several feet of drift-gravel. At Wonersh Common the river-deposits are buried under 5 to 8 feet of Lower Greensand débris, shed off from the adjacent ridge.

(8) *The Thames Valley.*—Some of the gravel on the slopes of the hills and at low levels in the Thames basin may possibly have the same origin—that is to say, it may be derived from adjacent older and higher beds of gravel: such, for instance, as some of the thin and irregular beds scattered over the lower plains skirting the high and gravel-capped hills of Frimley, Chobham, and Ascot; or in similar positions in the main valley of the Thames; or on some higher slopes, as north of Burnham, where mammalian remains have been found in a bed of brick-earth. I mention this merely as a suggestion, for I have not been able to revisit the ground.

These observations apply, however, only to a portion of the lower gravels. Well-marked low-level river-gravels occur along the Thames Valley, though they are sometimes so mingled with this later Rubble-drift that it becomes difficult to separate them. Or, when this drift reposes on a Chalk surface, it may often be a question whether the irregular surface of the Chalk results from original erosion accompanying the deposition of the gravel, or is due, as the gravel is so permeable, to subsequent solution of the Chalk; but when the underlying bed consists of clay, the irregularity of the surface can have been caused only by the manner in which the overlying gravel has been deposited. As an example of the latter, we may take a section that was exposed on the Great Western Railway at Midgham near Newbury, in the tributary valley

[1] Quart. Journ. Geól. Soc. vol. vi. (1850) p. 90, and vol. xi. (1855) p. 112.

of the Kennet, where a rubble derived from the plateau of gravel capping the adjoining Bucklebury range of hills (446 feet) skirts the base (210 feet) of the hills, and the drift-gravel has clearly been driven into the London Clay at the time of deposition. The section is as follows:—

	feet
Brick-earth—very irregular	0 to 4
Flint-gravel, with Tertiary débris, indenting on the clay .	2 to 8
London Clay, with Septaria.	

In the lower part of the Thames Valley a rubble-drift overlies the river-drift at Chislet, Crayford, and Grays Thurrock; while elsewhere around London it lies on an old land-surface of the same period. One such instance I have described at West Hackney, where I showed that on the plain, 60 feet above the Thames, there were two drift-gravels separated by an "interval of dry-land surface," the lower bed being sandy and stratified, and the upper one loamy, unstratified and capped by brick-earth.[1]

(9) *Chilton.*—We will now pass on to a section I described a few years ago[2] at Chilton, south of Oxford. An angular local drift there fills a depression on the plain of Lower Chalk, at a level of about 290 to 400 feet above sea-level, and of 160 feet above the Thames at Moulsford. It consists of chalk-rubble with very sharply angular fragments of flint, mostly of small size, and generally very closely packed together. On the south side, the Chalk hills rise to between 400 and 600 feet, the higher ones being capped by Tertiary strata. With the exception that there is no precipitous cliff, this drift with mammalian remains is an exact counterpart of the Elephant Bed at Brighton, only that the materials are finer, and there is a larger proportion of chalk-rubble and marl, the Chalk-with-flints being more distant. Its structure is precisely similar—not stratified in the usual sense, but sweeping into an old gully in broad lenticular masses, giving a false appearance of bedding. The flints are neither stained nor worn, and the chalk-rubble is in places almost angular, and in others is reduced to the state of a cream-coloured paste or marl. It is in one of these latter that the land-shells were most abundant. The whole of the materials become finer as the drift recedes from south to north, and they are all of local origin, being derived from the Lower Chalk, Chalk-with-flints, and overlying Tertiary Beds. In the lower half of the drift there were found, irregularly dispersed in various parts of the cutting, a few blocks of very hard and compact sarsenstone (Lower Tertiary sandstone). Two of the largest measured 2 ft. × 10 in. × 9 in. and $1\frac{3}{4}$ ft. × $1\frac{1}{2}$ ft. × 10 in. The angles were rounded, but otherwise the blocks were not much worn.

The shells are all of terrestrial species except two, and these are so rare that they constitute the exceptions which prove the rule. Besides, Gwyn Jeffreys informed me that the *Planorbis albus,* which

[1] Quart. Journ. Geol. Soc. vol. xi. (1855) p. 107.
[2] *Ibid.* vol. xxxviii. (1882) p. 127.

lives on water-plants and frequents marshes, can pass over land-surfaces, while the *Limnæa truncatula* is nearly amphibious, being more frequently met with out of the water than in it; it is also found in very elevated spots. The relative numbers of the various shells are given below. The bones that occurred in quantities at a few places, and none elsewhere, were mostly broken, but not at all rolled or water-worn. The state of preservation of some of the bones is remarkable; they have lost so little of their animal matter that the bone hardly adheres at all to the tongue, and looks almost as fresh as a recent bone. Dissolved in dilute hydrochloric acid, they leave a mass of flocculent gelatinous matter as residue. A bone of Bison from near the base of the rubble was found to contain 17·35 per cent. of organic matter. Recent bones of Ox contain about 30 per cent.

The organic remains of the Chilton Drift comprise:—

Elephas primigenius.	*Equus caballus.*
Rhinoceros tichorhinus.	*Cervus elaphus.*
Bison priscus (?).	*Cervus tarandus.*

	No. of specimens found.		No. of specimens found.
Pupa marginata	226	*Limnæa truncatula*	3
Helix hispida	53	*Planorbis albus*	1
Limax agrestis	1	*Succinea oblonga*	11

My object at that time being only to direct attention to the interest of the section, I did not give the further extension of this deposit. This has since been done by Mr. Jukes-Browne,[1] who mentions also several analogous deposits in other areas; but though analogous, they are wanting in the palæontological and stratigraphical evidence of the type-sections at Brighton and Sangatte. He thinks also that rainwash would account for much of the Chilton deposit, but for various reasons I cannot subscribe to this opinion, nor can I think that the contour of the ground has been greatly modified since the accumulation of this deposit.

A trail of large blocks of sarsenstone is prolonged by the Hagbourne villages, to a level about 100 feet lower, on to the outcrop of the Upper Greensand. Other slopes along these Downs exhibit similar trails of sarsenstone.

(10) *Wallingford.*—It is probable that the spread of unstratified, coarse flint-gravel covering the corresponding Chalk plain which, on the east side of the Thames Valley, extends from Turner's Court above Wallingford to the neighbourhood of Ewelme, may be of the same age. It presents, however, a very different appearance, forming a more persistent bed, composed of somewhat large angular and unrolled chalk-flints embedded in an ochreous sandy clay, but containing a few small irregular patches of chalk-rubble, as though caught up when in a more compact state, and a few seams of sand. The difference of structure is no doubt owing to the circumstance that the adjacent Chiltern Hills are capped by a Red Clay-

[1] Proc. Geol. Assoc. vol. xi. (1889) p. 204.

with-flints, whence this gravel would be derived. Flint implements of the pointed type are said to have been found in the Turner's Court pits, but I did not succeed in obtaining any. A tooth of a Mammoth was found in the same gravel near Britwell House, and the horn of *Cervus elaphus* in a pit near Blenheim Farm.

There is, however, on the slopes of the Chalk hills between this gravel terrace and Crowmarsh, some undoubted chalk-rubble, from which I saw three Mammoth teeth, very white and much decomposed, in the collection of Mr. Davis of Wallingford.

(11) *The Cotteswolds.*—A peculiar form of the Rubble-drift occurs at different levels on the Cotteswold Hills along the scarped edges and slopes of the Inferior Oolite. It consists of a fine Oolitic débris, slightly worn and roughly bedded, derived from the Oolite slopes above, and occurs at intervals along the whole line of the Cotteswold Hills. It is to be distinguished from ordinary fallen-down débris by its fineness of grain and evident stratification.[1] These deposits have been taken to represent the vestiges of a true sea-shore beach. That they are not taluses is clear from their projection far beyond the angle of repose, their compactness, and the alternation of seams of finer grit and sand; but their position at all levels, and never, that I am aware of, at two alike, and also their structure render the opinion of their being old beaches equally improbable, and I believe that this view is now generally held.

Prof. Hull states that this rubble-bed may be seen at the Cleeve Cloud quarries, above Corndean, on the northern side of Crickly Hill, at Coopers' Hill, on the eastern side of Painswick Hill, and above Hill House near Brimscombe. I have seen a section where it is quarried for gravel on the side of the hill north-west of Syreford at a height of about 650 feet, and could find neither shells nor bones. The slope there was gentle and prolonged. Mr. W. C. Lucy mentions several other places, and says that the elevation of the rubble-bed varies from 500 to 700 feet, but at Longford near Nailsworth it is only 300 feet; whilst it occurs in holes or hollows on Cleeve Hill, at an elevation of at least 900 feet. He remarks on the absence "of any fossils or even recent shells," and is opposed to the idea of the rubble-banks being old beaches.[2] Mr. Lucy further mentions the occurrence of a distinct drift, composed of Oolite débris, overlying the Lias on the slopes of the Cotteswolds, and to this he applies the term of 'Oolite Gravel.'

A separate notice of this drift has also been given by Mr. E. Witchell, who describes it as lying on the slopes of the hills and descending in places into the valleys where it overlies the River Gravels. I cannot, however, agree with him that it is intercalated with those gravels. He notes the absence of organic remains, and attributes its origin to subaerial waste during a period of extreme cold.

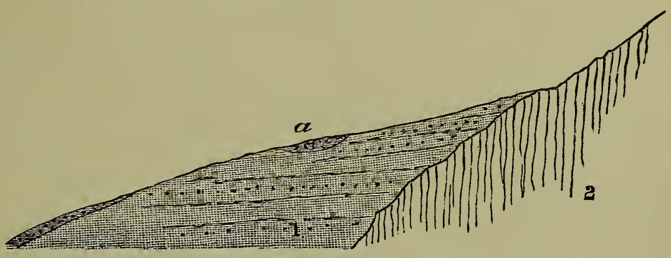
[1] Mem. Geol. Survey, 'The Geology of Cheltenham' (1857), p. 87; and Quart. Journ. Geol. Soc. vol. xi. (1855) p. 477.

[2] 'The Gravels of the Severn, Avon, &c.' p. 113, Proc. Cottesw. Nat. Field Club, vol. v. (1869).

I take these rubble-beds to be the equivalents of the Head on the coast, and of the angular drift at Chilton. They have not the characters of a beach, and they are all on different levels, dependent on the shelter afforded. The water-worn appearance of the Oolite fragments is due solely to the action of the rain-waters in dissolving off their angles (just as the broken fragments of limestone and Oolite on the surface of those rocks have been rounded in place by the same action), though, owing to the softness of this Oolite, even the slight attrition attending their descent might have sufficed to take off the sharper angles.

(12) *The Malvern Hills.*—As with the Cotteswolds, a local angular drift, occasionally containing mammalian remains, occurs at several places on the slopes of these hills. The Rev. W. S. Symonds [1] mentions that a number of large bones were discovered in digging the foundations of the Imperial Hotel adjoining Malvern railway-station, the height of which is about 300 feet above sea-level. The ground rises steeply westward to the crest of the hills, and slopes down to the plain below. The excavation passed, Mr. Symonds remarked, "through a thick mass of local angular débris, accumulated from the hills above, and had exposed a stiff red Till or Boulder Clay which contained Northern Drift pebbles and angular erratics. . . . . Several of the bones of *Rhinoceros* were as fresh and unworn as if

Fig. 15.—*Diagram-section on the side of Malvern Hill.*



a. Rubble-drift (local), with mammalian remains.
1. New Red Sandstone.
2. Metamorphic rocks.

they were derived from newly opened Cave-earth, but very brittle. There were also the remains of molar teeth and broken tusks of the Mammoth. . . . . The red Till was found at two other localities not far from Malvern; it contained mammalian remains, but there were not, as far as I know, any Northern Drift pebbles." When I visited the spot, the section was no longer visible. Its position is shown in the above diagram-section (fig. 15).

Mr. Symonds particularly noticed the *perfect* preservation of mammalian remains not only at this, but at other high levels,

[1] 'The Severn Straits' (1883), p. 30.

because all those he had seen from the lower valley-levels were more rolled and worn. This bed, however, is not a high-level Valley Drift. We are here out of the Severn Valley proper, and there is no stream with which this deposit can be connected. Nor do I take the red clay to be Boulder Clay, but merely a clay derived, like the angular rock-fragments, from the older rocks and red marls higher up the hill, whence also, if not from a glacial sprinkling, the quartzite and old rock-pebbles may have been derived. This deposit and others described by Mr. Symonds have in fact all the characters of the angular drift and Head, which I have been describing, and should be associated with them.

To return to the South Coast.

(13) *Cornwall.*—Beacon Hill, near St. Agnes, on the north coast of Cornwall, rises to the height of 628 feet. Its slopes are covered by a Rubble-drift varying from 6 to 20 feet in thickness, which is here rendered more conspicuous than in other parts of Cornwall, from its extending, beyond the limits of the slate-rocks, over the eroded surface of the Tertiary sands and clays forming the lower slopes of the hill. The rubble consists of slate and granite-fragments with a few quartz-pebbles, all of local origin, and is analogous in its character to the débris which overlies the Raised Beaches. Mr. Ussher sees no reason to doubt the contemporaneity of this drift, which he terms 'overburden,' with the Head on the cliff-line.[1]

As before observed, the Rubble-drift always proceeds from higher ground above the Raised Beaches, whence it descends to the sea-level, though it is generally cut off from the shore by subsequent encroachment of the sea. In a similar manner, when that drift has been shed down the hill-slopes inland, it has descended to the adjacent old valley-level; and where the valleys pass through lode-bearing rocks, the detritus carries with it its contingent of those lodes, and it is this, which corresponds therefore with the Head of the Beaches, that in Cornwall constitutes the Stream-tin Gravel. The valleys themselves are of older date, and were at that time of abnormal depth, for, in addition to the depth to the base of the Stream-tin Rubble-drift, we must add the height of the Raised Beaches; nevertheless, as in none of them has there been found an ordinary worn and rolled river-shingle or sand, we must presume either that the force of the stream kept the channels clear (which in the case of such small rivers was hardly likely), or else that the tin-gravel was propelled by such force as to sweep and drive out any previous deposits. This was the opinion of De la Beche,[2] and is, I think, the most probable solution of the difficulty.

The relation of the Raised Beaches and Rubble-drift to the Stanniferous Gravel is shown in the diagram, fig. 16.

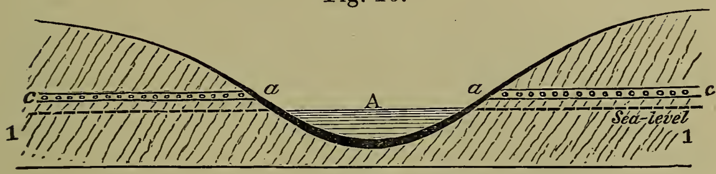
The Stream-tin detritus, which consists of angular and subangular fragments, and often contains, like the Head, blocks of large size

[1] 'The Post-Tertiary Geology of Cornwall' (1879), pp. 13, 39.

[2] 'Report on the Geology of Cornwall, &c.' p. 398. Mr. Carne was the first to direct attention to this origin of the Stream-tin Gravel.

(200 lbs. and upwards) varies in thickness from 1 to 20 feet, and rests on an eroded bed of Palæozoic and granitic rocks. No mammalian remains have been recorded from the workings; but then none have been found in the Head in this district, and the opportunities for search are rare. The Stream-tin drift is immediately

Fig. 16.



A. Alluvial beds with submerged Forest at base.
a. Rubble-drift (Stream-tin detritus).
c. Raised Beach.
1. Substratum of rock.

succeeded by alluvial beds containing only recent forms of life. It will suffice to give an abstract of Colenso's well-known general section, as the Stream-tin works all present similar features:—

Section of the Stream-tin Works in the Pentuan Valley.[1]

River-sand and gravel	20 feet.
Alluvial beds with recent marine shells	22½ "
Forest-growth with stumps *in situ*	2 "
Stream-tin detritus	8(?)"

The depth from the surface to the Stream-tin drift is here 54 feet; but such a depth is unusual. It is more generally from 10 to 30 feet. The more usual depth to rock below the present high-water mark may be taken at from 20 to 40 feet.

The position of the Forest Bed in these sections corresponds with that of the submerged forest at Porlock, in being above the angular Rubble-drift—the equivalent of the Head, and therefore these submerged forests are newer both than the Raised Beaches and the Head. A different opinion is held by some geologists in consequence of the teeth and bones of the Mammoth being found on the ground of the submerged forest at Torbay.[2] But this may be accounted for by the circumstance that the sea-bed off shore must frequently be formed, as at Porlock, of the angular rubble, and as this, where the conditions are favourable, frequently contains mammalian remains, their occurrence on the washed and denuded submarine surface of this drift would be nothing extraordinary. They have been found in the Head at Plymouth, and I have already spoken of the occurrence of Horse at Hope's Nose.

[1] For details, see Colenso, Trans. Roy. Geol. Soc. Cornwall, vol. iv. (1832) p. 29, and De la Beche's 'Report on the Geology of Cornwall, &c.' p. 401.
[2] Godwin-Austen, Quart. Journ. Geol. Soc. vol. vii. (1851) p. 131; and W. Pengelly, 'On the Submerged Forests of Torbay.'

(14) *Devon.*—Godwin-Austen has stated that a drift of this character occurs on the hill-slopes and high ground at a number of places in Devon, including amongst others the sides of Exmoor, but without giving particulars. De la Beche, as before mentioned, gave several instances in the Western Counties of the occurrence of gravel in positions where "we can scarcely explain its transport from the adjoining high lands by means of river drainages, such as we now see."[1]

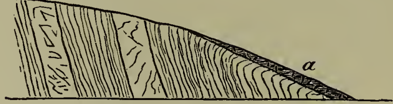
Mr. H. B. Woodward has noticed the great extent and variable character of the drift-beds in the valleys in some parts of South Devon, and a section which he gives shows how far they extend up the slopes of the hills[2]; and Mr. Ussher has described a number of anomalous beds of gravel in various parts of Devonshire disconnected with the present lines of drainage.[3]

Round the flanks of Dartmoor there are local drifts which should probably be referred to this rubble. Mr. Maw[4] mentions one such at Petroclistow, where there is an isolated bed of gravel composed almost entirely of the detritus of Dartmoor granite, and distant 12 miles from the nearest granite in place. "From its situation, it is impossible that it can be a mere alluvial deposit brought down from Dartmoor by [along] any existing or ancient river-valley."

Mr. Ormerod[5] has also noticed some gravels and boulders at various heights on the flanks of Dartmoor, for which he cannot account by glacial action. These may belong to the Rubble-drift. Trunks of trees were found, in one instance, in what he called the 'Contour gravel,' consisting of an angular rubble covering the slopes of the hill. Mr. Belt[6] has also described great patches of angular gravel and blocks at heights of from 900 to 1200 feet on the flanks of Dartmoor, as well as in the valleys of Devon and elsewhere in the South of England, for which he could not account by any of the ordinary causes assigned for the formation of gravel-beds. Both he and Mr. Ormerod seem, however, to have included in one category drifts of different ages, but that certain of them belong to the Rubble-drift I have little doubt, though I am not sufficiently well acquainted with the district to specify particular cases.

There is a small section near the top of Kitson Hill, between

Fig. 17.—*Section of a road-cutting, near Ilfracombe.*



Devonian Rocks with quartz veins.
[Height=about 400 feet above sea-level.]
a. Rubble-drift, 3 feet

[1] 'Report on the Geology of Cornwall, &c.' p. 409 *et seq.*
[2] Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 230.
[3] *Ibid.* vol. xxxiv. (1878) p. 449.
[4] *Ibid.* vol. xx. (1864) p. 451.
[5] *Ibid.* vol. xxiii. (1867) p. 418.
[6] *Ibid.* vol. xxxii. (1876) p. 80.

Ilfracombe and Berrynarbor, which is of interest from the circumstance of its showing the relation of the Rubble-drift to the reversed edges of the outcropping strata.

(15) *Plymouth.*—The connexion of the Rubble-drift with the Caves and Ossiferous Breccia of the Plymouth district is not so apparent as in Gower, though there is reason to suspect its existence. It is difficult to say how far some of the ossiferous fissures of Oreston and Cattedown may have served as caves, but there can be little doubt that the rock-fragments and bones now filling them were carried in from the outside at a time subsequent to the habitation of the Caves, if these ever existed. There are differences of opinion as to the manner in which the filling-in was effected, yet all observers agree in the essential points, namely, that the condition of the bones is very different from those found in Caves, and that they were brought in with the Rubble by natural causes, not by hyænas or other beasts of prey.[1]

The materials filling the fissures are all of local origin—limestone, clay, and sand. The limestone is in pieces and blocks of various sizes, which are all angular; a few fragments of slate and quartz-pebbles are also occasionally met with. There has since been a large infiltration of carbonate of lime, which has often cemented the whole into a hard compact breccia. The bones are found from time to time in patches, both in the consolidated and unconsolidated portions. Many of them are uninjured, and those which are broken have sharp unworn fractures. *None are rolled, and none show traces of gnawing.* Some are very much decomposed and fragile, others retain a good deal of animal matter. The fissures in the limestone are sometimes vertical, at other times they are inclined or horizontal, and often extremely irregular. Owing to this, cavities were occasionally left in the mass of the breccia, some of which still remain open, while others have been filled by the intrusion of sand and clay, or calcite. The remains of the animals found in these fissures belong to—

Elephas primigenius.
Hippopotamus major.
Rhinoceros tichorhinus.
—— *megarhinus.*
Equus caballus.
Bison priscus.
Bos longifrons.
—— *primigenius.*
Cervus capreolus.
Cervus tarandus.
Sus scrofa.
Felis leo (F. spelæa).
Canis lupus.
—— *vulpes.*
Hyæna crocuta (spelæa
Mustela erminea.
Ursus arctos.
—— *ferox.*

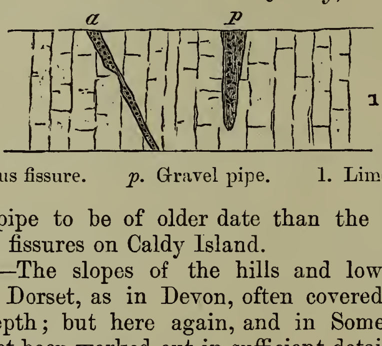
Similar fissures occur near Chudleigh, and in other limeston districts.

[1] A full account of these ossiferous breccias, and of the papers thereon, i given by Mr. Pengelly in 'The Literature of the Oreston Caverns,' Trans. Devon Assoc. vol. v. (1872) p. 249. See also Mr. R. N. Worth, 'On the Bone Caves of the Plymouth District,' *ibid.* vol. vii. (1879) p. 87, and another paper by the same author on a subsequent find of bones, with parts of reputed human skeletons, *ibid.* vol. xix. (1887) p. 419. These so-called 'Caves' were originally described geologically by Buckland in 1824, in his 'Reliquiæ Diluvianæ.'

(16) *Tenby and Caldy Island.*—I may here refer also to the ossiferous fissures at these two localities, which, like those of Oreston, have been spoken of as Caverns. Those on Caldy Island are now quarried away, but it is evident, from Mr. G. N. Smith's description of them, that they were fissures with vertical walls containing ossiferous breccia, though it is by no means certain whether there was not also a true cave, as gnawed bones are said to have been found on the island. The bones were so numerous that, besides a number that were shovelled into the sea, three sackfuls were shipped away to be used as manure. The bones that I saw in the Tenby Museum were in a singularly good state of preservation, being almost as fresh-looking and heavy as recent bones, and having lost so little animal matter that they did not adhere in the least to the tongue. The animals recorded there are *Felis leo*, *Canis lupus*, *C. vulpes*, *Hyæna spelæa*, *Ursus spelæus*, *Elephas primigenius*, *Rhinoceros megarhinus*, *Equus caballus*, *Bos*, and *Cervus*.

At Black Rock, near Tenby, I found an inclined fissure (*a*) in the Carboniferous Limestone, full of limestone-débris and earth with bones of Mammoth, Rhinoceros, &c., and was told that an almost entire skeleton of Rhinoceros had been found in it. In the same quarry there was to be seen a nearly circular vertical pipe (*p*), filled with red soil, and apparently 50 to 60 feet deep, but without any animal remains.

Fig. 18.—*Section in Black Rock Quarry, near Tenby.*



a. Ossiferous fissure. *p.* Gravel pipe. 1. Limestone rock.

I take the pipe to be of older date than the fissure, which is coeval with the fissures on Caldy Island.

(17) *Dorset.*—The slopes of the hills and lower parts of the valleys are in Dorset, as in Devon, often covered by a drift to a considerable depth; but here again, and in Somerset, the Valley Gravels have not been worked out in sufficient detail to separate the drifts of different ages. I feel uncertain whether the Mammoth remains found near Charmouth belong to the later drift or to the Valley Drift. The Rubble-drift at Encombe I have already noticed.

(18) *Hampshire.*—In the neighbourhood of Southampton we find traces of the Rubble-drift on the slopes of the surrounding hills, as, for instance, Red Hill and Otterburn Hill, but there are no well-marked sections. Possibly some of the high-drift gravel with flint implements on Southampton Common should be placed in this group. I think it also probable that the patch of drift at Downton [1] (in which I found a sharp-pointed flint implement) should be

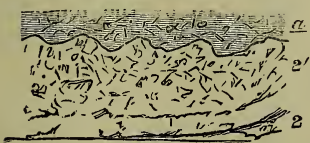
[1] Quart. Journ. Geol. Soc. vol. xxviii. (1872) p. 39.

referred to this drift, and not to a high-valley or fluviatile drift with which, though with a feeling of doubt, I associated it, as I then saw no other alternative.

The large erratic blocks of Tertiary sandstone, several of which have been recorded by Col. Nicols,[1] occasionally met with at different levels up to 200 feet or more, may possibly be of this age. There are no foreign boulders amongst them,—all are derived from adjacent Tertiary strata.

(19) *The Chalk District of Kent and Sussex.*—In my paper on the formation of the Darent Valley[2] I briefly alluded to a red loam or clay lying on the slopes of the Chalk hills, and overlying the white Chalk Rubble so common in that district. This red loam is, like the Chalk Rubble, rarely more than a few feet thick, and contains chalk-flints but little worn. It reposes upon a very uneven surface of the Chalk Rubble, the line of division between the two being sharp and distinct.

Fig. 19.—*Section on Sepham Farm, near Shoreham.*



a. Red argillaceous rubble, with dispersed chalk-flints and Tertiary pebbles.
2′. Chalk-rubble of broken chalk and sharp angular flint-fragments in a chalk-paste, passing into—
2. Solid Chalk, with layers of flint.

In freshly ploughed fields this drift may be seen draping, as it were, the slopes — sometimes forming a fringe extending for a short distance from the brow of the hill, and at other times descending the whole length of the slope down to the valley below. In the first case it forms a belt of red ground, which gradually tones off on the lower part of the slopes to quite white. It is clear, from this fact of its becoming fainter and often finally disappearing as it descends the slopes, that it has its origin from matter above and higher up the hills. It is, in fact, closely associated with the Red Clay-with-flints, which so constantly caps the higher Chalk hills, for it is only in the valleys intersecting these hills that this red and white colouring of the slopes is to be seen. It is due to a slight wash from the hill-tops of the plateau-drift; but, though it consists of a basis of this clay, it is more or less mixed with sands from the associated Tertiary outliers, and with flints fresh from the Chalk.

It is impossible to ascribe this red ground either to surface-decomposition—for, in that case, it should extend over all the bare Chalk slopes—or to rainwash, for then it should have formed rills scoring the hillsides and leaving cones of débris at their base, whereas the spread of it has all the uniformity and regularity of an even tint of colour. I can only ascribe it to the one general cause to which I would assign the origin of the Head and the other contemporary drifts.

[1] Geol. Mag. for 1866, p. 296.
[2] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 155.

I have already described (*antea*, pp. 307–310) other forms of the Rubble-drift in Kent.

These do not exhaust all the phases assumed by this variable drift, which includes the 'Head' of De la Beche, the 'subaerial beds' of Godwin-Austen, the 'angular drift' (in part) of Murchison, the 'trail' (in part) of O. Fisher, the 'warp' (in part) of Trimmer, the 'gravels on slopes' of Tylor, and various remnants, which, in default of affinity with recognized drifts, have remained unclassified. It is probable also that drift-deposits that have been, for want of a better assignment, referred to some of the river-drifts, may have to be transferred to this latter drift, but it would lead me too far were I to attempt to follow it farther. My object has been to give its main features, and to name the localities where its special characters can best be seen and tested. At the same time, from my inability to revisit all the ground since the explanation I have to propose suggested itself to me, I may be mistaken in some, but only a few, of the places I have included.

The land fauna existing at the date of the Rubble-drift, or Head, and Ossiferous Breccia is probably represented by the following species. To all appearance, the mammalia, with possibly one or two exceptions (*), were the same as those of the Gower Caves.

LAND MOLLUSCA.

Bythinia tentaculata.	*Limnæa peregra.*
Cyclostoma elegans.	—— *truncatula.*
Helix concinna.	*Planorbis glaber.*
—— *hispida.*	—— *albus.*
—— *nemoralis.*	*Pupa marginata.*
—— *pulchella.*	*Succinea putris.*
—— *rufescens* (?).	—— *oblonga.*
—— *virgata.*	*Zua lubrica.*
Limax agrestis.	

MAMMALIA.

Elephas primigenius.	*Ovibos moschatus* *.
—— *antiquus.*	*Sus scrofa.*
Rhinoceros tichorhinus.	*Hippopotamus major.*
—— *megarhinus* *.	*Felis leo.*
Equus caballus.	*Canis lupus.*
Bison priscus.	—— *vulpes.*
Bos longifrons.	*Hyæna crocuta.*
—— *primigenius.*	*Mustela erminea.*
Cervus capreolus.	*Ursus arctos.*
—— *elaphus.*	—— *ferox.*
—— *megaceros.*	—— *spelæus.*
—— *tarandus.*	

Of marine or freshwater shells there are none.

§ 8. ON THE ORIGIN OF THE 'HEAD' OR RUBBLE-DRIFT.

Various explanations of the phenomena described in the preceding pages have been suggested, but none have embraced the whole series, nor have they been of a nature to satisfy all the conditions that arise from the assumed causes.

Mantell, who first noticed this drift in the Brighton cliffs, merely gave it the local name of 'the Elephant Bed' in consequence of its containing Elephant and other mammalian remains. He spoke of it as a confused mass of alluvial materials without stratification,[1] and thought it might have been formed by the action of inland waters after the communication with the ocean, which existed at the time of the old shingle beach, had been cut off.

Sir H. De la Beche,[2] who afterwards described the analogous phenomena in Devon and Cornwall, looked upon this deposit, which he named 'Head,' as a talus formed after the rise of the old beach, and the growth of the submerged forests. He accounted for its formation by the washing down from the slopes of the adjacent higher ground (owing to an excessive and long-continued rainfall towards the end of the Glacial period) of the débris of the rocks disintegrated by the destructive effects of the atmosphere. He considered that the Stanniferous Gravel indicated the sudden rush of a great body of water from the north.

We are indebted to R. A. C. Godwin-Austen for a more special investigation[3] of this drift, for which he retained De la Beche's term of 'Head.' He noticed "*that the materials are always strictly local as to origin*," and he attributed their accumulation to the "wash of a terrestrial surface under a far greater amount of annual rainfall than we have at present," combined with a great elevation of the land, *such as would place the whole of the higher portions of this country in regions of excessive cold.* He considered that the local angular drift of Exmoor, the detritus of the Wealden district, the broad alluvia of the Arun, and the gravelly clay and brick-earth of the Sussex Coast plain were formed under the same subaerial conditions; and he further correlated the Raised Beaches with the Norwich Crag, and the overlying drifts and submerged forests with the "freshwater deposits and mammalian remains (Westleton and Forest-beds) of the Norfolk coast."

Sir Roderick Murchison's paper 'On the Flint Drift of the South-east of England' appeared the same year.[4] Considering that 'Head' was a term of too limited significance for a drift which was not limited to the Raised Beaches, but had a wide spread over the whole country, Murchison employed the more general term of 'Angular Flint Drift.' He contended that, with a few exceptions in some of the larger valleys, all the Flint Drift of the South of England was to be attributed to one common cause—that cause being a local cataclysm or wave of translation resulting from the sudden elevation and breaking-up of a large tract of Chalk and Greensand in the

[1] 'Geology of the South-east of England' (1833), p. 348. In a later work he describes it as obscurely stratified.

[2] 'Report on the Geology of Cornwall, &c.' (1839) p. 432.

[3] 'On the Superficial Accumulations of the Coasts of the English Channel and the Changes they indicate,' Quart. Journ. Geol. Soc. vol. vii. (1851) p. 118; and 'On the newer Tertiary Deposits of the Sussex Coast,' *ibid.* vol. xiii. (1857) p. 42.

[4] Quart. Journ. Geol. Soc. vol. vii. (1851) p. 349.

Wealden area by earthquake-movements,[1] and the spread of the débris of those rocks by a great body of water flowing from that centre over the adjacent lands. Subsequent research has shown that this wide generalization cannot be admitted, that the larger proportion of the Flint Drift in the valleys is to be attributed to fluviatile action during late Pleistocene times, and that the drift on the Chalk hills is even of still earlier date. Murchison's paper, which was marked by his usual power of observation and width of grasp, has been the subject of sharp criticisms, but his critics overlook the fact that he and Godwin-Austen were the first to point out that there exist in the South of England certain flint-gravels, the origin of which could be explained either by fluviatile or by marine action. Murchison also showed that these rubble-beds varied according to the distance from their source: that, while angular and chalky in one place, they were worn and non-calcareous in others, and sometimes passed into brick-earths. But it is impossible to accept the view that all the Flint Drift is due to one sole cause—and that cause one of the nature described. On this point, however, I have reason to know that Murchison's opinion was subsequently much modified.

Mr. F. Dixon, in a work of later date, expressed general agreement with the opinion of Mantell, and remarked that the calcareous rubble of the Elephant Bed of Brighton "shows every appearance of having been spread out in successive horizontal layers by water in motion," but without specifying in what manner or when this was done.[2]

Sir Charles Lyell conceived that the materials of the Elephant Bed of Brighton were "such as might have been heaped up above the sea-level in the delta of a river draining a region of white chalk," and that this delta might have been slowly subsiding while the strata accumulated.[3] He remarked also that the river and its tributaries might have been occasionally frozen over, so that the carrying power of ice co-operated with that of water to transport fragile rocks and angular flints. In a later edition of his work Sir Charles speaks of this calcareous rubble as probably contemporaneous with the similar rubble in the cliffs on the Norfolk coast.

Mr. Pengelly considers the Head on the Devonshire coast to be a subaerial accumulation of long growth, mainly derived from the adjacent heights, and that it is not a mere talus,[4] to which some geologists had likened it.

By other geologists the accumulation of these and of analogous beds has been ascribed to the action of ice and snow. The Rev. O. Fisher,[5] speaking of the 'Trail,' remarks that it consists "of materials transported from higher grounds in rear, by some agent" which

[1] *Op. cit.* pp. 388 & 394.

[2] 'The Geology of Sussex,' 2nd ed. (1878) by Prof. T. Rupert Jones, p. 79.

[3] 'Manual of Elementary Geology,' 5th edit. (1855) p. 288.

[4] Trans. Devon Assoc. vol. ii. (1867) pp. 52–54.

[5] Geol. Mag. for 1867, p. 193, and Quart. Journ. Geol. Soc. vol. xxii. (1866) p. 554.

he believes to have been land-ice, and that, "whatever its origin may be, [it] is evidently connected with the last denudation of the surface."

Mr. A. Tylor has described a series of deposits, accumulated on slopes by the action of water, and "separated from the ordinary aqueous action, such as is performed by rivers, lakes, and seas, as well as from ordinary subaerial action." These deposits, in which he includes the 'Head' of Godwin-Austen, the 'Elephant Bed' of Mantell, and other beds equivalent to the 'Trail' of Fisher, he attributed to intense pluvial action.[1]

Mr. S. V. Wood[2] was of opinion that the Elephant Bed of Brighton and the 'Head' of Portland and other places were formed by the rills of water which resulted from the periodical thawing of the ice and snow, carrying with them rubble and land-shells from the higher ground above over the face of the cliff, during his period of 'minor glaciation.'

Col. Godwin-Austen[3] looked upon the drift bed in the Guildford railway-cutting as formed under glacial conditions, and observed that "it is not necessary to suppose anything of the nature of a glacier as we know them in Alpine regions; but what would result, if the cold were great enough, would be the formation of frozen snow-beds on the higher grounds lasting through the heats of summer, and such would be the exact counterparts of those patches of ice, many square acres in extent, that are to be seen at the present day on the wide level plateaux of the Chang Chingmo in Thibet—that is to say, solid ice not more than 20 feet thick, with a flat but much broken surface, and with a wall-like margin in most places. These I noticed lasted until the winter snows began again, and in very warm summers they may almost entirely disappear."

Mr. Ussher[4] thinks the Head affords evidence of a period of great subaerial waste, rain-floods, and a more rigid climate. Though from its general appearance it "might be regarded merely as an old talus, shed from the adjacent heights......, in some cases fragments have been incorporated which could not have been derived by mere weathering, but were probably carried down by torrential surface-waters or melting snows from higher lands not far off . . . . The appearance of stratification sometimes exhibited might be satisfactorily explained by seasonal changes." The whole marks a time of greater elevation of the land, producing possibly continental conditions.

In accounting for the origin of the dry valleys in Chalk districts, Mr. Clement Reid suggests that it was the débris from them that went to form the Coombe Rock of Brighton. He considers that during the period of great cold the ground was frozen to the depth of several hundred feet, and consequently that, the Chalk being thereby rendered impermeable, the surface-waters, instead of passing

[1] Quart. Journ. Geol. Soc. vol. xxv. (1869) p. 98.
[2] *Ibid.* vol. xxxviii. (1882) p. 721 *et seq.*
[3] Quart. Journ. Geol. Soc. vol. xl. (1884) p. 612.
[4] 'The Post-Tertiary Geology of Cornwall,' p. 42.

underground as now, ran off immediately and formed violent transitory mountain-torrents, which tore up the surface, and carried the Chalk-rubble to the mouth of the valleys. He is of the same opinion as other writers that the loam and flints spread over the plain between Chichester and the sea are due to the same cause as that which formed the Coombe Rock, and contests the erosion and wearing back of those Chalk valleys by ordinary running water—a view which, by mistake, he ascribes to me.

Other geologists would attribute certain portions of the Rubble to waste left by the recession of the hills.

The Rubble-drift or Head has thus been referred to—

1st. The wash of the surface-débris over the edges of the old cliffs by an excessive annual rainfall, and during a period of great cold either caused by an elevation of the land or due to glacial conditions.

2nd. The agency of ice and snow sliding down the hill-slopes, aided by the running off of the water resulting from the melting of the ice and snow.

3rd. A wave of translation or a cataclysm caused by earthquake-movements in the central area.

4th. Fluviatile and torrential action, during a period of great cold, aided by floating ice.

5th. Subaerial action in part.

The idea that the Head is a mere talus caused by ordinary weathering of the cliff may be discarded at once. The angles of slope are too small and too extended from the base of the cliff, and the mass is too compact, for an ordinary subaerial talus, while the presence of débris and occasionally of blocks foreign to the immediate spot indicates a transport of the material from some point other than the face of the cliffs.

1. To the first of the above explanations there is the objection that the rain would at once run off along the lines of lowest level, and, in the course of time, these channels would be worn into gullies more or less deep, and the débris carried down through them would be spread out fan-shaped at their end, as—to compare small with great things—in the case of the great cones of débris in the Upper Indus basin described by Mr. F. Drew.[1] The edge of the cliffs and the heights above would in such a case be scored by these gullies, and 'cones of dejection' be formed at given intervals; but no such water-channel and no such 'cones of dejection' exist in the face of these old cliffs. The drift follows the line of pre-existing slopes and coombes, which it may have deepened, but in which it has not eroded special channels; the edges of the cliffs present, so far as can be seen, one unbroken line, and the rubble extends in a mass of uniform character the whole length of that line,—results

[1] Quart. Journ. Geol. Soc. vol. xxix. (1873) p. 441.

which could have been produced only by the sweep of a far-reaching broom. Further, débris (and bones more especially), if carried down by swollen streams, and subject to frequent and much exposure, must inevitably have been more or less worn, whereas both retain the sharp angles of fracture. All observers agree upon the sharpness of the harder débris and the absence of wear on the bones.

With regard to deposits formed on a Chalk surface these objections are of still greater force, for the wear of the rock would be more rapid, and more deeply cut gullies would result. In either case it is not easy to see how the delicate land-shells found in this rubble could have escaped without injury, or rather destruction, or how to account for the presence of the mammalian remains in the condition in which they are found. Their presence there at all is unaccountable, whether on the supposition that the animals were carried down by freshets, or that their remains had been left after death on the spot where they died. In the one case they would not have been dispersed as they now are, and in the other, if by chance they had escaped injury from predaceous animals, they must have been more or less weathered—but of neither do they, as a rule, show any traces.

2. The agency of ice and snow is open to fewer objections. By this means débris might be propelled over the edge of the cliff along its whole face, without wearing very definite channels, but in times of thaw the escape of the surface-waters must have ended in producing results analogous to those caused by heavy rainfalls. By ice and snow the rubble might also have been driven over smaller gradients and to a greater distance beyond the cliff, but I doubt whether it could, as at Godrevy (*antea*, p. 281), have been propelled for a distance of above 200 feet from the face of a cliff; for the cliff is not more than 40 feet high, and the hill at the back does not rise higher than 150 feet, and that at a distance from it of some 250 feet. Besides, the slope of the rubble does not exceed an angle of 10° to 12°, whereas the angle of repose of loose gravel is 40° and that of rubble 45°, though these would be somewhat diminished, but not to that extent, by the greater fluidity of the mass produced by the snow. Nor would a sludge of ice, snow, and rock-débris in motion be more favourable than running water for the preservation of the land-shells and mammalian bones.

Another difficulty in the way of the ice-and-snow hypothesis is the small size of the areas (at times to be measured by acres,—see Pl. VII. figs. 3, 5) that form the centres of dispersion, and the small gradients and short lengths of the slopes. It is very different in a mountainous district, where the frozen masses are large and the slopes steep; but with the gentle slopes of the South Downs (Pl. VII. fig. 2) how would the winter's ice and snow on them have been equal to the propulsion of the débris of flints and loam across the Sussex Coast plain—a distance of from 2 to 5 miles over a comparatively level surface? Or, to take the case of the Isle of Portland, is it likely—with its length of 3 miles and its gradient of about 1 in 40 feet—that the ice and snow could have forcibly driven down the Head in one direction over the Raised Beach southward, and in the other direction have sent the large mass of Chesilton débris northward? Even in the case cited by Mr. Drew, where the mountains rise several thousand feet above the valley, the cones of dejection do not extend more than 1 mile from the point of discharge, while at the base of the cones the débris has a thickness of 500 feet. Nor is it possible that either snow or rainfall on open ground could have transported the huge blocks found in the Head.

For these reasons I do not think that either of those subaerial agencies, although meeting some of the conditions of the case, would suffice to account for the whole of the phenomena, and on the other hand they must also have led to results which are not in accordance with the known facts.

3. While agreeing with much of Murchison's reasoning, there is, besides the objections already named, the question whether his hypothesis does assign an adequate cause for the origin of the Head and analogous deposits. It certainly suggests a force adequate to drive a drift of flints and clay a considerable distance over nearly level surfaces, tumultuous enough to fracture the bones, and yet, owing to its short duration and being subaqueous, productive of less wear of the rubble. The cause assigned is, however, obscure and not supported by the evidence. Nevertheless, Murchison's paper is a valuable contribution to the subject, and touches, I believe, the true keystone in assuming the Head to be the result of disturbed accumulation under water and due to a widespread cause.

4. Lyell rightly considered that the Head (as seen at Sangatte) extends too far from the old cliffs to have been a mere talus, but he adduces no evidence in support of fluviatile agency in the structure of the Brighton rubble, nor of traces of river-deposits in any of the valleys at the back of Brighton. At that time the configuration of the surface was nearly the same as at present; therefore, even had the strata been impermeable, the very limited drainage-area of those valleys could only have given rise to small streams. But, with a substratum of Chalk, no permanent river could have existed, for the water-level would have been, then as now, below the level of the valleys, and the rain falling on that area must have passed underground and escaped on the shore-line, as it does at present, leaving the upper valleys dry, with the water-level at a depth of 50 to 100 feet beneath the surface. Occasionally bourns might have broken out in the lower part of the valleys, but nothing more.

There is no doubt that during a period of much cold the rain-waters would run at once from off the frozen surface of the Chalk hills, but that is not sufficient to prove Mr. Clement Reid's suggestion, which also is based upon sections in the Chalk area alone, and does not take cognizance of the general phenomena in other localities. Besides being liable to some of the objections I have urged in the other cases, such as the condition of the organic remains, the fluvial interpretation of Lyell and Mr. C. Reid would centre the 'Heads' at the mouths of valleys, whereas their chief development is at the base of slopes connected with hill-ranges.

We must therefore seek for some other explanation than these to account for the origin of the Rubble-drift forming the Head and the contemporary inland drifts.

§ 9. Theoretical Considerations: The Rubble-Drift due to a wide Submergence of the Land.

The points on which all the geologists who have treated of this drift in any form agree are:—

1. The angularity and sharpness of the harder constituent débris.
2. The derivation of all the materials from the higher ground behind the Raised Beaches.
3. The absence of marine and fluviatile shells.
4. The occasional presence of mammalian bones and land-shells.
5. The want of regular stratification.

It is obvious from the above that we may at once dismiss marine and fluviatile agency, and although subaerial agency has its claims, it is clear that it fails in many essential particulars. We require a cause that will not only account for all the above-named results, but one that also must not involve other consequences at variance with the assumed cause. The cause I would suggest is not free from difficulties, especially in connexion with the subsequent distribution of life. These, however, need separate enquiry, and are not, I am satisfied, incapable of solution. On the other hand, my hypothesis will, I think, be found to answer, in the purely geological and physical points, to all the conditions of the case.

The elevation of the land to a height of 2000 feet or more was a suggestion made in order to account, by the greater cold to which the land would thereby be exposed, for such a surface-disintegration as would supply the large quantity of detritus forming the Head. But that object must have been attained independently by the exposure of the surface during the preceding severe Glacial times. Nor is there anything in the resulting land-conditions to show the need of so great an elevation. Had the land been raised to the great height named, the river-channels in their lower reaches would have been excavated to a depth corresponding with the altitude of the land. Of the actual depth of the river-channels at those times we have opportunities of judging by the depth of the tin-streams in the valleys of Cornwall, and by the excavations for the Tilbury Docks. The Cornish sections show that in no case does the bed of the river-channels underlying the Stream-tin gravel exceed 80 feet below present high-tide level; while the old bed of the Thames, beneath its gravel and alluvial covering, does not exceed 70 feet in depth. If we add to this the difference between the level of the old Beaches and of the present high-water mark—say, 20 feet on the average—it would show that the elevation need not have exceeded 100 feet. This, or a little more, would have given quite sufficient height to the land for the growth of the forests on the surface of the Stanniferous gravels in Cornwall and on the surface of the basement-gravels in the Thames Valley. This limit agrees also with the estimate of about 120 feet based on the presence of the old Dunes, whereas at a height of 2000 feet the

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Beaches would have been out of the reach of the blown sands that overlie the Raised Beaches of Cornwall and Devon, and the valleys would have been much deeper. Taking the concurrent testimony of the two facts, I would conclude that the elevation of the land after the formation of the Raised Beaches did not exceed, if it attained, 120 feet.

It will be seen by reference to the Map (Pl. VIII.) that even this extent of elevation would have converted large tracts of the Bristol and English Channels into dry land and the old sea-coast into a line of inland cliffs. In the face of these cliffs the Caves on the Gower coast, formed by the waves and surface-waters at the time of the Raised Beaches, now became the resort of the group of mammalia of which the list is given on p. 306, and of which we have no further traces except in the Rubble-drift that overlies both Caves and Beaches. It was at this time also that the old Dunes drifted on the Beaches. Those sands are therefore contemporary with the Caves, and mark another period of lengthened rest.

Thus far the order of the successive changes is clear, whilst the succession of life seems to have been continuous from early Quaternary times. We now come to a stage showing a marked break, caused by the interposition of the Rubble-drift. There are no passage-beds between the stage just described—with its Dunes, Caves, and lower-level valley deposits—and the alluvial and shingle-beds which rest immediately on the Rubble-drift. Whatever may have been the lapse of time represented by the break, there is no evidence beyond that afforded by the Rubble-drift. It is not represented by any known sedimentary deposits, and the alluvial beds, which in all instances are next in stratigraphical succession, show a complete break in structure and in continuity of life. The change is great and comparatively sudden. I do not mean sudden in the old sense of the word, but that the change was effected in a comparatively short space of time geologically speaking.

We have only to take the evidence of facts, as they present themselves in this case, to recognize the remarkable revolution effected by the intrusion of the Rubble-drift or Head which separates the two stages, and which occupies a position discordant with the deposits which both precede and succeed it. Moreover, whereas those marine and river deposits have a general horizontal bedding, and occupy in given areas definite zones, the Rubble-drift lies on the slopes of hills at all angles and at all levels, and only assumes a horizontal position when it reaches the adjacent plain or valley.

At Folkestone the 'Chalk-and-flint rubble' descends from the slope of the Chalk escarpment, and must originally have reached the shore. Amongst the Chalk hills of Mid Kent it ascends to heights of 400 and 500 feet and descends to the Thames level. The blocks of Tertiary sandstone and flint-pebbles in the Rubble cliff at Brighton could only have been derived from those outliers of the Tertiary strata which lie in patches on the Downs at heights of from 500 to 600 feet: and Murchison states that "towards the higher portions of the Downs" Mr. Hennah discovered many years ago the bones of *Elephas* and *Cervus* in an angular flint-drift in one of the cavities of the Chalk.[1] The Rubble-drift at Chesilton on the northern end of Portland rises from the shore to the height of 200 feet. In Devon this drift occurs on the high slopes of Exmoor and Dartmoor, and in Cornwall it descends from the summit of Beacon Hill (600 feet) to its lower slopes. The great mass of rubble, that extends over the Chalk plain above Didcot to a height of 400 feet or more, comes from strata which southward rise 100 to 200 feet higher. In Gower the Head at Rhos Sili is derived from hills behind, rising abruptly several hundred feet above the Beach terrace; while the highest well-marked instances of this drift are those (the so-called Old Beaches) on the Cotteswold Hills which attain a height of from 800 to 900 feet.

It is evident that the force—whatever it was—which determined the formation of the Rubble-drift acted from above downwards. This, under certain circumstances, might have been the result of the descent from the hill tops of ice and snow, or of water. Ice might have acted in some respects in accordance with the observed phe nomena, but in other respects there are the objections I have already named; and with regard to rain and surface-waters, the results are, as I have shown, irreconcilable with their agency. But there is another form under which we may consider the action of water, and this, although not free from objections, answers to all the physical conditions of the case.

It is that of water in a body, not moving rapidly over the surface as in a wave of translation, but displaced from a state of rest, while the land is in process of elevation from beneath it. There is the objection, amongst others, to a wave of translation that it would carry the débris in one prevailing direction, and in each locality we should have foreign elements more or less largely introduced, and the drift assuming a 'crag-and-tail' arrangement behind the hills; whereas no such distribution prevails, but on the contrary we have in the area we have described a number of local centres from which the drift diverges in different or in quaquaversal directions and combines in the intervening valleys. This is a result which would necessarily follow on the emergence of land from beneath a body of water, and such seems to me the most probable solution of the problem we have before us.

I am therefore led to suppose that a submergence of the land which, judging from the heights at which the Rubble-drift is found, could not have been less than 1000 feet, followed immediately upon the epoch of the low-level valley drifts and the Caves. There is little or nothing to show as a direct consequence of the submergence. The land over which the waters spread seems to have undergone but trifling alteration or denudation. The Raised Beaches exhibit in consequence thereof no apparent erosion, and the Blown Sands only slight denudation; and this may be due to the impact of the Head. It is even difficult to say whether their irregular thickness and eroded surface resulted during the submergence or emergence of the land. I can only conclude that the submergence was slow and

[1] Quart. Journ. Geol. Soc. vol. vii. (1851) p. 367.

gradual, yet sufficiently rapid to prevent wave-action from removing the whole of the Blown Sands, or from forming terraces, which it would have done had the fall been prolonged or subject to long interruptions. For the same reason no portion of the strand was washed on to the land.

The absence of marine shells in the submerged land may seem a difficulty. Had the submergence been of long duration, a marine fauna would necessarily have established itself; and I can only account for its absence by supposing that re-elevation followed, after but a short interval, on the previous subsidence. The physical results of that elevation are sufficiently definite to justify our assumption, and are explanatory of the conditions under which it was in all probability effected.

Mr. Hopkins[1] has shown that if a considerable area at the bottom of the sea were *suddenly* elevated, a *wave of translation* accompanied by a current, the velocity of which would depend principally upon the depth of the sea, would diverge in all directions from the central disturbance. Calculations, he says, "prove beyond all doubt that paroxysmal elevations, beneath the sea, varying from 50 to 100 feet in height, may produce currents of which the velocities shall vary from at least 5 or 6 to 15 or 20 miles an hour, provided the depth of the sea do not exceed 800 or 1000 feet." In considering the magnitude of the blocks which might be moved, he found that the force exerted on a surface of given magnitude *increases as the square of the velocity*, and that it "varies as *the sixth power of the velocity of the current*." But the movements must be repeated for large blocks to travel beyond short distances.

It is evident that we have in this form of disturbance an engine of enormous power; and though our hypothesis does not deal with the great changes and powerful currents contemplated by Mr. Hopkins, we may infer what the results might be with even a fractional proportion of such changes. Movements of this character would, like Nasmyth's hammer, be capable at times when the uplift was rapid of exerting enormous force; while at other times, when the uplift was slow, the action might be of the most gentle character. Hopkins's calculations were made for one central area of elevation, and dealt with surrounding level surfaces. In the case before us the area of elevation consisted of a variable and uneven land-surface, so that each hill or group of hills formed a centre for the divergent currents, the velocity of which would further vary according to the varying gradients and lengths of the slopes.

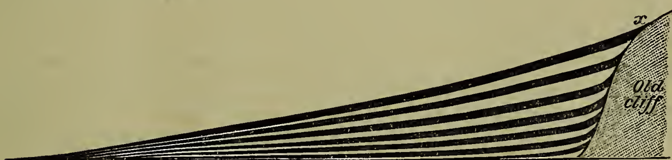
It follows from these premises that the character of the deposits formed under such circumstances will afford a relative measure of the velocity and duration of the currents under which they were accumulated. Where, for example, the sediment is fine, we may conclude that the velocity was slow and the rise which gave origin to it small. When, on the contrary, the materials are coarse, we may suppose the rise to have been more rapid and the velocity of the current greater. Where, again, large blocks have been trans-

[1] Quart. Journ. Geol. Soc. vol. iv. (1848) p. 90.

ported, a more energetic movement is made manifest. Some indication also of the duration of the uplift is afforded by the mass of the material moved and distance traversed.

The effects produced by this re-elevation of the land were necessarily simultaneous throughout the whole of the disturbed area, but varied with the depth of water and the gradients of the ground, so that the sweep of the Oolitic débris on the summit of the Cotteswolds proceeded concurrently with the first drifting-in of the Chalk-rubble at Brighton; but while the growth of the former ceased with its early emergence above the water, the latter was prolonged to the last stage of the emergence, and therefore affords an index of the changes going on during the whole period of elevation. As the Brighton section (*antea*, fig. 3, p. 268) varies with every fall of cliff, and all the points are rarely seen together on each occasion, my meaning will be best illustrated by a diagram.

Fig. 20.—*Diagram showing the successive increments in the formation of the Head where the strata are of variable resistance, as in a Chalk district.*



The dark lines represent the coarser and heavier detritus of angular flint-fragments mingled with Chalk-rubble—sometimes in large proportion, at other times so small as to leave scarcely anything but a mass of sharp broken flints. The white spaces represent Chalk-rubble with few or no flints, and sometimes so fine as to pass into a pure marl, occasionally laminated.

These beds succeed one another without any definite order, and it is difficult to say how many there may be—possibly not less than 12 or more.

The coarser beds indicate the action of the stronger, and the finer beds that of the more gentle, effluent currents. Each of these may be taken to indicate an elevatory movement more or less rapid. There may have been intervals when the movement was so slow as not to give rise to any effective currents, or there may have been short intervals of rest. The whole series is continuous, and the beds, as it were, interdigitate with one another.

Judging from this structure, we may infer that at times the rise of the land from beneath the sea proceeded with sufficient rapidity to cause the effluent waters to carry masses of flints and coarse Chalk-rubble over the cliff from the slope of the hills behind, and even to roll down occasionally blocks of Tertiary sandstone from the higher ground at a distance of one or two miles from the coast; while at other times it proceeded so slowly that only the finer sediment was removed from the same surface. It is evident that it was not one uniform uplift, but that the rise, though on the whole continuous, was sometimes slow, and at other times comparatively rapid, the maximum uplift and force being displayed in the final stage *x*. This last addition to the Head filled up all previous hollows, and levelled the surface flush with the summit of the cliff, though no doubt the uneven underlie of this top bed in Chalk districts has been increased by the percolation of surface-waters. The force with which this last bed has been propelled downwards has often driven back a portion of the débris upon itself—a reversal particularly well shown at Portland Bill (*antea*, p. 277), and at Chesilton, where a tongue of Kimmeridge Clay, 20 to 30 feet high, is squeezed up from the bed beneath by the impact of the rubble on the soft clay.[1]

The well-marked alternation of fine and coarse materials is confined to areas where the substrata consist of soft alternating with hard beds, such as the Chalk-with-flints. Where, as in Devon and Cornwall, the substrata consist entirely of hard rocks, no such divisions are at first sight apparent. Nevertheless, traces of these divisional planes generally exist in the form of thin, intercalated seams of smaller rubble or of sand and loam. At Falmouth, as before mentioned, there are five beds of impalpable sand intercalated in the Head. In the sketches drawn by De la Beche this form of structure is sufficiently apparent[2]; Mr. Ussher also speaks of the Head presenting in several instances a stratified appearance with a seaward inclination. In some places, however, the Head has the appearance of a homogeneous deposit without divisions. In no case is there any appearance of a break in continuity between the successive layers.

There are instances where the force of the currents and their frequent renewal have been sufficient to carry the débris over the comparatively flat plain at the foot of the hills, as on the coast of Sussex between Brighton and Pagham, and, in a less degree, between Eastbourne and Pevensey. The long trail of flint-rubble in many of the dry Chalk valleys may be ascribed to the same cause. These trails rarely contain any organic remains in their upper course, though there is a notable exception at Green Street Green; but where they shoot out into the main river-valley, and the velocity of the current has been checked, as at Faversham, Upchurch, &c., mammalian remains are of common occurrence.

Where a cavity or terrace has been traversed by this drift in its descent from the higher ground, it has filled up the one or lodged on the other, as on the eastern slope of the Malverns (p. 315), and on the Chalk plain at Chiltern (Pl. VII. fig. 4). Minor instances have been cited at Chilworth and at Sandling. A similar cause has led to the masking of many Caves, where the entrance is on the slope of hills, as at Brixham, or in the face of a bluff with higher ground above. The great stream of Tertiary sandstone-blocks (sarsenstone) in the Chalk valleys near Marlborough, and in several

[1] See Quart. Journ. Geol. Soc. vol. xxxi. (1875) p. 38, fig. 6.
[2] 'The Geological Observer,' 1st ed. pp. 526–27.

lesser valleys on the northern slopes of the same Chalk range, would readily be accounted for by the same cause. The red loam-with-flints before mentioned, carried down from the Red Clay-with-flints on to the slopes of the Chalk hills in many parts of Kent, is explicable in the same way. It would swell this paper to too great dimensions were I to describe the innumerable instances of the occurrence of this drift in the South of England. I have marked some of the most notable on the Map (Pl. VIII.), and have in each case indicated the direction of the current by an arrow.

Ossiferous Fissures.—Nor do I see any other explanation that so well meets all the conditions of the ossiferous breccia in the fissures of the limestones of Devonshire and Pembrokeshire. The use of the term 'cavern' in speaking of these fissures, which still prevails,[1] is misleading. In a few instances, the open fissures may have been the resort of animals before they were filled by detritus, though that is doubtful. De la Beche used the better term of 'Ossiferous Fissures.' Still Buckland spoke of the bones occurring in caverns,[2] but he made his meaning clear in a subsequent page (p. 73) when he said: "The bones appeared to us to have been washed down from above at the same time with the mud and fragments of limestone, through which they are dispersed; they were entirely without order, and not in entire skeletons; occasionally fractured, but not rolled." Dr. Buckland also noticed that in one of the fissures at Oreston the drift "was stratified, or rather sorted and divided into laminæ of sand, earth, and clay, varying in fineness," but all referable to the surface of the adjacent district.

The fissures are sometimes vertical, at other times inclined. Mr. Pengelly remarks that at Oreston the bones occur alike "in the cemented and uncemented portions of the bed. They were found alike at all heights or levels, in the lumps of breccia, in the pure stalagmite between them, and in the looser and less coherent portion of the accumulation, thereby suggesting that the cavern was slowly and gradually filled with limestone-débris . . . with occasional pauses or periods of cessation; the proof of such pauses being the frequent presence of the portions of pure stalagmite separating series of brecciated masses . . . lying one above another in the same nearly vertical plane."[3]

I need add nothing to these passages, for they accurately describe the character of the breccia and the position of the bones. But, not having been fortunate enough to be at Oreston at the time when bones were found there, I felt a little doubt about the meaning to be attached to the terms 'cavern' and 'stalagmite.' Mr. Pengelly informs me, however, that in the use of these terms he by no means intends to imply that besides the ossiferous fissures there had been caves "inhabited by man or any of the inferior animals," and that he has no doubt the fissures were filled in from above.

Similar fissures, filled by the introduction of accumulations through

[1] Phillips's 'Manual of Geology,' new ed. (1885) vol. ii. p. 685.
[2] 'Reliquiæ Diluvianæ,' p. 67.
[3] 'The Geologist' for 1859, p. 442.

vertical openings communicating with the surface, in several adjacent limestone districts are also described by him. There was one at Brixham 27 feet high, in which bones of Cave animals were extremely abundant and in excellent preservation. Another in Warren Road, Torquay, was 140 feet high, measured along its inclination of 40° E.S.E. Others traverse Daddy's Plain and the hills between Anstey's Cove and Babbacombe. As it is generally in quarrying that these fissures are discovered, it is obvious that many must escape notice.

The angularity and local character of the rock-fragments composing the breccia, the broken and splintered condition of the bones, the sharpness of their fractured edges, their frequent fresh state, and the absence of wear or traces of gnawing, show the close analogy between the Rubble-drift or Head and the Ossiferous Breccia, and indicate a similarity of origin. The occasional 'sorting' of the deposits spoken of by Buckland, and the "occasional pauses or periods of causation" of Mr. Pengelly, exactly tally with the successive additions to the Elephant Bed of Brighton, as a result of intermittent uplifts, and, consequently, of intermittent displacement and transport of the surface-débris,—in the one case over the old cliff-edge, and in the other into the open fissures.

There is further stratigraphical evidence on the coast of Gower, where there are both ordinary caves and fissure-caves. Speaking of these Caves, Dr. Falconer remarks on the presence of the angular detritus "to which Mr. Godwin-Austen has applied the name of 'Head' . . . sometimes in vast accumulations in the immediate vicinity of the Caves," and at other times intruding, so to speak, into the interior of the fissures and Caves, where it occurs "cemented by stalagmite, overlying the marine sands and stretching seaward upon the face of the cliffs." Describing Bosco's Den, he says that this detritus was there 6 to 14 feet in thickness, and the materials corresponded in general character with the bed of angular débris observed on the Raised Beach of Mewslade Bay. [1]

Although, owing to the seaward dip of the rock, there is no thick lodgment of Head on the beach, large sheets of it lie in places on the slopes of the limestone, often masking both beach and caves, and choking the fissures. The limestone plateau above the caves is covered with a red clay and angular fragments of limestone, and it is from this that the materials of the Head have been chiefly derived. (See fig. 11.)

I cannot, however, accept the explanation of the origin of the Ossiferous Breccia suggested by Buckland and adopted with some modification by De la Beche,—an explanation which is still generally current. They were of opinion that fissures which long remained open were formed in the limestone by earthquake-movements. Into these the animals which ranged the country fell from time to time, or were driven in when chased by beasts of prey; while fragments of the limestone-rock dropping from the sides of the fissures, with the clay and sand washed in by the rain and streams, gradually filled these

[1] 'Palæontol. Memoirs,' vol. ii. pp. 517, 533.

fissures. Buckland saw that in such cases the entire skeleton ought to be found, and suggested that after the decay of the carcasses the fall of water and débris into the fissures broke up and dispersed the skeletons. But this only shifts the difficulty.

The objection seems to me a fatal one. It is impossible to conceive that, out of the many fissures explored, entire skeletons, or at all events all the separate bones of the skeletons of the animals that are supposed to have fallen in, should not be commonly met with. But this has only happened in a few rare instances, of which Wirksworth is one, although the bones of separate limbs are said to be occasionally found in connexion. Yet the abundance of separate bones in some cases is remarkable. In the collection made by Mr. Cottle on two visits to Oreston, there were [1]:—

1587 teeth of Horse, Ox, Deer, Wolf, Hyæna, Tiger, Hare, Water-rat, Weasel.
147 jaws of Wolf, Horse, Fox, Deer, Hyæna, Ox, Tiger, Hare, Boar.
250 vertebræ and 26 skulls and portions of skulls of various of the above. 3 horn-cores of Ox.
1000 fragments without distinct characters.

So far from the fissures having been long open, a diametrically opposite conclusion is forced upon us. They certainly were not open during Glacial times, otherwise they would have received the worn and characteristic débris of that period. Nor could the ossiferous fissures of Devonshire have been open during the Cave period. For they were so numerous that, had it been so, the result anticipated by Buckland could hardly have been avoided, and many animals must have been lost in them whose entire remains should be found, according to this view, in all such fissures. But this is not the case. In many fissures bones are absent, while in others they occur detached, isolated, and unrelated, in patches throughout the breccia. Nor is the difficulty removed by another suggestion that the fissures during the Glacial winters were filled with snow, so that they served as traps to the animals. This no doubt would be under certain conditions a *vera causa*, but the same objection remains as that which applies to the original suggestion.

I conclude therefore that the fissures were opened out at a time immediately preceding the Rubble-drift or simultaneously with it, and that they were in all probability one of the results of the disturbances accompanying the several uplifts of the land which followed after the submergence.

De la Beche observed of some of the clay at Oreston that it was "apparently impregnated with animal matter," [2] and the remark has been frequently repeated, but I am not aware that any definite analysis of the clay has been made. Mr. Worth says that "the intimate association and order of many of the bones proves that at the

[1] Quoted by Mr. Worth, Journ. Plymouth Inst. vol. vii. (1879) p. 92.
[2] 'Report on the Geology of Devon, Cornwall, &c.' p. 413.

time of deposition these [limbs] were partially united by ligaments." [1] This may be so, though it has not been generally noticed, and, as a rule, the bones are mingled together in the greatest confusion. All of them belong to species which are found likewise in the Rubble-drift and in the Coast Caves.

Mr. Worth moreover refers to instances of the occurrence of bones, supposed to be human, in the Ossiferous Breccia. Although this wants confirmation, there can be no doubt about the probability of finding human remains in this breccia, as Palæolithic flint implements have been found in the Rubble-drift at Portslade and at Sangatte. There is, in fact, probably a better chance of finding human bones in this association than in the implement-bearing fluviatile deposits, inasmuch as, though man might have avoided the partial floods of the rivers, he must have succumbed to the more general effects of an extended submergence.

I have given the reasons which lead me to suppose that the submergence was effected with extreme slowness, so as to disturb but little the surface of the land. Under such conditions, the land-animals would, as the waters rose, gradually retire to the higher grounds of the district, and, when these sank below the level of the flood, would be eventually drowned. Their bodies in some cases may have been carried by currents to a distance and lost, and in others they may have decayed and fallen in fragments to the bottom without travelling far from the spot. Where they fell on an old disintegrated land-surface, they would share with the débris in the displacement and drifting which that débris afterwards underwent.

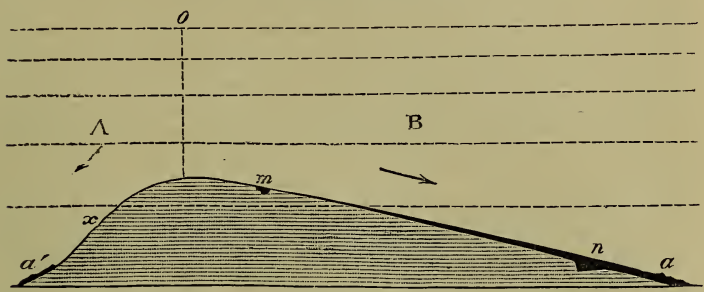
Let us then suppose that, after a submergence of short duration, the submerged land was again raised—not by one continuous movement, but by a succession of uplifts more or less rapid, with intervals of rest or of slow movement. This would produce, on the slopes on all sides of the hills of the submerged area, divergent currents which swept down the loose surface-débris with varying rapidity and for varying distances. These uplifts, repeated at indefinite intervals, led to the transport of successive portions of detrital matter, which, when projected over the old cliffs, was carried forward to distances in accordance with the force of each particular current. The successive layers of the Elephant Bed at Brighton and Sangatte may be taken as indices of the varying force of the currents, and consequently of the extent and rapidity of the successive uplifts. They do not, however, owing to their lenticular form and overlap, afford a true index of the number of uplifts, which there is reason to believe were more numerous than indicated in any single section. They vary in number in each of them, while many beds have been disturbed and partially displaced by the force of impact of the stronger shoots or throws.

The volume of detritus carried forward would depend upon various circumstances, such as the depth of water, angle and length of slope, &c. Thus, if we take a range of hills (fig. 21), presenting

[1] Journ. Plymouth Inst. vol. vii. (1879) p. 109.

on one side a short steep slope, and on the other a long slight incline, as in the instance of the Chalk Downs of North Kent, the result would be as follows:—

Fig. 21.—*Diagram showing the direction of the currents on a hill-range during uplift.*



o being the parting-line or watershed between the superincumbent waters A B, the divergent currents during uplift will be in the directions ⟶ ; but while A moves down a short steep slope for a distance x, B passes over a surface equal to some multiple of x in the same time. Consequently there will be, independently of other causes, a larger volume of drift collected at the base of a than of a', and this disproportion is very apparent in the case of most of our Chalk ranges.

Where the course of the ossiferous drift is along made, narrow channels, it would pass down them and spread out fan-shaped at their termination, as at Upchurch and Farnham. (See Map, Pl. VIII.)

But if any cavity (*m*) should exist on the surface of the open ground, the drift in travelling downwards from *o* will necessarily pass over, fill, and level it; or if there should be a trough (*n*) such as that formed by the old cliff of a Raised Beach, the detrital matter will there accumulate until full to the brim, when the surplus will pass on to the lower level *a* (see the Brighton and Portland sections, figs. 3 and 6).

In the same way, if an open fissure should exist on ground over which the body of detritus passes, that detritus will fall into, and will, if sufficiently abundant, level the fissure with the surface. Generally the detritus has fallen in without order and tumultuously, but in the instance mentioned by Buckland (*antea*, p. 335) there are indications, as in the rubble of the Head, of alternate action caused by successive uplifts, or by oscillations to and fro in the superincumbent body of water.

The final uplift was the most important, for it moved the largest volume of débris, and propelled it to the greatest distances, though the gradients were often very small, as between Portslade and Southwick (Pl. VII. fig. 2) or in the case of the Godrevy outlier (fig. 7).

Not only is the rubble of a character which can be best explained by the agency of a body of water on a submerged land, but the character of the organic remains likewise accords with what we might expect to result from the destruction of a land-surface. In the several forms assumed by this Rubble-drift, the organic remains are invariably confined to those of *land-shells* and *land-animals* (see list, p. 300). No subaerial action could have entombed those fragile shells entire. Ice or running surface-water that could have moved the surface-débris would have shattered the shells, or they would have perished if exposed to atmospheric agencies on the surface. The shells seem also to have been living at the time of the submergence, for had they been dead shells they would have been floated off and lost, whereas they remained on the spot where drowned, until swept down with the general mass of débris. When the currents were strong and the débris coarse the shells have been destroyed, while they have been preserved when the currents were gentle and the sediment fine and suitable in character.

The animals, on the other hand, had, as their carcasses decayed and sank, their detached members scattered over the submerged land-surface, whence, on the re-elevation of that land, they were swept by the effluent currents and entombed in the mass of rubble. That the action was from time to time short and rapid, and the débris swept along tumultuously is evident from the condition of the fractured and shattered bones, as well as from that of the broken rubble. Both are free from wear by long erosion in water, and their fractured fragments retain their sharp angles uninjured.[1] Nor is there any appearance of wear by exposure to atmospheric influences, although the action of water filtering underground is sometimes apparent. Many of the animals may have been carried out to sea, and it is not unlikely that some of the teeth and bones which are now dredged up from time to time in the North Sea and English Channel may have this origin.

Few vestiges of the land-vegetation are preserved. Here and there in the rubble there are traces of carbonaceous matter, and fragments of wood have been found in the Elephant Bed at Brighton, and plants, nuts, and insects in the Brixton (I. of W.) drift and elsewhere, but it is readily conceivable that either the wood may have floated to a distance or have been lost by decay. There is a remarkable mass of driftwood, probably of this age, in the North of France.

We have no accurate measure of the depth of the submergence. It apparently exceeded 900 feet, and may have been not less than 1000 feet.[2] That it was temporary and not of long duration is indicated by the absence of marine mollusca on the submerged land; and that the emergence was continuous, by the absence of terraces within the area, as well as by the absence of any break in

[1] The Rev. G. N. Smith, speaking of the Ossiferous Breccia in Caldy Island, remarks that "the whole seemed to have been forcibly carried into the cave by the action of water Some of the bones were wedged into the fissures of the rock at the cave's ends, just as pieces of driftwood and wreck are observed to be on the shore beneath." See 'The Bone-Caves of Tenby,' p. 6.

[2] A map showing the extent of land left dry, supposing the British Islands were submerged to the depth of 1000 feet, is given by De la Beche in the 'Geological Observer,' 1st ed. p. 301.

the successive layers of rubble forming the Head. At the same time it is manifest that the rise was not uniform, but consisted of a series of uplifts with intervals of slow movement or temporary lulls.

There is another point for consideration in connexion with an emergence of the land. As the bed of the Channel is swept by currents which drift the sand and shingle on to particular portions of its bed, and leave other portions denuded and bare, so in like manner, whilst the effect of the effluent currents on the emerging land has been to sweep the loose detrital matter (the Rubble-drift) down to the lower levels of the surface, it has necessarily left other portions denuded and free of all drift.

The Rev. O. Fisher, approaching the subject from another point of view—that of the denudation of certain areas—has remarked[1] that he did not see any other way of accounting for such a form of surface as obtains in many of the valleys of the soft clay and Chalk districts in the South of England than by a superincumbent mass of water draining off from a flat or slightly dome-shaped area. He infers "that the land must have been elevated by a sudden movement sufficient to have caused a rush of water from the raised portions to seek a lower level,—either the land being raised high and dry at once, or the sea-bottom raised, though still remaining beneath water. Such an elevation might be repeated again and again with intervals of submergence." Allusion is made also to the effects of the uplifts, which agree with several named in this paper. This agreement in conclusions arrived at independently—in the one case on purely geological evidence, and in the other upon the abstract physical problem—cannot be regarded otherwise than as confirmatory of the truth of the hypothesis.

As illustrations of surfaces denuded in this manner I would instance amongst other places the South Downs. There patches of Tertiary and Plateau-drift beds occupy the high summits, and in the valleys and low ground lies the Rubble-drift derived from those beds, and from the Chalk of the intermediate tracts that now remain denuded and bare. It is the same, in a less degree, with the North Downs, the débris of the Tertiary strata and of the Red Clay-with-flints of the higher summits, together with that of the bared Chalk, commingling to form the rubble in the main valley at their base. So likewise with the Wiltshire Downs and the Cotteswold Hills, which are fringed, the one with Tertiary and Chalk débris, and the other with Oolitic rubble, leaving the sides and slopes of the hills bare. Again, in the Wealden area the débris has been shed from off the central high dome, which is left bare, with a fringe of detritus derived from Chalk and Tertiary strata along its encircling valley; whatever Rubble-drift there may be in the valleys of the central area is hardly to be distinguished from the soft sandy and argillaceous beds from which it is derived.

[1] 'On the Denudation of Soft Strata,' Quart. Journ. Geol. Soc. vol. xvii. (1861) p. 1. [I was not aware, when writing the preceding pages, of this paper of Mr. Fisher's.]

In the above remarks I do not overlook the effects of denudation by ice-action, but this preceded by a long period of time the introduction of the Rubble-drift, which was the result of agencies independent of, and subsequent to any visible exhibition of ice-action.

That the disturbance indicated by the Rubble-drift was accompanied by a change of climate is shown by the circumstance that whereas during the time of the Raised Beaches subglacial conditions obtained, and a northern fauna survived, the deposits immediately overlying the Rubble-drift exhibit no glacial characters, and both fauna and flora are of species living at the present day. The change may, however, have begun at the time of the Sand-zone.

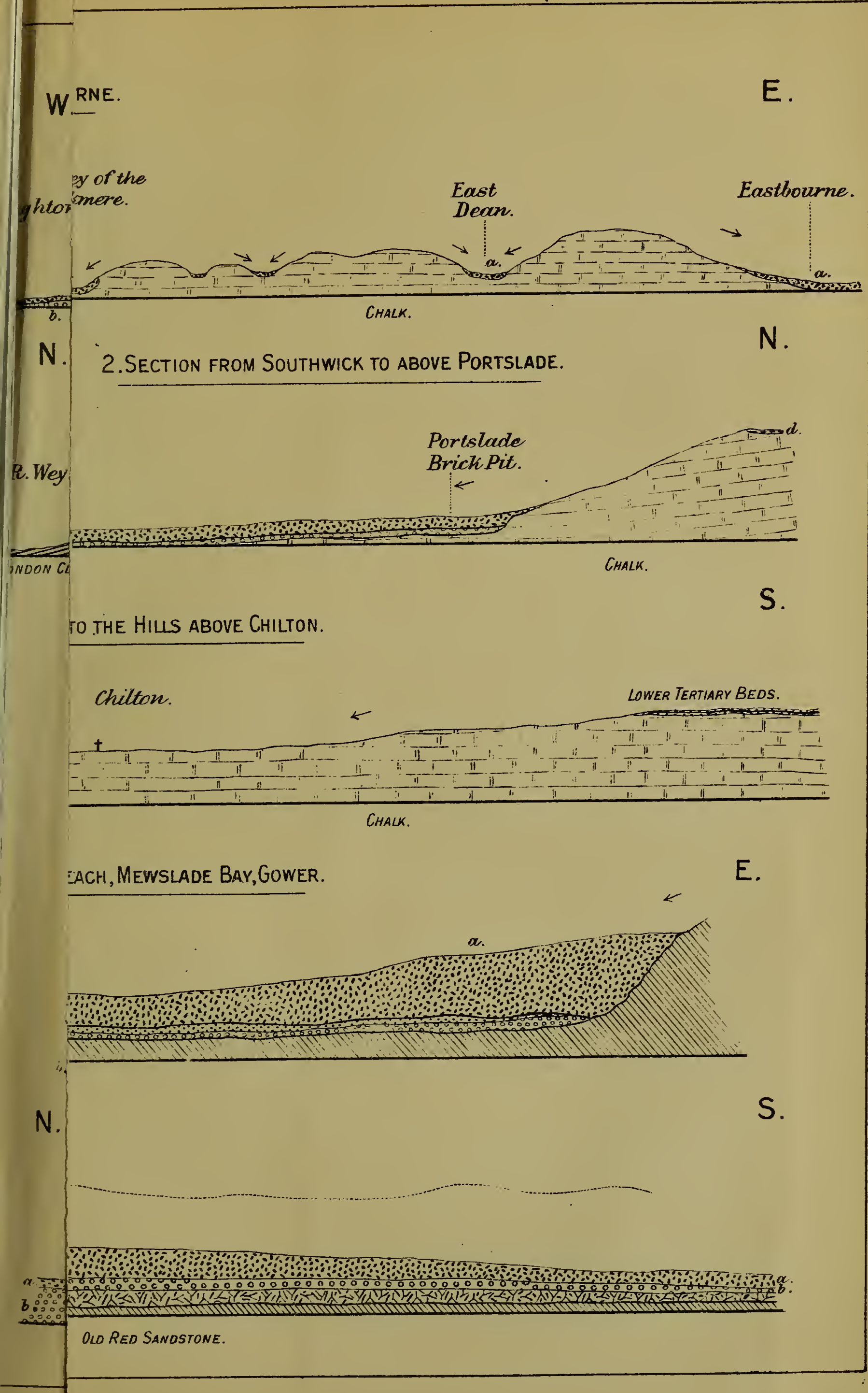
At the commencement of the subsidence whence the Rubble-drift originated, there is reason to suppose that the land stood about 100 or 120 feet higher than at present, and it is certain that after the emergence it regained approximately the same level, though since then it has sunk to within 10 to 30 feet of the level it had during the time of the Raised Beaches.

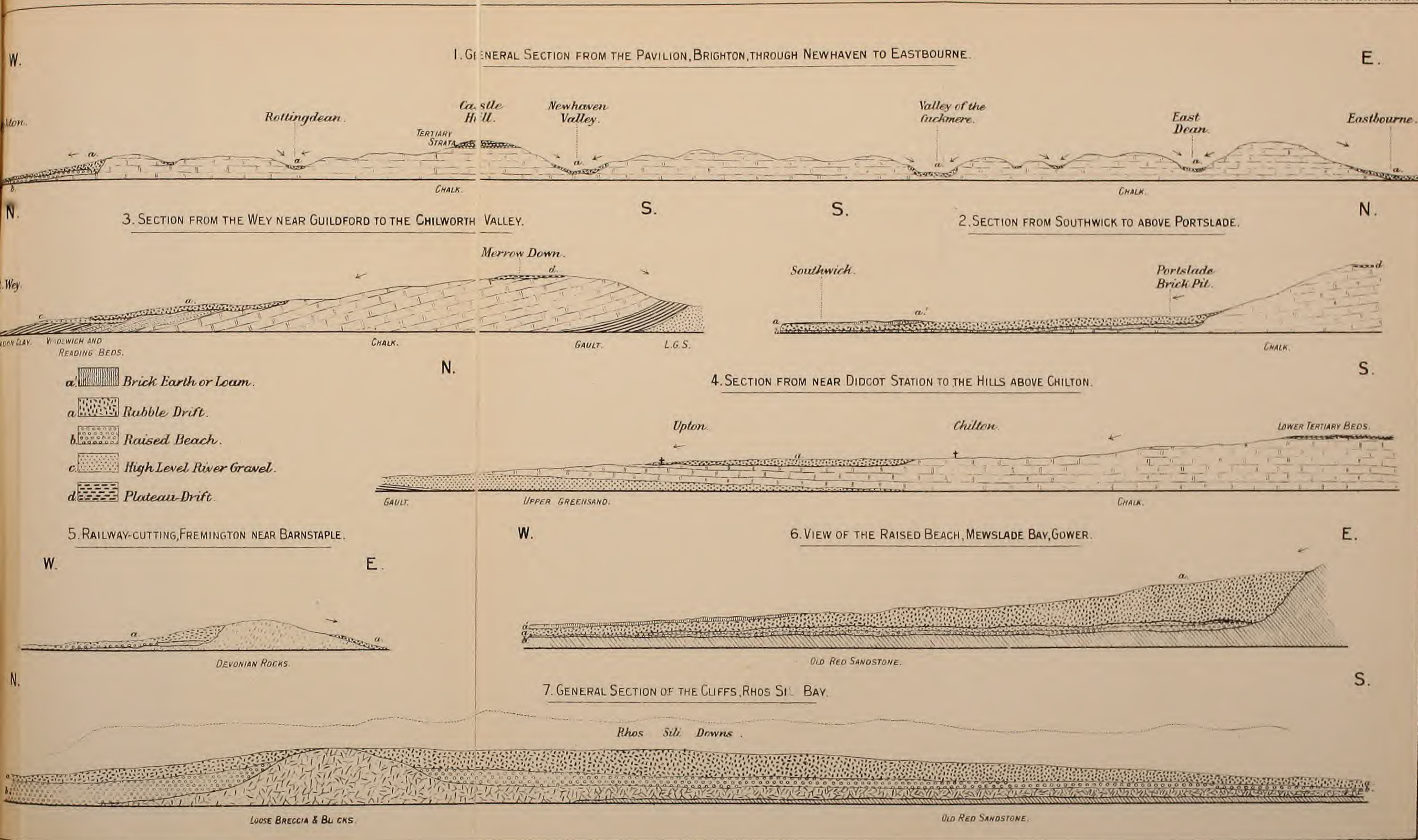
In conclusion, the Rubble-drift embraces :—

1. The mass of angular detritus and rubble forming the Head overlying the Raised Beaches.
2. The beds of angular gravel and loam on hill-slopes or projected into the plains at their base, and not referable either to marine, fluviatile, or glacial action.
3. The trails of gravel—not referable to river-action—in subsidiary valleys, ending at their junction with the main valley in a fan-shaped spread of gravel and brick-earth.
4. The basement-gravels of most valleys and the stanniferous gravel of Cornwall.
5. Trails in some valleys of blocks of local origin.
6. Slight, irregular scatterings of angular débris, clay and loam, or brick-earth on the sides and at the base of hills; these can scarcely be classified, although of frequent occurrence.
7. The ossiferous breccias in fissures of the limestones of Devonshire and South Wales.

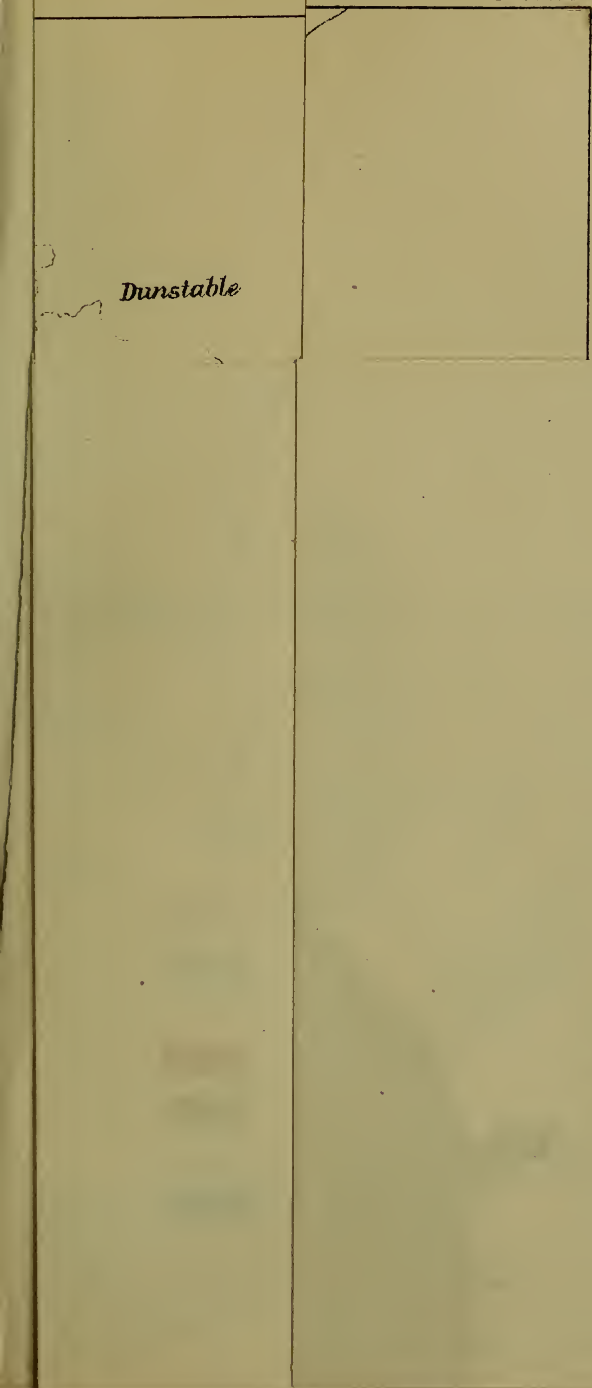
That the submergence is of very late geological date is evident from the fact that no beds intervene between the Rubble-drift and the recent alluvium of our rivers, notwithstanding that the conditions of land and sea were, in many instances, favourable for their development.

Nor, seeing how closely the Raised Beaches follow the present lines of cliff, is it possible to conceive that any great length of time can have elapsed since the formation of the old line of cliffs and beaches. Still, it must not be forgotten that in the interval the land stood for a time some 120 feet higher than at present, so that the first erosion of the land, after the elevation of the beaches, took place at a lowel level than that on which the cutting back of the cliffs has since proceeded. But, allowing for that, the line of 20 fathoms (120 feet) is everywhere within so short a distance of the shore that, had the whole space between that line and the shore


W.
RNE.
E.
ey of the
mere.
ghton
East
Dean.
Eastbourne.
a.
a.
b.
Chalk.
N.
N.
2. Section from Southwick to above Portslade.
Portslade
Brick Pit.
d.
R. Wey
ondon Cl
Chalk.
S.
to the Hills above Chilton.
Chilton.
Lower Tertiary Beds.
Chalk.
each, Mewslade Bay, Gower.
E.
a.
N.
S.
a
b
a.
b.
Old Red Sandstone.



1. General Section from the Pavilion, Brighton, through Newhaven to Eastbourne.
W.
E.
Rottingdean.
Castle Hill.
Tertiary Strata.
Newhaven Valley.
Valley of the Cuckmere.
East Dean.
Eastbourne.
Chalk.
3. Section from the Wey near Guildford to the Chilworth Valley.
N.
S.
Merrow Down.
Wey.
Woolwich and Reading Beds.
Chalk.
Gault.
L.G.S.
2. Section from Southwick to above Portslade.
S.
N.
Southwick.
Portslade Brick Pit.
Chalk.
a'. Brick Earth or Loam.
a. Rubble Drift.
b. Raised Beach.
c. High Level River Gravel.
d. Plateau-Drift.
4. Section from near Didcot Station to the Hills above Chilton.
N.
S.
Upton.
Chilton.
Lower Tertiary Beds.
Gault.
Upper Greensand.
Chalk.
5. Railway-cutting, Fremington near Barnstaple.
W.
E.
Devonian Rocks.
6. View of the Raised Beach, Mewslade Bay, Gower.
W.
E.
Old Red Sandstone.
7. General Section of the Cliffs, Rhos Sili Bay.
N.
S.
Rhos Sili Downs.
Loose Breccia & Blocks.
Old Red Sandstone.


Dunstable


MAP ILLUSTRATING
THE OCCURRENCE OF RAISED BEACHES
AND HEAD OR RUBBLE DRIFT IN THE
SOUTH OF ENGLAND.
EXPLANATION.
Rubble Drift & Head.
Direction of Divergent Currents.
Emerged area after upheaval of Raised Beaches (Cave Period)
Raised Beaches.
Probable line of Raised Beaches.
Submerged area at the Raised Beach epoch.
Emerged area at the Raised Beach epoch.
Miles
LINE OF 20 FATHOMS
DOVER STRAIT
St. David's
CAERMARTHEN.
PEMBROKE
Tenby
Caldy I.
SWANSEA
The Mumbles
ABERDARE
NEWPORT
CARDIFF
River Severn
GLOUCESTER
CHELTENHAM
G. Malvern
Upton
Cropthorne
R. Usk
R. Wye
Stroud
Cirencester
BRISTOL
BATH
WESTON SUPER MARE
Mendip Hills
Wells
Lundy I.
Morte Point
Ilfracombe
Exmoor
Porlock Bay
Watchet
Buggy Point
Croyde
BARNSTAPLE
Westward Ho
Fremington
Bideford
BRIDGWATER
TAUNTON
Padstow
New Quay
Fistral B.
St. Agnes
St. Ives
PENZANCE
Cape Cornwall
Land's End
Marazion
Mousehole
Falmouth
Lizard Head
St. Austell
Pentuan
Looe
R. Fowey
Dartmoor
PLYMOUTH
Dartmouth
Salcombe
Start Point
Eddystone
Brixham
TORQUAY
Hope's Nose
Teignmouth
EXETER
R. Exe
R. Tamar
Axminster
Lyme Regis
Dorchester
Chesil
Portland
Weymouth
I. of Purbeck
Poole
BOURNEMOUTH
Lymington
Solent
Freshwater
Brixton
St. Catherine's Hill
RYDE
Bembridge
PORTSMOUTH
Bracklesham
Bognor
Pagham
Selsey Bill
Havant
Arundel
Worthing
BRIGHTON
Newhaven
Pevensey
EASTBOURNE
Beachy Head
HASTINGS
Rye
R. Rother
Dungeness
New Romney
Hythe
FOLKESTONE
DOVER
South Foreland
Walmer
Deal
Pegwell B.
RAMSGATE
MARGATE
Herne Bay
Whitstable
CANTERBURY
Faversham
Chilham
Ashford
MAIDSTONE
R. Medway
Tunbridge
Sevenoaks
Westerham
CHATHAM
Strood
GRAVESEND
Dartford
Isle of Sheppey
Sittingbourne
CROYDON
Bromley
REIGATE
GUILDFORD
R. Wey
R. Mole
Farnham
Basingstoke
Wokingham
READING
WINDSOR
LONDON
Maidenhead
Henley
R. Colne
R. Lea
Hertford
ST. ALBANS
Dunstable
Chelmsford
Maldon
Brentwood
OXFORD
Abingdon
Wallingford
Wantage
Faringdon
Swindon
Marlborough
R. Kennet
NEWBURY
Devizes
R. Evenlode
Cotswold Hills
R. Avon
SALISBURY
R. Stour
WINCHESTER
R. Itchen
SOUTHAMPTON
R. Ouse
R. Arun
CALAIS
Sangatte
C. Gris Nez
BOULOGNE
Abbeville
The Varne Shoal

been removed—which is not probable, as during a certain and not inconsiderable part of the interval the existing level has been maintained—it would involve no very long period of time. For we have to bear in mind that, with the soft Cretaceous and Jurassic strata of great part of the South Coast, 1500 to 2500 years would have sufficed to wear back the cliffs for the distance of a mile. In the case of the harder Palæozoic rocks of Devon and Cornwall, the wear has been singularly small, the difference between the outline of the coast at the time of the Raised Beaches and that which it has at the present day not exceeding 100 to 200 feet, if so much (see Map, Pl. VIII.).

It would follow from this evidence that the Raised Beaches and Caves are but little removed in space or time from the Alluvial beds of the Recent epoch—a conclusion which corroborates the inference I had before drawn [1] from other data, that the Glacial times came, geologically speaking, to within a measurable distance of our own times, and that the transition was short and almost abrupt.

I have limited this paper to the consideration of the area with which I am best acquainted and in which the phenomena are well defined. I reserve for the present the consideration of the extension of the submergence over other areas.

Plate VII.

Sections illustrating the occurrence of the Raised Beaches and 'Head' or Rubble-drift in the South of England.

EXPLANATION OF MAP (PLATE VIII.).

The Rubble-drift.—On a Map of this scale it is not possible to give exact details of the inland distribution of this drift. Therefore only a few of the localities inland, where its various types are best seen, are given. Where these form sufficiently distinct or fossiliferous deposits, they are indicated in solid colour; where they only form thin beds or mere trail, they are indicated by bars or dots. There are, however, few areas free from this drift in mass, though it is often a mere surface sprinkling.

The Raised Beaches.—All the known Beaches are shown. Their probable position on the coast, where it no longer exists, is marked by a dotted line. The area so enclosed shows the extent of land removed since the period of the Rubble-drift, while the area forming dry land after the uplift of the Beaches is shown in light blue.

The red bars mark the area of land lost since the Raised Beach epoch.

[1] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 393.

20. *The* Pleistocene Deposits *of the* Sussex Coast, *and* their Equivalents *in* Other Districts. By Clement Reid, Esq., F.L.S., F.G.S. (Read February 24th, 1892.)

[Communicated by permission of the Director-General of the Geological Survey.]

The geological survey of the district lying between the South Downs and the Sussex coast has been completed, but the time needed for finishing and engraving the maps will make it impossible to publish a memoir for several years to come. It seems advisable, therefore, to bring before this Society an outline of the general results obtained, especially as certain of these results may seriously modify our views as to the succession of the deposits, and also as to the climatic changes in late Tertiary times in the South of England. A previous communication, published in this Journal,[1] dealt with the question of the origin of the Coombe Rock and of dry Chalk valleys; I now propose to continue this work by showing the relation of the Coombe Rock to the various Pleistocene strata which occupy the plain lying between the southern edge of the Downs and the sea. I propose also to indicate briefly the probable correlation of these strata with the glacial deposits of other parts of England.

The literature of the subject is somewhat extensive, for many good observers have examined the deposits between Brighton and Selsey Bill, especially the 'Pagham erratics,' the 'mud-deposit' of Selsey, and the Brighton 'elephant-bed.' It will scarcely be necessary here to speak of the whole of the writings relating to the district, but certain important memoirs and original observations must be referred to; otherwise it would be impossible to show in what respect the recently completed Survey supplements our previous knowledge of the subject, or obliges us to modify preconceived ideas. The following abstract has been prepared, therefore, to show what were the accepted views as to the succession of the deposits, in the year 1884, when the Drift Survey of the Sussex coast was commenced.

Mantell, in 1822, in his 'Fossils of the South Downs,' mentioned that the mammaliferous Coombe Rock of Brighton was underlain by an ancient beach-deposit, containing sea-shells and waterworn erratic blocks of granite, &c.

The first edition of Dixon's 'Geology of Sussex,' published in 1850, alluded to the erratic blocks found on the shore near Selsey, and suggested their probable transportation by glaciers. The author also alluded to the deposits containing *Elephas primigenius* and southern marine mollusca at Selsey, but in his description there is a great deal of confusion between the true Pleistocene strata and the recent estuarine deposits. Dixon correctly correlated certain ancient beach-deposits near Worthing with the Raised Beach at Brighton, though at the same time he did not clearly distinguish between the Coombe Rock and the underlying marine strata. The

[1] Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 364.

second edition of Dixon's 'Geology of Sussex,' which appeared in 1878, showed the same confusion between the ordinary alluvial deposits and the much older 'mud-deposit' of Selsey, some of the notes evidently referring to the one, some to the other.

In 1855 Godwin-Austen[1] divided the gravels near Chichester into an older or 'red-gravel' and a newer or 'white-gravel' series. I can find no evidence in favour of this classification, for the red gravel of that district is merely the decalcified and oxidized representative of the white and chalky Coombe Rock. Sometimes, however, through the long-continued action of percolating water, a still further change has taken place, and the red gravel is bleached in its upper part into a white gravel. The absence of fossils in the red gravel, mentioned by Godwin-Austen as additional evidence for its distinction from the white gravel, is a usual and necessary result of the decalcifying process. The "diagram-section showing the general relations of the newer Tertiary deposits of the Sussex Levels," given by Godwin-Austen, does not agree in the order of the deposits with any sections that I have been able to examine. This paper gave, however, a number of details which added largely to our knowledge of the strata. Godwin-Austen recorded the occurrence of a colony of gigantic *Pholas crispata* in crypts in the Bracklesham Beds; he noticed also that inside the *Pholas*-shells were found some of the characteristic southern shells belonging to the overlying mud-deposit; and he revised the list of fossils from the mud-deposit, rejecting several species of doubtful origin included in the list by Dixon. Godwin-Austen discussed also the climatic and other conditions indicated by the molluscan fauna, and, on the ground of the occurrence in each of *Elephas primigenius*, he correlated with the Selsey deposit various subaerial accumulations found in other parts of Sussex. This correlation is unsafe, for we now know that the Mammoth had a considerable range in time.

Above the mud-deposit came 'yellow drift clay' containing chalk, and also littoral shells; but here Godwin-Austen appears to have confounded two or more distinct strata, the yellow chalky and stony clay which is the equivalent of the Coombe Rock, and the stony clayey gravels with marine shells and erratics, belonging in reality to the mud-deposit, or to still older strata. At the base of the brick-earth one occasionally finds broken shells and masses of the *Pholas*-bored chalk, derived from an older marine deposit, and this probably has tended to support a mistaken correlation.

Godwin-Austen attempted to trace the various erratics to their respective sources; but he recorded only the hard rocks, such as are found loose on the shore, or re-deposited in the mud-deposit. He apparently did not see the softer masses from Sussex and the Isle of Wight, which are so abundant in the true boulder-gravel. Though I cannot speak positively on the point, it seems probable that the succession given in Godwin-Austen's diagram-section[2] is not altogether accurate, and that the erratic deposit *d* is really the same as

[1] Quart. Journ. Geol. Soc. vol. xiii. (1857) p. 40.
[2] *Ibid.* p. 49, fig. 4.

the lower red gravel *f*, and lies below the marine strata with southern shells, instead of above them. It will be observed that Godwin-Austen nowhere says that he has seen the complete section as shown in his figure; it is only given as a diagram to explain the general relations of the deposits. However, this paper by Godwin-Austen is by far the most important contribution to the Pleistocene geology of the Sussex coast.

The next important memoir relating to the district was read before this Society in 1858 by Prof. Prestwich,[1] who traced the Raised Beach of Brighton westward to near Arundel and Goodwood, and recorded several species of marine fossils from the latter place. West of Goodwood he found unfossiliferous gravels, probably of the same age, at Bourne Common, around Portsmouth, and in the Isle of Wight. In a later paper[2] Prof. Prestwich announced the discovery of a similar raised beach at Portsdown Hill, at a height of 125 feet. The work of the Survey having thoroughly corroborated Prof. Prestwich's view that these deposits all belong to one period, there will be no occasion here to discuss the question.

Mr. A. Bell in 1871 published an account of the mud-deposit at Thorney, near Selsey,[3] and this was reprinted, with additions, in the second edition of Dixon's 'Geology of Sussex.'

That edition also contained a note by Mr. E. H. Willett on the discovery of a Palæolithic implement at a depth of fifteen feet in the Coombe Rock (p. 112); and another by Mr. H. Willett on bones and freshwater shells discovered "near East Wittering in a deposit beneath the glacial beds of Selsey" (p. 19). The note by Mr. H. Willett probably refers to the deposit at West Wittering described below.

The general state of opinion as to the succession of the Pleistocene deposits of the Sussex coast at the time when the Drift Survey was commenced (in 1884) may therefore be thus summarized:—It was generally recognized that an old sea-beach lay beneath the irregular chalky deposit known as the Coombe Rock. This later gravel was commonly considered to indicate a period of excessive rainfall. The fossiliferous strata at Selsey, with southern mollusca, were believed to underlie a glacial deposit with erratic blocks.

The study of the geology of the Sussex Levels has proved to be a task of considerable difficulty, and even a long residence in the district left many points in doubt. It is only by the aid of the clear sections exhibited during the long-continued south-westerly gales of the past autumn and winter that I have been able satisfactorily to examine the area in Selsey Bill which may be regarded as furnishing the key to the whole district. The points to which my attention has been more especially directed were: 1st, the origin of the wide-spread deposit known as the Coombe Rock; 2nd, the succession of the Pleistocene strata; 3rd, the source from which the erratic blocks

[1] Quart. Journ. Geol. Soc. vol. xv. (1859) p. 215.
[2] *Ibid.* vol. xxviii. (1872) p. 38.
[3] Ann. Mag. Nat. Hist. ser. 4, vol. viii. p. 45.

were derived, and their mode of transport; 4th, the stratigraphical position of the deposit containing large erratics, whether above or below the marine clays with southern mollusca; 5th, the character of the fauna and flora found in the several deposits; 6th, and lastly, what succession of events and what variations of climate are indicated by the evidence now collected? Many other questions incidentally arise, but these I propose merely to allude to briefly in the present paper, which is mainly confined to the area minutely examined during the past seven years.

The mode of origin of the Coombe Rock and of the dry Chalk valleys has been dealt with, but since the paper on that subject was published I have examined large additional areas in the South Downs. This work thoroughly bears out the conclusion already arrived at—that the erosion of the valleys, and the deposition of the eroded material in the form of widespread sheets of angular chalky detritus, resulted from the fall of summer rain on a shattered surface of Chalk, rendered impervious by freezing during a winter of Arctic severity.

The second question, What is the true succession of the deposits? I have not before dealt with, except that in the discussion on a paper by Mr. A. Bell I drew attention to the fact that erratics are not confined to strata above the mud-deposit of Selsey, and that the period of floating ice was not only earlier than the Coombe Rock, but earlier than the underlying clays with southern shells.[1] The only way to show what is the true succession will be to describe the newly exposed sections in Selsey Bill. This must be done in some detail, for on the accuracy of the observations depend, not only the conclusions as to the succession of the deposits, but also our view as to the occurrence or non-occurrence of an interglacial or mild episode during the Pleistocene period in the South of England.

During the year 1885 I stayed at Chichester, Bognor, and Selsey, and succeeded in examining the marine clays with *Chiton siculus*, and also the borings of *Pholas crispata*, but the sections were not extensive, and I came across only one erratic block in the clays. This block was, however, sufficient to show that the dispersal of some, at least, of the erratics dated back to the period when the marine clays were being deposited, or was still earlier. To the view that the two were contemporaneous there was this objection: the fauna of the clay was distinctly southern, and showed a sea at least as warm as the present English Channel; whereas, to allow of ice floating for a sufficient length of time to carry erratics long distances, the water must be near the freezing-point. Therefore it seemed evident that the marine clays must be newer than the deposit in which the erratic blocks were first dropped. I have taken every opportunity during the past seven years to search for evidence of this problematic earlier glaciation, but it was not till last October that new exposures enabled me to fill up the gap in the series, and to discover the glacial deposit in place. As this erratic-gravel is the oldest Pleistocene deposit yet discovered on the Sussex coast, it will be the first stratum to be dealt with.

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) *Proc.* p. 173.

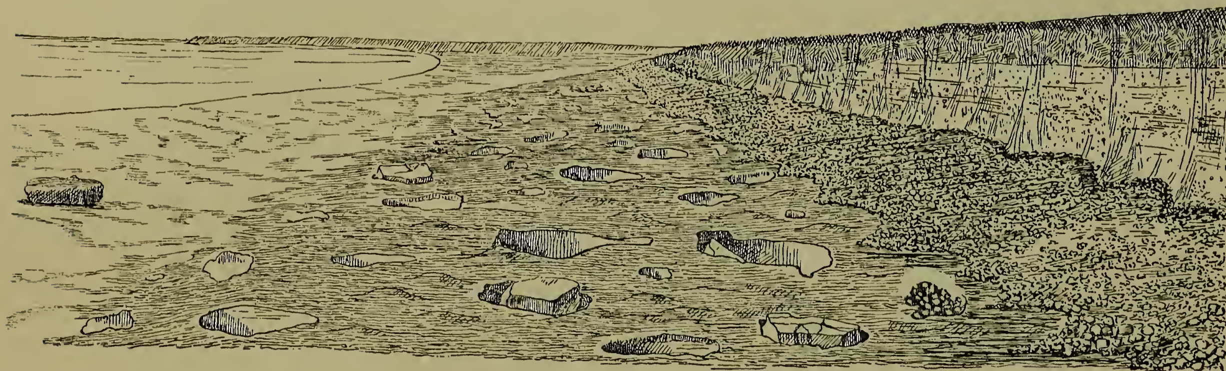
During the continuous south-westerly gales of last autumn and early winter, the loss of land on the west side of Selsey Bill was extremely great. Not only was the cliff-line cut back several yards, but the scour was so strong as to remove most of the beach and lay bare platforms of Eocene and Pleistocene strata at a level where we usually find nothing but beach-shingle. Immediately after the storm of Oct. 24th I re-examined the coast close to Selsey, and found that erosion had been exceptionally marked opposite Medmerry Farm, where the sea had undermined one corner of the farm buildings, though in 1889 it was about 20 yards away. This cutting back of the cliff, and the concurrent removal of most of the beach on the foreshore opposite, exposed a section unlike anything which had before been seen, though the unusual abundance of large erratics on the foreshore had always led me to suspect that this was the critical point, and that there was a probability of finding the glacial deposit in place in the immediate neighbourhood.

Below the level of mean tide there was seen only a wide expanse of fossiliferous Bracklesham Clays full of *Corbulæ*, but at a level slightly higher, on the part of the foreshore first laid bare by these storms, the junction of the Eocene and the Pleistocene strata was exposed. The relations of the two deposits were so peculiar as at once to attract attention. The junction was neither smooth nor channelled, as is ordinarily the case, but the whole surface of the hard Eocene clays, for a quarter of a mile, was full of basins or pits from 2 to 6 feet across. These pits were usually unconnected with each other, and strike one as a feature totally unlike the irregular eroded channels formed by running water between tide-marks. Many of the pits had nearly vertical sides and were 2 feet or more in depth, but it was difficult to ascertain the extreme depth, for on each occasion when the section was well exposed the pits were full of water, and time and the tides would not allow me to bale out or drain many of them.

Fig. 1.—*Diagram-section to show the relation of the erratic blocks to the floor of Bracklesham Beds.*

Four out of every five of the basins contained nothing but loose gravel, with a few valves of *Balanus* and rare fragments of marine mollusca. The loose material, except where cemented by iron oxide, had been almost entirely removed by the recent storms, which were not able to make much impression on the harder Bracklesham Clays. The remainder of the basins were much more interesting, for each of them contained an erratic block, which had not merely been dropped, but showed signs of having been forcibly squeezed or screwed into the clay, until its upper surface was flush with the

View of the coast at Medmerry, near Selsey, after the storm of Oct. 24th, 1891.



To the left are wet flats of Bracklesham Clay, channelled by recent marine action. In the foreground is seen a Pleistocene surface of Bracklesham Clay, full of isolated pits containing erratics. To the right is a recent shingle beach, banked against a low cliff of Raised Beach, overlain by stony brick-earth. Medmerry Farm stands at the edge of the cliff, a few yards to the right of the sketch.

general level. In this process the softer or more splintery rocks had been crushed, so that they are now found with their angular fragments slightly separated by gravel, or by fossiliferous Eocene clay. The harder masses were sometimes driven into the clay (see fig. 1, p. 348), so that I was obliged to cut away fossiliferous Eocene clay to get out the Pleistocene erratic. It seems clear that most of these pits are not hollows eroded by water, but dents made by the ice or by erratics; for the stratified Eocene clays generally become much disturbed and contorted around the margin of the hole. The pits filled with finer material probably mark the spots where large erratics were formerly deposited, though, becoming again frozen into the ice-foot, they were lifted out and transported to fresh sites.

About a hundred of these pits were examined, and the conclusion seemed irresistible that they afforded clear evidence of the agency of floating ice. Drift-ice grounding on the ancient foreshore dropped its burden of erratics between tide-marks. Here they were pressed deeper and deeper into the clay, for the rise and fall of the tide at high-water piled ice upon any projecting rock, while at low-water the rock was pressed down by the weight of the ice till it was flush with the general surface. Often, however, the still-projecting boulder would be firmly frozen into a new ice-foot, or accumulated mass of pack-ice, and would then be gently lifted out of the hole at the rise of the spring-tides. It is thus that I would account for the occurrence of empty pits, for they seem to mark the former sites of blocks which may have shifted their position several times before finally coming to rest. Perhaps some of the basins were produced by the stranding, packing, and revolving of masses of ice during a storm, but the general appearance of the section suggests fairly tranquil water in a sheltered bay. No signs of furrows ploughed in the clay were observed, and the ice was probably entirely in the form of flat-bottomed ice-foot, which, at a spot like this, sheltered from the prevalent winds by the Isle of Wight, would ground gently and would tranquilly melt away without being driven violently into the shoals, as on a more exposed coast.

Besides the section opposite Medmerry Farm just described, several erratics have been noticed embedded in Eocene clay near West Wittering, five miles to the north-west. The floor was at a slightly higher level and was much cut into by later marine deposits; as, however, only a vertical section was visible, nothing more can be said about these boulders.

There has always been some uncertainty as to which of the far-transported blocks found on the Sussex coast were genuine erratics, and which had been brought in ballast, or had been derived from wrecks. Every opportunity was therefore taken to obtain specimens of each variety of rock found unmistakably embedded in Pleistocene deposits [1]; the following is a list of the erratics found in the pits near Medmerry, with the measurements of each block, and the

[1] I have to thank my colleague, Mr. J. J. H. Teall, F.R.S., for determining the igneous and plutonic rocks.

source from which it was probably derived. No boulder is included in the list unless it was firmly fixed in the clay; the large detached erratics have been well described by Godwin-Austen.

Erratic Blocks from Medmerry, near Selsey.

[*Measurements are given in feet. A note of interrogation shows that the full measurements could not be obtained, owing to the boulder being sunk in a pit or surrounded by water.*]

Bembridge Limestone (from Bembridge Ledge, Isle of Wight).	Cream-coloured limestone, full of casts of *Limnæa*: $1\times\frac{1}{2}\times\frac{1}{2}$; $1\times(?)$; $2\times(?)$; $1\frac{1}{4}\times(?)$; $1\times(?)$.
Bognor Rock (from Bognor Ledge).	Hard sandstone or calcareous grit, usually with *Pectunculus brevirostris*: $3\frac{3}{4}\times3\frac{1}{2}\times1$; 12 (much shattered: perhaps more than one erratic); $5\times4\times(?)$ (striated); $4\times4\times(?)$; $2\times1\frac{1}{2}\times(?)$; $1\frac{1}{2}\times1$; $2\times(?)$; $5\frac{1}{2}\times4\times(?)$; $1\times(?)$ (bored).
Eocene (probably not carried far).	Greywether Sandstone, $1\frac{1}{2}\times1\frac{1}{4}$; $2\times2\times1\frac{1}{2}$; $1\times(?)$; $2\times(?)$.
Upper Chalk.	Black flints.
Upper Greensand (probably from the Isle of Wight).	Glauconitic sandstone with phosphatic nodules: $8\times5\times(?)$. Green calcareous sandstone: $2\times1\times1\frac{1}{2}$. Cherty sandstone with phosphatic nodules: $1\times(?)$. Dark-coloured chert, usually full of sponge-spicules: $1\times(?)$; $1\frac{1}{4}\times1$; 1×1; $1\times(?)$; $1\times(?)$.
Palæozoic.	Hard, pale-green, and reddish sandstone: $1\frac{1}{2}\times1$. Greenstone: $1\times(?)$. Muscovite-biotite-granite: $1\times\frac{1}{2}$.

For comparison, I add a list of the erratics found in newer deposits in the neighbourhood of Selsey:—

Bognor Rock.
Greywether (sometimes large blocks).
Greensand chert (small pebbles).
Hard purple grit.
Felsite.
Felspar-porphyry.
Diorite.
Greenstone.
Granite, coarse-grained gneissose biotite (in the Selsey mud-deposit).
Granite, coarse-grained biotite.
Granite, fine-grained biotite.
Granite, with large porphyritic crystals of white orthoclase.
Granite, hornblende-biotite.
Granite, hornblende-biotite, or possibly quartz-mica-diorite.[1]

The first thing that strikes one in the above list is the preponderance of erratics from known localities not more than 20 miles from Selsey. Previous writers do not allude to the occurrence of characteristic Isle of Wight rocks, and before the exposure of the

[1] Prof. Bonney, who examined the specimens immediately before the reading of the paper, remarked that many of the rocks reminded him of types met with in Britanny. One specimen—the granite with large crystals of white orthoclase—was, he observed, more probably of Cornish origin.

GLACIALLY STRIATED ERRATIC FROM MEDMERRY, NEAR SELSEY.

(Portion of a block weighing upwards of two tons.)

[From a photograph, half natural size, by Mr. J. J. H. TEALL, F.R.S., F.G.S.]

new section at Medmerry most of the large detached boulders had been found to belong to igneous, granitoid, or gneissic rocks, with a certain admixture of hard Eocene sandstone. This peculiar assemblage had always puzzled me, for I could not understand how shore-ice could bring various rocks from the Channel Islands or other more distant localities without bringing anything from the Isle of Wight. It now appears, however, that the granitoid rocks are in a small minority, and that the bulk of the material comes from the Isle of Wight and the Sussex coast; but the Isle of Wight rocks being either calcareous or else much jointed, the boulders fell to pieces through the action of frost, or were crushed into moderate-sized fragments, and these are soon destroyed when once dislodged.

It would appear that every previous observer had been able to examine only the erratics loose on the shore, or re-deposited in various parts of the strata overlying the gravel. This would account for nothing but hard rocks being contained in the list published by Godwin-Austen, and would also explain the mistake in his diagram-section, which placed the erratic deposit above instead of below the marine bed with *Pecten polymorphus*. As I shall show farther on, re-deposited erratics of moderate size are particularly abundant in the mud-bed directly overlying clay with *Chiton siculus*. The occurrence of blocks at this level probably misled Godwin-Austen as to the true succession.

The discovery of a striated erratic fifty miles south of the nearest glacial deposits in the Thames Valley deserves comment.[1] The block was a large mass of Bognor Rock, measuring 5 × 4 feet and probably weighing upwards of 2 tons. It was full of *Pectunculus brevirostris* and *Voluta denudata*, but as it lay with the smooth face embedded in the Bracklesham Clay, the striæ were not at once observed, and the piece figured on the opposite page was broken off and taken as a characteristic fragment of a known Eocene rock. Only on unpacking and washing the specimen, after my return to London, were the striæ noticed, so that it is impossible to say whether the whole of the buried surface of the erratic was grooved in the same way. The striæ probably were formed whilst the rock was still part of the solid projecting ledge that yet exists off Bognor. A ledge of this sort in an icy sea would form an obstacle to the drift-ice, which swept backward and forward with every change of tide and wind. The surface would thus tend to become irregularly scored and striated, and occasionally, through the formation of packs, the ledge would be shattered and pieces carried away. The striated erratic found at Selsey must not be taken as evidence of the occurrence of glaciers on the shores of the English Channel, for everything points to the agency of shore-ice and frost alone.

[1] Ramsay, in a note on p. 85 of the 'Catalogue of the Tertiary and Post-Tertiary Fossils in the Museum of Practical Geology,' mentions the occurrence of ice-scratched stones at Selsey. The account given by Ramsay, both in the 'Catalogue' and elsewhere, seems, however, to be taken from Godwin-Austen, who speaks of boulders 'presenting beautifully smooth and polished surfaces,' alluding evidently to the action of the sea and not of ice. The chalk-flints placed by Ramsay in the rock-collection at Jermyn Street are not striated.

Opposite Thorney Coastguard Station, and also still nearer to Medmerry Farm, the surface of the Bracklesham Clays is bored into by that colony of *Pholas crispata* which struck Godwin-Austen as so remarkable, owing to the size of the individuals. I have had many opportunities of examining the colony, and cannot help thinking that the resemblance of the shells to the gigantic specimens found in the Arctic seas, or in glacial deposits like the Bridlington Crag, is no accidental coincidence, but shows that the specimens lived under Arctic conditions.

It will be observed that Godwin-Austen distinctly states that the southern *Pecten polymorphus* is found within the crypts occupied by the large *Pholas crispata*. The contents of a large number of these crypts were therefore examined; but, instead of containing southern species, those nearest to Medmerry yielded nothing but *Balanus porcatus*, a northern cirripede not recorded from the overlying mud-bed, but always associated with the large *Pholas crispata* in the recent state.

This observation seemed difficult to reconcile with the statement of Godwin-Austen; but better sections showed that in all probability the *Pholas*-borings belonged to an older Arctic deposit. The crypts ought thus usually to contain shallow-water *Littorinæ* and *Balani*, like those found in the glacial gravels; but where the newer marine strata happened to cut down to the Bracklesham Beds, the crypts in hard clay might readily be partly scoured out and re-filled with southern mollusca, indicating a greater depth of water.

No Arctic mollusca have at present been noticed in the erratic-gravel, though valves of *Balanus* are abundant, and *Littorina* also occurs. The scarcity of shells is not surprising, for a shoal on which ice-foot constantly forms, and ice strands in spring, must be a most uncongenial habitat for littoral shells. Thus far no characteristic Arctic mollusca have been discovered in our southern counties, but the deposit at Medmerry is worth further search.

The next question to be discussed is the stratigraphical position of the gravel with erratics: is it older or newer than the marine clays? If the suggestion above thrown out be correct, the gigantic *Pholas crispata* belongs to a cold period older than the incoming of the southern mollusca, and therefore probably equivalent to a period when erratics were being transported. But, unfortunately, we cannot trace the erratic-gravels till they pass under or over the clays with southern mollusca, and there remains a gap of about half a mile between the two deposits. No doubt the shingle of the old raised beach can be seen to pass over each, but, as the relation of the beach to the mild period is not perfectly clear, the succession cannot be proved by direct superposition. Another method is available: to observe the occurrence of material derived from the one stratum and re-deposited in the other. No fragments of southern mollusca have yet been found in the erratic-gravel, but the clays with southern mollusca often contain re-deposited erratics. The gravel with erratic blocks is therefore the older of the two.

Turning now to the strata yielding evidence of a mild period, we find characteristic fossils at two localities and in deposits of two distinct types. The first is the well-known marine mud-deposit of Selsey; the other is the little-known freshwater and estuarine gravelly loam of West Wittering. The Selsey mud-deposit has so often been described that it is curious to find that two strata seem to be included under the term. One of them probably gives the name, the other yields the characteristic southern fossils. A section, seen nearly a quarter of a mile south-east of Thorney Gap during the recent gales, is shown in fig. 2, but under ordinary circumstances little or nothing is visible between tide-marks, except beach-sand and the Bracklesham Clays.

Fig. 2.—*Section of the cliff and foreshore at Selsey Bill.*

(Scale, vertical, 20 feet = 1 inch; horizontal, 100 feet = 1 inch.)

	feet
6. Stony loam, gravelly at base, chalky where unweathered (= Coombe Rock)	6
5. { Shingle, with occasional fragments of Greensand chert and other erratics (= Raised Beach of Brighton ?)	4
5. { Sand and shingle	3
Hidden under recent beach (probably all sand and shingle, as above)...	6
4. Black, stony, estuarine mud, with driftwood, acorns, *Scrobicularia* in the position of life, *Hydrobia ulvæ*, *Littorina obtusata*, *Rissoa parva*, *Utriculus*, *Tellina balthica*, *Cardium edule*	2
3. Stony clay with numerous re-deposited erratics (base of No. 4)	0½
2. Hard greenish clay, full of derivative Bracklesham fossils, and with Pleistocene marine mollusca. *Chiton siculus*, *Rissoa cimex*, &c. Occasional large Chalk flints and erratic blocks. (This deposit is likely to be confounded with the underlying Eocene strata, for it is mainly formed of re-deposited Bracklesham material, and contains more Eocene than Pleistocene fossils)	2
1. Bracklesham Beds.	

The first thing to strike one in this section is that three different types of sediment are represented among the brackish-water and marine strata. The lowest bed is a purely marine deposit, with a molluscan fauna of southern type, showing a depth probably of 10 or 25 fathoms. The next is a *Scrobicularia*-mud, with estuarine shells and land-plants, and was clearly formed between tide-marks.

The third is a mass of littoral sand and shingle, resting irregularly on the fossiliferous strata, and within a short distance overlapping on to Bracklesham Beds. All three deposits, notwithstanding their different lithological character and fossils, belong, I believe, to one series, and point to a gradual shoaling of the water and change from an open sea to a sheltered estuary.

The fossils in Bed 2 clearly show the influence of warmer seas than those which now wash our shores; for among the large number of mollusca already recorded, several have a range exclusively southern, and none are boreal. From Beds 3 and 4 we have a much smaller list, and the species are not characteristically southern, though certainly not Arctic. The associated plants include the oak, blackberry, dog-rose, bird-cherry, bugle, lousewort, orache, horned pond-weed, and two or three sedges. They point to a climate sufficiently mild for forest-trees such as the oak, and therefore too mild to allow of the formation of ice-foot. Bed 5 does not appear yet to have yielded fossils at Selsey, but deposits, probably of the same age, at Worthing and Brighton contain only common littoral species such as inhabit our seas at the present day.

The fossiliferous strata at West Wittering are seen on the foreshore, nearly half a mile north-west of the Beacon and due south of the farm near the edge of the cliff. The relations of the deposits are so difficult to make out, except after long-continued gales, that it will be advisable to describe what was seen during last autumn and winter on the half-mile of coast between West Wittering Beacon and the extreme point of the peninsula. To the west I found the stony loam, which overspreads the whole of the district, resting on an irregular surface of Eocene clay. The clay rose to above the level of high water, and at several spots erratic blocks were noticed embedded in pits or channels in its upper surface. A quarter of a mile to the south-west, shingle like that seen at Selsey comes in between the stony loam and the Eocene clay. Then, within a few yards, appear indications of an ancient eroded channel, and beneath the shingle is seen a series of freshwater and estuarine strata having a gravelly base full of re-deposited erratics. This channel cuts down into the Eocene clay to the level of low-water, but is only about $\frac{1}{4}$ mile wide. Eastward, however, appearances are most deceptive, for the more modern channel of an existing valley has cut through the Pleistocene deposits and breaks into the side of the older river-bed. One thus occasionally finds re-deposited bones of Elephant at the base of the later alluvium. The juxtaposition of the two deposits will lead to much confusion, unless the greatest care is taken; for the strata were formed under somewhat similar conditions, though the fossils are different. In the newer deposits bones of *Bos* are abundant, and the mollusca are all species common in the immediate neighbourhood at the present day. In the older series the bones belong to *Rhinoceros* and *Elephas*; *Corbicula fluminalis* is the most abundant shell, and *Succinea oblonga* and *Hydrobia marginata* are both common.

The deposits in the older river-channel are so irregular and thin that it would be difficult to give any but the most diagrammatic section of them. The general succession seen on the foreshore on the west side of the channel is :—

Laminated peaty clay, with *Corbicula*, &c.
Clayey gravel, with large flints, blocks of granite, &c.
Eocene Clay.

A short distance to the east we find :—

Mass of rolled clay pebbles.
White marl with Chalk grains.
Clayey gravel with erratics.

Still farther east the marl dies out, and peaty clay full of *Corbicula* comes on again. The deposits here described are seen on the foreshore, but the low cliff above shows that the old beach-shingle extends right across the channel, and is overlain by stony loam.

In the peaty clays overlying the gravel with re-deposited erratics were found several bones of *Rhinoceros*. Between and around the bones were seen numerous land and freshwater shells and seeds of plants. So that there might be no doubt as to the contemporaneity of the different fossils, a large sample of the peaty and sandy clay was taken from the same spot where the bones were found. The material, after washing and picking over, yielded a large series of shells and plants ; and, as this is the first case in which any considerable number of plants has been found in this country associated with Pleistocene mammalia and mollusca, I give the complete list of these classes, leaving the coleoptera and entomostraca for future work. For the determination of the mosses I am indebted to my friend Mr. A. Gepp.

Mollusca from West Wittering.

Cardium edule, Linn.
Scrobicularia piperata, Bellon.
Tellina balthica, Linn.
Corbicula fluminalis, Müll.
Sphærium corneum, Linn.
Pisidium amnicum, Müll.
—— *pusillum*, Gmel.
Bythinia tentaculata, Linn.
Valvata piscinalis, Müll.
—— *cristata*, Müll.
Hydrobia marginata, Mich.
—— *similis*, Drap.
—— *ulvæ*, Pen.
—— *ventrosa*, Mont.
Planorbis carinatus, Müll.
—— *complanatus*, Linn.
—— *contortus*, Linn.
—— *nautileus*, Linn.
—— *nitidus*, Müll.
—— *spirorbis*, Linn.
Limnæa auricularia, Linn.
—— *palustris*, Müll.
—— *peregra*, Müll.
Ancylus fluviatilis, Müll.
Velletia lacustris, Linn.
Limax agrestis, Linn.
Succinea elegans, Risso.
—— *oblonga*, Drap.
Zonites fulvus, Müll.
Helix hispida (?) Linn.
—— *nemoralis*, Linn.
—— *pulchella*, Müll.
—— *rotundata*, Müll.
—— *rupestris*, Studer.
——, sp.
Zua lubrica, Müll.
Pupa muscorum, Linn.
Vertigo edentula, Drap.
Clausilia biplicata, Mont.
Carychium minimum, Müll.

Flowering Plants from West Wittering.

Thalictrum flavum, Linn.
Ranunculus aquatilis, Linn.
—— *sceleratus*, Linn.
—— *Lingua*, Linn.
—— *repens*, Linn.
—— *bulbosus*, Linn.
—— *sardous*, Crantz.
—— *parviflorus*, Linn.
Caltha palustris, Linn.
Nuphar luteum, Sm.
Viola (?).
Silene maritima, With. (seed small).
Stellaria media, Cyr.
Prunus Cerasus, Linn. (or *P. avium*, Linn.).
Spiræa Ulmaria, Linn. (fruit small).
Rubus fruticosus, Linn.
Poterium officinale, Hook. f.
Rosa canina, Linn.
Hippuris vulgaris, Linn.
Myriophyllum spicatum, Linn.
Hydrocotyle vulgaris, Linn.
Œnanthe crocata ? Linn. (fruit small).
—— *Phellandrium*, Lam. (fruit small).
Angelica sylvestris, Linn.
Cornus sanguinea, Linn.
Sambucus nigra, Linn.
Viburnum Opulus, Linn.
Scabiosa succisa, Linn.
Eupatorium cannabinum, Linn.
Cnicus lanceolatus, Hoffm.
Lapsana communis, Linn.
Menyanthes trifoliata, Linn.
Lycopus europæus, Linn.
Ajuga reptans, Linn.
Atriplex patula, Linn.
Polygonum Persicaria, Linn.
Rumex conglomeratus, Murr.
—— *obtusifolius*, Linn.
Mercurialis perennis, Linn.
Corylus Avellana, Linn.
Quercus Robur, Linn.
Ceratophyllum demersum, Linn.
Sparganium ramosum, Curtis.
Potamogeton natans, Linn.
—— *heterophyllus*, Schreb.
—— *trichoides*, Cham.
Ruppia maritima, Linn.
Zannichellia palustris, Linn.
Eleocharis palustris, R. Br.
Scirpus pauciflorus, Lightf.
—— *lacustris*, Linn.
Carex distans, Linn.
—— *riparia*, Curtis.

Mosses (determined by A. Gepp, F.L.S.).

West Wittering.

Neckera complanata, Huebener.
Homalothecium sericeum, Br. & Sch.
Eurhynchium prælongum, Br. & Sch.
—— *speciosum*, Schimper.
Hypnum cupressiforme, Linn.
—— *Schreberi*, Willd.
—— *fluitans*, Linn.
—— *aduncum*, Hedw.

Selsey.

Leucodon sciuroides, Schwaegr.
Homalothecium sericeum, Br. & Sch.
Eurhynchium prælongum, Br. & Sch.
Brachythecium populeum, Br. & Sch.
Hypnum cupressiforme, Linn.

The mammalian remains as yet found all belong to Rhinoceros and Elephant, though gnawed hazel-nuts show that a rodent, according to Mr. E. T. Newton, F.G.S., probably the squirrel, ought also to occur. Bones of fishes are extremely rare, and none belonging to amphibia have been met with.

The mollusca, with four exceptions, are common British forms. *Corbicula fluminalis* and *Hydrobia marginata* are, however, entirely extinct in Britain. *Succinea oblonga* is not now found in the South-east of England, while *Hydrobia similis* is confined to the Thames. Three of these species are abundant in Pleistocene deposits in various parts of England. It may be observed that none of the characteristic species of the South of England have been met with at West Wittering, but as these southern forms are all dry-soil species the circumstance is not surprising. As most of the mollusca included in our list have a considerable climatic range, nothing definite can be said as to the climate they indicate, though the general *facies* of the collection is certainly not boreal.

The plants yield much more satisfactory evidence as to climate, and several of the species in our list have a limited range to the north. In fact the assemblage distinctly points to climatic conditions similar to those of England at the present day. The oak, wild-cherry,[1] cornel, elder, guelder-rose, and hazel are the only trees yet met with, but of these the cornel does not extend into the North of England. All except one of the plants still live in Sussex; but *Potamogeton trichoides* does not now occur in the South of England.

The lower part of the deposit at West Wittering, though extending below the level of half-tides, is of purely freshwater origin; but the upper part of the loam contains many estuarine *Hydrobiæ*, occasional cockles, and some salt-marsh plants. The incoming of marine species would seem to indicate depression, and perhaps direct continuity with the marine shingle which overlies the fossiliferous deposit. The freshwater and estuarine strata at West Wittering may therefore represent the deposits lying between the purely marine clay at Selsey and the old beach; but on the other hand it is quite possible that they are older, and that they help to fill the gap between the clay with southern mollusca and the underlying erratic-gravel. In any case, all these fossiliferous deposits are of later date than the erratic-gravel and earlier than the Coombe Rock; but on the first hypothesis there is a sharp break between the littoral Arctic erratic-gravel and the immediately overlying marine clay with southern shells; while on the second hypothesis a land period is gradually followed by depression, becoming more and more marked, and then changing again into an upward movement. Which may be the true succession of these minor horizons the evidence is not yet sufficient to decide.

From what has already been stated it will be clear that on the Sussex coast a deposit of glacial origin is overlain by one yielding a temperate fauna and flora, this latter being without Arctic species, but including a few southern forms. Above these fossiliferous strata lie stony and chalky brick-earth and Coombe Rock, which, if my conclusions are correct, indicate a recurrence of Arctic conditions. The strata yielding evidence of a temperate climate seem therefore to belong to an interglacial or mild episode.

It may be interesting, before leaving the subject, to sketch the probable correlation of the Pleistocene deposits of the Sussex coast with those of other districts which I have specially studied; for much additional evidence has recently been obtained, and it now appears that there exists in various parts of this country a characteristic interglacial fauna.

In the Thames Valley there seems to be a threefold division

[1] The bird-cherry (*Prunus padus*) is the species found at Selsey; the common sloe (*Prunus spinosa*) has not occurred at either locality.

similar to that found on the Sussex coast. We begin with Chalky Boulder Clay: a natural equivalent of the lower-lying marine glacial deposit 50 miles farther south. Next come fossiliferous loams, full of *Corbicula, Succinea oblonga*, and *Hydrobia marginata*, as in Sussex; and yielding also bones of Rhinoceros and Elephant, and leaves of plants, among which I may mention the ivy, a species which cannot bear great cold. Above the fossiliferous loams usually occur widespread sheets of rough flint-gravel and stony brick-earth, with Palæolithic implements and occasional bones, exactly as in Sussex, except that the material, being derived largely from older morainic deposits, and not directly from Cretaceous rocks, yields little chalk.

It has been usual to speak of the gravels in the Thames Valley as river-gravels, or terrace-gravels, marking successive stages in the excavation of the valley. A study of the Sussex levels, however, makes me incline to the opinion that the widespread sheets of gravel in the Thames Valley were deposited in the same way as the similar sheets in Sussex. In short, they were not river-gravels, but frozen-soil gravels, laid down on plains sloping gently towards the River Thames. They may have been deposited at all heights contemporaneously, as long as the slope did not exceed about 100 feet in the mile. In favour of this view of the origin of the greater part of the Thames Valley gravel and brick-earth, may be mentioned the rarity of all fossils except land mammals, and the absence of aquatic species; as is the case also in the Coombe Rock. There is moreover the occurrence of old land-surfaces on which flint-chips were scattered, and on which the flakes occur in close proximity to the cores from which they were struck. The bearing of this last fact seems to be important, for these floors may be covered with coarse detritus, which needed considerable force to move it, and under existing conditions would be accompanied by considerable erosion. If, however, the climate were colder, the flakes would freeze into the soil, and a sudden fall of rain might wash gravel or loam over them, without disturbing the old surface, which at the time was frozen into a solid rock.

This view of the origin of the Thames Valley gravels is so contrary to the ordinarily accepted opinion that for several years I have hesitated to bring it forward: but I may point out that it will greatly simplify the geology of the district. Instead of our having to deal with a complicated series of gravel-terraces formed when the Thames stood at different levels, or formed during a Pluvial Period, there is probably one sheet, belonging to a single period. Beneath this sheet of gravel and unfossiliferous loam are found, at different levels, relics of lacustrine strata belonging to an earlier mild period when *Corbicula fluminalis* flourished, exactly as in Sussex. The excavation of the Thames Valley dates back to still earlier times, when the river flowed parallel with the southern margin of the ice-sheet, and received the sub-glacial drainage of this sheet as well as that of the present catchment-basin. No trace of truly pre-glacial deposits has yet been found in the Thames Valley.

As we travel northwards the deposits of the mild interglacial period seem to be represented by the raised estuarine and fluviatile strata of Clacton, in Essex, with *Corbicula fluminalis*, *Unio littoralis*, &c. In Norfolk we find on the coast at Mundesley a series of loams with *Hydrobia marginata* and *Emys lutaria*. These rest in an eroded channel in Boulder Clay and are covered by coarse gravels without fossils. The same period is probably represented in the Fenland by the gravels of March, which contain a somewhat boreal assemblage of marine mollusca, but are also full of *Corbicula fluminalis*.

Still farther north the same assemblage of marine mollusca that characterizes the March gravels is found to lie between two Boulder Clays, but there again it is full of the *Corbicula*. At Bridlington and Speeton fossiliferous strata underlie a great thickness of Boulder Clay, but rest directly on Secondary rocks. These strata my friend, Mr. G. W. Lamplugh, is inclined to speak of as 'pre-glacial'; but after carefully reading his paper[1] and re-examining my notes I still think that the correlation adopted in my memoir on Holderness is correct. North of Flamborough Head no trace of this characteristic fauna has yet been found, and the so-called 'interglacial' deposits of Scotland yield so large a proportion of plants generally considered to have been introduced as weeds of cultivation that I cannot help feeling that some mistake has been made, and that landslips or creep have in most cases been the cause of the appearance of Boulder Clay above the fossiliferous strata.

Though the land and freshwater species show little change of climate between south and east, there exists a marked difference in the marine mollusca. In Sussex the marine fossils seem to indicate a sea warmer than the air, while in the Eastern Counties the air was apparently warmer than the sea. This discordance may have been due to the want of connexion between the two seas, but we do not yet know at what date England was separated from the Continent.

From what has been said in the foregoing remarks it will appear that the South and East of England show evidence of two distinct periods of Arctic cold. During the earlier of these periods all Britain north of the Thames was buried under ice, excepting certain *nunataks*, or isolated hills rising through the ice. Then came a mild episode, during which a characteristic mammalian and molluscan Pleistocene fauna inhabited this country, and southern species of the Cromer Forest-bed re-appeared. Afterwards, an increase of cold caused a second glaciation of the area north of the Wash, whilst in non-glaciated areas rain falling on frozen soil led to the formation of extensive sheets of gravel.

Discussion (on the two preceding Papers).

The President gave expression to what he felt sure was the general feeling of regret that continued indisposition again prevented Prof. Prestwich from being present at the reading and discussion of his important paper. He also complimented Mr. Reid on

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 384.

the good use he had made of his time on the Sussex coast, pointing out that, on the whole, his conclusions were somewhat different from those of Prof. Prestwich.

Dr. Evans deeply regretted the indisposition of the Author of the first paper, in whose absence he did not care to discuss the theoretical part of the paper, with much of which he was at present unable to agree. At the same time, looking at the submergence during the Glacial Period of so much of England north of the Thames, he saw no reason why the south should not have been submerged likewise. He said that all must feel grateful to the Author for having brought together his observations, ranging over so many years, and so carefully arranging his facts. He might, however, ask the question whether too many different deposits had not been classed together under the name of Head or Rubble-drift.

The speaker regarded Mr. Clement Reid's paper as a most important contribution to Glacial history. His observations seemed to show that, besides the transportation of erratics from northern centres, they were also occasionally derived from southern and western sources. In fact a new field of observation had been opened up. He enquired whether the fluviatile beds mentioned by the Author might not be connected with the valley of that old river the bed of which had been widened by marine erosion to form the Solent Sea, and at the same time referred to some old speculations of his own, published in his 'Ancient Stone Implements of Great Britain.'

Mr. W. A. E. Ussher corroborated Mr. Reid's evidence as to the stranding of erratics upon the Raised Beach platform on the South Coast, having lately discovered two large granite-boulders upon the well-marked Raised Beach platform between Start and Prawle Points in the South Hams, Devon, at the base of a cliff composed of stony loam ('Head'), occupying a broad shelf at the foot of a steep craggy slope composed of mica-schists. He commented on a section of an isolated pinnacle of 'Head' at Godrevy in Cornwall figured by him in 1879 ('Post-Tertiary Geology of Cornwall'), and quoted by Prof. Prestwich as negativing the idea of the 'Head' being due to subaerial waste on account of the low elevation of the neighbouring coast-line, pointing out that further data as to the contour adjoining the cliff-line were wanting. As to the accumulation of the 'Head' on the Devon and Cornwall coast being due to submergence, he ventured to differ from Prof. Prestwich on two grounds. First, the only obtainable measure of submergence we had was furnished by the heights of the Raised Beaches relative to present high water; and Prof. Prestwich's explanation of the 'Head' necessitated the continuance of the submergence for at least 100 feet without a pause, whereas he had shown in 1879 that in the Camel estuary opposite Padstow a pause in the elevation of the Raised Beach of that coast had permitted the formation of a beach now represented by reefs of consolidated sand, surrounded by the present sand beach between the tide-lines. This proved the presence of two old beaches on the same coast, the one at 5 feet or so above high-water mark, the other at about the present mean tide-level; so that there was *a priori* reason to conclude that a subsidence of 100 feet or more would have been marked by at least some pauses during which raised beaches would have been formed and rock-platforms or notches cut at higher levels.

In the second place he pointed out that, whilst the rude semblance of stratification in the 'Head' of Cornwall and Devon could readily be explained by fluctuating meteorological conditions and local variations in the rocks disintegrated, there were no signs of current-bedding in the 'Head,' although the rapid submergence and emergence necessitated by Prof. Prestwich's explanation would involve the operation of currents.

He was pleased to find that Mr. Reid, in correlating the 'Head' and the Coombe Rock, had come to pretty much the same conclusion as that expressed by himself in 1879 respecting the 'Head' on the Devon and Cornish coasts, viz. that it indicated a more rigorous climate.

Mr. J. Allen Brown believed that rubble deposits had been formed at all times since the last period of emergence. He thought Prof. Prestwich had not attached sufficient importance to the action of subterranean waters, which, after saturating the Chalk, carried off in solution and mechanically the carbonate of lime, thus massing the strata of flints together by the removal of the Chalk, and causing the formation of rounded chalk-rubble beneath as well as intermixed with them. Prof. Prestwich had shown in previous papers that subterranean water did not flow in direct lines, but followed the lines of least resistance arising from the difference in density of the Chalk, and that such agency was most frequently seen in action in combes or valleys having egress to the sea.

Such a valley was that at East Dean, which he had occasion to examine recently, as implements of Palæolithic type had been found there in the aggregated flint-bed. The section at Birling Gap, near East Dean, from the contortion and irregularity of the deposits had the appearance of being due to glacial action, but on closer examination was found to be formed by subterranean water-erosion, as the beds of flint could be seen *in situ* in the adjoining cliff. Such rubbly deposits could also be formed in depressions on the slopes of hills, by the same action combined with subaerial agency.

He noticed that Mr. Clement Reid had thrown some doubt upon the fluviatile origin of the high-terrace gravel deposits, as at Highbury; but he hardly thought there could be any uncertainty in the matter, although his own investigations, which he hoped to complete and submit to the Society, led him to believe that the action of ice or of an ice-sheet impinging on the river carried with it much more transported matter than had been generally admitted, and that such ice-borne detritus varied locally according to the superficial deposits of the country over which it travelled—here depositing the pebbles of a Bagshot or Westleton bed, and elsewhere, perhaps, the foreign rocks emanating from a distant glacier.

Prof. Hughes felt that Prof. Prestwich's paper covered so wide a field of enquiry that it was hardly possible to discuss it in one evening; but he thought that it would probably bear fruit in many papers which would hereafter be written, dealing with the several points, by those acquainted with the special districts and sections referred to. With regard to the views of Mr. Clement Reid, he criticized the evidence offered of a mild age between two cold ages, and said that he had much difficulty in understanding how, during a period of such severe glaciation as to allow of the transport of boulders in ice from Britanny to Sussex, there should not have been northern ice pushing its way south; unless we supposed a great elevation in Britanny, and a great depression in the English Channel. He drew attention to the manner in which single boulders were carried along a shore, and the mode of settlement of stones into non-calcareous strata, and asked whether the boulders noticed by Mr. Reid might not have been merely fragments of local rocks, with here and there a boulder, the relic of patches of drift now all washed away; and whether they might not all have been trundled along by the sea to the place where he found them, and have been half buried by one or other of the processes which he had just described.

Dr. Hicks said he did not think the evidence was quite conclusive that the erratics of non-local origin referred to by Mr. Reid had not been brought from a northern source, either by ice floating down the Channel, or passing across some part of England.

Prof. Seeley, Mr. Whitaker, and the Rev. H. H. Winwood also spoke.

Mr. C. Reid replied to the observations made on his paper.

21. *The* NEW RAILWAY *from* GRAYS THURROCK *to* ROMFORD: SECTIONS *between* UPMINSTER *and* ROMFORD. By T. V. HOLMES, Esq., F.G.S. (Read March 9th, 1892.)

THIS railway, which has been in process of construction during the last two or three years and is still incomplete, diverges from the London and Tilbury line about a mile west of Grays Thurrock station. Thence its range is either northerly or north-westerly. It crosses the Mardyke about half a mile west of Stifford, and its course lies westward of the villages of North and South Ockendon and eastward of Stubbers and Cranham Hall. From Cranham Hall to Romford its direction is more westerly. At Upminster it joins the railway from Barking to Langdon Hills and Pitsea, and then, leaving it again close to Upminster station, keeps on the northern side of the road between Upminster and Hornchurch, and crosses that ranging northward from the last-named village at Butts Green. Then, passing close to, but southward of, the farmhouse called Great Gardens, it joins the Great Eastern Railway about half a mile east of Romford station. The portion of the line south of Upminster is in a more advanced state than that between Upminster and Romford, the mile nearest Romford being at present (Feb. 1892) in the most backward condition.

Having described elsewhere the sections seen between West Thurrock and the Mardyke,[1] I will only remark with respect to that part of the line that the junction of the Chalk with the Thanet Sands was once visible where Back Lane crosses the railway. Thence, to the end of the cutting north of Back Lane, Thanet Sands (below gravel) appeared. The Woolwich Beds would naturally come on in the Mardyke Valley, where the cutting is replaced by a viaduct, and there is an alluvial flat below, on each side of the stream; they are, consequently, nowhere to be seen. But in the cutting on the northern flank of the valley London Clay, below gravel, appears; and from the Mardyke to Romford London Clay is the oldest formation anywhere visible beneath the superficial drift.

Between the Thames and the Mardyke, on the southern flank of the Chalk, there is Thames Valley Gravel at various levels, the highest point reached by it being the 50-feet contour-line. Towards the northern flank of the Chalk the old Thames gravel and loam forms a plateau, the surface of which, from a point about a mile south of the Mardyke to another about a mile south-east of Upminster, at which the railway begins to run on an embankment, is from 60 to 70 feet above Ordnance datum. The London Clay is but little seen anywhere below this gravel terrace except within about half a mile of the Mardyke, the cuttings between that stream

[1] 'Essex Naturalist,' vol. iv. (1890) p. 143; Proc. Geol. Assoc. vol. xii. (1891) p. 195.

and Upminster rarely exceeding 9 to 10 feet in depth; and they show gravel, almost wholly, south of North Ockendon, and loamy beds thence to Cranham Hall, as depicted on the map of the Geological Survey.

In the cutting west of Upminster station and east of the Ingrebourne London Clay appears, capped here and there somewhat irregularly by a variable amount of gravel or loam, the former predominating. The gravel is seldom more than 6 to 7 feet thick in this cutting, and its base is from 85 to 90 feet above Ordnance datum. It therefore belongs to a higher terrace than that of the plateau between Cranham Hall and the Mardyke. And on crossing the Ingrebourne we find that the sand and gravel capping the surface of the ground along the course of the line north of Hornchurch, and thence to the junction with the Great Eastern Railway at Romford, belongs to this same terrace, which is the highest and oldest of the Thames Valley deposits in this district.

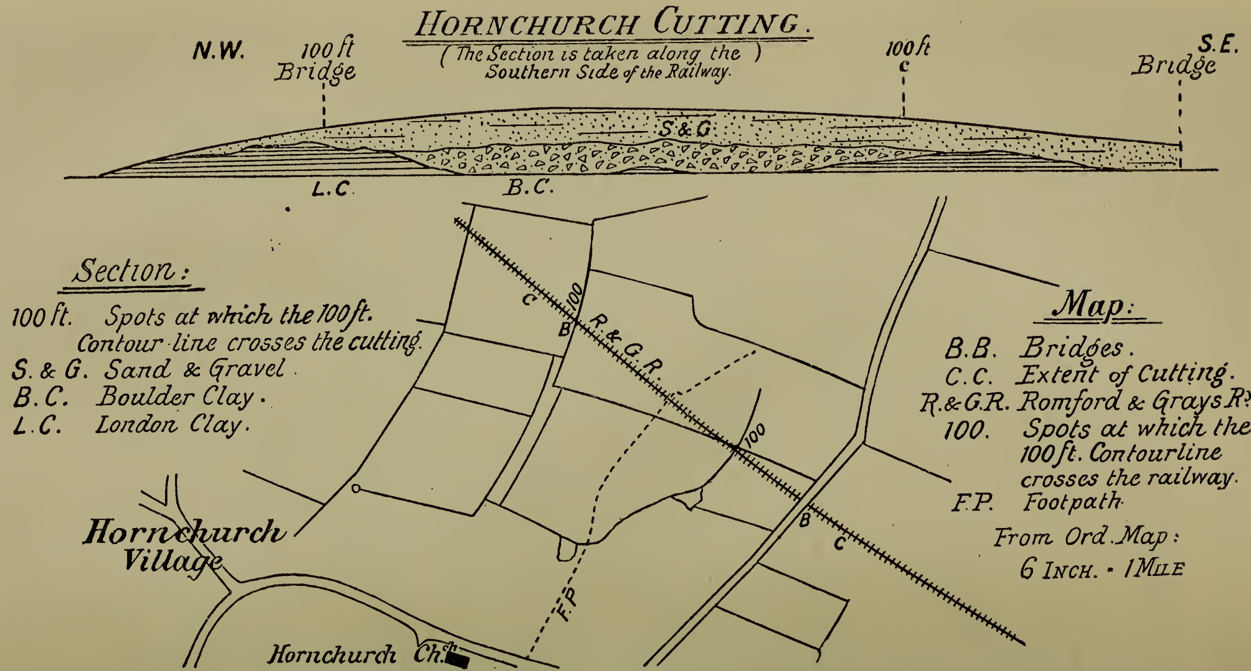
As might be expected from its greater age, this highest terrace occupies a much more limited area than the lower terraces of later date which occupy the ground between Hornchurch and Romford on the north and Barking and Rainham on the south. And its character as an old river-deposit is not quite so evident at a glance as is that of the lower gravels, on account of the much greater number of valleys which have been carved in it as a consequence of its superior antiquity. On the map of the Geological Survey this oldest terrace is coloured as Thames Valley Gravel, but no attempt has been made to indicate the boundaries of the various terraces. In fact no such separation is practicable, inasmuch as the underlying formation, the London Clay, is much too soft to show definite terraces for any appreciable distance. The result of this state of things is that all the old Thames Valley Gravel between the Lea and the Mardyke might be supposed, from uniformity of tint and the absence of any distinguishing signs, to consist of one sheet at a nearly uniform level, though the height of its surface above Ordnance datum varies from less than 20 feet to more than 100 feet.

A railway journey from Barking to Hornchurch across this broad expanse of old river-gravel is one of gradual ascent. At Barking station the surface-level is rather below 20 feet. At Dagenham it averages about 25 feet, and a mile beyond Dagenham it is about 30 feet. About three quarters of a mile south-west of Hornchurch the railway runs through a cutting in gravel at a greater elevation, the height of the surface at Hornchurch station being more than 60 feet. And on alighting at Hornchurch and turning northwards it becomes obvious that, above the gravel and loam which have been so largely excavated south of Hornchurch station, there is another terrace to which the gravel worked between Hornchurch Church and the windmill belongs. This highest gravel-pit averages 14 or 15 feet in depth, and the gravel taken from it must have been almost entirely above the 100-feet contour-line, as the surface at the church is a little over 117 feet in height. But the boundary of this highest terrace, though fairly well marked for a few yards near the windmill, on the right of the road connecting Hornchurch station with the village, soon becomes lost in a vague slope both eastward and westward.

I have mentioned that in the cutting east of the Ingrebourne and west of Upminster station there is much London Clay, with a thin and variable covering of gravel and loam. Turning to the Romford end of the new line for a moment, we find that but little excavation has been made between the junction with the Great Eastern Railway and the stream which unites with the Rom to form the Beam a little farther to the south. East of the Beam—if it may be so called at this part of its course—and west of Butts Green, London Clay appears below sand and gravel. On the eastward side of the road at Butts Green the easterly continuation of what may be termed the Butts Green cutting is not yet sufficiently advanced to show anything but sand and gravel. Between the eastern end of this cutting and the western end of the next there is a space of about 250 yards destitute of sections. Then, still travelling eastward, we enter a cutting of peculiar geological interest, the description of which is the main object of this paper.

As this cutting between that of Butts Green and the Ingrebourne is by far the most geologically important part of the Grays and Romford Railway, it may be well to point out the best way of getting to it, without reference to the rest of the line. About 250 yards east of the church at Hornchurch the road to Upminster is crossed by others ranging northward and southward. About 400 yards from this point of junction the northerly road passes over the new railway towards the eastern end of this most interesting section. At the bridge the cutting is only from 9 to 10 feet deep, and gradually dwindles away to nothing eastward, towards the Ingrebourne; but west of the bridge the cutting gradually deepens. About 130 yards from the bridge the 100-feet contour-line crosses the railway, and about 325 yards to the north-west of this point we again meet with the 100-feet contour-line, which crosses the railway where a bridge is to be thrown over it to facilitate access to farm lands. The ground between these contour-lines does not appear to rise (close to the railway) to a height of more than 106 or 107 feet; but, as the level of the line appears to be about 80 feet, this gives the cutting a maximum depth of 25 or 26 feet.

Towards the two ends of the cutting only London Clay covered by sand and gravel can be seen; but at a point about 100 yards west of the road by which the cutting was approached Chalky Boulder Clay appears above the London Clay, the latter sloping down gradually towards the north-west from a height of 7 or 8 feet above the line to a depth slightly below it. The Boulder Clay, on the other hand, gradually thickens till we find the cutting to consist, where it is deepest, of from 10 to 15 feet of Boulder Clay covered by 10 to 12 feet of sand and gravel. The line of junction between these deposits is in places nearly horizontal, in others wavy, and, though usually clean and distinct, is occasionally somewhat doubtful, owing to the presence, towards the base of the gravel, of clay consisting



Note.—The length of the section is about 540 yards, and the distance between the two bridges is 450 yards; the greatest depth of the cutting is 25 feet. For 'Contourline' in Explanation of Map, read 'Contour-line.'

apparently of Boulder Clay somewhat rearranged and without boulders, and having a thickness of 1 or 2 feet. At a point between 50 and 60 yards east of the second or more westerly bridge, the Boulder Clay abuts against the London Clay, which rises to a higher level and is less covered by gravel at this end of the cutting than at the other. Thus this mass of Chalky Boulder Clay, which extends along the cutting for a distance of 300 yards, owes its preservation to its deposition in a slight hollow on the surface of the London Clay. And as the cutting will very shortly be entirely obscured through the sloping and turfing of its sides, it is perhaps worth noting here that the space within which Boulder Clay can now be seen nearly coincides with that between the 100-feet contour-lines. It comes in about 30 yards east of the contour-line nearest the road, and ends between 50 and 60 yards east of the other. The thickness attained by the Boulder Clay does not, probably, anywhere much exceed the 15 feet actually measured, as London Clay rises, for a space of 4 or 5 yards, to a height of between 2 and 3 feet above the bottom of the cutting, towards its centre.

This Boulder Clay is in all respects like a typical example of that common in Essex. The great majority of the stones in it are chalk or flint, the latter being both worn and unworn. During a visit to the cutting on February 6th last Mr. Herries found a quartz-pebble and a small fragment considered by Mr. Whitaker to be Lower Greensand. And the foreman of navvies at work there brought me one day a glacially-scratched lump of dark bituminous shale from it containing small shells, which Mr. H. B. Woodward identified as Kimeridge Clay, the shells being *Lucina minuscula*.[1]

A glance at the map of the Geological Survey will show that, except in this cutting, Boulder Clay has never been seen in conjunction with the deposits of the Thames Valley, either north of Romford in Essex or in the neighbourhood of Finchley in Middlesex, the most southerly spots at which it has been known. In the Romford district the nearest point at which it appears is about three miles north-east of this Hornchurch cutting. It there rests on the London Clay, around the house called Maylands, a little east of the Ingrebourne, and appears to come down some distance below the 200-feet contour-line, though the great mass of the Boulder Clay north of Romford lies above that level. We thus find at Maylands a slight tendency towards the still lower level of the Boulder Clay in the Hornchurch cutting.

Readers of the very interesting chapter in Mr. Whitaker's latest Memoir[2] on the Literature of the Thames Valley Drift must have

[1] On the visit of the Geologists' Association to this cutting on March 5th, Mr. Robertson, the engineer of the line, very kindly showed us a collection of the most interesting specimens obtained from the Boulder Clay. They included many lumps of Kimeridge Clay, some examples of *Gryphæa dilatata* from the Oxford Clay, and a vertebra which had been determined by Prof. Seeley as plesiosaurian.

[2] 'The Geology of London and of part of the Thames Valley,' vol. i. p. 35 London, 1889.

wondered at the extraordinary diversity in the opinions which have been expressed from time to time as to the age and affinities of these deposits. Two influences seem to have been chiefly instrumental in producing this variety of view. In some cases the stratigraphical evidence, considered as a whole, has been neglected or greatly undervalued, while that derived from some special class of fossils from one of the few fossiliferous beds has been considerably over-estimated. In others the presence of signs of ice-action in some form, a thing common at various horizons in these deposits, has led to the supposition that these indications imply that the beds showing them date from the Glacial Period. Feeling that ice has been a geological agency from the earliest times, and that it did not cease to be one at the close of the Glacial Period, I have lately taken more than one opportunity of protesting against an assumption which seems to me based on insufficient grounds.[1] For where could we expect to find signs of the action of river-ice if not in the drifts of the Thames Valley, formed when the land was higher than it now is and the climate consequently more severe? The question, therefore, whether certain beds should be classed as of, or later than, the Glacial Period in this locality, depends simply on their stratigraphical position as regards the Boulder Clay. In this case it seems evident that there is a strong natural presumption that the Thames Valley deposits at higher levels are older than those at lower elevations, the highest terrace being the oldest—a presumption which, in the absence of stratigraphical evidence to the contrary, becomes almost a certainty. Previous to this discovery of Boulder Clay in connexion with the oldest terrace of Thames Valley Gravel I had always felt that Mr. Whitaker's conclusion that the Thames Valley deposits are (locally) post-Glacial, or newer than the local Boulder Clay, was, in all probability, correct, and the truth of this view has now been demonstrated by the section in the cutting at Hornchurch.

Discussion.

The President said that geologists were much indebted to Mr. Holmes for drawing attention to this interesting section before it was too late. Amongst the many points arising from the discovery of Boulder Clay at less than 100 feet above Ordnance datum was one as to the probability of the pre-Glacial age of the Thames Valley system.

Mr. H. B. Woodward, who had seen the section at Hornchurch under the guidance of Mr. Holmes, remarked that it afforded a better exposure of Boulder Clay than he had elsewhere seen in Essex during two years' work on the Geological Survey. Attention had previously been drawn to contortions that may be seen in exposed portions of the Thames Valley deposits, as at Grays, and these had been attributed to Glacial action, while some of these superficial

[1] Proc. Geol. Assoc. vol. xi. (1890) p. 334; 'Essex Naturalist,' vol. iv. (1890) 7.

beds had been regarded as relics of Boulder Clay. The superficial disturbances might be connected with some form of ice-action, but the evidence now brought forward showed that they had nothing to do with the main Boulder Clay of East Anglia.

Mr. H. W. Monckton said that the manner in which this Boulder Clay rested on London Clay without any intervening Glacial Gravel did not strike him as extraordinary; in many localities round Ongar he had found it difficult to determine where the London Clay ended and the Boulder Clay began.

The Thames Valley at this part was bounded on the north by the Warley Hills, and on the south by Swanscombe, both more than 300 feet above O.D., and as the Boulder Clay described was 200 feet below that level it seemed probable that a valley of some size existed when it was laid down.

On the other hand, as the false-bedded sands and gravels above the Boulder Clay seemed to be part of a terrace higher and older than the beds with *Corbicula fluminalis*, &c., there seemed little doubt that these latter are newer than the Great Chalky Boulder Clay.

Mr. Clement Reid agreed with the Author in his main conclusions, but ventured to suggest that mere height above the River Thames was insufficient to prove the relative age of the deposits in the Thames Valley, and that the highest gravels were not necessarily the oldest.

Dr. Hicks said that there was abundant evidence to show that the Brent Valley at Finchley and Hendon had been scooped out almost to its present level before the Middle Sands and Gravels, and the Upper Boulder Clay, had been deposited in that area, and these deposits can now be traced along the slopes almost to the level of the present stream. His examination of the deposits in the Thames Valley had convinced him that the conditions there were almost identical with those in the Brent Valley. There the deposits mantled the slopes in the same manner, and he thought it incorrect to speak of them as terrace-gravels. He was of the opinion that the Thames Valley had in the main been scooped out in early Glacial times, and that the deposits on the higher levels and on the slopes had been accumulated during and at the close of the Glacial period. There was, he thought, some evidence to show that there had been a spread of Boulder Clay over the district anterior to the so-called Middle Sands and Gravels, and it was not impossible that the Boulder Clay referred to by Mr. Holmes might be a portion of that deposit.

Messrs. Lewis Abbott and Whitaker also spoke.

The Author, in reply, said that though the Boulder Clay at Hornchurch was at a lower level than that north of Romford, yet there must have been, here and there, much low ground at the time of its deposition, as it was found at various levels in many different places. And it was evident that the Boulder Clay at Hornchurch was older than the gravel of the highest and oldest terrace of the Thames Valley deposits. He admitted that it did not necessarily happen that the highest terrace was the oldest, but the presumption that it was so became, in the absence of stratigraphical evidence to the contrary, almost a certainty. The terraces themselves were but faintly marked, and their limits were seldom even moderately clear for more than a few yards, but this resulted simply from the softness of the underlying London Clay, and not from any other peculiarity.

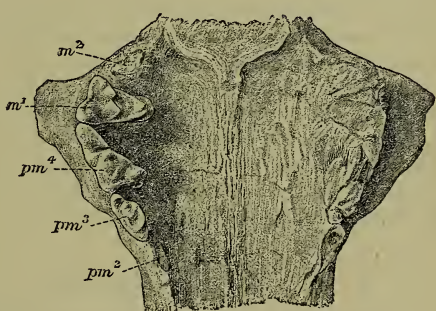
22. *On the* Occurrence *of the* so-called Viverra Hastingsiæ *of* Hordwell *in the* French Phosphorites. By R. Lydekker, Esq., B.A., F.G.S. (Read March 23rd, 1892.)

Some few years ago[1] the late Mr. William Davies described and figured the imperfect skull of a small Carnivore from the Upper Eocene (Lower Oligocene) of Hordwell, under the title of *Viverra Hastingsiæ*. With his accustomed care, Mr. Davies pointed out that the species so named agreed very closely with a so-called *Viverra* from the Lower Miocene of St. Gérand-le-Puy, in the Allier, known as *V. antiqua*, and also with one from the Quercy Phosphorites described by M. Filhol[2] as *Viverra angustidens*. Indeed, Mr. Davies gives no characters whereby *V. Hastingsiæ* can be distinguished from *V. angustidens*, at that time known only by several mandibular rami.

The chief point of resemblance to *V. angustidens* was shown by the great height of the blade of the lower carnassial tooth in *V. Hastingsiæ*. It was also pointed out that the first upper premolar of the latter was of unusually small size in regard to the other teeth; and since the same feature occurs in the lower jaw of *V. angustidens* (the first lower premolar of *V. Hastingsiæ* is wanting), we have another point of resemblance between the English and French Civets.

It may clear the ground here to say that the skull figured by M. Filhol[3] as *Viverra antiqua* has been referred by Dr. Schlosser[4] to *Herpestes lemanensis*, which has lower teeth of quite a different type.

So far as I am aware no description of the cranium of *V. angustidens* from the Phosphorites has hitherto been given. Recently, however, the British Museum has acquired the hinder part of the cranium of a Civet from those deposits, of which the palatal aspect is represented in the accompanying figure. With the exception of the last molar, the hinder cheek-teeth are in a fine state of preservation; and on com-



Imperfect palate of *Viverra angustidens*, nat. size, from the Quercy Phosphorites.
pm^{2-4} = premolars. m^1, m^2 = molars.

[1] Geol. Mag. for 1884, p. 437.
[2] Ann. Sci. Géol. vol. vii. (1876) art. 7, p. 144.
[3] *Ibid.* vol. x. (1879) art. 3, p. 152, pl. xix.
[4] Beitr. zur Pal. Oesterr.-Ung. vol. viii. (1890) pp. 17, 18.

paring these teeth and the palate with the type cranium of *V. Hastingsiæ*, I find so exact a correspondence between the two that there can be no doubt as to their specific identity. Accordingly, we have proof that *Viverra Hastingsiæ* occurs in the Oligocene deposits of both sides of the English Channel.

But having in the Quercy Phosphorites *Viverra Hastingsiæ* represented by the cranium, and *V. angustidens* by the mandible, the question naturally arises whether these two so-called species are not really one and the same.

On comparing Mr. Davies's figure of the mandible [1] of the former with M. Filhol's [2] of that of the latter, it will be observed that the French specimen is considerably the larger of the two. A reference to M. Filhol's text shows, however, that there is great individual or sexual variation in the mandible of *V. angustidens*, the two smallest out of four examples having a vertical depth of 12 millimetres, while the figured example has a depth of 16·5 mm. Similarly the length of the lower carnassial varies from 8 to 9 mm. in different specimens, although the height is constantly 5 mm. The smaller specimens from the Phosphorites would thus apparently agree in size with the Hordwell mandible. A seeming difference in the latter, presented by the separation of the penultimate premolar from the carnassial, is due solely to fracture of the ramus.

Having proved that *V. Hastingsiæ* is common to the Oligocene of France and Hordwell, and finding no characters by which the lower jaw of the type of the latter can be satisfactorily distinguished from the type of *V. angustidens*, I consider, if M. Filhol is right in including all the French lower jaws which he describes under one species, that we must regard *V. Hastingsiæ* as specifically inseparable from *V. angustidens*, and I accordingly figure the French cranium under the latter and earlier name.

The Mammals now known to be common to the Headon Beds of Hordwell and the Isle of Wight and to the French Phosphorites are *Acotherulum saturninum*, Gervais, *Adapis magna*, Filhol, *Dacrytherium ovinum* (Owen), *Necrogymnurus minor*, Filhol, *Palæotherium annectens* (Owen), *P. medium*, Cuv., *P. minus*, Cuv., and *Viverra angustidens*, Filhol.

Discussion.

Mr. Smith Woodward remarked upon the extensive acquisitions of mammalia from the French Phosphorites lately obtained by the British Museum. All the principal forms were now represented, and it thus became possible to make direct comparisons with the Hordwell fossils, as Mr. Lydekker had done with such interesting results.

[1] As pointed out by Dr. Schlosser, *op. cit.* p. 8, the restoration of the ascending ramus by Mr. Davies is incorrect; it should rise much more obliquely to the horizontal ramus.

[2] Ann. Sci. Géol. vol. vii. (1876) pl. xxvi. figs. 121, 122.

23. Note *on* Two Dinosaurian Foot-Bones *from the* Wealden. By R. Lydekker, Esq., B.A., F.G.S. (Read March 23rd, 1892.)

Bones of the feet of the Sauropodous Dinosaurs of the Wealden are of such rare occurrence that all specimens seem worth record, even in cases where we are unable to determine definitely the species to which they pertain. The specimens of these bones in the British Museum hitherto recorded comprise one huge claw-phalange, together with another associated bone of the foot (No. R. 986) provisionally referred to *Hoplosaurus armatus*[1]; and several associated metatarsals and phalangeals (Nos. 36559, *e*, and R. 206) assigned to *Morosaurus brevis*.[2] In addition to these, Prof. Seeley[3] has described and figured the metapodium (? metatarsus) of a Sauropod from the Cambridge Greensand under the name of *Acanthopholis platypus*, showing the whole five bones in their natural position. The genus *Acanthopholis*, it need scarcely be observed, belongs to the Stegosaurian section of the Ornithopodous Dinosaurs, and the Sauropodous nature of the so-called *A. platypus* was subsequently admitted by its describer,[4] who suggested that it might prove identical with his *Macrurosaurus semnus*, of which the specific name ranks later. Quite recently Dr. Baur[5] has observed that the type of *A. platypus* is indistinguishable from the metatarsus of *Morosaurus*, of the American Jurassic, to which genus it may perhaps belong.

The two specimens forming the subject of this communication are represented in the figure on the following page; they comprise a perfect metapodial (? metacarpal) bone and an associated phalangeal. Both were obtained by Mr. C. Dawson from the Bone-bed of the Wadhurst Clay, near Hastings; and they were extracted from a single lump of matrix by myself. These bones exhibit the articular surfaces and edges in a perfect condition, and appear to have belonged to a fully adult animal. The metapodial has a length of 3·4 inches, and a distal transverse diameter of 2 inches. In the process of extraction from the matrix the shaft was fractured, thus revealing the absence of a medullary cavity. Apart from their great difference in form, the solid nature of the shaft of the metapodial clearly shows that they do not belong either to the Megalosaurians or to the Iguanodonts. Moreover, since the specimens are unlike the corresponding bones of *Scelidosaurus* and *Stegosaurus*, while they resemble such as have been referred to the Sauropoda, I have no hesitation in regarding them as belonging to that group.

Compared with the figures of the type of the so-called *Acanthopholis platypus*, and remembering that the extremities of these bones have been much worn, the metapodial under consideration accords so closely in general contour with the third or median bone of that

[1] Cat. Foss. Rept. B. M. pt. i. p. 151, as *Ornithopsis Hulkei*; see pt. iv. p. 243.

[2] *Ibid.* pt. i. pp. 140, 141, as *Cetiosaurus brevis*; see pt. iv. p. 237.

[3] Ann. Mag. Nat. Hist. ser. 4, vol. viii. (1871) p. 305, pl. vii.

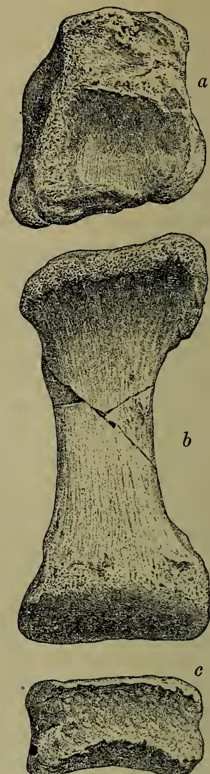
[4] Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 444.

[5] 'American Nat.' for 1891, p. 452, note.

series that it may be pretty safely regarded as the third metapodial of the opposite side to that to which the Cambridge metapodium belonged. This is especially well shown by the contour of the proximal extremity,[1] which is broad and squared, with a distinct process at the antero-external angle, where it overlapped the fourth metapodial. The Cambridge specimen belonging to the left side, our example will pertain to the right.

There are, however, certain differences in the contour of the third metapodial in the two sets of bones, which suggest that while the one belongs to the metatarsus the other should be regarded as pertaining to the metacarpus. The small size of the Hastings metapodial is in favour of its being a metacarpal; while, since the third metapodial of the Cambridge specimen is a comparatively large bone, having a length of some six inches, Dr. Baur is very probably right in referring that specimen to the metatarsus.

The Hastings metapodial would seem too small for *Hoplosaurus armatus* (*Ornithopsis Hulkei*), and it is therefore probable that it may be referable to the smaller Dinosaur known as *Morosaurus brevis*.[2] Unfortunately, the foot-bones of the typical American representatives of the latter genus have not yet been figured on a scale such as to admit of comparison with our specimen. The present specimens are smaller than the metatarsals and other bones mentioned above as being provisionally referred to *M. brevis*, but might well belong to the manus of the same animal. The metatarsals of the last-named series are lateral, and therefore differ in contour from the present specimen. The phalangeal, which was probably separated from the metapodial by an intervening segment, shows the extreme shortness characteristic of the Sauropodous Dinosaurs. I believe these specimens to be the first remains of the Sauropoda which Mr. Dawson obtained in all his large series from the Wadhurst Clay.



Proximal (*a*) and anterior (*b*) aspects of the third right metapodial (? metacarpal), and (*c*) anterior aspect of an associated phalangeal, of a Sauropodous Dinosaur (?*Morosaurus*). From the Bone-bed of the Wadhurst Clay. ½ nat. size.

Postscript.—Since the above description was written, Mr. Dawson has been good enough to send me some more imperfect metapodials belonging to the same foot, but I have been unable to assign them to their proper position.

[1] In Prof. Seeley's figure the front border of the proximal end is placed upwards, whereas in the present figure it is downwards.

[2] = *Cetiosaurus brevis*, Owen.

24. *On the* Microscopic Structure *and* Residues Insoluble *in* Hydrochloric Acid *in the* Devonian Limestones *of* South Devon. By Edw. Wethered, Esq., F.G.S., F.C.S., F.R.M.S. (Read March 23rd, 1892.)

[Plate IX.]

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§ 1. Introduction.

The complicated nature of Devonian Geology in South Devon is well known. In this paper I shall confine my remarks to the microscopic examination of the limestones, and shall not enter on the stratigraphical and palæontological problems which have been worked out by such geologists as De la Beche, Jukes, Godwin-Austen, Holl, Champernowne, Etheridge, Ussher, Davidson, Whidborne, H. B. Woodward, and others.

For the purpose of collecting specimens of limestone to be examined I spent a month in South Devon during the summer of 1890, and I desire to express my thanks to Mr. W. A. E. Ussher, of H.M. Geological Survey, for the very ready assistance and friendly advice which he gave me.

§ 2. Detailed examination of the Organic Structure.

(a) *Hope's Nose Limestones.*—At Hope's Nose, near Torquay, there is a quarry opened in limestone of varying light and dark colour, and this is capped by a shaly limestone, which Mr. Ussher regards as belonging to the Calceolen Kalk, "apparently completely inverted upon massive bedded limestone containing *Heliolites porosus*."[1]

Commencing with the *Calceola* Beds, as representative of the basement limestones, thin sections, seen through a microscope, show a light grey, finely-crystalline groundmass traversed by fissures filled with calcite. In the groundmass are ferruginous patches and minute rhombohedral crystals, apparently of dolomite.

Passing to the limestones below—which, it must be remembered, are assumed to be above the *Calceola* Beds when in their normal position—thin sections of the lowest beds exposed show them to be composed of broken calcareous fragments, the structure of which has, for the most part, been obliterated. Those which could be determined are fragments of corals, shells, and one or two ossicles of

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 500.

crinoids. Rhombohedral crystals of dolomite similar to those noticed in the *Calceola* Beds are here also present.

Higher up in the quarry weathered surfaces of the limestone show that it is largely made up of coral débris, polyzoa, and stromatoporoids, the latter, in some instances, growing round portions of coral. Thin sections of the rock confirm this interpretation and show that the structure of the coral-fragments is well preserved.

Towards the middle of the quarry the coral limestone disappears and is followed by a series of beds very dark in colour. Thin sections show an almost structureless groundmass traversed in all directions by infilling calcite, the whole suggestive of an original tubular structure. Some aggregations of tubules can be made out, and in these the tubules measure 0·2 mm. in diameter (Plate IX. fig. 3). They resemble the tubules of *Girvanella*, but there is no clearly defined wall; they are, apparently, forms of vegetation. There are also present ossicles of crinoids, valves of ostracoda, and one or two fragments of shell. All these have the appearance of being enclosed by the groundmass. As to the nature of the original organic structures now represented by this groundmass there is no clear evidence on which to base an opinion; but it is suggestive of a vegetable growth that has enclosed the calcareous organisms whose remains appear in it.

A portion of this limestone was dissolved in hydrochloric acid, and with the ultimate residue was 4·6 per cent. of black material of very slight specific gravity, which disappeared on ignition in a platinum crucible. There is little doubt that this substance was carbon, a fact which gives support to the view that the groundmass in this limestone is, in part at least, of vegetable origin.

(b) *Daddy Hole Limestones.*—The specimens were collected in a quarry opened out at the sea-level. Commencing near the bottom of the quarry, on the Torquay side, dark limestone occurs. Thin sections show a groundmass and tubular aggregations similar to those noticed in the dark limestone at Hope's Nose, but in some instances the outlines are nearly obliterated. Several fragments of organisms are present, including ossicles of crinoids and one or two fragments of coral. As in the case of one of the slides from Hope's Nose, the groundmass appears to have enclosed the fragments of organisms which are noticed in it.

The next specimens were collected from a limestone at a higher horizon, containing yellow patches which might at first sight be taken for concretions. Microscopic examination, however, has not confirmed this supposition, but shows a structure very like the groundmass referred to in previous slides.

Other sections of this limestone show an absence of the groundmass noticed in slides of the yellow patches, and prove that it is made up of very fragmentary calcareous organisms; among these fragments, corals and echinodermata, the latter probably ossicles of crinoids, the main outlines of which have been obliterated, may be traced.

Near the top of the quarry is a bed of limestone which, judging from indications on weathered surfaces, gave hopes of interesting slides being obtained from it. When, however, these were made the rock was found to be made up almost entirely of the remains of crinoids, some of which are remarkably well preserved.

(c) *Lummaton Limestones* (Upper horizon of the Middle Devonian).—At Lummaton, near St. Mary Church, there is an extensive quarry in white crystalline limestone. From this rock thin sections gave the following results when examined with a microscope:—

No. 1. Entirely crystalline; no sign of organisms can be detected. Several rhombohedral crystals of dolomite occur.

No. 2. Microscopic examination of this slide shows that the limestone has also undergone considerable molecular change. Calcareous fragments of undoubted organic origin occur, but the structure is mostly obliterated and there is often little else but a granular mass left. Among these organic calcareous fragments are portions of coral and ossicles of crinoids.

No. 3. Similar to the last. Rhombohedral crystals of dolomite are numerous, mostly as single crystals, which are slightly tinged with iron.

Specimens were also collected from Barton Quarry, situated about half a mile from Lummaton. The limestone in which this quarry is opened is for the most part less crystalline than that quarried at Lummaton, but it is otherwise similar. The following slides were made from it and examined:—

No. 1. Very crystalline; no sign of organic structure could be detected. The limestone is altered, but a distinction can be drawn between the original organic portion and the infilling calcite.

No. 2. This is mainly a coral limestone with a quantity of infilling calcite.

No. 3. This limestone also shows signs of molecular change. There is a quantity of infilling calcite and of dark granular fragments, some of which can be recognized as the remains of corals, mollusca, &c.; in others the outlines of organic structure cannot be detected. There are also numerous crystals of dolomite present, mostly in aggregates (Pl. IX. fig. 1).

(d) *Coomb End Limestone.*—Coomb End, near Kingsteignton, is situated between Teignmouth and Torquay. The quarry from which the specimens were taken is opened in a limestone in which no bedding could be traced.

Three specimens, collected respectively from the base, middle, and top of the quarry, show coralline structure.

Apparently the Coomb End Limestone represents an old coral-reef, and this explains the absence of bedding.

(e) *Lower Dunscombe Limestone.*—The specimens were obtained from a quarry at Whiteway Farm, near Chudleigh. The limestone is indistinctly bedded, and in colour is dark.

Specimen No. 1 shows a more or less dark granular groundmass traversed, in part, by fissures. One or two obscure fragments of organisms can be traced, and among them the ossicles of crinoids.

No. 2. Full of organic calcareous fragments, but these are much broken. Among them are portions of coral and joints of crinoids.

No. 3 also shows very fragmentary calcareous objects, with infilling calcite. Ossicles of crinoids can be distinguished.

No. 4. At the top of the quarry occur beds representative of the Goniatite Limestone which Mr. Ussher[1] considers to be of Upper Devonian age.

The specimens collected as typical of this limestone show it to be quite different in structure from the beds below. There is a fine crystalline groundmass in which are several fragmentary remains of organisms. One of these appears to be a foraminifer, and it is especially interesting as being the only one found in my slides of the South Devon Limestones. The Goniatite Limestone seems to have been formed by an accumulation of small shells, foraminifera, &c., which have been filled in with a fine calcareous mud.

§ 3. Conclusions drawn from examination of the Slides.

The microscopic examination of the Devonian Limestones is not very satisfactory so far as structure is concerned. There is, indeed, ample evidence that these limestones have been built up by the calcareous remains of organisms, but the outlines of structure have, for the most part, been obliterated by molecular changes. These South Devon limestones are, therefore, a proof that by such changes the structure of the calcareous organisms, of which they are mainly formed, can be rendered indistinguishable, and the rock become entirely crystalline.

It is well known that in more recent limestones the interstices of the constituent organisms are generally occupied by a quantity of calcite. This is also the case with such Devonian Limestones as I have examined. In the best preserved types the calcite can easily be recognized by its large clear crystals. On the other hand, the altered portion of the limestone is represented by small crystals in aggregates, and these are usually stained by iron oxides.

So far as the evidence warrants a conclusion being drawn, the Devonian Limestones of South Devon appear to have chiefly originated from corals, crinoids, ostracoda, stromatoporoids, and fragments of shell; while the Goniatite Limestone alone contains foraminifera.

The Coomb End Limestone is almost entirely made up of coral; indeed, it appears to represent an ancient coral-reef.

Some of the beds at Hope's Nose and Daddy Hole are almost entirely of coralline origin, but differ from those at Coomb End in that they represent accumulations of coral débris.

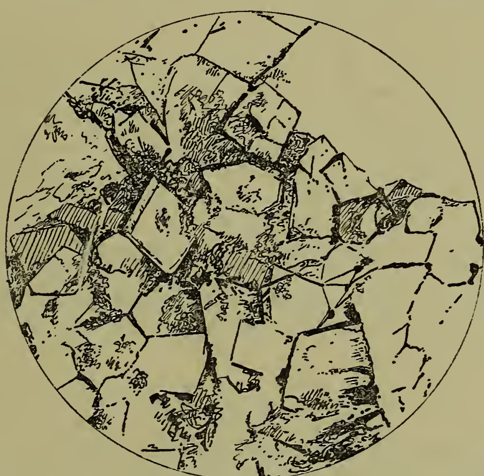
The question may now be fairly asked, what makes the Devonian Limestones of South Devon so crystalline? Mr. Ussher, quoting the remarks of Prof. H. S. Williams, of Ithaca, N. Y., says that "in South Devonshire the rocks are greatly disturbed, broken by faults, standing at various angles, folded and distorted; eruptive

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 507.

rocks frequently cut through them, and beds of volcanic ash are interstratified with them."[1] There is evidence which seems to indicate that the molecular changes (crystallization) which have taken place in these limestones were influenced by, if not directly due to, the disturbances mentioned by Mr. Ussher.

This observation leads up to another very interesting question, namely, the origin of the rhombohedral crystals of dolomite. Though I have so far only made a passing mention of these crystals in one or two slides, yet they are to be found in most of those that I have examined, more especially in No. 3 from the Barton Limestone (see the accompanying figure). Sometimes they appear in aggregates, at other times as single crystals, and there is no doubt that they are of secondary origin.

Crystals of Dolomite in Devonian Limestone.



×50 diam.

[Since this paper was written I have learnt that attention had already been called to the occurrence of dolomite crystals in Devonian Limestone by Dr. Sorby, F.R.S., Quart. Journ. Geol. Soc. vol. xxxv. (1879) *Proc.* p. 89.]

Several theories have been advanced to account for the formation of dolomite, and they may be all quite correct, for I see no reason why this mineral should not originate as the result of more than one process; as, for instance, the percolation of sea-water through limestone. The Devonian Limestones, however, are only partially dolomitized, and I think it possible that the magnesia may have come from the decomposition of magnesian silicates deposited as detritus with the limestone. In support of this hypothesis it may be mentioned that dolomite is sometimes present as one of

[1] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 487.

the constituents replacing a magnesian silicate. Thus, Prof. Bonney and Mr. F. T. S. Houghton state, in their paper 'On some Mica-Traps from the Kendal and Sedbergh Districts,'[1] that they consider "much of the mineral in these mica-traps to be dolomite."

But is there evidence of magnesian silicates having been deposited with the limestone? When I come to describe the residues left after boiling the limestone in hydrochloric acid, I shall show that detrital minerals deposited with the limestone have undergone decomposition; that being so, the bases would be liberated in a soluble condition. The question then arises whether we have evidence that magnesian silicates are or have been present in the residues. Of the decomposition of silicates of some sort there is proof, but not that any magnesian silicate other than biotite has been represented. That micas of this group do not easily undergo decomposition is well known, but it must be remembered that some of the limestones of South Devon have been subjected to influences which have greatly altered their normal condition; I mean, of course, that they have been rendered crystalline. It is in this crystalline limestone that the dolomite crystals are most numerous, and the detrital residue most decomposed. I must moreover point out that, in searching for instances of decomposed micas in the residues, the process of boiling in acid would tend to remove the decomposed portions, leaving only the silica. The same observation would apply to other silicates.

It is worthy of remark that the rhombohedral crystals of dolomite are mostly associated with calcareous organic fragments. This may, perhaps, be explained by the greater solubility of the aragonite as compared with the other form of carbonate of lime of which shells are mostly constructed.

§ 4. Residues insoluble in Hydrochloric Acid.

The residues were obtained by boiling portions of limestone in strong hydrochloric acid. The residues from this treatment were allowed to subside in the boiling flask and the liquid was poured off. Distilled water was then added and the flask shaken so that the residue might be cleared of calcium chloride. This process was repeated four or five times, the residue being allowed to subside each time before the liquid was decanted. The calcium chloride having been removed by this means, the finer portion of the residue was poured off into a watch-glass and portions were removed to a glass slide. These were then dried over a small flame and covered with Canada balsam and a cover-glass. The heavier portion of the residue was mounted in the same way.

The following table shows the percentages of residue obtained from various typical examples of Devonian Limestone from South Devon:—

[1] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 167.

	Percentage.
(a) *Hope's Nose Limestones.*	
Calceola Limestone 1	13·5
,, ,, 2	18·6
Below the Coral Limestone	1·1
Coral Limestone	2·0
Above the latter	3·5
(b) *Daddy Hole Limestones.*	
Base of Quarry	0·6
Other residues in ascending order: No. 1	0·6
No. 2	1·6
No. 3	2·0
No. 4	3·4
No. 5	3·5
Top of Quarry, No. 6	3·3
(c) *Lummaton Limestones*: No. 1	0·6
No. 2	0·2
(d) *Barton Limestones*: No. 1	2·0
No. 2	2·9
No. 3	0·2
(e) *Dunscombe Limestones.*	
Main mass, below the Goniatite Beds	1·8
Goniatite Limestone	10·2

The most noticeable feature in the above table is the small percentage of residue in the Lummaton Limestones, and the variable nature of the Barton rock. But the detailed examination of the residues, which now follows, shows that the small amount at present existing is no guide to what may have been originally deposited—because of the decomposition which has taken place.

I have already referred to the Goniatite Limestone as exhibiting structural differences compared with the beds below, a fact further illustrated by the high proportion of residue which the Goniatite Limestone contains.

§ 5. Detailed examination of the Residues.

(a) *Hope's Nose Limestone Residues.*—Commencing with the lowest beds exposed in the quarry, I find the residue to consist of a very fine, light grey material, and a further quantity of heavier material.

The very fine portion is made up of small flakes of mica, quartz grains, and rutile; there also occur incipient micro-crystals of quartz, microlites, and a quantity of very minute crystals resembling, in some respects, the clay-slate needles of rutile. These minute crystals are a great puzzle; they occur in numbers so vast as to become an important feature and cannot be passed over. Being in doubt as to the nature of these objects, I propose, for the present, to refer to them as microlitic needles. They occur sometimes in aggregates and then appear to be associated with decomposing mineral fragments; sometimes they occur singly in great numbers.

The material of greater specific gravity includes aggregates of micro-crystals of quartz, cryptocrystalline siliceous flakes, and micas. The siliceous flakes, and apparently some of the micas, contain numerous liquid inclusions, and in some instances the microlitic needles referred to in my account of the last slide.

Residues from the Coral Limestone consist (1) of a black substance of low specific gravity, suggestive of carbon; (2) a very fine, light brown material; (3) mineral grains which rapidly subsided in the boiling flask.

A portion of No. 1 was dried and ignited in a platinum crucible; the result was that it disappeared. This is confirmatory evidence that the substance is carbon, and is further supported by the occurrence of some few bodies, measuring 0·1 mm. in diameter, which I have no doubt are the carbonized spores of plants.

The second portion of the residue (2) is a micaceous, siliceous paste in which are small crystals of zircon and great numbers of the microlitic needles. In Pl. IX. fig. 4, I have represented the paste and microlitic needles.

The heavier residue (3) contains a few fragments of tourmaline, quartz, mica, and pyrites; the quartz-fragments vary from 0·1 to 0·2 mm. in longest diameter, and are mostly in the form of grains or crystals. Some of the micas appear to be decomposing; they contain numerous liquid inclusions, and in some instances microlitic needles.

The residue from the *Calceola* Beds consists of schistose material, which is obtained in flakes or masses 1 centimetre in diameter. There is also a very fine residue resulting from the breaking up of the schistose flakes, and this is crowded with microlitic needles.

(b) *Daddy Hole Limestone Residues.*—Specimen No. 1 was from a bed near the base of the quarry, to which reference was made when describing the thin sections of the Daddy Hole Limestones. The very fine portion of the residue is dark in colour, and consists of a micaceous siliceous paste. The dark colour is imparted by the minute microlitic needles. The heavier portion includes siliceous substances and micas, some of which are full of inclusions.

No. 2. This is made up (1) of a fine groundmass or paste, and (2) of material of higher specific gravity. The latter includes grains of quartz, mica, and some other mineral fragments. A further residue was taken from a bed near the top of the quarry. This is made up of mica, quartz, and numerous fragments of what appear to be decomposed mineral substances; and some of these are apparently micas.

(c) *Lummaton Limestone Residues.*—No. 1 is a micaceous siliceous paste crowded with microlitic needles; there are also in it very small crystals of zircon, and some others not determined.

The heavier portion of this residue is made up chiefly of mica and siliceous substances, many of them crowded with the minute microlitic needles.

No. 2. The heavier portion contains micro-crystals of quartz similar to those represented in Pl. IX. figs. 1, 2, & 5, and these contain numerous liquid inclusions.

The finer portion is a siliceous paste.

No. 3. Chiefly made up of micro-crystals of quartz, containing liquid inclusions, and of flakes of mica.

(d) *Barton Limestone Residues.*—No. 1. The very fine portion is a siliceous paste similar to that described as occurring in previous residues.

The heavier portion includes (1) micro-crystals of quartz, most of which contain inclusions, and to such an extent do these inclusions occur that masses of them resemble nuclei; (2) flakes and small masses of siliceous material which are important as throwing light on the origin of the micro-crystals of quartz referred to in describing this and previous residues. This siliceous material is crowded with liquid inclusions (Pl. IX. figs. 1 & 2) and around the edges passes into the crystalline condition, portions of which become detached and then appear as aggregates of, or single micro-crystals of quartz, the origin of which is thereby explained.

No. 2. In this we get a quantity of siliceous and micaceous material, some fragments of which are remarkable for the great number of microlitic needles which occur in them. Micro-crystals of quartz are also present, and contain the usual inclusions.

No. 3. The residue is entirely made up of micro-crystals of quartz containing inclusions. As these are the most perfect that I have obtained, I have represented them in Pl. IX. fig. 5. They vary in length from 0·1 to 0·5 mm., and their form is the typical prism with pyramidal terminations.

(e) *Dunscombe Limestone Residues.*—These are from the same quarry as the specimens from which the thin sections were taken (see p. 379).

No. 1. A siliceous paste, crowded with microlitic needles and microlites.

No. 2. The portion of least specific gravity is a micaceous siliceous paste, crowded with microlitic needles and microlites.

The heavier portion includes siliceous and micaceous flakes, some of which are crowded with microlitic needles.

No. 3. From the Goniatite Limestone. This is similar to No. 1, the only difference being that microlitic needles are more numerous, and there are siliceous flakes so crowded with these needles as to be much darkened.

It may be well to again emphasize the fact that the Goniatite Limestone contains 10·2 per cent. of residue as compared with 1·8 per cent. in the limestones below it. The residual constituents are similar, but the great difference in the quantity points to a dissimilarity in the conditions under which the two limestones were deposited.

§ 6. Conclusions drawn from examination of the Residues.

The variety of mineral constituents in the residues is small, and has therefore necessitated considerable repetition in the descriptions, but the conditions of preservation differ. Of the detrital elements it is difficult to speak; it is indeed doubtful which minerals are of detrital origin. In residues which I have obtained from the Carboniferous Limestone of Clifton, near Bristol, well-rounded grains of detrital quartz were found,[1] but in the case of the Devonian Limestone residues which I have examined, no such detrital grains have been met with.

As to the zircons, and what little tourmaline and ordinary rutile there is in the residues, these may be of direct detrital origin, but the sharply-defined angles of the crystals constitute an argument against this presumption, and I am rather disposed to regard these crystals as having been liberated by the decomposition of minerals in which they were originally included.

Considerable interest centres around the very minute crystals which I have referred to as 'microlitic needles.' I have adopted this term for convenience, and because of the resemblance of these minute objects to the 'clay-slate needles' of rutile. They are not, however, always straight (Pl. IX. fig. 4). Indeed, it is most difficult to determine the true form of these crystals. They occur in every one of the residues that I have examined, and, as I have before pointed out, are so numerous as to be an important feature.[2]

The needles appear in the very fine residue, which is usually a siliceous and micaceous 'paste'[3]; also as inclusions in siliceous and micaceous flakes (Pl. IX. fig. 4), and in such numbers as to impart a dark hue to these objects, which seem to be remnants of decomposed minerals. There is little doubt that the paste is formed by the breaking-up of the siliceous and micaceous flakes, and this explains the presence of the needles.

I have said that the microlitic needles resemble 'clay-slate needles' of rutile in some respects. To determine accurately the optical properties of objects so minute is obviously a most difficult matter. It is, of course, possible that they may be identical with the clay-slate needles of rutile, and they certainly correspond closely with those figured by Rosenbusch.[4] I have not, however, observed twin crystallization, so characteristic of that mineral.

The fact that the microlitic needles occur so frequently in siliceous fragments containing liquid inclusions does not necessarily imply any connexion between the liquids and the needles, yet it is impossible to escape the thought that possibly there may be a connexion between the two.

The discovery of micro-crystals of quartz in limestone is not new. I have referred to them as occurring in the Carboniferous Limestone of Clifton[5] and in the Inferior Oolite of the Cotteswold Hills.[6] Prof. Sollas[7] also notes the occurrence of micro-crystals of quartz in Carboniferous Limestone from Caldon Low, Derbyshire, and in a footnote he states that "similar but much larger

[1] Quart. Journ. Geol. Soc. vol. xliv. (1888) pl. viii. fig. 1.

[2] To make them out a good light is required; I find lamp illumination the most effective.

[3] A term which I borrow from Mr. Hutchings, Geol. Mag. for 1890, p. 269.

[4] 'Microscop. Physiogr.' (transl. Iddings), pl. xv. fig. 4.

[5] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 191.

[6] *Ibid.* vol. xlvii. (1891) pl. xx. fig. 6.

[7] Ann. Mag. Nat. Hist. ser. 5, vol. ii. (1878) p. 361.

crystals (0·02 inch long) are left on dissolving Devonian Limestone containing the so-called *Stromatopora concentrica* from Kingsteignton, near Teignmouth. These are completely riddled internally, and much excavated on their faces externally by irregular cavities."

I do not, therefore, notice the occurrence of these crystals as new to geology, but with the object of discussing their origin and the nature of the inclusions which they contain. Prof. Sollas ascribes [1] the crystals in the limestone of Caldon Low to the displacement of the silica of sponge-spicules by carbonate of lime, and the subsequent crystallization of the freed silica. Of the fact that micro-crystals of quartz do, in some instances, originate from sponge-spicules I have seen evidence in the Carboniferous Limestone of Clifton, but in the Devonian Limestone that I have examined I have noticed no such process, nor have I met with any siliceous organisms. The micro-crystals of quartz that I have obtained from these rocks appear to have originated from the silica of decomposing silicates, but I am not prepared to say that there may not be exceptions. I would suggest that the 'riddled' appearance in the crystals from Kingsteignton, to which Prof. Sollas refers, is really due to the liquid inclusions that occur so numerously in the crystals to which I have referred in this paper (Pl. IX. fig. 5).

As to the nature of these inclusions I am in doubt. All the evidence we have may be summed up by saying that the inclusions occur in the siliceous and apparently micaceous flakes and masses which ultimately give rise to the micro-crystals of quartz, and that the liquids are enclosed by the latter. As I have before stated, I regard the siliceous masses and flakes as the residuum of decomposed siliceous minerals; and if this be so, it is possible that the liquids may be products of this decomposition. It is also of interest to note that the crystals of quartz are most numerous in the Lummaton and Barton Limestones, *i.e.* in those which are most altered by crystallization.

EXPLANATION OF PLATE IX.

Fig. 1. Insoluble Residue. Illustrates the formation of micro-crystals of quartz. A siliceous mass is represented, containing liquid inclusions and becoming crystalline, the crystals retaining some of the liquid inclusions. The siliceous mass is, apparently, the remnant of a decomposed silicate. × 65 diam.

Fig. 2. A portion of Fig. 1 × 230 diam. Shows the liquid inclusions.

Fig. 3. Limestone from Hope's Nose, showing a tubular organic structure suggestive of Algæ. × 65 diam.

Fig. 4. Insoluble Residue. A siliceous paste crowded with microlitic needles. From Hope's Nose Limestone, near Torquay. × 220 diam.

Fig. 5. Micro-crystals of quartz containing liquid inclusions, originating from the crystallization of siliceous material; as illustrated by Figs. 1 & 2. × 65 diam.

Discussion.

Dr. Sorby said that he was probably the first to study the microscopical structure of the Devonian Limestones of Devonshire, but

[1] *Op. et loc. cit.*

did so chiefly on account of the valuable evidence they afford in connexion with the cause of slaty cleavage. Probably on the whole no group of limestones presents a greater range of characters. Not only must their original nature have varied much, but the amount of the changes due to chemical reactions and mechanical squeezing has been very variable and great. He congratulated the Author on having done so much to elucidate the structure of such interesting rocks.

Prof. BONNEY expressed his sense of the great interest of the Author's observations. Through the generosity of the latter he had had the opportunity of examining some of these residues, and could fully confirm several of the Author's conclusions. He thought that the quartz crystals, which had often a nucleus of silicate, must have been developed rather slowly in the rock. He considered that these investigations were of great value as illustrating the history of mineral growth and development.

Dr. HICKS said that the limestone at Hope's Nose, referred to by the Author, had been much folded and broken; and when examining the section, during the visit of the Geologists' Association in 1884, he pointed out the presence in it of a well-marked overthrust fault, simulating an unconformity.

He asked the Author whether the tubular structures, found in parts of the limestone, were not allied to the so-called *Serpulæ* described by Mr. Salter from the limestone in South Pembrokeshire.

Prof. RUPERT JONES thought that Mr. Wethered would find an analogous occurrence of carbon in limestone in Mr. Fulcher's account of the Hirnant Limestone (Geol. Mag. for 1892, p. 114); and of the quasi-tubules in Herr Rothpletz's description of fossil calciferous Algæ, published in the 'Zeitschrift der Deutsch. geol. Gesellsch.' for 1891, p. 295. He further suggested that minute parallel veins of calcite in limestones occurred without stratal disturbance having taken place, as for instance in a *Cyrena*-limestone of the Hastings Series.

The PRESIDENT observed that the Society had been indebted to the Author for work on the same lines on former occasions, and would doubtless welcome this fresh instalment.

With reference to the source of the carbonate of magnesia which occurred in the dolomite crystals, he pointed out that sufficient of the carbonate was present at the bottom of modern oceans to give rise to such crystals. There was a large percentage of carbonate of magnesia in the coral-sand from Bermuda. He referred to the possibility that carbonaceous material such as the Author had described was of animal origin rather than vegetable.

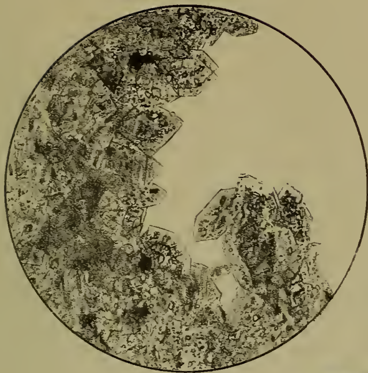
Prof. HULL, Dr. HINDE, and Mr. ETHERIDGE also spoke.

The AUTHOR, in reply, thanked the Fellows who had discussed his paper, and especially Prof. Bonney, to whom he would always be under an obligation for the encouragement given to him in the past.

In reply to Dr. Sorby, Mr. Wethered said that the Devonian

Quart. Journ. Geol. Soc. Vol. XLVIII. Pl. IX.

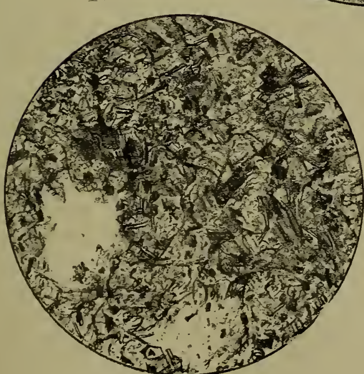
1 x 65.



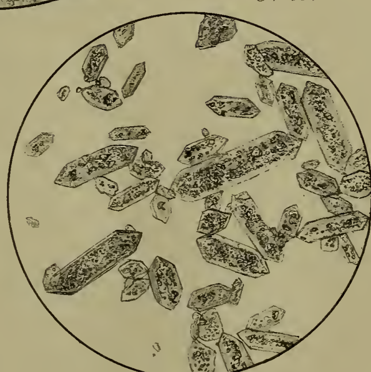
2 x 230

3 x 65.

4 x 220.



5 x 65.



F. H. Michael del. et lith. Mintern Bros. imp.

MINUTE STRUCTURES IN DEVONIAN LIMESTONE.

dolomites were not typical dolomites—that was to say, there were only isolated aggregations and crystals of that mineral in the limestone. As to the origin of the micro-crystals of quartz, there could be no doubt that those in the Devonian Limestone had originated from the decomposition of silicates.

In reply to Dr. Hicks, the Author suggested that he should examine his slides in which the tubular structures occurred, and he thought that the evidence would be such that Dr. Hicks would agree that the tubules were organic.

He was much obliged to Prof. Rupert Jones and Mr. Etheridge for the references to which they had called his attention.

25. *On the* so-called 'Gneiss' *of* Carboniferous age *at* Guttannen (*Canton Berne, Switzerland*). By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S. (Read May 11th, 1892.)

As a text precedes a sermon, so two quotations may fitly begin this communication. The first comes from a letter written by Dr. Heim, and printed in this Journal[1] as a part of the discussion on my paper entitled 'On the Crystalline Schists and their relation to the Mesozoic Rocks in the Lepontine Alps':—"In the Central *massifs* occur rocks which exactly resemble true crystalline schists in mode of occurrence. Petrographically, they are related to them by passage-rocks: at least the line of separation is not easily distinguished. Such rocks are *phyllites*, *chlorite-schists*, *felsite-schists*, *mica-schists*, and especially *sericite-gneisses*, all of which we regard with certainty as Palæozoic. The proofs are the following: . . . Traces of fossils have been often found (trunks of *Calamites* from Guttannen, in the Haslithal. &c.) . . . The *Palæozoic* formations mostly show an intimate tectonic relation to the crystalline schists, and have been converted petrographically into crystalline schists." The second quotation is from the reply which I was permitted to append to the above letter:—"Some of these [Carboniferous rocks] I have examined, and think I know them well enough to demur to Dr. Heim's statements concerning them. I have seen, in the Berne Museum, the specimen with 'the Calamite-like stem.' When this rock is proved to be a gneiss I shall be prepared to consider the propriety of extending this name to the *Grès Feldspathique* of Normandy, or that of mica-schist to some rocks of Carboniferous age at Vernayaz, in Canton Valais, or of calling the Torridon Sandstone of Scotland a granite."

From these quotations it is obvious that to some extent the question on which we are at issue is one of nomenclature. By gneisses and schists[2] I mean rocks which have assumed a crystalline condition *in situ*; which, if originally clastic, have been so completely changed by molecular re-arrangement that their former constitution is a result of inductive inference, and is not immediately revealed by minute study of the structure of the specimen.[3] Suppose a painstaking workman had so ingeniously fitted together quartz, felspar, and mica as to deceive the eye even when a lens was used, this would not justify us in calling the mosaic a granite. It would be only a

[1] Vol. xlvi. (1890) p. 236.

[2] I always use the term 'schist' to mean a foliated rock—the only legitimate sense. See Jukes, 'Student's Manual of Geology,' p. 142 (3rd ed., by Sir A. Geikie).

[3] As we now know, many schists and some gneisses are the result of the crushing, followed by mineral change, of rocks that probably, and in some cases certainly, are of igneous origin. Some gneisses and schists also may be simply peculiar conditions of igneous rocks. These, however, I exclude from the present discussion because they have no direct bearing on the question at issue.

clever imitation of that rock. Thus, if Nature has done the same in a few limited instances, or if, by subsequent crushing of the materials or secondary development of minute minerals, she has made it difficult now and again to distinguish between any such mosaic and a truly crystalline rock, we are not thereby justified in calling the former a gneiss or a schist, unless we are prepared to use a scientific terminology in a merely popular sense. We must also remember that identities cannot be legitimately inferred from the comparison of damaged specimens from the two classes of rocks.[1]

On the map of the Swiss Geological Survey (Blatt xiii.) a belt of sericitic phyllites and gneisses—presumably of Carboniferous age—is represented as crossing the Haslithal at and above Guttannen. Here it is rather more than a mile wide, and extends diagonally across the map in a direction roughly from E.N.E. to W.S.W.[2] Below that village the valley of the Aar is excavated in gneiss. This rock at last (near Imhof) disappears under the thick zone of Mesozoic strata which enclose the Lake of Brienz. A short distance above Imhof the road mounts gradually towards Guttannen, and the traveller can examine, here and there, the aforesaid gneiss. This has a general resemblance to the rock over which I passed in 1883 as I walked up the Gadmenthal. It commonly varies from a rather fine-grained to a moderately coarse gneissoid rock, sometimes banded, but usually not conspicuously so. It exhibits indications of crushing, but is not, as a rule, very fissile.

As Guttannen is approached, erratics of a rather dark schistose or gneissose rock—the Carboniferous rock in question—become fairly abundant, and at last, about a furlong or two from the village, are very numerous on the western side of the road. They are darker in colour and rather more micaceous than the ordinary gneiss of the district, from which as a rule they are readily distinguished. The blocks have obviously descended, at any rate in great part, from a combe beneath the crest of the mountain-ridge on the western flank of the valley.

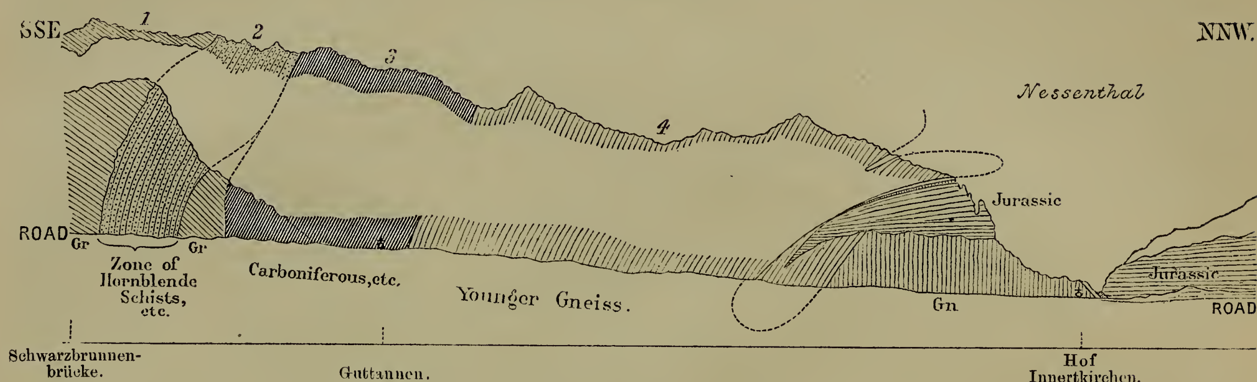
Lying by the road on the opposite side, as the village is entered, are two very large erratics,[3] which, however, have been reduced in

[1] I mean this: Crushing gives to a crystalline rock a clastic structure and is favourable to the development of secondary minerals. On a rock already clastic it has the latter effect, and sometimes injures the characteristic outline &c. of the fragments. Thus the two rocks, so different in origin, may be reduced nearly to the same condition. But to a similarity thus produced we must not appeal: we might as reasonably argue that two coins were of the same reign when both were rubbed smooth, or that the language on two pieces of manuscript had been identical when the characters on each were blurred beyond recognition.

[2] That is to say, it extends for several miles. On the northern side is 'Gneiss,' on the southern '*Bank-granit, Gneiss-granit, Augen-gneiss.*' Into minor details it is needless to enter. We are agreed, I believe, that these are very ancient rocks.

[3] About 60 yards from the door of the 'Bär' Inn. We got this information from an elderly man, who lived in the next house to the Inn, and was, I think, a relation of the landlord. After hearing the details into which he entered we felt no hesitation in accepting his statement. From this block I took specimens which will be presently described.

Section along the Haslithal (Eastern side).



[Scale, roughly, four-fifths of an inch =1 mile.]

1. Central granite-gneiss zone. 2. Complex of hornblendic schists, potstone, gneiss, &c. 3. Gneissoid rock, phyllite, &c. 4. Gneiss, more recent than (1). Gn. Gneiss, position uncertain.

*** The above section is a rough copy of that given in the *Beiträge zur Geol. Karte der Schweiz* (vol. xxiv. pt. 4, pl. 3). As will be seen from the text, I consider 3 to be partly true detrital rock (Carboniferous), partly a normal gneiss, but I have not attempted to make a correction; for to do that accurately would have taken a long time, and all I cared for was the point discussed in the paper. No. 4 and Gn are both normal gneisses, and did not appear to me to differ materially one from the other.—T. G. B.

size by blasting. The slabs now in the Berne Museum were obtained from the first and bigger block.

We decided to examine a continuous section of the belt of the 'Carboniferous gneiss,' and selected, after some reconnoitring, the eastern side of the valley.[1] We did not, however, entirely neglect the western side, for we studied many of the erratics in the 'scatter' from it below Guttannen, and the rock itself in crags which rise from the bed of the valley some distance above the village.

We crossed the Aar and followed its course till we reached the indubitable gneiss; then, mounting to a height of some three or four hundred feet above the river, we worked back, scrambling up and down the grassy slopes so as to touch as many outcrops of rock as was possible without greatly altering our level.

Commencing at a waterfall which plunges over rock into a ravine descending in a S.W. direction, we found on the right bank of the latter the normal gneiss, on the left the 'Carboniferous gneiss.'[2] But on the former rock a marked cleavage-foliation has been impressed so as to make it quite slaty; in the latter also there is a rough cleavage—so that in the field the exact line of demarcation cannot easily be determined. After a time indubitable 'cleaved' gneiss is again struck,[3] on the right bank of a little stream which joins the Aar about two furlongs below Guttannen. This can be followed for some distance on the other side. The bosses of ice-worn rock, however, which project from the slopes N.E. of Guttannen and some 450 feet above it, consist of 'Carboniferous gneiss.' But it is doubtful whether the latter extends far; for the rock exposed in some other outcrops a little distance onwards bears more resemblance to crushed normal gneiss; and this certainly seems to occur about due E. of Guttannen. We traced the last-named rock down to the neighbourhood of a pathway which leads into that village by a bridge over the Aar. Here it consists of alternating bands of quartzo-felspathic and of more micaceous rock—the former rather more than a quarter of an inch in thickness, the latter about one inch; a common type in the gneiss of the valley below Guttannen, though here much contorted. But at a distance of a few yards, close by the path, we again found the 'Carboniferous gneiss,' in which are spots of a white mineral, rather smaller than a pea, suggestive of a fragmental structure. Beyond this place, though we passed many erratics and crossed a slope of débris (avalanche), we were not so fortunate as to discover any more of the 'Carboniferous gneiss' *in situ*, so long as we were on open ground. But on entering the forest we felt doubtful whether one or two crags which we found near the margin might not be this rock. Coarse gneiss, however, soon sets

[1] It is needless to enter into the reasons for our choice, as they could be understood only by those who have a minute knowledge of the ground. I was accompanied and aided in the field work by Mr. Jas. Eccles, F.G.S., to whom I tender my best thanks for invaluable assistance then and since.

[2] It will be convenient to use this term to indicate the rock of clastic origin which is the subject of this paper, though, as will be understood, I maintain that it is improperly designated a 'gneiss.'

[3] At the base of a wood near the chalets of Vorsaas.

in. Over this we worked for some distance, without seeing more of the 'Carboniferous gneiss,' either in crags or tumbled blocks, until we were well beyond the limit laid down on the map. Thereupon we made our way to a bridge over the Aar and crossed to its left bank. Hereabouts the granitoid and gneissose rocks in which the upper part of the Haslithal is excavated[1] are well exposed, and on our way back to Guttannen we passed, in the crags which here and there rise near the road, firstly true gneiss, next 'Carboniferous gneiss,' then more true gneiss, much crushed, and lastly more 'Carboniferous gneiss,' though of this, in the field, it was difficult to be sure.

Before describing the microscopic structure of the specimens selected for examination, it may be well to state the conclusion at which I arrived in the field. It was as follows: Here and there it is difficult to distinguish between the 'Carboniferous gneiss' and the normal gneiss, where it has been more crushed than usual, but as a rule the two rocks can be easily separated. The former does not resemble closely any true gneiss known to me in Switzerland. Though composed of the same minerals as the normal gneiss of the district, it is darker in colour and more carbonaceous in aspect. Though it is sometimes banded with micaceous layers like a gneiss or mica-schist, these disappear in other parts of a large block, and the texture altogether is more variable than is usual in a normal gneiss. The structure throughout is suggestive of a grit somewhat modified by pressure and by slight mineral change, rather than of a rock which has become crystalline *in situ*. The reasons which led me to this conclusion cannot be fully expressed in words. They depend upon a number of minute peculiarities which one can only learn to recognize after long study of crystalline rocks and of clastic rocks derived from these, in different aspects and under various circumstances.[2]

At this stage also of the investigation I think it well to call attention to two points in the account which has been published in the 'Beiträge.'[3] One is an omission. The stems in the block from Guttannen are fairly well-preserved, inner and outer casts

[1] These rocks, which we examined rather more closely next day in walking up the Haslithal to the Grimsel Hospice, bear a general resemblance to those found in the Reuss Valley from some distance below Wasen to near Göschenen. The foliation is very probably, as a rule, the result of pressure; but a rock like a fine-grained granite appeared in one or two places to cut across the foliated structure and so to be of later date. Nearer to the Grimsel the coarse granitoid rock becomes more distinctly porphyritic, and there are more conspicuous zones of crush. We spent little time over the small infold of rock, marked as 'Sericitic gneiss, &c.,' which crosses the Haslithal rather higher up than the above-named bridge, because, as the published section indicates and the tumbled blocks showed, it is a tangled mass of a variety of rocks, and thus was not likely to be helpful in regard to the question which we were attempting to solve.

[2] An experienced worker gets to know one rock from another as a huntsman knows one hound from another in a pack, or a shepherd knows one sheep from another in a flock, by a number of characteristics which it is often impossible to express in words.

[3] Vol. xxiv. pt. iv. p. 161.

being retained, with some indications of the intervening material, much as may be often seen in a sandstone from the Carboniferous system. But if the molecular changes among the constituents have been sufficient to transform a shale or a grit into a gneiss, is it not strange that anything more than a mere trace of the plant should be preserved? I do not say that the difficulty is insuperable, but it exists, and ought, it appears to me, to have been carefully discussed. Yet we do not find a word on the subject. The occurrence of a fairly well-preserved fossil in a rock which has passed into a crystalline condition seems to be regarded as a thing perfectly normal and natural.[1]

Here is the second point. We might have expected ample evidence that the rock of the Guttannen boulder had been carefully compared with numerous specimens of gneisses and crystalline schists from other parts of the Alps, at least, in order to show that it agreed completely with them in its characteristic structures. We find only this statement: that it differs from the ordinary gneiss of the northern part of the Finsteraar *massif* in its conspicuous '*Mörtelstructur*' (for the description of which reference is made to a foreign writer), in the deformation of the felspars, and the production of sericite from them. This statement ends with a remarkable clause:—"Inwiefern gerade diese Mörtelstructur auf einen klastischen Ursprung des Gesteines hinweist, kann nicht mit Bestimmtheit entschieden werden, da die Wirkungen der Dynamometamorphose auf Grauwacken noch zu wenig bekannt sind." As I have been for some years familiar with greywackes which have been thus modified, and as ample material for study could be obtained without going beyond the limits of the Alps, I must beg leave to dispute the accuracy of this remark.

The Alps provide an abundant series of rocks illustrative of the various stages of pressure-metamorphism. Restricting ourselves on the present occasion to a single group only, we can readily obtain a series at one end of which is an almost normal granite or granitoid gneiss, at the other a fine-grained quartzose or micaceous schist. We can study under the microscope the gradual detrition and change of the original constituents—the crumpling, tearing, and partial reconstitution of the micas, the cracking and crushing up of the quartzes, the progressive pulverization of the felspar and its replacement by filmy 'sericite' and chalcedonic quartz. With such specimens, of which I possess a large series (not a few from the Central *massif*), these 'Carboniferous gneisses' can be compared, on the one hand, and on the other with greywackes composed of the débris of crystalline rocks which have been subsequently subjected

[1] It may be said, 'But this is not regarded as a gneiss in the sense in which the term is applied to the rock farther down the valley.' If it be not—if the rock be only a slightly modified grit, *looking like a gneiss*—there is of course an end of the matter. But if so, where is the importance of the discovery, what bearing had it on the questions discussed in my paper 'On the Crystalline Schists, &c.,' and why import confusion of thought into a perfectly simple matter by the employment of a misleading terminology?

to considerable pressure and have undergone some micro-mineralogical change. In both these groups the constituent minerals, as a rule, exhibit a general similarity: the main difference consists in their constitution and ordering.

Thus, in these specimens of the 'Carboniferous gneiss' from Guttannen, we found, as usual, quartz, felspar (generally much decomposed, but with both orthoclase and a plagioclase sometimes recognizable), white mica (sometimes in fair-sized flakes, but generally in crowded tiny films), biotite (often in well-developed flakes, but occasionally in filmy aggregates or replaced by a greenish secondary product), a dark mineral (sometimes an iron oxide, or even pyrite, sometimes probably a carbonaceous mineral), together with occasional rutile, zircon, epidote, apatite (?) and zoisite (?). One specimen, at least, contains the remains of a garnet which has been partly replaced by a green chloritic mineral. In short, we find in these 'Carboniferous gneisses' the same constituent minerals as in the normal granitoid and gneissoid rocks of the Bernese Alps.

I took two specimens from the block in which plant-remains had been found; each having a banded structure, but one being coarser in texture than the other.[1] From the coarser specimen I have had two slices cut: one parallel with, the other transverse to the mineral banding; from the other specimen a single slice. All these, when studied under the microscope, at the first glance, much resemble a gneiss, but reveal, on a closer examination, a greater structural variation than is usually found in a gneiss or a crystalline schist. At one moment a granitoid gneiss seems to occupy the field of the microscope, at another a schistose aggregate of mica flakes, interspersed with decomposed felspar and occasional quartzes. Although a clastic structure is not as conspicuous as in an ordinary arkose or greywacke, still the rock appears to be made up of fragments tightly squeezed together; the boundaries of these being indicated by darkish lines, composed of minute minerals, such as mica, opacite, &c. In one place a roundish constituent, in structure resembling a bit of granite, is sharply appressed against a band composed of biotite and decomposed felspar; in another we find chiefly quartz and felspar with hardly any biotite. The mica also differs from that usually found in a crystalline rock which has been rendered fragmental by crushing. It is not, as in such a case, sheared, tattered, and converted into a string or 'cirrus' of little flakes, but is simply crumpled and pushed about. The felspars, also, though sometimes they pass by crushing into a 'stringy' aggregate of minute micaceous minerals, as is so common among crushed crystallines, have often escaped fairly well and are only replaced by microlithic decomposition-products. Two other specimens, taken from rock *in situ* nearly opposite Guttannen (one from near the path leading up from the bridge), exhibit under the microscope more distinct indications of an original clastic structure, and are, in my opinion, grits composed of rather fine-grained (decomposed) detritus from a biotite-gneiss,

[1] One was from near the bottom of the block, the other from about a yard above it.

on which a rude cleavage has been subsequently impressed. Traces of a like structure can also be distinctly recognized in the rock with white spots, already mentioned as occurring at the above-named locality. These spots are felspar; they bear no resemblance to authigenous minerals, though the outline of the fragment in places is a little obscured by the formation of a narrow zone of chalcedonic quartz, calcite (?), and other secondary products. The specimen from the crag which rises by the path on the left bank of the Aar consists of rather coarser detritus than the last-named example, that is, of the débris of a normal granitoid rock.

The crystalline rocks of the Haslithal above and below Guttannen, already briefly mentioned, must now receive a little further notice. On the Swiss map, those north of the 'Carboniferous gneiss' are coloured as *gneiss*: those south of it (with an unimportant exception) as *bank-granit*, *gneiss-granit*, *augen-gneiss*. The former undoubtedly are less coarse-grained and granite-like than the latter; in short, the Haslithal section is generally similar to those obtained in crossing the Oberland range at some few miles distance to the east or to the west; the rocks, as we proceed inwards, becoming coarser, more obviously granites rendered gneissoid by pressure, sometimes even porphyritic; so that for general descriptive purposes the above distinction may be maintained. My collection includes a fair selection of various types of these gneisses or gneissoid granites from the more central part of the Oberland, and I have examined a few from the Haslithal itself. For our present purpose it is needless to enter into minute descriptive details either of structure or constituents. The dominant minerals are quartz, felspar (orthoclase and plagioclase), and mica, commonly biotite. The rocks are sometimes much crushed, when the quartz becomes a mass of variable-sized granules, occasionally almost chalcedonic; the felspars are partially altered in the usual ways; the mica flakes are more or less broken up; but in other cases the modifications are but slight, the felspars sometimes being fairly idiomorphic, though more often, like the quartzes, they are more or less irregular in outline, and contain small grains of the latter mineral. The broad petrographic distinction, mentioned above, is commonly maintained in the slides, those from the upper part of the valley being more like normal granites. Two specimens from above Guttannen contain, it may be noted, small garnets.

While it is evident that, if we restrict ourselves in a microscopic examination to very small portions of the 'Carboniferous gneiss,' these are identical both in structure and mineral constituents with the above-mentioned gneisses (from which I consider them to have been derived); yet, if we examine the slide as a whole, instead of keeping our eyes fixed on what is really a fragment of the true gneiss, we find that the 'Carboniferous gneiss' is more variable and heterogeneous. It presents the aspect of a rock composed of fragments derived from slightly different sources; the other, that of a rock locally crushed to fragments. The distinction is very marked in the specimens identified as gneiss in or close to the infold of

Carboniferous rock; for instance, in that from Vorsaas (p. 393). This is finer grained and more definitely banded with biotite than is usual; still, under the microscope, the distinction noted in the field becomes yet more manifest, and the rock is evidently very different from its neighbours of clastic origin. The quartzes and felspars are granular in outline, but they show obvious signs of having been structurally affected by subsequent pressure. The biotite, however, is still fairly idiomorphic, and is very different from the streaky groups of flakes in the 'Carboniferous gneiss.' In the coarser varieties also of the true crystalline rocks, the distinction is not less marked; these exactly resemble the ordinary types of the granitoid gneisses and gneissoid granites of the great *massif* of the Oberland.

To sum up: my study of these Guttannen rocks, both in the field and with the microscope, leads me to the following conclusion. As is the case with other rocks of Carboniferous age elsewhere in the Alps, they are composed exclusively, or almost so, of the débris of the crystalline rocks of the neighbourhood. Hence they often, like the Torridon Sandstone of Scotland or the *Grès Feldspathique* of Normandy, are *mineralogically* identical with a granite or a granitoid gneiss, and occasionally cannot be readily distinguished even structurally. But as they are really composed of fragments, water has found a rather easy passage through them, and the pressure to which they have been exposed has facilitated micro-mineral change. The latter agency, by squeezing together and slightly distorting the original fragments, renders the clastic structure less easily recognizable. To some extent a new structure has been impressed upon the rock, such as is very conspicuous in the *Grès Feldspathique* at Tourlaville, near Cherbourg, when this is compared with the same rock from Omonville (about fifteen miles away to the west), or in a specimen of Torridon Sandstone, which has been taken from the region of the thrust-faults. But the secondary change in the Guttannen rocks is not greater than in either of these instances; indeed, it is sometimes surpassed in them. It is very similar to that which occurs in rocks of the same age in the district between the Tête Noire and Vernayaz.[1] So far as I know, then, this is the only peculiarity: that, in most parts of the Alps, these curious imitations of crystalline rocks are limited in extent, and the fraud is quickly revealed by the incoming of beds of conglomerate or of slate, while at Guttannen I did not happen to discover either the one or the other. So, if we are prepared to call the Torridon Sandstone a granite, and the *Grès Feldspathique* a gneiss, simply because here and there it would be difficult to point out a distinction which would appeal at once to an inexperienced eye—simply because they are rather clever imitations—then we may call the Guttannen

[1] See Geol. Mag. for 1883, p. 507: also A. Favre, 'Recherches Géol. dans les Parties de la Savoie . . . voisines du Mont Blanc,' § 522; and Sterry Hunt, 'Chem. and Geol. Essays,' p. 339 (ed. 1875), for a history of like confusion as to these imitation-schists of Carboniferous age.

rock a gneiss, but in that case we may as well admit frankly that petrology is a hopeless muddle, and that any attempt to investigate the history of the schists and gneisses is a waste of time; or in other words—for I do not see where we are to stop in applying the principle—that the banker or the archæologist is at the mercy of the accomplished forger.

Discussion.

The President observed that this, an old controversy, was likely to remain one for some time to come. Firstly, it was necessary to define a gneiss, and such definition must be based entirely on petrographical characters. In the case described by the Author, we have a rock which is clearly detrital (containing as it does recognizable fossils), and this exhibits a structure to a certain extent gneissic, though he presumed that the Author would deny that it was a gneiss; but supposing that alteration had gone on a step farther, and nearly all trace of organic structure was gone, he (the speaker) thought that the gneissic structure would increase in intensity, so that it could not be distinguished from what he supposed the Author would admit to be a normal gneiss. He considered that an argument used by the Author, as to its being extraordinary that fossil plants were preserved in true gneiss, cut both ways. If a detrital rock be chemically and mineralogically allied to a gneiss, then, on the occurrence of further change, one can only say that the rock is a gneiss, without defining what sort of a gneiss it is.

Prof. Judd congratulated the Author of the paper on having so satisfactorily disposed of an erroneous observation. For himself, he had always doubted cases of the alleged occurrence of fossils in holocrystalline rocks. If the rocks are holocrystalline, how could original structures like fossils be preserved? If, on the other hand, the rock did preserve the structure of a fossil, how could it be said to have been perfectly recrystallized? He thought the doctrine of dynamometamorphism (and we must remember that the doctrine is much older than the name it now bears) had suffered from *trop de zèle* on the part of some of its supporters. He regarded many of the observations of Prof. Bonney, even in the present paper, as affording valuable support to the doctrine of dynamo-metamorphism.

Mr. Eccles fully believed in the Carboniferous age of these 'Sericite Schists' at Guttannen, and considered them to belong to a prolongation of one and the same infold, which includes fossiliferous strata of the same age in the *massif* of the Tödi to the N.E., as well as those of the Lower Valais to the S.W., all the three occurrences being approximately on the same strike-line. But he was not prepared to admit that Carboniferous strata, altered or unaltered, entered in any considerable degree into the composition of the crystalline zone which extends from the Tödi to Dauphiné, and of which these Guttannen schists form a part. In support of this contention he pointed out that all the known Carboniferous exposures in this zone except one, which may not after all be an exception, are synclinals of comparatively limited width sharply in-folded between older crystalline rocks; and in the locality where the sedimentary beds attain their greatest development, the lower strata contain well-marked conglomerates which include quartz-pebbles together with many rolled fragments of gneiss and crystalline foliated schists.

Gen. McMahon remarked that the term 'gneiss' ought nowadays to be restricted to crystalline rocks of metamorphic origin, and not applied to foliated eruptive rocks, on the one hand, or to clastic rocks of detrital origin, on the other, however much the latter might simulate metamorphic rocks in appearance. The use of the term in a purely mineralogical sense led to many misconceptions. It seemed unscientific to give the same name to rocks of totally different origin. A vague term might have its convenience as a cloak for ignorance, but now that the geologist had the microscope to aid him a more precise terminology seemed desirable.

Mr. Rutley commented upon the possible ways in which gneissic and gneissoid structures may be produced.

Prof. Blake remarked that the careful description given by the Author put us in possession of the facts, and all that was left was the logic of the nomenclature. If the rock in question showed the fragments of the rocks whence it had been derived, so did every detrital rock, though in the latter they might be smaller. The only difference was the extent of the excursion from the original crystalline character. Hence the only way to escape calling this rock a gneiss was to confine that term to such as show no trace of their previous clastic character, in which case many of the pre-Cambrian 'gneisses' would be excluded.

Prof. Seeley also spoke.

Prof. Bonney, in reply, stated that the specimens with fossils were not less gneiss-like than the others. The best imitation of gneiss among the specimens which he had collected was from the block with plants. He quite agreed with Prof. Judd as to the importance of dynamo-metamorphism: it was a truth, but not, he thought, the whole truth. He knew the schists with Trilobites to which Prof. Blake had referred, and they were very different from ordinary crystalline schists. His whole argument—and this applied to the President's remarks—was not that these fragmental rocks had gone back to a crystalline condition, but only that they looked like it, and so misled observers. He maintained that a terminology could not be founded upon appearances, and that if the same name was to be applied to a crystalline rock and a rock which could be shown only to imitate a crystalline rock—in short, to be only a forgery—the whole science of petrology would be thrown into hopeless confusion.

26. *The* Rise *and* Fall *of* Lake Tanganyika. By Alexander Carson, Esq., B.Sc. (Communicated by R. Kidston, Esq., F.R.S.E., F.G.S. Read April 27th, 1892.)

[Abridged.]

After alluding to certain observations of Cameron, Livingstone, and Stanley on the changes of level of Lake Tanganyika, the writer states that the most interesting point in connexion with the rise and fall of the lake is the question :—How is it possible for a great lake to rise 30 feet above its normal level by the blocking up of its outlet?

This is to a large extent accounted for by Cameron. He says: "On going down the river [Lukuga] we found that it was blocked by vegetation similar to that on which we had crossed the Sindi, and also to that over which we had had to pass to reach the shore from our boats at the southern end of Lake Tanganyika, and which I afterwards found existed on Lakes Kassali and Mohrya. The presence of this mass of vegetation is easily accounted for. Every day that there is a gale of wind, and the consequent sea on the lake, blocks of this peculiar growth are detached, and such as survive the passage to the outlet getting jammed together commence to grow, and form a sort of porous stopper in the neck of the outlet."[1] He then quotes Sir Samuel Baker's experience on the Nile when the whole channel "was blocked up and the expedition to Gondokoro impeded for a year, the country above the stoppage having been converted into a series of swamps and shallow lakes, while Egypt was suffering from all the evils of a low Nile."

Only those who have seen this vegetation will be likely to give due weight to Commander Cameron's argument. The writer has seen the channel of the Shiré blocked by the same vegetation. But in order fully to explain the blocking up of the Lukuga it is necessary to take into account another phenomenon observable on Lake Tanganyika. At the southern end of the lake there is a series of promontories formed of uptilted strata and between them deep bays with shallow water, while the valleys between are only a few feet above the present level of the lake. Across one of these valleys, close to the water, the lake since its recent fall has left an embankment about 20 feet high, completely closing up the valley: so much so that when the missionaries occupied the hill overlooking it and the people made gardens in the valley (which had not before been cultivated), the first heavy rains made a lake of it 4 feet deep at the lower end and a channel had to be cut through the embankment to carry off the water. The sketch on the following page shows the form of this embankment, which is probably 300 feet long and about 20 feet above the level of the valley. The same phenomenon has been

[1] 'Across Africa' (1885 ed.), p. 555.

observed in other bays on the lake; the embankments are all largely composed of shingle and are of exceedingly compact formation.

Diagram-section of embankment near southern end of Lake Tanganyika.

Now Cameron describes the entrance of the Lukuga thus: "Shortly before noon I arrived at its entrance, more than a mile across, but closed by a grass-grown sandbank, with the exception of a channel 300 or 400 yards wide. Across this there is a sill where the surf breaks heavily at times, although there is more than a fathom of water at its most shallow part."[1]

Here we have a bank similar to that described at the southern end of the lake, but with a break 300 or 400 yards wide and six feet deep in it, and the top of the bank was probably uncovered in the dry season, when grass would grow on it, for each year towards the end of the rains the lake rises about 2 feet and again gradually falls. Behind this bank we have precisely the conditions necessary for that dense growth of aquatic vegetation which blocked the Lukuga. To appreciate how the river at first became blocked we must remember that in its normal condition Lake Tanganyika has a considerable quantity of water to discharge after the rains, but very little (perhaps none) towards the end of the dry season, and the first two months of the half-year rainy season have no appreciable effect in raising its level. The effect of this is that when the lake has regained its normal level the basin of the Lukuga will for several months of the year be only mud pools and be rapidly covered with dense vegetation, while the first rains will only have the effect of assisting to silt up the bed. There will thus be a continual struggle between the choked bed and the waters of the lake swollen after the rains, and for years, perhaps ages, the lake scours in its flood the channel as often partially choked by vegetation. It is therefore easy to understand how in these circumstances—with the bank continually forming across the bay, the dense growth of aquatic vegetation within the bank, and the large quantity of floating vegetation from all the rivers that enter the lake and which ultimately finds its way to the Lukuga, where it is deposited at the entrance and is jammed into the neck of the outlet—this neck becomes ultimately plugged with a porous stopper as described by Commander Cameron. It may be that these embankments play even a more important part in the blocking up of the Lukuga; but we have at least in Lake

[1] *Op. cit.* p. 227.

Tanganyika an example of a great lake having its outlet practically closed for many years by a natural process of damming.

The writer then mentions the common occurrence of earthquakes in the district, and particularly the slight shocks that took place in October 1887 in the Island of Kavala (only a few miles from the mouth of the Lukuga). These shocks were also felt at Ujiji on the opposite shore.

Discussion.

The Chairman (Prof. Judd) referred to the rapid advance of our knowledge of Central Africa in recent years. In this paper we had the evidence of an eye-witness as to curious processes which were going on in Lake Tanganyika. The causes which the Author considered competent to produce the described changes were of interest in themselves, whether or not they were actually sufficient to produce those changes.

Mr. E. T. Newton called attention to the remarks on this subject made by Major von Wissmann in his recently published work, 'Through Equatorial Africa,' 1891 (English edition, p. 255).

Prof. Hull and Dr. Hicks also spoke.

27. *The* Geology *of the* Gold-bearing *and* Associated Rocks *of the* Southern Transvaal. By Walcot Gibson, Esq., F.G.S. (Read April 6th, 1892. Abridged.)

[Plates X. & XI.]

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I. INTRODUCTION.

(1) *General Sketch of the Geology of the Southern Transvaal.*

The rocky floor of the Transvaal is very distinct from that of South Africa in general. Travelling for several hundred miles through the northern parts of Cape Colony and the Orange Free State, such strata as are seen consist of horizontal sandstones and shales of Karoo and Stormberg age. These are injected and overflowed in numberless directions by masses and thin sheets of igneous matter, while worn-down stumps of volcanic necks can be frequently recognized. But in the Transvaal the nature of the strata undergoes a complete change. Instead of flat-lying sandstones and shales of the wide-spreading Karoo formation, we find twisted and highly inclined quartzites and conglomerates of undetermined geological age. The igneous rocks occur more in the form of bosses than sheets, and make rugged hills with precipitous slopes which are almost bare of vegetation.

At first sight the geological structure of the southern part of the Transvaal appears quite simple, the impression being that the rocks merely form an ordinary basin. So far, however, from this simplicity being real, the geological structure of the country is in fact highly complex, and is rendered still more difficult to unravel from its being apparently impossible to find any distinctive petrological band, available as a means of mapping the ground, or any group of fossiliferous strata, which might be used as a stratigraphical index. The difficulties of mapping the district are also increased by the fact that most of the country is covered by a deep red surface-layer, which is often many feet thick, and entirely conceals any outcrops over large areas. So far as is at present known the rocks are wholly unfossiliferous; while they are highly faulted, and in many cases sheared and overthrust.

The dominant rocks of the Southern Transvaal are sandstones, quartzites, and conglomerates, with here and there a few bands of shales and slates. A large portion of the country is also occupied by a later intrusive set of igneous rocks of basic and sub-basic types. Sometimes however—as near Vredefort and to the north of Johannesburg—the crystalline floor of South Africa, with its granites, gneisses, and schists, comes to the surface from below the stratified formations already noticed (see Map, Pl. XI.). These crystalline rocks, together with a dark-coloured limestone, become the chief geological features in the Northern Transvaal, and, unlike the same rocks in the south, rise up into hills of moderate height, particularly round Zoutpansberg.

The area more particularly described in the present paper is that lying immediately to the east and west of the town of Johannesburg. This area will be regarded as constituting the typical district for the development of the stratigraphy of the Transvaal. The rocks are well displayed both in the numerous mines and in natural and artificial cuttings; and the writer has had abundant opportunities, especially in inspecting many of the mines, of studying somewhat thoroughly the nature and the local sequence of the beds and the amount of movement and alteration they have undergone. With respect to other districts the information of the writer is more general, being founded largely upon occasional observations and sometimes upon facts gained in hasty traverses. The sections across these more distant portions are therefore to be viewed as broad generalizations, to which future observation will certainly add much in the way of detail.

(2) *Summary of previous Geological Work bearing on the District.*

Our knowledge of the geology of most of South Africa, and more particularly of the Southern Transvaal, is still of an imperfect character.

The collective results of the researches of the large number of geological workers in South African areas outside the Transvaal proper have, of course, proved more or less helpful towards a general understanding of the relationship of the beds of the Transvaal area to those of other districts. In this respect Prof. Green's recognition of an unconformity between the Dwyka-Ecca Beds and the overlying Kimberley Shales appears to the author to be especially important, and will probably be found of wide application in South Africa. The fact also that palæontological evidence has shown the Karoo and Uitenhage Beds to be homotaxial with the Lower Mesozoic and Cretaceous formations of other countries is another factor of the highest value in the correlation of the South African strata.

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GREY, Dr. G., 'Remarks on some Specimens from South Africa,' Quart. Journ. Geol. Soc. vol. xxvii. (1871) p. 49. With Notes by T. RUPERT JONES.

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MOULLE, A., 'Sur la Géologie Générale et sur les Mines de Diamants de l'Afrique du Sud,' Annales des Mines, 8ème sér. vol. vii. (1885) p. 193.

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——, 'On some points in the Geology of South Africa,' Quart. Journ. Geol. Soc. vol. xv. (1859) p. 195.

SAWYER, A. R., 'Diamond-mining at Kimberley,' Trans. N. Staffs. Inst. Min. & Mech. Eng. vol. x. (1889).

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STEPHENS, W., 'Attempt to Synchronize the Australian, South-African, and Indian Coal-measures,' Proc. Linn. Soc. N. S. W. vol. iv. (1889) p. 331.

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——, 'Notes on an Ancient Boulder Clay of Natal' (Dwyka-Conglomerate), Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 514.

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WIBEL, Dr. F., 'The Fibrous Quartz of the Cape, a Pseudomorph after Krokydolite,' Geol. Mag. for 1874, p. 135.

WYLEY, A., Report on the Maitland Mines, &c. 1855.

Wyley, A., Report on the Copper Districts of Namaqualand. 1856.
——, Report on the Neighbourhood of Smithfield. 1856.
——, Report on the Central Districts of the Colony. 1859.

Of published information bearing directly upon the geology of the area here dealt with the writer has been able to discover but little. The following publications, however, should be noticed, though the present paper was all but completed before Mr. Penning's 'Contribution,' mentioned below, was read at one of the Geological Society's meetings:—

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Dorsey, E. B., 'On the Witwatersrand Goldfields,' Report Brit. Assoc. for 1889 (Newcastle Meeting), p. 592.
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II. GEOLOGY OF THE WITWATERSRANDT.

A. The Gold-bearing Conglomerates and Associated Rocks of the Johannesburg Area.

1. The District in General.

This district embraces an area of about 2000 square miles. It is variously known as the Witwatersrandt, Randt, or Johannesburg Goldfield.

The chief towns in its northern portion are Johannesburg, Heidelberg, and Pretoria; of these Johannesburg occupies the most central position. The Vaal River forms the southern boundary of the district. East and west the area has no defined limits, but it certainly extends eastwards to where the older strata are concealed by later deposits of Karoo age, and westwards until they are buried beneath igneous matter or lost under the expanse of open veldt.

As a whole the district may be said to form the northern part of the great central plateau of South Africa. Gradually rising from the Vaal River, its highest point is reached near Johannesburg in an elevation of 5600 feet. Here three parallel ridges extend in an east-and-west direction for about 45 miles, and the high ground thus formed constitutes the watershed between the Limpopo and Vaal Rivers; the streams to the north are tributaries of the former river, while those to the south flow into the Vaal. Most of the stream-courses are mere dry channels during the winter months, but in the summer they become filled with rushing turbid torrents.

Broadly speaking, the visible rocks in this district consist of a sedimentary series of sandstones, quartzites, and conglomerates, and an igneous and much later series of basic and sub-basic lavas and intrusive sheets. Here and there in the folds of the former set of rocks, shallow deposits of coal-bearing strata have been laid down; but these do not, so far as the writer's knowledge goes, cover any great extent of surface in the Transvaal, although coal-beds of apparently the same age extend over a large area in the Orange Free State.

The quartzites and conglomerates have generally a southerly dip, with an east-and-west strike. Behind Johannesburg, and again to the south, they constitute two main parallel lines of elevation composed of several smaller ridges running east and west.

The discovery of gold in the conglomerate-beds around Johannesburg in 1885 has caused this town to spring up in what five years ago was a desert, and has given these strata a world-wide reputation. Since the goldfields have been started mining operations have been extensively carried on along the outcrop of the conglomerate. There are now (1890) over 70 mines, the workings extending in an east-and-west line from Johannesburg for nearly 40 miles. The greater number of these mines are situated on what has been named the Main Reef, the course of which is marked all along its outcrop by derricks, hauling machinery, and all the usual adjuncts of mining operations.

2. The Main Reef Series.

(a) *The Type-sections of the Main Reef Series in the Salisbury and Henry Nourse Mines.*

As it is impossible for the geologist to locate his position definitely in the Witwatersrandt conglomerate series, and as neither the summit nor the base of this group of strata has been discovered, he is driven to take some arbitrary starting-point. It is most convenient to begin with the line of conglomerate-bands which have been opened up by the various gold-mines. The sections are complete, and the data, if ordinary care be exercised in selecting them, are reliable.

(1) *The Salisbury Gold-mine* is situated almost in the centre of the line of conglomerates, and shows very clearly the relationships of the beds to each other. The strata are very little metamorphosed and only slightly disturbed by faulting; and the mine is well opened up, so that a complete section can be obtained.

The conglomerate-beds and the associated rocks make no appearance at the surface, their outcrop being concealed beneath the superficial red soil. The mine is worked by two levels at a depth of 66 feet and 130 feet respectively. Both levels give a very instructive section from north to south of nearly 150 feet in length. The dip is high—85° S.; the strike due east and west. The dip remains constant throughout the mine and on both levels. On the upper level a 'cross-cut,' north and south, near the western boundary of the mine passes through the sequence of strata, beginning at the north, enumerated in the explanation of fig. 1 facing this page.

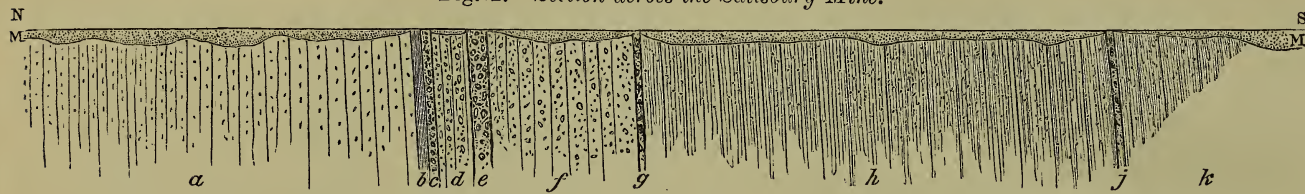
The four conglomerates (*c*, *e*, *g*, *j*) are collectively termed the Main Reef Series. On Wyld's map of the Witwatersrandt Goldfields (1888) and in the map accompanying the present paper (Pl. XI.) this Main Reef Series is represented as one bed, the scale in both cases being too small to admit of the separate beds being shown.

The word 'reef' must not be taken in its ordinary meaning; the reefs are not veins in any sense, but are true conglomerate-beds. The term 'banket' is often applied in the district to any conglomerate-bed whether it contains gold or not, and a series of sandstones and conglomerates is often spoken of by Afrikanders as a 'banket formation.'

The four conglomerate-reefs are strikingly similar in appearance, though a miner who has worked for any length of time in any one mine recognizes distinct differences between them.

The *Main Reef* proper, in the Salisbury Mine, and indeed in most of the other mines, is the thickest and least coherent of the series. The pebbles are numerous and of all sizes, varying from half an inch to two inches in diameter. They are chiefly of milk-white quartz, very much broken; but others, formed of a yellow talcose material, looking something like hardened clay, are not uncommon. The cementing-material, or that in which the pebbles are embedded, is

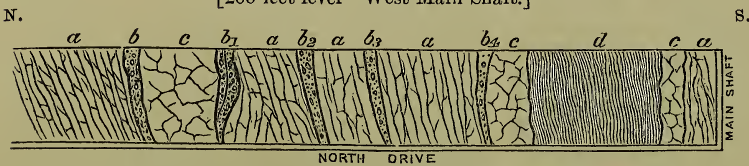
Fig. 1.—*Section across the Salisbury Mine.*



a.	Red, flaggy, decomposed sandstone-rock...	30 feet.	*f.*	Fine, mottled conglomerate and grit	24 feet.
b.	White and blue clay	6 inches.	*g.*	*Red conglomerate* (Main Reef Leader)......	6 inches to 2 feet.
c.	*Red conglomerate* (North Reef)	1 to 3 feet.	*h.*	Coarse compressed grit........................	34 feet.
d.	Red and white micaceous sandstone	8 feet.	*j.*	*Red conglomerate* (South Reef)	6 inches to 2 feet.
e.	*Red loose conglomerate* (Main Reef).........	12 to 15 feet.	*k.*	Hard grit	to end of cross-cut south.

Fig. 2.—*Section across the Henry Nourse Mine.*

[200-feet level—West Main Shaft.]



a. Quartzite.
b–b_4. Conglomerate-bands.
c. Decomposed Igneous Rock.
d. Chloritic Schist.

composed of silvery-grey micaceous matter, and is schistose in character.

The composition of the *North Reef* is very similar to that of the Main Reef, but the pebbles are on an average smaller, and many composed of quartzite are met with.

The *South Reef* has usually a larger number of black quartz-pebbles, and the rock is much more compact than any of the other reefs. It is most like the Main Reef Leader, and is generally the richest in gold, though there are patches in the other reefs which are sometimes as rich. In one or two places this reef is very considerably narrowed, but it is never quite lost.

The *Main Reef Leader* calls for little remark, except that, when traced east and west from the central shaft, it is found to 'pinch out' in many places, giving it the local appearance of a series of lenticles.

The predominating colour both of the reefs and of the rock between them (called in the district the 'country rock') is chocolate-red. Many of the harder portions, however, which are unchanged, are blue or bluish-grey in colour; and in the lower (130 feet) level the whole of the rock is found to be blue, except along joints and faults where water can find its way. The whole of the strata at this lower level, but more particularly the conglomerates, are crowded with cubical crystals and ellipsoidal particles of iron pyrites, and it is clearly by the oxidation of these and the consequent iron-staining that the red colour is produced. The reefs also at this lower level are found to retain their relative positions, but a complete change has taken place in the character of the cementing material and of the rock between the reefs. The conglomerates and sandstones, which on the upper level are soft and incoherent, become lower down dense and hard.

The surfaces of the adjacent rocks in contact with the conglomerates—that is, the 'foot and hanging walls,' as they are called—are smooth and polished, as if the beds had been pushed over one another from the south. That this movement has taken place, at least partially, is made clear in the eastern half of the mine, where there is a reversed fault of a few feet upthrow. The pebbles and cementing-material of the conglomerates show signs of having undergone great pressure. The pebbles, which are of a beautiful milk-white colour, are completely shattered; while the cementing-material is decidedly schist-like, and is squeezed in and out and around the pebbles. Much silica appears to have segregated out from the rock and exists now as quartz-veins. These are not numerous in the Salisbury Mine, but in the mine next to be described they form a very prominent feature.

In the eastern half of the Salisbury Mine the strata are broken through by a dyke of altered igneous rock whose original composition the writer has not yet been able to determine. The dyke is about 40 feet wide, and strikes across the beds at a very acute angle along a line of fault which shifts the reefs horizontally for a foot or two.

(2) *The Henry Nourse Mine* is situated about 3 miles east of

the Salisbury Mine, on the outcrop of the Main Reef. There is in this mine, as in others, a great difference between the rocks at the upper and lower levels. No one, probably, examining the beds at the surface alone, would think that the red-stained, crumbling, soft pebble-beds and shales looking like a series of ordinary sedimentary deposits above, become below bluish conglomerates, schistose rock, and hard quartzites. Surface-outcrops in the Transvaal, therefore, are not to be relied upon as showing the true nature of the rocks as they appear below.

The sequence of the beds on the lower level is shown in the section on p. 411 (fig. 2).

The quartzite (*a*) is intensely hard and reveals planes of movement. It carries a large proportion (sometimes as much as 10 per cent.) of crystals of iron pyrites. Much of the silica has segregated out in the form of quartz-veins, many of which reach a thickness of 2 feet.

The conglomerate-bands or reefs (b–b_4) are here *five* in number, and appear from the strike to be continuations of those in the Salisbury Mine. As far, however, as can be judged from a section of such limited height (5 feet) as a 'drive,' the bands are always distinctly wedge-shaped, the thin end of the wedge being downwards. The pebbles are shattered, and the cementing-material is in a schistose condition. On the surface of the ground only two reefs are seen. This difference can be accounted for in two ways: either the bands (b–b_4) are lenticles of conglomerate, which die out above and below, and are replaced by others at different horizons; or they are duplications of one or more bands by overfaulting. Looking at the metamorphosed nature of the surrounding rock, the latter view seems the more likely.

It should be noticed that it is one of the commonest results of mining operations in this district, as they are continued in depth, to cut through more reefs on the lower than are to be found on the upper levels, or at the surface. This is so in the 'Meyer and Charlton,' the 'Village Main Reef,' and the 'May Deep Levels' mines. Indeed the writer is unaware of a single instance in which this is not the case.

With the exception of band (b_1), which is nearly twice the thickness of any of the others, the bands are all of the same size, are identical in composition, and the beds between them are quite similar to each other. It is, however, impossible to say exactly to what extent the same beds have been repeated. Even one band may have been repeated several times. The conglomerate-band (b_1) is divided in the centre by a curved 3-inch layer of milk-white quartz. It looks, from the amount of displacement in the cementing-material of the conglomerate, and from the crushed nature of the pebbles, as if the conglomerate-bed had snapped and been thrust forward along a divisional plane marked by the thin quartz-layer.

The igneous rock (*c*) is probably a decomposed diorite. It is not crushed, and thus belongs to a later period than that of the disturbance which has affected the quartzites and conglomerates.

The schistose band (*d*) shows distinctly that very great pressure has been exerted both on the conglomerates and on the adjacent rocks. This band is about 45 feet thick, the quartzites (*a*) on either side of it being the most highly metamorphosed of any in the mine. It seems clear that this band (*d*) marks the place and the direction in which the rocks have yielded most to pressure. The resulting schist is probably chloritic.

The dip of the reefs in the Henry Nourse Mine is nearly 90°. In the deep level another conglomerate has been struck by a diamond drill at a depth so slight as to lead to one of two suppositions: either the dip of the reefs has decreased very rapidly, or the reef passed through by the diamond drill is one of those in the cross-cut north of the main shaft *repeated by faulting*.

The sections in the Salisbury and Henry Nourse Mines, described above, undoubtedly prove that the strata have been considerably disturbed, crushed, and metamorphosed. The succeeding descriptions of the Main Reef Series, as it is developed in the mines east and west of the typical locality along the line of strike, will show to how small an extent the strata vary in their original lithological character, and how widespread is such metamorphism as has affected them.

(b) *The Main Reef Series west of the Salisbury Mine.*

In the Robinson Mine, which lies about a mile west of the Salisbury, the Main Reef and the Main Reef Leader have approached until they come close together, the surfaces on either side of the divisional plane being smooth, and suggesting that the quartzite has been nipped out. There are thus in this mine only three reefs—a North Reef, a very thick Middle Reef, and a South Reef. The lower levels alone reveal the true nature of the strata. The schist-like character of the cementing-material is very apparent, portions of it exactly similar to true silvery mica-schist being common. The dip of the three reefs varies from 45° to 50° S., the change from that observed in the Salisbury Mine coming in west of the spruit which divides the Robinson property into two parts.

In the Langlaate Estate Mine, situated still farther west, we find a band 10 feet thick, lying to the north, called the Main Reef, another 5 feet thick (to the south) called the South Reef, and a very inconstant middle reef which may be the Leader. The true North Reef, if it exists at all, has not been reached.

In the Crœsus and other mines west of the Langlaate only two reefs, thinner than those described, are found, called respectively the Main Reef and the South Reef. The dip is 30° S. The South Reef is very variable, seldom exceeding 2 feet in thickness, while in many places it disappears altogether.

In the Durban Roodeport and Princess Mines this reef is sometimes represented by a single line of pebbles, while in other parts of the mines it thickens out. The rocks in both mines are highly cross-faulted. The composition of these reefs is almost identical with that of the reefs in the Salisbury Mine.

A drill-hole placed on 'Block B, deep level' reached a depth of 800 feet without striking any reef, the cores showing a schistose material with much iron pyrites. Another drill-hole in the Vogelstruis property (see Map, Pl. XI.) after passing through about 60 feet of the altered surface-rock, entered a bluish schist which continued for a depth of over 100 feet, when a diorite dyke was struck. The depth ultimately reached by the drill-hole was 423 feet, several layers of white crystalline quartz being passed through. Both in this quartz, and in the quartzite, crystals of iron pyrites were exceedingly numerous.

From the Robinson Mine to the Bantjes Mine an average dip of 45° prevails; from the latter to the Kimberley Roodeport Mine the average dip is 70°, and thence to the Banket Mine the dip gradually decreases until at last it is only about 15°. At the Banket Mine the reefs suddenly assume a northerly strike (see Map, Pl. XI.); a deep gully then intervenes, on the opposite side of which the reefs cannot be traced.

(c) *The Main Reef Series east of the Salisbury Mine.*

East of the Salisbury Mine we meet with much the same variation in the disposition of the reefs as in going west. In several of the mines we have more reefs below than are found at the surface. In the Jumpers Mine, 3 miles east of the Salisbury, three reefs are found. The dip between the two mines is never much less than 70°, the strike being nearly due E. and W. At the Jumpers Mine a break occurs, and the dip to the east is found to have decreased to 45°. The dip is still further lowered in the Simmer and Jack Mine to about 10°, after which it again increases; but, so far as the writer is aware, it never goes beyond 65°. East of the Jumpers Mine the strike has a slight northerly trend.

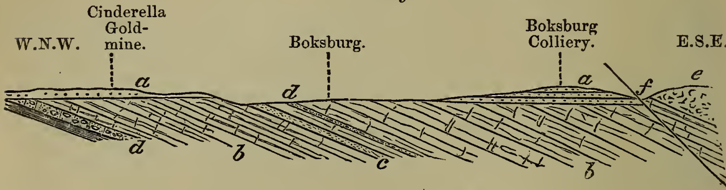
East of the Simmer and Jack Mine the distinction into 'north,' 'main,' and 'south' reefs vanishes. Several reefs are found, but in composition they differ somewhat from those of the Main Reef Series, and resemble more closely those presently to be described as lying to the south. In the United Main Reef Company's Mine a reef has been struck at a depth of 100 feet, which is a true conglomerate dipping at about 64° S.S.W. Immediately below is a band, a few inches in thickness, of glossy black shale. The cementing-material, or matrix of the reef, is very much greyer than that of any of the conglomerates of the Main Reef Series, and a few pebbles or fragments of black shale like that lying below are met with.

In the Cinderella Mine (see fig. 3, p. 416), a little north of Boksburg, a conglomerate or reef striking nearly N.E. and S.W. is worked for gold. Immediately beneath it is a blue slaty shale about a foot thick. The surface of the pebbles in the conglomerate is of a rich peacock-blue colour due to a coating of an oxide of iron. East of Boksburg the reefs are soon cut off by a large mass of diorite.

So far as the writer has observed, the thinning out and partial disappearance of some of the reefs is quite as common to the east as to the west of the Salisbury Mine; and the soft surface-rocks are also replaced below by hard beds having a schistose character.

In the May Deep Levels Mine five hard and compact conglomerates are admirably shown. These dip at 45°, and associated with them are thick beds of crystalline quartz, having the same dip. These are probably segregation-veins.

Fig. 3.—*Section across the Cinderella Gold-mine and Boksburg Colliery.*



[Length of section = about 1½ mile.]

a. Coal-bearing beds.	*d.* Conglomerates.
b. Quartzites.	*e.* Diorite.
c. Volcanic Ash.	*f.* Fault.

The distance over which the Main Reef Series can thus be definitely traced, from the Banket Mine to the Simmer and Jack Mine, is about 25 miles. Both east and west of the Salisbury Mine, as we have seen, only two conglomerates are found at the surface. Very varying dips are met with, but on the whole the dip decreases both east and west, and the beds gradually assume a southerly trend. Finally, it appears to be invariably the case along the whole line of strike of the Main Reef Series that the rocks, when traced downwards, assume more and more a schistose character.

3. The Gold-bearing Conglomerates south of Johannesburg.

On 'deep-level' properties it is always found that the reef is struck at a much shallower depth than would be calculated from surface indications, and that more reefs are met with below than appear at the surface. These facts are generally considered to show that the conglomerate-beds form a basin, and are decreasing in dip towards its centre. But there is scarcely a mine on the Randt that does not reveal abundant evidence of reversed faulting. In the case of the two diamond drill-holes placed on the Vogelstruis property (see Map, Pl. XI.) there can scarcely be a doubt that the apparent decrease in the dip of the reefs is due to this cause. In one of the drill-holes a sheet of diorite, apparently in a line of fault, was passed through immediately after the reef was struck: while the shaft north of the second drill-hole showed a reversed fault, with the upthrow portion of the beds flat, while the reef still farther north had a dip of nearly 70°. Such facts are decidedly opposed to the theory that the conglomerate-beds lie in a simple basin.

(a) *Second Reef Series, south of the Main Reef.*—There are some conglomerate-beds struck by the diamond drills which, so far as position is concerned, lie nearest to the Main Reef on the south, but these do not apparently come to the surface.

Two conglomerates called the Red and Yellow Reefs crop out, however, about a mile to the south of the Main Reef Series. The Red Reef is best seen in the Great Britain and Kimberley Roodeport Mines, situated about 9 miles west of Johannesburg; while east of Johannesburg both the Red and Yellow Reefs can be studied near Elsburg and Boksburg.

The outcrop of these reefs cannot be traced for any great distance, being generally hidden beneath the ubiquitous, superficial red soil. Where seen, their dip is always lower than that of the Main Reef Series, but proportional to it. As these reefs are not mined to any great depth it is impossible, from the limited nature of the observations, to state exactly what their composition is. Judging from surface-outcrops, they are unlike any one of the members of the Main Reef Series. The cementing-material of the reefs is much softer, and quartz-pebbles are rarer; while white and grey quartzites, together with black speckled sandstones, are very common. The associated rocks are grits and sandstones.

(b) *Third Reef Series, still farther south.*—The next well-marked conglomerates crop out about 5 miles south of Johannesburg, and form a line of escarpment facing the north. They are mined in only one or two places, and, except in the case of the Aurum Mine, never to a sufficient depth to reach the undecomposed strata. There are several of these conglomerates, and they are associated with grits and sandstones. In a shaft on the Aurum estate (see Map, Pl. XI.) the sandstones are found to assume more and more the character of quartzites, and to become slightly pyritous as they are traced downwards. The pebbles in the conglomerates are very much larger than in any of the reefs to the north—the pebbles averaging about 3 inches in diameter, while some are as large as a man's head. They are nearly all of a pure white quartzite, a few being of sandstone.

These conglomerates can be traced along the escarpment for about 15 miles, east and west. In the direction of the dip they are soon cut off by an immense outflow of basaltic and quartz-amygdaloid lavas, forming the heights called the Eagle's Nest (see Map, Pl. XI.). Along the whole line of strike the conglomerates have a uniform dip of 15° S. This is an interesting point, for north of a line drawn up the Klip River valley the strata are affected in the same manner, as to dip, as the Main Reef Series; while the conglomerates now under discussion, and the associated rocks which lie to the south of this line, are uniform in dip and strike for the whole distance mentioned above. It is thus probable that a fault runs up the Klip River valley. This hypothesis is further strengthened by the fact that the material thrown out at the surface of the 'Klip

Riversberg' Mine, which is situated on this probable fault-line, consists of highly schistose and cleaved rocks very much slickensided.

(c) *Beds near Germiston.*—Near Germiston, a small village S.E. of Johannesburg (see Map, Pl. XI.), three or four conglomerate-beds are shown in the Spruit near the village. This stream also cuts through a greyish-black band of volcanic ash about 15 feet thick, which breaks with a highly conchoidal fracture, and in appearance resembles a fœtid limestone. The only other locality known to the writer where volcanic ash comes in is near Boksburg (see fig. 3, p. 416). As the ash-band near Germiston lies more than a mile south of the Main Reef Series, whereas near Boksburg an ash-band closely resembling it, and also associated with similar conglomerates, lies only a few hundred yards south of what is mapped as Main Reef Series, we have either two separate beds of ash associated with conglomerate-groups and lying at different horizons, or there is but one bed of ash, and the associated conglomerates are the same. If the latter is the case, are we to suppose that the beds are thinning out towards Boksburg, or that a strike-fault brings the ash-bed at Boksburg nearer to the Main Reef?

Another solution may be suggested, viz., that the conglomerate-beds near Boksburg, and in fact those east of the Simmer and Jack Mine (situated a little west of Germiston), are *not* the Main Reef Series which occurs farther north, although they are mapped as such. They do not resemble the Main Reef as it occurs nearer to Johannesburg, but are rather more nearly allied to the Red and Yellow Reefs lying to the south.

Unfortunately the ground north of Boksburg is covered with grass, and exposures are rare. Taking into consideration, however, the change of strike in the Cinderella Mine, and the appearance of conglomerate-beds identical with the Main Reef Series to the N.N.E. (as shown in the Chimes and Van Ryn properties), together with the fact that the ash-band is similar to that near Germiston, it seems at least probable that the real Main Reef Series lies farther north of the Cinderella Mine.

4. The Conglomerates north of the Main Reef Series.

North of the Main Reef Series conglomerates seem to have been met with in only two places. One or more bands are said to exist north of Durban Roodeport, but these the writer has not examined. An interesting and excellent exposure, however, occurs in an isolated hill behind Jeppe's Township, situated about a mile east of Johannesburg.

The hill is about a mile and a half long by half a mile wide, and rises to a height of nearly 200 feet above the level of Johannesburg. It is partially cleft in the centre by a gully in which a section (see fig. 4, p. 419) was obtained. Two very marked groups of beds are exposed. The lower one is composed of quartzites of varying hardness, and quartz-schists resting on hardened red shales; the upper one is composed of conglomerates and compact sandstones. The lower set suggest the beds of the Main Reef Series highly compressed; the upper set bear a strong petrological resemblance to the conglomerates and sandstones described as occurring about 5 miles south of Johannesburg, and therefore about 6 miles south-west of this hill.

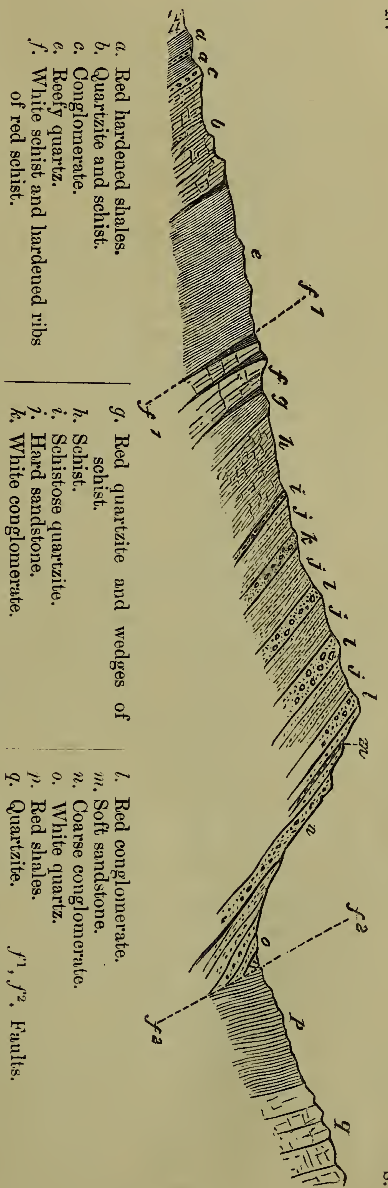


Fig. 4.—*Hill behind Jeppe's Township.*

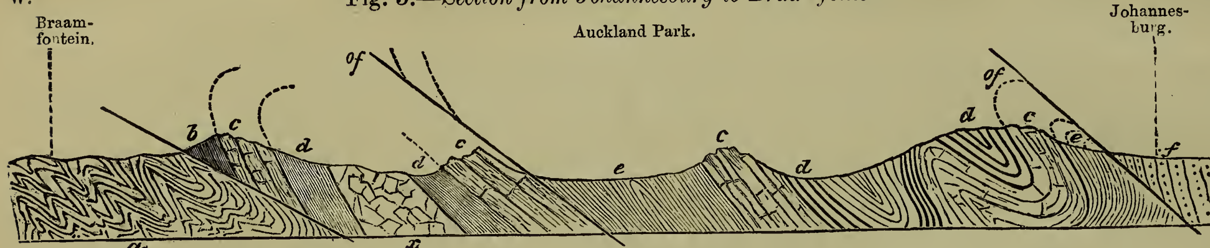
The shales (*a*) dip at an angle of 60° S. Traced westwards from the gully they thin out like a wedge; eastwards they broaden, ascend the hill, become intensely hard, black, and much twisted, and finally end off against hard white quartzites. There is no sign of break or fault where the junction occurs, nor do the two sets of beds interdigitate. This curious phenomenon is possibly due to a thrust-plane. The schist and quartzites (*b*) and the conglomerates (*c*) climb the hill with the black shales and end off similarly against the white quartzites. The reef-like beds (*e*) consist of very hard white quartzite with a few scattered and broken pebbles. The quartzites and micaceous schist (*g*) show signs of great pressure. The bands of schist are distinctly wedge-shaped, and are caught up and twisted in and out among the associated quartzite in a remarkable manner. There is also at this point a change of dip from 60° S. below to not more than 30° S. above. This seems to mark the place where the beds have given way most, though any distinct plane of movement is not apparent. The conglomerates and sandstones (*j* to *n*) do not call for special mention. Assays give no trace of gold. They dip to the S. at an angle of 30°, and are soon faulted against red shales apparently identical with band (*a*). These red shales (*p*) have a slight northerly dip close to the fault; they then become vertical, assume a southerly dip, and finally pass beneath nearly perpendicular quartzites (*q*). The whole of the red shales mentioned appear to be identical in composition, and probably in thickness, with those presently to be described as lying north of Johannesburg. The fault (f^2) is marked by a two-foot band of white quartz.

The remarkable conglomerates, &c., of this hill must either be above or below the Main Reef Series. If, as their composition and poorness in gold tend to show, they belong to the series lying south of the Main Reef Series, they can have come into their present position only in one of two ways—either they have been faulted down, or they have been brought up from below. If the latter be the case, and if their close resemblance to the more southerly reefs may be relied upon as proving the identity of the two, then the apparent sequence of the conglomerate-beds of the Randt is a false one, and the reefs which are now the highest are the oldest. If, however, they have been faulted down they are of course newer.

5. The Lower Quartzite-and-Shale Group north of Johannesburg, and its relation to the Main Reef Series.

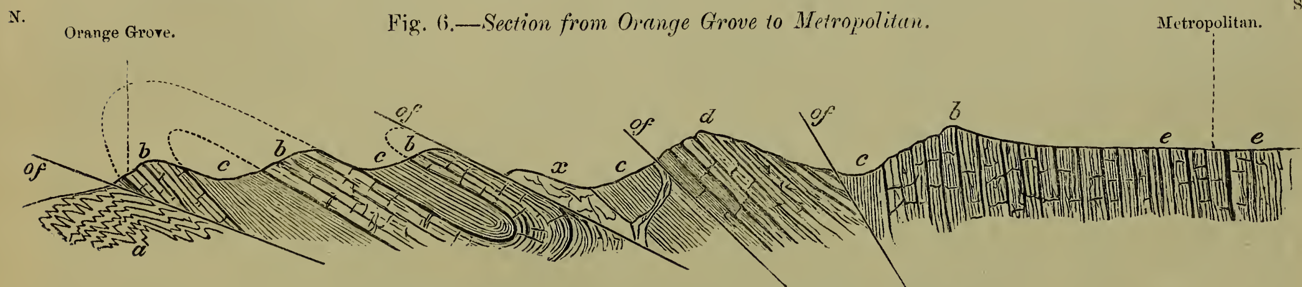
Immediately north of Johannesburg the ground rises in an abrupt ridge to the height of about 130 feet above the town. This ridge is one of four, all of which present steep escarpments to the north, and are separated from each other by deep valleys running east and west. The ridges consist for the most part of white quartzite, while the valleys between are excavated in red and highly ferruginous shales. The quartzites have an average dip of about 45° S., but the shales show varying dips—sometimes nearly 90°, and never much below 45°. The first ridge consists of white quartzite underlain by grey and yellow flaggy sandstones, the second and third ridges are entirely of white quartzite, while the fourth is in places a white, crystalline quartz-rock. The first valley is widest and reveals more of the strata than the other two. In it the shales underlying the flaggy sandstones are beautifully ribbed with layers of crystalline quartz; they are black above, but pass down into red shales of the same character. Both are considerably hardened. The two succeeding valleys to the north are occupied by red shales alone. Quartz veins, often crossing each other at right angles, are frequent both in the shales and quartzites, but are far more numerous in the fourth ridge than in the others. The bands of quartzite and shale can be traced westwards for nearly 20 miles to a little beyond Krugersdorp. Eastwards the third and fourth bands of quartzite soon unite and finally end off against a strongly-marked fault (see Map, Pl. XI.). (See figs. 5 & 6, facing this page.)

Fig. 5.—*Section from Johannesburg to Braamfontein.*



a. Gneiss and schist.
b. Altered shale.
c. Quartzites.
d. Black shales.
e. Red shales.
f. Main Reef Series.
x. Diorite.
of. Overthrust faults.

Fig. 6.—*Section from Orange Grove to Metropolitan.*



a. Crystalline rocks.
b. Quartzites.
c. Red shales.
d. Conglomerates and schists.
e. Main Reef Series.
x. Igneous rock.
of. Overthrust faults.

The quartzites are identical in thickness, but the shales occupying the first valley are as thick again as those filling the other ravines, owing to the presence of the ribbed black shales, A section across the latter may be seen behind the Landdrost's house. Their disposition is such as to afford most unquestionable evidence that the rocks have been much folded and overthrust. The beds have been thrust forward to such an extent that the axes of the folds have passed the vertical; and even hand-specimens are marked by minor ripplings, which *in situ* have the same general southerly dip and east-and-west strike as the beds themselves. The red shales following the black ones to the north are as a rule inclined at a much steeper angle.

A tunnel on the Houghton Estate (see Map, Pl. XI.), driven into the escarpment formed by the northernmost band of quartzite, passes first of all through an exceedingly crushed and altered shale. Pressure has almost entirely disguised its true nature; it is crossed and recrossed by numerous veins of crystalline quartz, while the original felspathic constituents have become highly talcose, and the banding caused by the different tints of red and green resembles that of serpentine. Traced westward the shale becomes less altered, and can finally be recognized as a hardened red shale identical with that occupying the valleys. In the road-cutting, a little west of the tunnel, the shales are seen to be twisted in and out among the quartzite. They are not, however, so metamorphosed as in the tunnel, and are still recognizable as shales, although intensely hardened and partially changed into schist. Farther in the hill the tunnel shows the strata curving upwards. This is very markedly the case with a two-foot band of conglomerate. The pebbles in it are small and much shattered. The cementing-material (matrix) is a green chloritic substance of schistose character, and this flows between and around the pebbles, forming a rock resembling in appearance an *augen-gneiss*. Gold is present, but is not equally disseminated through the rock.

The crushed state of the shale, the upward curving of the strata, and the visible features of the conglomerate are all strong evidences that a thrust-plane of great importance is being approached; and before long we find the quartzites of the series resting at once on gneisses and schists, the plane of contact being probably the plane where the maximum differential movement of a powerful thrust was brought about.

The third valley is largely filled up by a sheet of diorite. This is very fresh-looking and apparently unaltered. It is clearly later in age than the powerful crust-movements to which the quartzites and shales have been subjected.

The first band of quartzite which has just been mentioned lies about a mile to the north of the Main Reef conglomerate series. Throughout the whole length of its outcrop it retains an average dip of 45° S., never being much higher or lower. The Main Reef Series, on the contrary, is nearly vertical in the centre, while east and west the dip decreases to an average of 15° S. Now the strata occupying the ground between the Main Reef Series and the Quartzite-and-Shale Group are everywhere found to have the same dip as the Main Reef Series. It has also been already stated that the quartzite bands die out eastwards against a fault. There cannot therefore be any doubt that a fault separates the Main Reef Series and its associated beds from the Quartzite-and-Shale Group below. The strata occupying the ground between the outcrops of the two groups are composed of lenticular bands of sandy quartzite, compact quartzite, and red shales. It will be seen, on referring to the Map (Pl. XI.), that the beds composing the Quartzite-and-Shale Group keep the same relative distance from the Main Reef Series from Johannesburg to the Banket Mine on the west, and to the Jumpers Mine on the east. Evidently the two groups form portions of one larger series, but the exact sequence and relationship of the beds cannot be fully made out, owing to the break occasioned by the fault.

B. Physical Relationships of the Witwatersrandt Rocks.

1. *Relation of the Lower Quartzite-and-Shale Group to the underlying Rocks.*

The rocks underlying the entire series of quartzites and shales already described are found to consist of highly crystalline and metamorphosed beds, which have been intensely crumpled and plicated. The nearest approach to an absolute junction between the two sets is found on the Houghton Estate (see Map, Pl. XI.). It has been previously mentioned that a tunnel driven into the fourth ridge of quartzite passes first of all through some highly metamorphosed shales. In a vertical shaft, a little to the north, gneissic rocks were struck at a depth of about 30 feet; the ground between the mouth of the tunnel and the shaft is quite flat. Small isolated patches of an intensely hard and highly schistose quartzite are found in several localities north of the Houghton Estate. In one or two places these patches can be seen to overlie gneissic rocks, but any absolute junction of the two could not be discovered. In one spot, about 3 miles north of the manager's house, a small boss of pegmatite crops out. The crystals of quartz in this are sometimes 3 inches long and about $\frac{1}{8}$ in. across. The felspar is of a faint pinkish-white colour, the crystals being sometimes very large. The exposure is not sufficiently extensive to show whether this coarse granite is intrusive. To the east, and not more than 200 yards off, a dyke of fresh-looking diorite is found with a north-and-south trend.

In the main shaft of the Houghton Gold-mine a vein of quartz enclosed in quartzite suddenly dies out, at a depth of about 60 feet, against a pinkish-red granite. It was stated by the manager that the quartz-vein and the associated rock commence with a southerly dip, which considerably decreases in amount to the south, till finally the rock becomes horizontal, and then assumes a northerly dip till it ends off against the granite. It is to be noted that the nearer the quartzites and shales approach the gneissic rocks the more schistose they become, and in no case can it be said with certainty that the granite is intruded into the sedimentary beds.

About six miles west of the Houghton Mine a conspicuous hill rises up from the veldt. It is composed of white schists and quartzites having a high dip to the south. Farther north the surface of the country is composed mainly of igneous rocks.

These igneous rocks are of two dates. The older set have been intensely altered by pressure, and strike roughly east and west. They appear to have been highly basic in character, and many secondary minerals have been formed—chlorite, talc, and asbestos being the commonest. The chlorite occurs in large plates; the asbestos fibre is short, and not of first-rate quality.

The newer set also consists of basic rocks, but the strike is here north and south, and the material is unaltered. The principal rock is a diorite, which occurs in dyke-like masses and cuts across the older metamorphosed series.

2. *Relation of the Quartzite and Conglomerate Series to the overlying Strata.*

We have seen that the age of the quartzites and conglomerates can be determined neither from the strata themselves, for they are unfossiliferous, nor from the underlying rocks, as these consist of gneisses and schists. All that can safely be said is that there is a marked unconformity between them and the rocks below; and it is disappointing to find that in the only locality where any of the overlying rocks have yet been discovered a very great unconformity also intervenes. The age of the conglomerates or reef-beds is therefore left wholly undetermined.

The unconformable beds overlying the conglomerate series are the coal-bearing strata of the Boksburg and Heidelberg districts. Good sections can be obtained in any of the coal-pits; but the relation of the coal-beds to the conglomerates can be best studied in the inclined shaft of the Cinderella Mine, and in the adjoining property of the 'Blue Skip.'

The section (see fig. 3, p. 416) displays about 30 feet of white and yellowish-white sandstones, resting nearly horizontally on the edges of the conglomerate-beds which dip 45° S.S.W. That these sandstones belong to the same series of rocks as those shown in the shaft of Wishaw Colliery is sufficiently clear from the contour of the ground and the identity of the beds in the gold-mine and the colliery. The strata in the colliery, lying above and below a seam of coal about 11 feet thick, consist of white and yellowish-white sandstones.

In many places around Boksburg and Heidelberg patches of coal-bearing beds exist, and in some cases are worked for coal. The coal-seams are without underclays; while olive-white and yellowish-white sandstones form the interstratified layers. Compared with English types the coals are of a very inferior quality, containing a very large percentage of incombustible matter. On the Nigel

Mynpacht Mine property (see fig. 8, p. 431), lying about 9 miles S.S.E. of Boksburg, coal has been discovered, and is worked for the use of the 'battery' and mine-engines. In a short visit which the writer paid to the coal-shaft there were found lying on the surface several pieces of dark limestone breaking with a conchoidal fracture and resembling in appearance the 'peldon' bands and *Spirorbis* limestone of the Upper Carboniferous measures of England. No fossils were discovered in it.

Wherever the writer has seen the coal-bearing beds of the Orange Free State—near Klerksdorp, Kroonstad, and Wynburg—they are identical with those of Boksburg and Heidelberg. In the river at Kroonstad a very good section of the horizontal olive-white and yellow sandstones is exposed. In the Heidelberg and Boksburg districts the coal lies in detached basins; these basins are very shallow in the Transvaal, but in the Orange Free State the coal-strata will probably be found to constitute much thicker deposits, while it is certain that they cover much wider areas than in the neighbouring Republic.

From the fact that the coals contain a large quantity of fine black shaly material, and that underclays are invariably absent—coarse sandstones forming both 'roof' and 'floor,'—it is highly probable that the coals are of drift and lacustrine origin. This conclusion is also supported by the fact that all the evidence tends to point to their Karoo or post-Karoo age. For, as it seems generally agreed among all those who are personally acquainted with South African geology that the present central plateau is of pre-Karoo age, the Karoo and Stormberg beds must be of terrestrial and freshwater origin. Now, in the Orange Free State the coal-beds are of acknowledged Upper Karoo and Lower Stormberg age, and it seems certain that the coals of the Transvaal and of the Orange Free State belong to one and the same geological formation.

A detailed account, however, of the coal-beds of the Transvaal is beyond the scope of this paper. What is learnt from them in reference to the Reef Series is, that the interval between the tilting and the denudation of the latter and the deposition of the coal-bearing strata was a long one. Ultimately the Southern Transvaal seems to have been converted into a lake-basin, or more probably into a series of lake-basins, into which logs of timber and other drift-materials were floated, their relics constituting the present coal-seams.

3. *The Faults, Dykes, and Igneous Rock-masses of the Witwatersrandt.*

In a series of rocks which from constitution and alteration are so similar that no distinctive band can be certainly settled to have a definite horizon, and where the outcrops are largely concealed beneath superficial deposits, it is of course impossible to lay down the position and direction of the faults with complete accuracy. The directions of those inserted upon the accompanying Map (Pl. XI.) are thus more or less inferential, but it is believed that in no case has any fault been laid down without strong evidence of its existence.

The majority of the smaller faults in the mines cut at a very acute angle across the beds, till in very many instances they become strike-faults having an east-and-west trend. Such faults are extremely common, scarcely a mine being without one or more examples. North-and-south faults are somewhat rarer, the outcrop of the Main Reef Series being very little shifted along its whole length.

It has been previously mentioned that west of the Banket Mine there is evidence for a large fault cutting off the Main Reef Series (see Map, Pl. XI.). Now, around Krugersdorp, about six miles north-west of the Banket Mine, several reefs are found having no definite relationship to the Main Reef beds, but resembling those that occur to the south. The dip is very various, a shallow dip at the surface becoming vertical below, and *vice versâ*, and the existence of numerous small faults is shown in the mines. None of these beds, however, can be traced far eastwards, while the Main Reef cannot be traced westwards. Taking all these points into consideration, it seems highly probable that these reefs to the south of Krugersdorp are dislocated portions of those lying south of the Main Reef, and that they are cut off eastwards by a strike-fault which is an extension, or a branch, of that running up the Banket Spruit. The Main Reef Series should, unless the thinning-out shown in the Durban Roodeport and Princess Mines represent an actual dying-out in the beds, be met with to the north-west of Krugersdorp.

On the map two nearly north-and-south faults are represented as cutting off the Main Reef Series to the east and west. The western fault has just been referred to, and the evidence for the existence of the eastern fault is nearly identical in character. At Boksburg the reefs are found to be turning sharply to the south, and finally to end off against a mass of diorite. In the Chimes Mine, 3 miles N.N.E. of Boksburg, a reef is worked, which, if mineralogical composition can be relied on as indicating identity, is one of the Main Reef Series. Even if the Boksburg reefs belong to those lying south of the series just mentioned, still the reef in the Chimes and Van Ryn's ground lies too far north to be one of the Main Reef beds, unless brought into its present position by faulting.

The great east-and-west fault behind Johannesburg can be easily detected by its cutting off one member after another of the quartzites and red shale-bands in going from west to east. My reasons for supposing this to be a reversed fault have been already given, as have also those for placing a fault up the Klip Riversberg valley.

Throughout the Randt the result of the faulting has been to cut up the country into a series of strips striking east and west. How much of the sequence of the beds is concealed, and how much of the apparent thickness is due to repetition, the writer is unable to say.

Very few instances occur of igneous rocks intruding into the

Main Reef Series. In the Vogelstruis Mine (see Map, Pl. XI.) a diamond drill cut into a dyke of diorite. The dyke, however, proved to be nearly vertical, so that boring was stopped before the thickness of the dyke could be ascertained. In the eastern portion of the same mine a nearly vertical dyke about 30 feet thick was drilled through. The composition of this diorite is unlike that of any other igneous rock in the Transvaal. A large proportion of the felspar is decomposed, and the lime has separated out in the form of calcium carbonate. From the evidence of the surface dumps of the Percy and Jumpers Mines it appears that a dyke of the same material has been passed through there.

With the exception of the thin grey ash-beds, already mentioned as occurring near Germiston and Boksburg, nothing else of a volcanic or igneous nature is associated with or interferes with the Reef Series.

In the western portion of the Princess Mine a dyke filled with blue clay, about 40 feet thick, runs nearly vertically across the beds. The clay is very much compressed, and seems to have filled up an open fault, the sides of which afterwards closed in. So far as seen there appears no tendency in the dyke to narrow as it descends.

None of the southernmost reefs are pierced, so far as I am aware, by any igneous rock, though they are in close proximity to a thick mass of basalt.

In the quartzites and red shales lying below the gold-bearing series there are abundant intrusions of igneous rock. In the second valley north of Auckland Park (see fig. 5, p. 421) a sheet of very fresh-looking diorite, with the crystals of hornblende but little decomposed, pierces the beds, sending veins into both the quartzites and the shales; and in the northernmost, or fourth, ridge of quartzite, previously described, thin sheets and small veins find their way along the joints and bedding-planes.

Igneous material, but of a totally distinct type, occurs locally at the surface and intrudes into the conglomerates and other beds constituting the hill behind Jeppe's Township (see fig. 4, p. 419). The rock is a quartz-amygdaloid lava of an intermediate character, containing porphyritic crystals of a dirty-white felspar. This rock also fills up a large portion of the valley east of Doornfontein.

Both these types of igneous rocks very strongly resemble in their general characters the dominant igneous material of the Southern Transvaal. They are but little altered, and have not been affected by the movements that have tilted, shifted, and often ground up the associated strata.

It is certain therefore that the upheaval, dislocation, and folding of the Witwatersrandt strata occurred before the grand eruptions or intrusions of igneous rocks, and that these eruptions and intrusions took place at least at two distinct periods. It seems equally certain that it was not the granitic base which moved, but that the overlying rocks were thrust over an underlying and much older crystalline series.

4. *Summary of Observations and Conclusions respecting the Physical Relationships of the Gold-bearing Conglomerates and Associated Rocks.*

The facts brought forward in the foregoing account of the more important sections within the limits of the typical Witwatersrandt district seem to the writer to show conclusively (*a*) that the Witwatersrandt strata have been subjected to great lateral pressure acting from south to north; that (*b*) they have been locally dislocated, and the dislocated masses have been driven forward over each other along more or less oblique thrust-planes. The crust-movements have not only induced overfolding and overthrusting to such an extent as in many cases to considerably alter the original relationship of the beds, but have frequently changed, almost completely, the original petrological character of the rocks.

It has not been possible, with such knowledge as the writer has been able to obtain, to determine with certainty the true geological succession of the beds of the district as a whole. So far as we are at present acquainted with the facts it appears possible to hold either of the two following views with respect to the sequence generally:—

First, that the observed order is a naturally ascending one, but is more or less disguised by faulting, folding, and thrust-movements. If this be so, and if further we assume that the igneous rocks of the Eagle's Nest repose on nearly the summit of the conglomerate series, and that the quartzites and shales overlying the schists of the Houghton Estate are the base, we have presented to us a group of strata which, trusting only to the apparent dip, would seem to be at least *three miles* in thickness. Moreover, this apparent sequence of quartzites and shale, quartzites and conglomerate, suggests an oscillating but gradually shallowing area of deposit. In this case the basal conglomerates of the series may lie farther to the north, and have yet to be discovered.

Second, that the apparent order of the strata of the district is the reverse of the true order. The quartzites, shales, and conglomerates forming the Main Reef Series will then be the highest, and will represent the deep-water deposits, of which the coarser conglomerates composing the southernmost reefs are the shallow-water equivalents.

Which of these views is the nearer to the actual truth remains at present an open question. So far, however, as our present knowledge goes, the conclusions to which the observations of the writer within the typical district definitely point may be briefly stated as follows:—

(1) The gold-bearing conglomerates, together with the quartzites and shales of the Witwatersrandt, form one definite geological series; but neither the base nor the summit of this series can as yet be fixed.

(2) This series is certainly much *newer* than the locally eroded schists, granites, and gneisses which now underlie it. On the other hand, the gold-bearing conglomerates and associated rocks are very much *older* than the horizontal coal-bearing beds which overlie them unconformably.

(3) The occurrence of pebbles of red sandstone in some of the reefs shows that there must have been a still older series of sandstones from which these pebbles were derived. This older sandstone series may yet be discovered.

(4) The entire series of beds associated with the gold-bearing conglomerates has been (at least locally) thrust over the gneisses and schists, and was not originally deposited in its present position.

(5) The movements to which the beds have been subjected have taken place in two directions—the more intense movement being from *south to north*, and a less effective one from *east to west*. The result of these two movements is that the beds now occupy a basin-shaped area, along the margins of which the strata have everywhere given way; while the rocks have been crushed, overthrust, and altered locally into schists, quartzites, pseudo-quartzites, and gneisses.

(6) After the cessation of these earth-movements the strata were injected with igneous material of basic and sub-basic types; and much of the country was flooded with lavas of the same character. The presence of the iron pyrites, so abundant in the quartzites and conglomerates, has probably some connexion with this volcanic outburst.

(7) The conglomerates seem to have been formed mainly at the expense of the underlying granites and schists, which may have contained numerous veins and larger masses of auriferous quartz.

(8) Some of the newer schist in the conglomerate-bands seems certainly due to metamorphism arising from pressure and movement acting since the conglomerates were deposited.

III. GEOLOGY OF DISTRICTS OUTSIDE THE TYPICAL WITWATERSRANDT AREA.

1. *The Chimes Mine and Heidelberg Districts.*

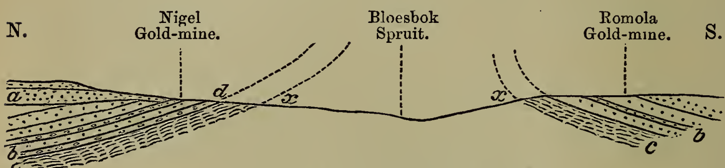
As the rocks of the typical area have been described somewhat fully, the strata of similar age met with in other parts of the Transvaal will be treated of in a more cursory manner, sufficient details only being given to throw light upon the general structure of the country.

Although the geology of these outlying districts looks at first sight far more complex than that of the Johannesburg area, their structure is really much simpler. It soon becomes evident on examination that the strata have been thrown generally into shallow folds, and afterwards pierced in all directions, and often overflooded by igneous rocks.

It has been previously mentioned that the reefs are cut off to the east near Boksburg by a mass of diorite, and that they come to the surface again, about four miles to the N.N.E., in the Chimes and Van Ryn properties (see Map, Pl. XI.). A true conglomerate with associated quartzite is here exposed, the strata striking nearly due north and south, and dipping to the west.

The conglomerate-beds also crop out about 15 miles S.S.E. of Boksburg, and are worked for gold in the Nigel and adjoining properties. In the Nigel Mine (see fig. 7) the lowest reef is under-

Fig. 7.—*Section across Nigel and Romola Gold-mines.*



[Length of section about 2½ miles.]

a. Coal-bearing beds. | *c.* Slaty shales.
b. Conglomerate-beds. | *d.* Nigel Reef.

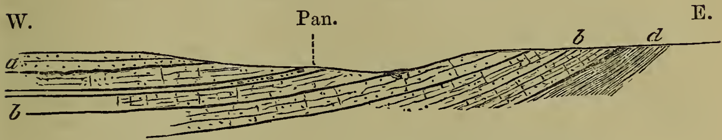
Between the points *xx* the country is grass-covered.

lain by red shale, about 60 feet thick; while the bed immediately above this reef is sandstone. The reef has an average thickness of 2 feet. Traced downwards the underlying rock approaches more and more in character to a slate or schistose rock, while the sandstone above it changes into a quartzite. The dip is 30° N.; the strike due east and west. The dip of the overlying conglomerates gradually decreases northwards, till in about a mile they become perfectly horizontal. Traced westwards the strike of the beds gradually assumes a southerly trend, while the dip is eastward. In the Remboro, Lavers-Nigel, and other properties towards the east, the Reef series changes its strike to a northerly one, the dip being then westward. Evidently the strata have been folded to form a basin.

In the eastern portion of the Nigel Mine and in the adjoining properties the reef is very thin. In the Lavers-Nigel a shaft sunk in the associated shale showed that this becomes intensely hard and schistose lower down, the usual red surface-colour changing to blue. The soft nature of the shale at the surface is due to oxidation. The banding and colouring in these oxidized shales are marvellous, tints from the brightest red to the dingiest brown, with deep and light blues streaked with orange and gold, predominating. Some of the colours may justly be likened to the cloud-colourings of an autumn sunset.

The reef at the surface is in all cases very narrow; but in a shaft sunk quite recently on the Remboro property, at some distance from the outcrop, the reef below is found to be 2 feet thick. Here, as in the typical area, we find that the strata have suffered considerable disturbance.

Fig. 8.—*Diagram-section, east of Nigel Mynpacht.*



a. Coal-bearing beds.
b. Conglomerate-beds.
d. Red slaty shales.

About 2 miles south of the Nigel Mine a reef, underlain by shale, has been struck in the Romola and Florida Mines; the dip is south. The intervening ground between these mines and the Nigel is thus seen to be occupied by strata forming the summit of an anticline. Unfortunately there are no exposures to be found. In the section (fig. 7, p. 430) it is made to appear that the low dip can be accounted for by denudation having removed the larger part of the anticline. The schistose nature of the rocks, where these are not decomposed, shows that disturbance has taken place. The ground between the Nigel and Romola Mines is occupied by a valley, north and south of which the strata gradually flatten out.

Near Heidelberg, about 9 miles S.S.W. of the Nigel Mine, conglomerates and sandstone crop out, forming the rocky foundation upon which the town is built. The same beds also compose the hills lying behind it. In the town section the beds are almost horizontal, but westwards the dip increases to an average of about 15°. On the eastern side of the town, however, immediately after crossing the Bloesbok Spruit, the strata are observed to have a very high dip.

A little farther to the N.E., in the Marais-Nigel Mine, a reef underlain by red shale, identical with that in the Nigel Mine, dips at an angle of 30° W. These frequent changes of dip and strike suggest very forcibly to the mind of the observer the fractured and disturbed state of the country.

The sandstones are exposed west of Heidelberg, along the Johannesburg road, for about 2 miles, when they are covered up by a quartz-amygdaloid lava. From this point westwards, all up the Klip River valley—and how much farther it is impossible to say,—the whole country is flooded by volcanic rocks. In one or two places, however, as in the Black Reef Mine, the quartzite-and-conglomerate series comes to the surface with a very gentle southerly dip. The writer had no opportunity of examining these beds carefully.

About 35 miles south of Johannesburg, on the Kimberley road, some high hills are composed of quartzite, dipping to the south at a small angle; but volcanic country soon comes in, and the strata are covered up. Farther on along the same road—three stages from Potchefstroom—horizontal olive shales and some sandy beds are exposed on the roadside; they are probably of Karoo age. Volcanic country again prevails as far as Potchefstroom.

On the banks of the Vaal, at the farm called Strykfontein (see Pl. X. fig. 1), 35 miles south of Johannesburg, thin conglomerate-bands and quartzites are shown dipping northwards at a low angle; it is said that these reefs can be traced as far as Heidelberg. Following the banks of the Vaal in the direction of the stream, a thick sheet of compact undecomposed basalt soon conceals everything.

2. *The Vredefort and Potchefstroom Districts.*

Crossing the Vaal River at Vaal Pont, and going in a direction a little to the west of Heilbron, we find gently undulating, grass-covered prairie land extending on either hand as far as Vredefort. Outcrops are very rare; where the rock is seen it is almost invariably of an igneous character. But in one spot, about 6 miles from Vaal Pont, in a S.S.W. direction, a section is exposed of conglomerates dipping at an angle of a few degrees to the west. As at Strykfontein, however, the strata are soon buried beneath igneous rocks. West of Vredefort, and in the immediate vicinity of the town, gneisses, schists, granites, and gabbros form the low hummocky ground, and large blocks of these crystalline rocks are scattered about the town and its neighbourhood. Possibly these blocks may be erratics; but it is much more probable that they are simply unweathered fragments of the underlying rocks. One fact bearing out this conclusion is that after travelling for about 4 miles to the west of Vredefort the ground rapidly rises into high and rugged hills, which are found to consist of quartzites and conglomerates, dipping at a very high angle to the west. This looks as if some disturbing influence had acted in the neighbourhood; and from what we know has happened on the Randt, as well as from other evidence, it seems reasonable to believe that the quartzites have been pushed up against a bank of crystalline rocks. So far as the writer is aware, there is no evidence of glaciation so far north in South Africa.

The hills just mentioned as lying west of Vredefort present precipitous slopes and bristling hog-backed summits; the beds of which they are composed are admirably displayed, and their twists and curves are easily traceable by the eye for several miles along the strike, which is roughly north and south. For some distance westwards the dip continues to average nearly 90°; but farther on in the same direction it is slightly less and to the west. This high dip is continued as far as Lindequisfontein, a distance which may be roughly estimated as 10 miles. Here the strata again form high hills, but the dip, although still high, is now to the east. Up to Lindequisfontein the beds are composed of red shales and quartzites, with here and there a thin conglomerate-band. The whole series is identical with the Quartzite-and-Shale Group lying beneath the Main Reef.

To the west of Lindequisfontein the strata consist of quartzites and thick conglomerates, the latter being poorly auriferous, and some of them being immediately underlain by a thin shale; these conglomerates and quartzites strike across the Vaal River near Schoeman's Drift; but they soon become covered up westwards by igneous rocks of a basic type. The series comes to the surface again a few miles west of Potchefstroom, and both easterly and westerly dips are frequent, showing that the beds are thrown into small folds. The country is again very much flooded with igneous rocks until the Buffelsdoorn Estate is reached, when quartzites and thin conglomerates with red shales come in, dipping at about 45° E.

The diagram-section (Pl. X. fig. 3) shows the probable structure of the country from Vredefort to Buffelsdoorn. That it is very much faulted and folded is unquestionable; but the actual details of the movements and disturbances can only be surmised.

3. *The Klerksdorp and Kroonstad Districts.*

South of Buffelsdoorn the country is again flooded with igneous rocks; but about 9 miles to the S.S.W. the conglomerate series comes to the surface around the town of Klerksdorp. The diagram-section (Pl. X. fig. 2) will afford a rough idea of the disposition of the rocks here exposed. The folding of the beds is unmistakable.

From Klerksdorp the conglomerates are seen to strike across the Vaal in a S.S.E. direction; but they are soon buried beneath horizontal white sandstones and coal-beds.

Exposures of conglomerates are found on the farms Damspruit, Er-is-geluk, and Welt-de-vreden, about 18 miles west of Kroonstad. The conglomerates are associated with yellow sandstones; they are said to be slightly auriferous, though from a few 'pannings' made by the writer no gold was obtained. The strata are thrown into a series of very sharp folds; but few outcrops are visible, and the beds are covered up on the west by igneous rocks and on the east by Coal-measures.

The same conglomerates, associated with similar yellowish sandstones, are exposed on the roadside, about 6 miles south of 'Kopje-Alleen.' The pebbles in these conglomerates are sometimes very large.

That the conglomerates around Klerksdorp are portions of the Witwatersrandt series the writer has no doubt, as the beds occur in the same order, and are associated with strata of the same kind. With reference to the conglomerates west of Kroonstad there is no proof of age, and they may possibly belong to a newer series than the Witwatersrandt beds. From a consideration of the facts, however, especially that the conglomerates seem identical in composition with some of those of the Witwatersrandt, and that the beds near Klerksdorp strike across the Vaal River towards Kroonstad, it seems far more likely that they belong to the same series.

4. *The Igneous Rocks of the Southern Transvaal.*

The description of the igneous rocks of the Transvaal generally is outside the object of the present paper. Those intimately connected with the Main Reef Series have already been discussed. The amount of volcanic activity displayed is enormous; the whole of the stratified country seems to be floating in igneous rocks, the chief varieties of which are dolerites, diorites, quartz-amygdaloid lavas, and basalts.

In Dunn's map of South Africa (2nd ed. 1887) these igneous rocks are represented as one vast sheet. Mr. Penning, in Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 451, represents the dolerite as contemporaneous and interstratified with the Witwatersrandt beds. Now the types of igneous rock in the Transvaal are similar to those that pierce the Karoo Beds of the Orange Free State. Moreover, the oldest sedimentary beds of the Transvaal are greatly altered, while the igneous rocks, where not weathered, are as fresh-looking as if they had cooled but yesterday. The volcanic rocks of the Gats Randt are not, in the writer's opinion, interstratified, but appear to have come up an east-and-west fissure, and overflowed the Witwatersrandt beds at the time when the main movement and faulting of the country took place.

So far as the writer's observations enable him to judge, the igneous rocks of the Southern Transvaal are much posterior in date to the formation of the Witwatersrandt beds. But whether the eruption of igneous material took place before or after the deposition of the Karoo Beds, or was contemporaneous with the laying down of the Upper Karoo Series, is uncertain. If similarity of type is of value in correlation, then, as previously mentioned, these igneous rocks are very probably of the same age as those of the Orange Free State, which certainly appear to be of Upper Karoo (Stormberg) age.

5. *Summary of Conclusions respecting the Relation of the Strata of the Neighbouring Areas to those of the Witwatersrandt Series.*

(*a*) Our examination of the beds in the districts lying more or less immediately outside the Witwatersrandt area thus shows them to be thrown into numerous folds, which vary greatly in intensity. Sometimes the beds form shallow basins (as in the Nigel Mine district), but more often the strata are bent into sharp anticlines and synclines, the axes of which run either north and south or east and west. On the whole the beds are of a similar lithological character throughout the Southern Transvaal, being composed of sandstones, shales, and thin conglomerates, variously arranged, and more or less locally altered into quartzites and schists.

(*b*) The direct local superposition of the conglomerates on shales shows that the beds were either laid down by currents varying greatly in strength, or that they were deposited in areas undergoing rapid changes of level.

(*c*) The subsequent outpouring of igneous rocks has been enormous. This extrusion was certainly later in date than the deposition of the conglomerate series, and may possibly be posterior to that at which the faulting and crumpling of the strata took place.

(*d*) The apparent base of the sedimentary series, where seen (as at Vredefort), clearly overlies granites, gneisses, and gabbros; but the sedimentary beds dip towards the crystalline rocks, often at high angles.

(*e*) Most of the conglomerates are more or less auriferous, though there are notable exceptions.

(*f*) The coal-bearing strata overlying the Witwatersrandt series rest unconformably upon the eroded edges of all the beds below, and are the newest stratified rocks of the district.

[The present paper deals essentially with the facts bearing upon the stratigraphy of the Southern Transvaal. It was the Author's intention in a second paper to give a detailed account of the lithology of the gold-bearing conglomerates, and to describe in this connexion various microscopic slides which he had caused to be prepared, and also to discuss the mode in which the gold occurs and the question of its origin. Before, however, he was able to complete this part of his work, Mr. Gibson had to leave England for Equatorial East Africa. His second paper is therefore necessarily deferred.]

EXPLANATION OF THE PLATES.

Plate X.

Diagram-sections across the Gold-bearing beds of the Southern Transvaal.

Plate XI.

Geological Sketch-map of the Witwatersrandt Gold-fields.

Discussion.

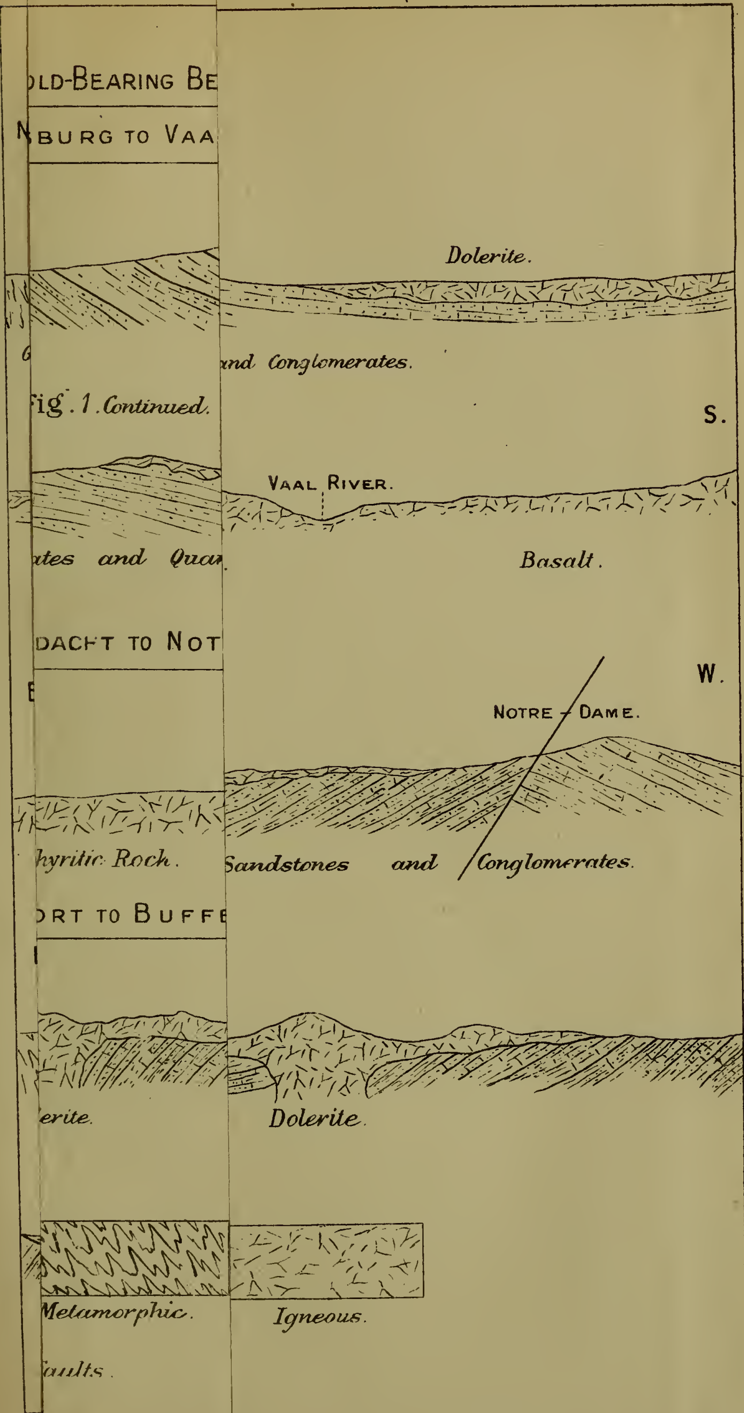
The President hoped that many papers similar to that just read would be offered to the Society, now that so many of its members were scattered over the world. Dr. Exton, who had sent specimens which were exhibited on the table, had noted the difficulty of accounting for the gold in the conglomerates. He (the President) had not exactly understood, from the reading of the paper, how the Author accounted for the mode of occurrence of this gold, further than that it was derived from the auriferous quartz-veins in the gneissose rocks, and he would be glad to hear the views of those who had made a special study of the distribution of gold.

Prof. Green pointed out the difficulty, in the present state of our knowledge, of correlating the beds described in the paper with the beds older than the coal-bearing rocks of Cape Colony. He thought that the intrusive masses of dolerite might belong to the same complex of dykes and sheets which form so marked a feature in the country to the south. He hazarded the opinion that the conglomerates were old alluvial gold-bearing deposits, and maintained that the mode in which the gold occurred was compatible with this view.

Mr. Attwood said he had not visited the Witwatersrandt gold district, so he found it a difficult matter to say much about the paper which had just been read; but as he had inspected many gold-fields in California, South America, and in different parts of the world, and obtained a practical knowledge of their surroundings, it appeared to him evident that the district now described by Mr. Gibson bore no resemblance, geologically speaking, to anything hitherto discovered, and therefore it was one of especial interest. The speaker did not think that the gold in the quartzites and conglomerates could be called alluvial gold, because from all the information he had on the subject the gold was found in a state of fine division, whilst in all true alluvial deposits the gold was found in various forms and sizes, varying from lumps of many pounds in weight to the finest dust. The only case which had come under his notice of metals being found in conglomerates (ancient river-beds being excepted) was that of the copper mines on the southern shore of Lake Superior, in Michigan, U.S.A. There the copper was found in a metallic state, sometimes in very fine dust and grains, and often in masses weighing many tons. It was most likely that the gold had been deposited in the quartzites and conglomerates, and was not derived from alluvial sources, as some would suppose.

Mr. Topley remarked that the Banket deposits of the Gold Coast seemed to contain gold introduced into the conglomerate at the time of its formation; whilst in the Witwatersrandt area the gold had frequently been deposited around the pebbles after the formation of the conglomerate.

Mr. Alford remarked that the paper dealt only with the gold-bearing deposits of the Witwatersrandt, and that nothing had been said about the very important series of auriferous rocks of the Barberton district, which were of an entirely different nature. The coal-bearing sandstones were by no means small deposits, as they occurred over an area of about 1000 square miles, and, although the coal-beds had not been proved throughout, there were strong indications of their existence. The coal-seam at Brakpan Colliery was 21 feet in thickness, and the output of coal at that colliery exceeded 13,000 tons per month. The outcrops of the conglomerate-reefs, though in places faulted a few feet, were traceable east and west of Johannesburg for a total distance of nearly 40 miles. They were by no means regular in gold-bearing value, which appeared generally to be greater where the beds had a high angle of dip and in the proximity of the intrusive igneous rocks. He did not consider the thickness of the quartzite-and-conglomerate series to be very great, but thought that the general break-up of the strata by the igneous intrusions had brought portions of the same beds repeatedly to the surface; and he entirely concurred with Prof. Green in his description of the multitude of trap dykes in the Orange Free State, which also agreed with many parts of the Transvaal. The origin of the gold in these conglomerate-beds was a most interesting, but at the same time a most intricate subject. The gold occurred in the matrix of the conglomerate, and seldom in the quartz-pebbles. On taking a pebble from its resting-place in the conglomerate, both the surface of the pebble and also that of the cavity from whence it



LD-BEARING BE
BURG TO VAA
Dolerite.
and Conglomerates.
ig. 1. Continued.
S.
VAAL RIVER.
tes and Quar
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W.
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hyritic Rock.
Sandstones and Conglomerates.
ORT TO BUFFE
erite.
Dolerite.
Metamorphic.
Igneous.
aults.

Diagram-Sections across the Gold-Bearing Beds of the Southern Transvaal.

Fig. 1. from Johannesburg to Vaal River, 40 miles.

Fig. 1. Continued.

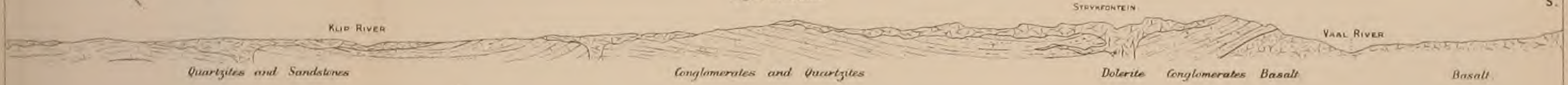


Fig. 2. from Nooitgedacht to Notre-Dame, 20 miles.

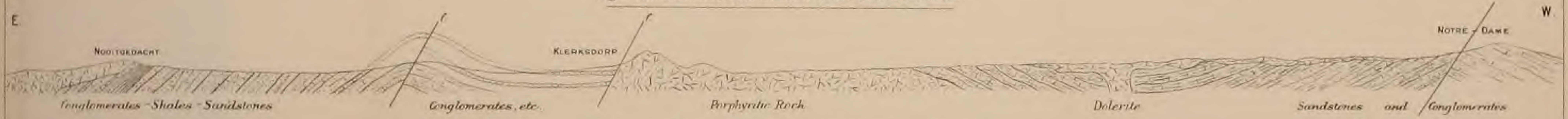


Fig. 3. from Vredefort to Buffelsdoorn, 30 miles.

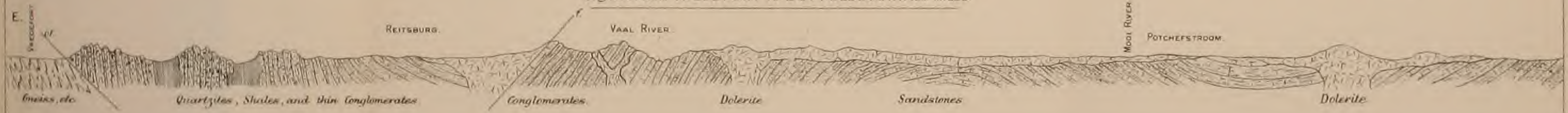
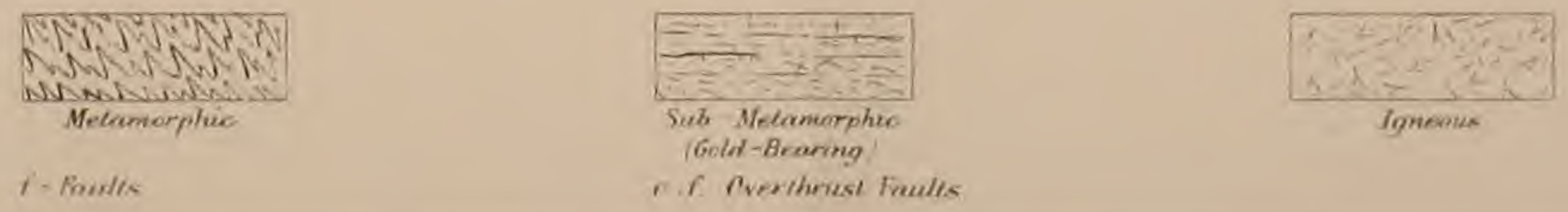
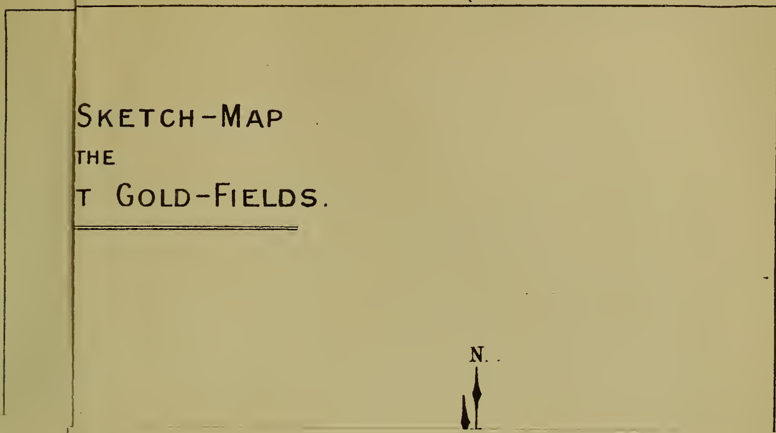
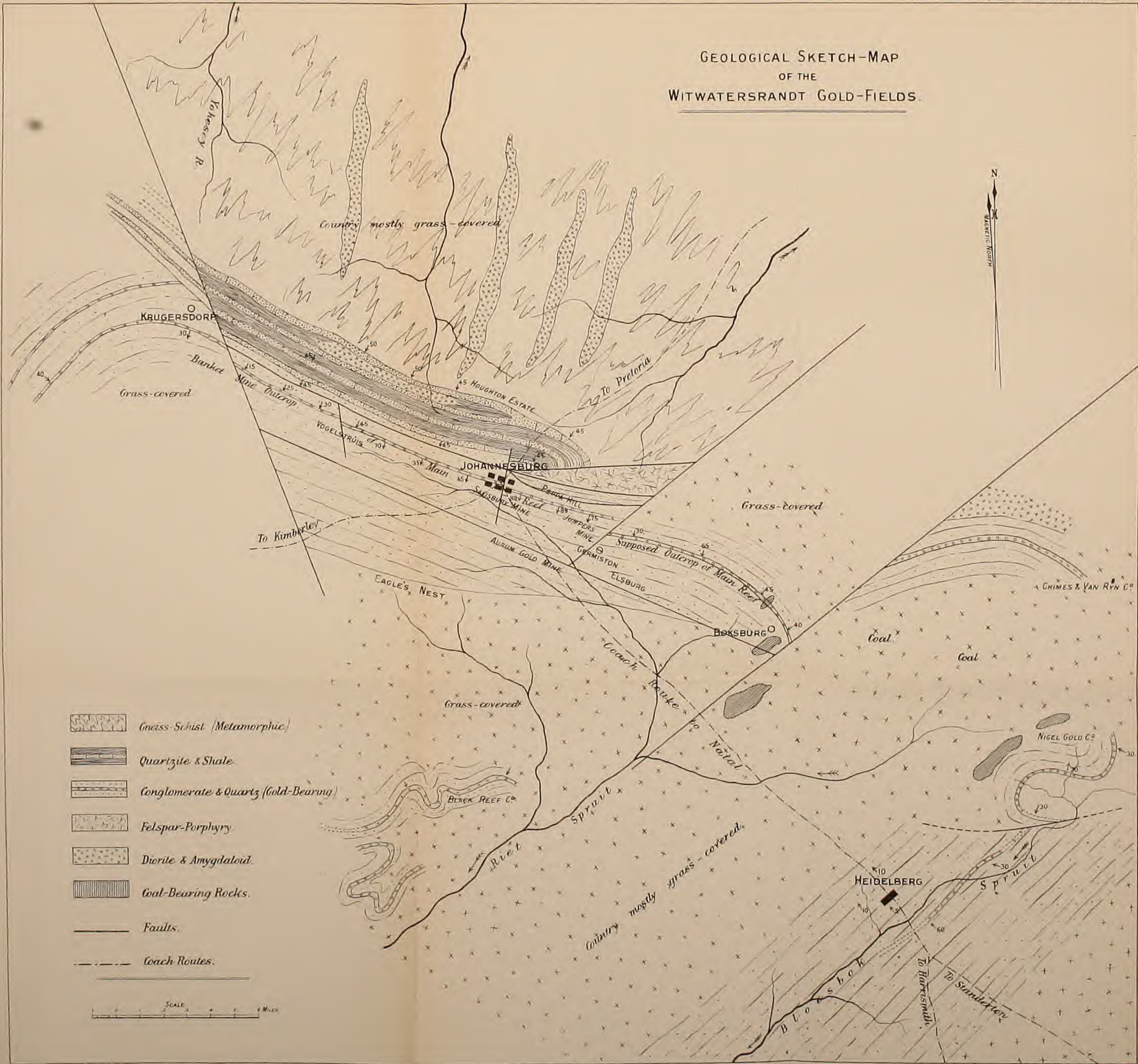


Fig. 3. Continued.




SKETCH-MAP
THE
T GOLD-FIELDS.
N.


GEOLOGICAL SKETCH-MAP
OF THE
WITWATERSRANDT GOLD-FIELDS.
N.
MAGNETIC NORTH
Vohesey R.
Country mostly grass-covered
KRUGERSDORP
Banket Mine Outcrop
Grass-covered
Houghton Estate
To Pretoria
Vogelstruis
Main Reef
JOHANNESBURG
Salisbury Mine
Jumpers Mine
To Kimberley
Grass-covered
Supposed Outcrop of Main Reef
Germiston
Aurum Gold Mine
Elsburg
Eagle's Nest
Boksburg
Chimes & Van Ryn Co.
Coal
Coal
Coach Route to Natal
Grass-covered
Nigel Gold Co.
Black Reef Co.
Riet Spruit
Country mostly grass-covered
Heidelberg
Spruit
Blesbok
To Harrismith
To Standerton
Gneiss-Schist (Metamorphic)
Quartzite & Shale
Conglomerate & Quartz (Gold-Bearing)
Felspar-Porphyry
Diorite & Amygdaloid
Coal-Bearing Rocks
Faults
Coach Routes
Scale
Miles

came were often to be seen covered with minute crystals of gold, and in the pyrites it occurred in small plates on the cleavage-planes. The gold might have been in the form of alluvial gold in the gravel-deposits from which the conglomerates were formed, then dissolved, and redeposited in its present condition; but its primary origin had still to be accounted for. The fissure-veins in the granite, worked for copper and silver at the Albert and other mines, had not been found hitherto to carry gold in any considerable quantity. The gold must at one time have been either created or evolved from something else: could that not as well have happened in its present position as elsewhere?

Prof. Lapworth noted that the Author had had unlimited opportunities of doing work in the district described. Before he went out it was believed that the district was a simple basin, the reefs margining the basin. The Author came to the conclusion that, whilst it was just possible that it was really a simple basin, it was far more probable that there had been overthrusting and shearing along the edges of the basin, and possibly great repetition in its interior; so that these gold-bearing rocks might quite well be found eventually within the basin itself. The Author certainly believed that the beds were repeated again and again, and need be of no great thickness. He knew that the Author had avoided giving any definite idea in the paper as to the source of the gold, as he proposed to treat of this subject in a separate memoir.

Mr. Teall also spoke.

28. *On the* Lithophyses *in the* Obsidian *of the* Rocche Rosse, Lipari. By Prof. Grenville A. J. Cole, F.G.S., and Gerard W. Butler, Esq., B.A., F.G.S. (Read May 11th, 1892.)

[Plate XII.]

The Rocche Rosse lava-stream, partly filling the pumice crater of Monte Pelato, Lipari, and breaching it on the north-eastern side, was described by Prof. Judd[1] in 1875. As recorded by him and by Cortese[2] we find in this locality all varieties of obsidian lava, from compact black glass to the pumice of commerce, or even a honeycombed material passing into 'thread-lace scoria.' A person who, arriving at the south-western or landward side of the crater, begins walking over the hummocky surface of the Rocche Rosse along the centre of that part which lies within the crater, cannot fail to be struck by the fact, emphasized by Cortese, that much of the lava here, as at the Forgia Vecchia, has a texture intermediate between that of pumice and compact glass. In fact, he might walk along the middle of perhaps the first third of the Rocche Rosse without finding anything that he would call obsidian. However, if he turn to the right and make his way towards the southern margin of the lava, he will find portions of it in which black glass predominates.

From one of the numerous outstanding hummocks of this part of the Rocche Rosse were obtained the specimens of black glass with vesicles, lithophyses, and spherulites, which have led to the writing of this paper, and from which the sections figured in Plate XII. have been taken. It must not be supposed, however, that the rock here differed in any essential from the lithophyse-bearing obsidian found elsewhere in this locality; or from the similar lava at the Forgia Vecchia described by Messrs. Iddings and Penfield[3]; or from the obsidian on the northern flank of Vulcano. But the specimens taken from this exposed hummock show in a specially striking manner the passage, through various stages of lithophysal structure, from indisputable steam-vesicles with glassy walls to the typical solid spherulites of these Lipari obsidians.

Messrs. Iddings and Penfield have described the characteristic structures in the obsidian of the Forgia Vecchia as 'hollow spherulites' and 'lithophysæ.' The following examination of the structures displayed by the Rocche Rosse mass will show that we are dealing with a mode of devitrification which is certainly lithophysal in character, in so far as it depends upon the liberation of

[1] 'Contributions to the Study of Volcanos,' Geol. Mag. for 1875, p. 66. See also Johnston-Lavis, Proc. Geol. Assoc. vol. xi. p. 394, and 'The South Italian Volcanoes' (1891).

[2] Boll. R. Comit. geol. d' Italia, vol. xii. (1881) p. 512.

[3] 'Fayalite in the Obsidian of Lipari,' Amer. Journn. Sci. vol. xl. (1890) p. 75.

steam; but that it is associated in a most interesting manner with normal spherulitic growths. Mr. Iddings [1] has himself remarked that "the essential character of spherulitic growths is the crystallization of minerals from one or more points with a radiating or diverging arrangement." Spherulitic growths of this accepted type undoubtedly occur in the Lipari obsidians round about and within the hollows that are visible to the naked eye. But, in addition to this divergent type of crystallization, convergent groups of crystallites have grown inwards from the surfaces towards the centres of the hollows.

In the obsidian of the Rocche Rosse, the internal surface of the steam-vesicles is often seen to be dusted over, as it were, with minute white aggregates; where the glass is less vesicular, these white growths are dense enough to completely line the cavity, and conical projections of the same materials are seen to run in towards the centre, usually terminating in a spheroid of rough exterior. These knotty growths may be so far developed as to bridge across the cavity; and, in practically all the cases where the vesicle is less than 1·5 mm. in diameter, porcellanous or clearer materials nearly or completely fill it. This process of infilling has been accompanied by the formation of crystalline zones in the glass around the vesicles; the outermost of these is dull grey and porcellanous, and it is often succeeded by a thin white zone, within which is a distinctly fibrous layer. This growth external to the original vesicle, together with the internal structures, builds up lithophyses which may closely simulate normal solid spherulites.

In microscopic sections the whole series of structures becomes beautifully displayed. We have first the vesicles of an almost pumiceous glass, breaking into one another, deformed, elongated, and without relation to products of crystallization beyond the fact that they thrust aside the abundant microlites that mark the lines of flow (Pl. XII. fig. 1). Then we find cases, in close proximity to the foregoing, where brown spherulitic aggregates have begun to form in the glass around the vesicle, producing for the most part hemispherical forms, their bases against the wall of the cavity, their convex surfaces directed towards the surrounding glass. These, as viewed with crossed nicols, are true spherulitic aggregates, dependent upon successive development of crystallites in the glass, growth thus taking place at their convex surfaces. Very often they become continuous around the vesicle, and form the dull zone, bluish-grey by reflected light, which is visible in the rock with the lens or with the unaided eye (Pl. XII. fig. 1). In this brown zone, conical or, rather, mushroom-shaped fibrous structures have developed, the stalk of the 'mushroom' projecting into the cavity of the vesicle. A colourless zone of crystallites, radially arranged, separates the surface of the 'mushroom' from the ordinary brown aggregation round it (Pl. XII. figs. 2 & 3). A

[1] 'Spherulitic Crystallization,' Bull. Phil. Soc. Washington, vol. xi. (1891) p. 462.

structure of this kind has been figured in Mr. Iddings's admirable paper on 'Obsidian Cliff, Yellowstone National Park.'[1]

In some of the vesicles nearest to the surface of the lava, the brown zone is absent, but small cones of clear or dusky crystalline fibres have arisen, their apices projecting into the cavity, while their bases are sunk in the wall. Where the development of rod-like crystallites, such as form these cones, has taken place with anything like regularity, a fibrous fringe is seen all round the vesicle, the growing points of the fibres being directed inwards. *But that a great part of this fibrous zone, as also of the cones, originates in the glass, spreading outwards as well as inwards*, is shown by the fact that the lines of crystallites, arranged by flow, pass continuously from the matrix, through the brown layer, into the dusky fibrous material (Pl. XII. figs. 2 & 3).

In the smallest examples, the fibres from opposite sides of the vesicle may meet in the centre, and a 'spherulite' results, which, but for the occurrence of intermediate stages, might be supposed to have originated entirely in divergent outgrowth. Thus there are spherulites in one of our sections that might have arisen in a normal manner; but doubt is thrown upon their character by the enormous preponderance of lithophysal forms.

In the larger examples, the irregularity and partial character of the growth at the centre usually suggest that they have resulted from the infilling of a vesicle. In the case of one or more of the conical aggregates, the 'stalk' grows out distinctly into the cavity, not by its fibres becoming sensibly parallel, but by the deposition of new fibres, originating at the point of convergence of the older ones and thence radiating outwards, often from more than one centre (Pl. XII. fig. 3). These additions, if continued, produce the spheroidal aggregates visible to the naked eye, and often result in actual bridging of the cavity (Pl. XII. fig. 4). At points along the 'bridge' further spherulitic deposition may take place; fibrous crystals of felspar, giving clear low colours between crossed nicols, may spring across to the adjacent walls (Pl. XII. fig. 5); and finally even a vesicle 2 mm. in diameter may become completely infilled by spherulitic matter radiating from various centres within it. Frequently two vesicles have opened into one another, leaving a partition of glass projecting from opposite sides into the common cavity; and this breached partition serves as the foundation for a crystalline 'bridge' across the cavity. At the Forgia Vecchia, spherulitic deposition, in a host of instances, has gone on so far as to obscure the lithophysal features. The prevailing type of 'spherulite,' indeed, both in Lipari and Vulcano, shows in section a dusky fibrous central area, which may possess concentric as well as radial structure; outside this is a thin, colourless, but crystalline zone, followed finally by a brown cloudy zone, irregular and of very variable width. Our studies lead us to the conclusion that this type of 'spherulite' owes its characters to the dual mode of growth

[1] Seventh Annual Report U. S. Geol. Survey, pl. xviii. fig. 3, p. 277.

which we have described, and thus to the original presence of vesicles in the rock.

Commonly, however, the process of infilling does not go so far as this. On the ends of the delicate branching fibres of felspar, plates of tridymite are deposited; and this seems to close the growth of the 'stalk' or of the 'bridge' (Pl. XII. figs. 3 & 4). The angles and edges of the tridymite crystals impart a serrated and toothed character to the spheroids within the vesicles, as is seen when the rock is viewed with an ordinary lens.

That the lithophysal structure in the Lipari obsidians was developed during the cooling of the mass, and not by subsequent amygdaloidal infilling of vesicles, is clear from the formation of the compact spherulitic zone in the glass itself, and from the rooting of the clearer fibres also in the glass, not merely upon the walls of the cavities. We conceive that in highly siliceous lavas the liberation of water, on relief from pressure, renders the mass rapidly more viscid. The heated vapour is liable to be retained after it has expanded, and even to become superheated as fluctuations of temperature travel through the mass. That solidified portions of the Rocche Rosse lava have thus become reheated has been shown in a previous paper.[1] While Mr. Iddings[2] has suggested that crystallization occurs in regions of greatest hydration of the glass, the water being liberated and forming vesicles during the development of the crystals, we should be inclined to regard the loss of water on relief from pressure as in itself an important factor in consolidation. Where the water has escaped freely, we have the pumice or the occasional vesicular layers. If the bubbles are very numerous, they open into one another, the extreme result of such confluent vesicles being the 'thread-lace scoria' of Prof. Dana.[3] If the vapours escape thus completely from the lava, their action upon the rapidly cooling and often filamentous glass around them is very transient or absolutely inappreciable.

Where, however, the vapours are confined, they may be kept at a high temperature for a considerable time, the vesicles being farther apart, and each becoming a sphere of hydrothermal action. If the surrounding glass remains at a temperature little below its fusion-point, crystallization will be promoted in it; and at the same time the hydrothermal attack of the vapour in the vesicle will produce reactions upon its walls.

Thus we conceive the zones formed around the vesicles to result from the crystallization of the constituents of glass that has been kept at a high temperature; and much interstitial glass remains in the outermost porcellanous region. The vapour, however, attacks and etches the walls of the cavity, like steam in an ordinary glass

[1] G. A. J. Cole, 'Devitrification of cracked and brecciated Obsidian,' Mineralog. Mag. vol. ix. (1891) p. 272.

[2] 'Spherulitic Crystallization,' Bull. Phil. Soc. Washington, vol. ix. p. 447; 'Nature and Origin of Lithophysæ,' Amer. Journ. Sci. vol. xxxiii. (1887) p. 43. Also Seventh Ann. Report U. S. Geol. Survey, p. 285.

[3] 'Characteristics of Volcanoes,' p. 164.

tube; evidence of this etching may be seen in the moat-like depressions around the bases of many of the cones or 'mushrooms.' Conical groups of fibres become thus deposited, projecting into the cavity in continuity with those already developed in the walls. In the same manner, the divergent groups of fibres are deposited on the ends of the cones and on the 'bridges.' Considering how the whole mass of a lava is permeated by fluids, materials may be brought, even from some distance, into the local sphere of hydrothermal action. Tridymite finally arises, and even the fayalite described by Messrs. Iddings and Penfield.[1]

Lastly, the possible intrusion of glass by pressure from without, as in the Yellowstone Park[2] and the Tynemouth Dyke,[3] must not be lost sight of in seeking the source of the materials in the vesicles. Such intruded glass would rapidly become attacked, if the vapour were still present in the cavity, and would quickly help in the infilling.

The following experiments show the differences between the materials in and around the lithophyses, and help to strengthen the above suggestions.

(i) The black obsidian contains sufficient water to allow of its fusion at about 4 of Von Kobell's scale; it froths up during fusion into a pumice or 'thread-lace scoria.'

(ii) The outermost porcellanous zone of the lithophyses behaves similarly, becoming transparent just before fusion, probably by reabsorption of its globulitic matter; when again cool, it remains transparent.

(iii) A compact grey rock from the Forgia Vecchia, appearing brown in section, and composed of densely-set spherulites, resembling the material of the porcellanous zone at the Rocche Rosse, also froths up as if it were a simple obsidian.

(iv) But the compact blue-grey spherulitic growths formed in the centre of the lithophyses of Lipari are only fusible at a temperature as high as that required for orthoclase, though at last they intumesce like the obsidian.

(v) The fibrous white rays, partly projecting into the cavities, also fuse at about 5 of Von Kobell's scale.

The fact that empty vesicles of all sizes lie in the pumice and obsidian side by side with almost completely infilled examples shows that the liberation of gas may occur prior to rather than during crystallization. There is doubtless every link between the structures at the Rocche Rosse and the lithophyses with large central cavities described by Von Richthofen[4] and Iddings, though we may differ as to the mode of origin of the cavities. Von Richthofen believes that hydrated silicates crystallize out and form an aggregate, which, on relief from pressure, becomes dehydrated and consequently

[1] Amer. Journ. Sci. vol. xl. (1890) p. 77.
[2] Iddings, Seventh Ann. Report U. S. Geol. Survey, p. 283.
[3] Teall, 'Amygdaloids of the Tynemouth Dyke,' Geol. Mag. for 1889, p. 481.
[4] 'Studien aus den ungarisch-siebenbürgischen Trachytgebirgen,' Jahrb. der k.-k. geol. Reichsanstalt, 1860, p. 180.

blown up by the liberated steam. Iddings holds that the separation of anhydrous silicates and silica releases the water in the region of crystallization. Approaching the problem with the advantage of the considerations put forward by these writers, we venture to affirm that the steam-vesicles have developed first, and independently of any crystallizing tendency; and that only under special conditions, such as prevail in the obsidians of Lipari, do vesicles play a part in modifying their surroundings and assisting spherulitic growth. Such modifications have been described by Mr. Rutley[1] as arising during the artificial heating of an obsidian from Montana, white crystalline pellets being formed in the interior of the vesicles.

The Rocche Rosse rock proves that Weiss[2] was right in stating that spherulitic aggregation may take place around a vesicle; and Prof. Judd[3] has remarked, when describing the rocks of Lipari, that in some cases the formation of spherulites "has been determined by the liberation, in the midst of the vitreous mass, of an infinitesimal bubble of volatile matter." But it seems that this structure is limited to highly silicated, viscid, and slowly moving vitreous lavas, where individual steam-bubbles can exercise prolonged hydrothermal action on the glass. We may mention in conclusion that Delesse,[4] in the almost unrivalled plates illustrating his 'Recherches sur les Roches globuleuses,' has figured an obsidian from Ischia, which has clearly the same type of lithophysal structure as that which we have endeavoured to describe.

APPENDIX.

On Lithophyses *and* Hollow Spherulites *in* altered Rocks. By Prof. Grenville A. J. Cole, F.G.S.

From the date of the publication of Mr. Iddings's memoir on Obsidian Cliff, above referred to, it has been felt, I think, that Von Richthofen's view of the primary origin of the cavities of lithophyses had received very valuable support. It became clear, at any rate, that, from one cause or another, spherulites might be formed with more or less regular hollows in their interior. It will now be necessary, in dealing with any old example, to endeavour to distinguish between primary and secondary hollows; and I fear that in some cases the distinction must remain a matter of opinion. The Rocche Rosse obsidian shows that we may expect the material of a 'spherulite' some 5 mm. or more in diameter to have a composite and many-centred character when it has accumulated within and round a vesicle. Traces of the 'bridges' may also be left, as I think is the case in some of the Ordovician examples so ably dealt

[1] 'On Alteration induced by Heat in certain Vitreous Rocks,' Proc. Roy. Soc. vol. xl. (1886) p. 435.
[2] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxix. (1877) p. 421.
[3] 'Contributions to the Study of Volcanos,' Geol. Mag. for 1875, p. 65.
[4] Mém. Soc. géol. de France, 2me sér. tome iv. pl. xxv. fig. 11; and p. 361.

with by Miss Raisin.[1] It is more difficult to decide as to the concentric coats which may be formed within the vesicle; these can be seen in an incipient stage in some examples from the Rocche Rosse, and attain their finest and most onion-like development at Obsidian Cliff, Yellowstone Park. The same structure is clearly traceable in a much altered condition in the lithophyses of the Conway Mountain.[2]

The lithophysal aggregates in the Lipari obsidians bear evidence of decay, which is doubtless largely due to the attack of vapours and liquids subsequent to the primary devitrification. Some of Mr. G. W. Butler's specimens from the Forgia Vecchia show a faint red zone in the spherulites between the porcellanous outer zone and the central fibrous area. Under the microscope this is seen to be due to a reddening of the crystallites included in the otherwise colourless second zone. Oxidation has taken place, resulting in the development of patches of powdery brown-red products. It is clear that extended alteration of this colourless and markedly crystalline zone is liable to leave a hollow shell in the lithophyse; and this accounts for the fact that the central fibrous mass appears again and again on fractured surfaces of the rock as a ball, loosely set in a socket formed of the outer and porcellanous zone. It will be seen, from the considerations put forward in the preceding paper, that this hollow shell does not mark the limits of the original vesicle, but lies in reality outside it.

In some specimens, as Mr. Butler has pointed out to me, two or more shells have arisen in the lithophysal matter; but the spaces separating them are of merely local extent, the crystalline mass being continuous in other parts of the lithophyse. These spaces appear to result from the partial removal of certain of the concentric layers.

I am not, then, prepared to abandon the suggestion put forward in the case of the Conway lithophyses, viz., that the interspaces between the successive coats result from alteration of a formerly solid mass. In the well-known spherulitic lavas of Esgair-felen and other Welsh localities, as well as in those near the Wrekin, where cracks full of chalcedony and quartz can be traced into the spherulites, I have no doubt as to the production of 'hollow spherulites' by ordinary agents of decay.[3] I need not recapitulate the arguments previously brought forward; but we must now be ready to recognize the fact that true spherulites and aggregates of lithophysal origin may closely simulate one another.

The typical Continental pyromerides are truly spherulitic; so is the great bulk of the lava of the Wrekin area, the lines of flow running through the boldly-developed spherulites. But in the

[1] 'Nodular Felstones of the Lleyn,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 260, fig. 5.

[2] G. A. J. Cole, 'Alteration of Coarsely Spherulitic Rocks,' Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 186, pl. ix. fig. 6.

[3] *Ibid.* p. 184, &c., and 'On Hollow Spherulites,' Quart. Journ. Geol. Soc. vol. xli. (1885) p. 162.

latter case, as at Bouley Bay in Jersey, it will be difficult to decide between infilled primary and secondary cavities. While I still assign a spherulitic character to the outer coats of the bodies in the Welsh 'nodular felsites,' and fail to find evidence of their contractile origin,[1] I am glad to find myself now in accord with Prof. Bonney in admitting that the central masses of quartz may frequently have resulted from the infilling of original vesicles.

EXPLANATION OF PLATE XII.

[The numerators of the fractions expressing the degree of enlargement of the figures represent in each case the magnifying-power of the objective used. All the sections are from the obsidian of the Rocche Rosse, Lipari.]

Fig. 1. Vesicles, with local development of fibrous ingrowths, and formation, in the upper example, of brown spherulitic matter in the surrounding glass. $\times \frac{32}{4}$.

2. Portion of edge of two confluent vesicles, showing conical and other structures. $\times \frac{100}{3}$.

3. Vesicle with brown spherulitic zone, and ingrowths bordered by tridymite. $\times \frac{100}{3}$.

4. Contiguous vesicles, with 'bridges' of spherulitic matter and tridymite. $\times \frac{32}{4}$.

5. Spherulitic 'bridge' becoming connected with the walls of the vesicle by felspathic outgrowths. $\times \frac{100}{3}$.

Discussion.

Prof. Bonney expressed his sense of the great value of the paper, which required careful reading and study before it could be properly discussed. He was himself quite of opinion that spherulites might form in more than one way, but he doubted, in cases where the glass of the rock seemed quite fresh, whether the hollow in a spherulite could be the result of decomposition. Hence he thought that hollow spherulites so formed would be exceptional. Also he believed that, as a rule, a solid spherulite with concentric shells was not partly formed in the glass and partly infilled afterwards, but had always been solid, cracks and crystallization being related. He thought this must be the explanation of spherulites he had examined in Arran, Jersey, and elsewhere, and he had seen solid spherulites in artificially melted tachylyte.

Prof. Judd congratulated the Authors on the clear and logical character of their paper, and was glad to find that a closer agreement was now being developed among those who had discussed the problem of the origin of lithophyses.

Gen. McMahon called attention to some of Prof. Cole's specimens, and suggested that lavas showing, as they did, a strongly striped appearance owing to lines of partially-filled vesicles between lines of dark glass might, when buried under the surface of the earth and subjected to the action of heated water and pressure, be converted in the course of time into a crystalline schist.

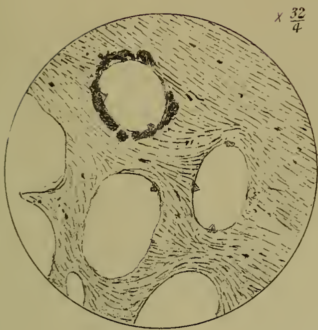
[1] T. G. Bonney, 'Nodular Felsites in the Bala Group of North Wales,' Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 295.

Mr. J. W. Gregory remarked on the close analogy between these Rocche Rosse lithophyses and those of the Obsidian Cliff. He quoted several facts which showed that many of the latter must have been formed prior to the consolidation of the rock, and were thus of a different origin from those of Lipari.

Mr. Rutley, while acknowledging the interesting nature of the views advanced by the Authors, wished to know how the original boundaries of the vesicles could be accurately determined. If, instead of the walls of vesicles, there were merely cracks in the vitreous mass, crystallization would then occur upon both sides of the fissure, but in the case of a vesicle, unless fresh matter were introduced, he failed to see from what source the material of the crystalline fibres lying within the vesicle was derived, except from the wall of the vesicle itself, in which case it would be difficult to fix its original boundary.

Prof. Cole stated, in reply, that hollows might occur by decay of spherulites although the glass around remained remarkably fresh, the fibrous and other structures in the crystalline materials rendering them more open to attack. Only 'spherulites' with the dual type of structure described could be claimed as of lithophysal origin, the great bulk of spherulites in other areas, with or without concentric structure, being formed by outward growth from a central point. The curvature of the outer surface of the mushroom-like bodies was independent of that of the vesicle on which they originated.

Mr. G. W. Butler explained that, in judging as to the original boundary of the vesicles, the Authors had been mainly guided by the flow-lines of the original glass, which can be traced through part, but not all, of the crystalline material.



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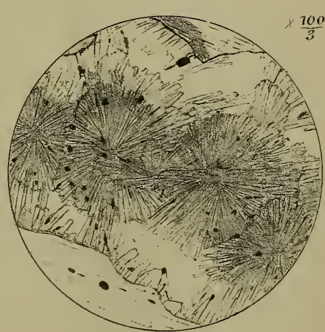


5.

G. A. J. Cole del.
F. H. Michael lith.

Mintern Bros. imp.

LITHOPHYSES IN OBSIDIAN OF LIPARI.

29. *The* Morphology *of* 'Stephanoceras' zigzag. By S. S. Buckman, Esq., F.G.S. (Read May 25th, 1892.)

[Plates XIII. & XIV.]

Introduction.

Many years must elapse ere I shall be able to describe *Stephanoceras zigzag* in the volumes of the Palæontographical Society. Meanwhile, the material which has come into my possession during the last few years throws an important light on the developments of this fossil; and such developments seem to supply a missing link in the connexion of Bathonian and Bajocian species. Not only is *Stephanoceras zigzag* raised from comparative obscurity to the position of probable progenitor of a large series of Bathonian species, but it is more than likely that the evidence now brought forward will be of considerable service to those engaged in studying the genealogy of the later species. For these reasons I submit the following paper to the Society.

D'Orbigny's figures [1] of *Ammonites zigzag* represent only small specimens of two varieties of the species. Quenstedt figures [2] as *euryodos* a more quickly-coiled, more coarsely-ribbed form; but this is also small. He says it is the same as d'Orbigny's *zigzag*.

In a former paper on Inferior Oolite Ammonites,[3] I remarked on the change of form which appears to have escaped previous notice; but the specimens then referred to were only a little larger than the Continental examples. The best figures of the species are those given by Quenstedt under the name *euryodos* in his last great work [4]; but they afford no adequate idea of the developments of the fossil. It may be noted that there are distinct differences in coiling and ribbing between the specimens depicted in his fig. 5 and figs. 4 and 6 —a matter to which I shall have to refer later (series γ).

The generic position of *zigzag* has been a matter of some uncertainty. Neumayr omitted it from his 'Systematik der Ammonitiden';[5] and, though the species has sometimes been placed in *Stephanoceras*, yet the peculiar ornaments which doubtless suggested to d'Orbigny the name *zigzag* are different from the ornaments of *Stephanoceras*; and, therefore, some authors have placed the species in *Perisphinctes*.

There are only two sources from which it would be possible to derive *zigzag*, namely, *Stephanoceras* and *Zurcheria*.

I have broken up some eight or nine specimens without very much success, on account of their crystalline condition; but the inner whorls show a rather globose form, which soon acquires small knobs.

[1] 'Pal. franç., Terr. jurass.' pl. 129, figs. 9–11.
[2] 'Der Jura,' pl. 63, figs. 20, 21.
[3] Quart. Journ. Geol. Soc. vol. xxxvii. (1881) p. 596.
[4] 'Ammoniten des Schwäbischen Jura,' pl. 74.
[5] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvii. (1875) p. 854.

Later on, there is considerable likeness to a youthful *Blagdeni*; and, while still very young, the distinctive *zigzag*-ornaments are assumed. So far as the inner whorls are concerned, there is no definite evidence against descent from *Zurcheria*, though descent from *Stephanoceras* is quite as probable. It is only in the later developments that the latter probability becomes almost a certainty. These developments, which I shall have to describe, are so much like the developments of the *Stephanocerata*, and so unlike those of *Zurcheria* and its allies (*Amaltheidæ*), that I come to the conclusion that *zigzag* is nothing more than a rather peculiarly ornamented development of the *pettus-Blagdeni* stem.[1] Its suture-line (see Pl. XIV. fig. 1) supports this view.

Stephanoceras zigzag and its Developments.

Series a.

Roughly speaking, there are two principal forms called '*zigzag*'[2]—a thin and a thick one. I consider it advisable for the sake of clearness to confine the specific name to the former. A specimen (exhibited when this paper was read) which agrees with d'Orbigny's fig. 9 may be considered as the type of the species. It is a little larger than d'Orbigny's specimen, and shows the change in ribbing not observable in the French fossil. A similar example, changing its ribs at the same period, possesses the complete mouth-border—a well-marked lateral spatulate ear, of which the outer portion had not, apparently, been properly calcified.

A most important specimen, illustrating the law of earlier inheritance, shows a change of ribbing beginning nearly a whorl earlier than in the first mentioned, and, in fact, this specimen is not a true *zigzag*, but a marked development thereof. (It should be noticed, in view of some remarks later on, that, on the core, there is a distinct interruption of the ribs in the middle of the ventral area.) In the specimen depicted (Pl. XIII. figs. 1, 2) a still further development in the same direction is to be noted. In this example nothing but the early whorls of the centre show the *zigzag* style of ribbing—all the rest of the specimen has what might very appropriately be called annulose and bifurcate-annulose ribbing,[3] with small knobs at the point of bifurcation.

This form is very near to Seebach's *procerus*,[4] and possesses the same kind of ribbing.[5] But Seebach's fossil is just the next step onwards, which has begun to acquire what may be called two new characters—increased inclusion and broader, more inflated

[1] See Monogr. Palæontogr. Soc. Part vi. p. 271.

[2] The claims of the word *zigzag* to a classical origin appear very doubtful, but it may be admitted on account of long usage.

[3] A single rib encircles the whorl or bifurcates at the edge of the lateral area. The alternation of the two styles of ribbing is not quite regular.

[4] Seebach, 'Der Hannoversche Jura,' pl. x. fig. 2 *a, c*.

[5] *Ibid.* p. 155.

whorls—and it has lost the small knobs on the ribs. If present at all, the *zigzag*-ribbing must end very soon; but the centre is imperfect in the specimen as well as in some older examples of the same species.

The characters of adult *procerum* are observable in the adolescent stage of the next development (Pl. XIII. figs. 3, 4), but there is a very noticeable increase in the inclusion which has brought about a renewal of the compression of the whorl. This form is very distinct from the last on account of its small umbilicus, and may be known as *subprocerum*. Still further increase of the inclusion produces the form shown in Pl. XIII. figs. 5, 6, in which, at the same diameter, the umbilicus is considerably smaller. In the early adult stage of this form it may be noticed that the primary ribs tend to become obsolete and are much more distant—serving four or five secondary ribs[1]—while the point of junction is altogether obscure. There is also at this stage a tendency to widen the umbilicus again; the same tendency is shown in regard to the continuation of the whorl in *subprocerum*. The form under discussion differs from *subprocerum* in the various respects noted above, and it may be known as *clausiprocerum*.

Series β.

The thick form of *zigzag*, as the specimens are usually called, is in reality either the parent of *zigzag* proper or else a less-developed type of the stock from which *zigzag* came. It differs in retaining the *zigzag*-ribbing and the broad-abdomened whorls until a later period of growth. For the sake of distinction it may be called *crassizigzag*. The most pronounced of the series is a form which retains its broad flat abdomen, to a diameter of 45 mm., a long time in proportion to the others; it may be called *crassizigzag a*.

Certain large examples, 130 to 155 mm. in diameter, though they differ somewhat among themselves, may be regarded as adults of this form, but, strictly speaking, they exhibit, each in their way, a certain progress in development and are biologically later than the form in question. One of them, in which the primary ribs have, so to speak, run together to form large bulgings on the inner area, is a most remarkable development. It is depicted in Pl. XIV. figs. 2, 3.

The usual form of *crassizigzag* is shown in Pl. XIII. figs. 7, 8, and may be known as *crassizigzag β*. A specimen which possesses the complete mouth-border shows that it was without any lateral lappets; but perhaps this ought not to be considered as a distinction from *zigzag*. A larger specimen of the same subseries forms the connexion with another example (Pl. XIV. figs. 4, 5) in which there is a very distinct change, with a marked increase in inclusion and an inflation of the whorl—in fact in every way a form homoplastic with the *procerum*-series. It differs, however, by its greater

[1] This is to a certain extent a reversion to the *zigzag*-ribbing—so far as concerns the number of secondary in relation to primary ribs.

thickness and in retaining the *zigzag*-style of ribbing a much longer time in proportion to inclusion. It may well be designated *pseudo-procerum.*

In considering the further developments of the *zigzag*-series there can be little doubt that both *arbustigerus* and *planula* [1] as figured by d'Orbigny [2] are certainly further developments of that series, probably derivations of *crassizigzag α.* The coarse ribs of their inner whorls suggest the *zigzag*-ornamentation very forcibly. It seems also very possible that both *Herveyi* and *macrocephalus* (d'Orbigny, Pal. franç., Terr. jurass. pls. 150, 151) may take their rise from a form like *pseudoprocerum.* If this idea be correct it may perhaps be advantageous to include the whole of the *zigzag*-series in the genus *Macrocephalites*, Sutner.[3] Two other species, which may possibly be derived from the *zigzag*-series, are *subcontractus*, Morris and Lycett, and *Morrisi*, Oppel.

Series γ.

This series is only known to me from Quenstedt's plates. The example depicted in 'Ammoniten des Schwäbischen Jura,' pl. 74, fig. 5, is certainly quicker-coiled than *zigzag* or *crassizigzag*; and not improbably the name *euryodus* may be retained for it. Quenstedt's figures allow us to surmise that this form is the ancestor of *anceps*, and in that case we have a remarkable instance of homoplastic development; for in the *anceps*-series there is the same ventral furrow as in *Parkinsonia*, which was itself an earlier development from the *Stephanoceras*-series. Now *anceps* is the type of a genus *Reineckeia*; and it seems very probable that the *Perisphinctes tyrannus* and *oxyptychus* of Neumayr [4] may be developments of forms of *anceps.*

The accompanying table shows the genealogy of the species dealt with. The *zigzag*-series is a branch from the coronate-radical manifesting the spinous stage at a later date than the *Humphriesianum*-series, to which it may be considered morphologically equivalent. Just as the *Humphriesianum*-series evolved forms belonging to the costate stage, so the *zigzag*-series gave rise to similar costate forms (*procerum*, *pseudoprocerum*, &c.); so that there is a parallelism in the developments of these two series as well as between the developments which take their rise from *zigzag* and *crassizigzag*, when considered in relation to each other.

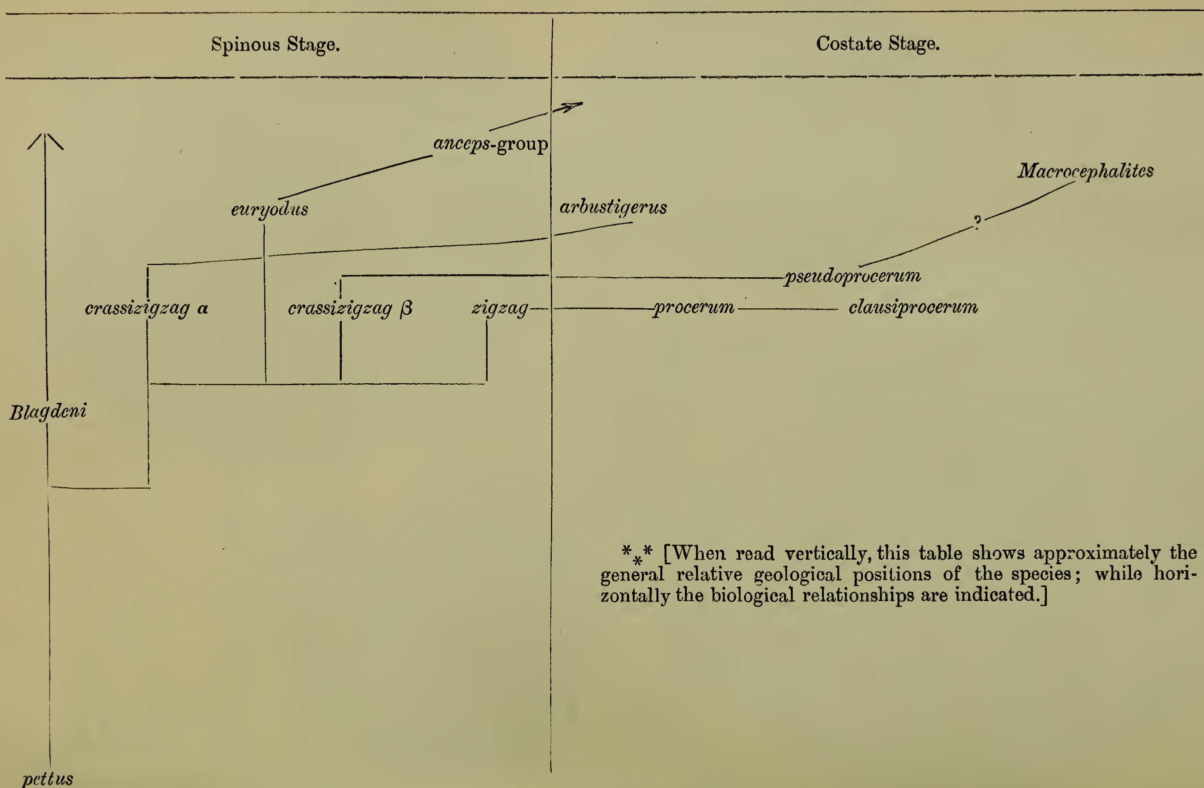
[1] The *planula* of Hehl (Zieten, 'Die Verstein. Württ.' pl. vii. fig. 5) is a different species, apparently derived from the *Martinsii*-group, looking at the ornaments of its inner whorls. The ornamentation of its outer whorls suggests that it is the ancestor of *Lamberti*, *Sutherlandæ*, *Mariæ*, and hence *Goliathus.*

[2] 'Pal. franç., Terr. jurass.' pls. 143, 144.

[3] It would be very interesting if homoplasy had produced from the *zigzag*-stock a later development so much like *Sphæroceras*, which is an earlier derivation of the same radical stem as that from which *zigzag* came.

[4] 'Ceph. der Macrocephalenschichten,' Jahrb. d. k. k. geol. Reichsanst. Bd. xx. (1870) pls. viii., ix.

Table showing the Genealogy of the Zigzag Series and its Developments.



*** [When read vertically, this table shows approximately the general relative geological positions of the species; while horizontally the biological relationships are indicated.]

EXPLANATION OF THE PLATES.

Plate XIII.

Fig. 1. *Stephanoceras*, a form intermediate between *zigzag* and *procerum* showing the *zigzag*-style of ornament in the inner whorls and the *procerum* style of ribbing in the outer whorls. Nat. size.

2. Outline of aperture.
3. *Stephanoceras subprocerum*, n. f., showing the decrease in size of umbilicus. About $\frac{2}{3}$ nat. size.
4. Outline of aperture.
5. *Stephanoceras clausiprocerum*, showing greater decrease in size of umbilicus and the greater distance between the obsolescent primary ribs. About $\frac{2}{3}$ nat. size.
6. Outline of aperture.
7. *Stephanoceras crassizigzag*, var. β, n. f., showing the change from the *zigzag*-style to a plain costate ornamentation. Nat. size.
8. Outline of aperture.

Plate XIV.

Fig. 1. Suture-line of a specimen of *Stephanoceras zigzag*, showing long siphonal, and dependent inner lobes.

2. *Stephanoceras crassizigzag*, var. α, n. f., a large specimen showing the *zigzag*-ornaments retained for a long time, and an exaggeration of the primary ribs on the last whorl. About $\frac{2}{3}$ nat. size. (This is an important link in the connexion of Bathonian and Bajocian species.)
3. Outline of the aperture. $\frac{2}{3}$ nat. size.
4. *Stephanoceras pseudoprocerum*, n. f. About $\frac{2}{3}$ nat. size. (This specimen suggests the connexion of *zigzag* with *Macrocephalites*.)
5. Outline of aperture. $\frac{3}{4}$ nat. size.

All the specimens figured are from Broad Windsor (Dorset), from the uppermost beds of the Inferior Oolite, representing the *zigzag*- and possibly part of the *fusca*-zones. They are rare forms, and were only obtained thanks to the great energy of Mr. Darell Stephens, F.G.S. They are now in my cabinet.

Discussion.

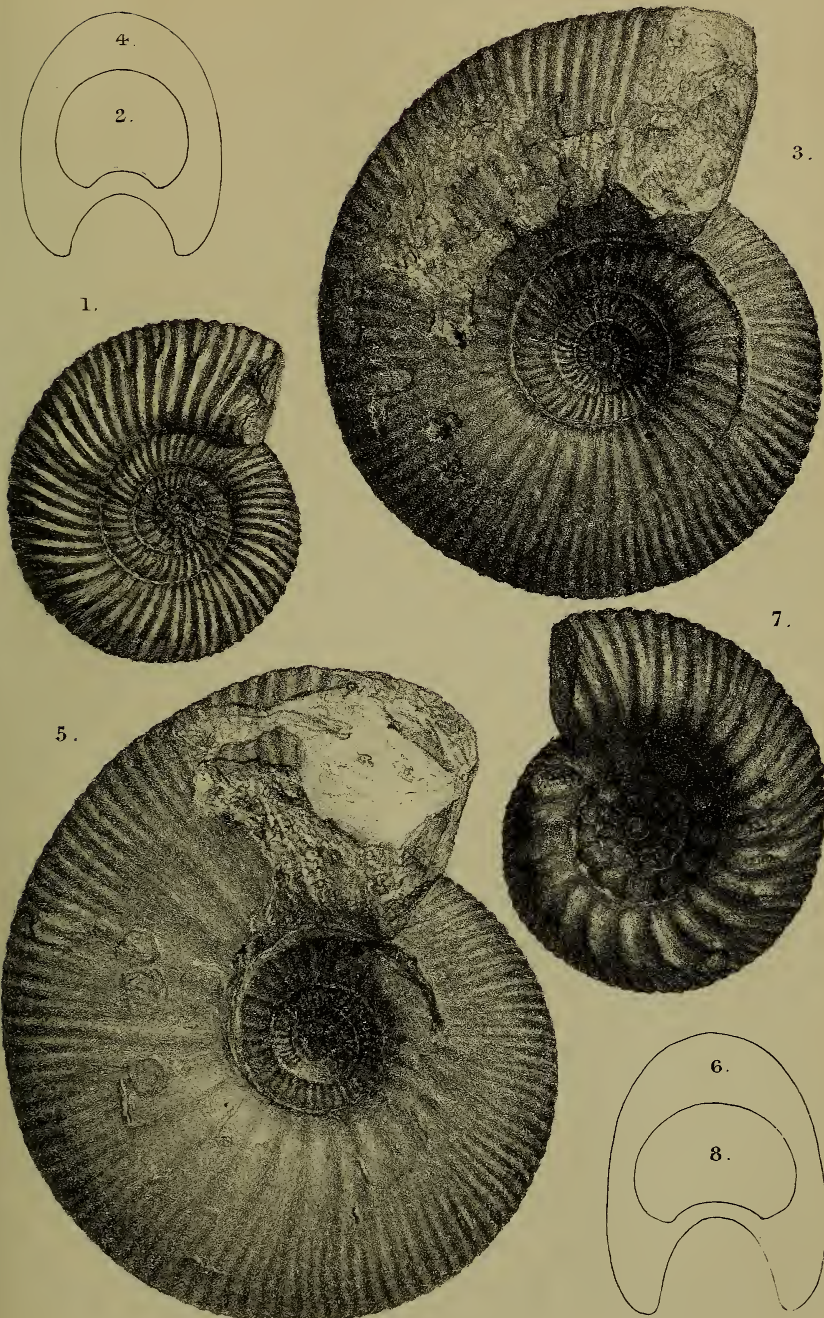
The President pointed out that we had long known that Ammonites varied in a remarkable way. He considered that there was much to be learned from what might be termed 'pedigree palæontology.'

Prof. Seeley regarded the paper as important in defining the nature of species and genera. He suggested that similar conditions of deposition had exercised an influence on both persistence and modification of type, in successive periods of geological time. He thought that the same types could in some cases be followed among Ammonites, from the Lias, through the Oxford Clay to the Gault, indicating persistence with modification. The principle of inheritance which had been urged applied, he believed, to Vertebrates and other groups of fossils.

The Rev. J. F. Blake also spoke.

The Author, after thanking the Society for the manner in which his paper had been received, remarked that it was absolutely necessary that zones should be subdivided in detail. With regard to genealogy it was only necessary, with a perfect series, to follow out the law of earlier inheritance to ensure correctness.

Quart. Journ. Geol. Soc. Vol. XLVIII. Pl. XIII.



F. H. Michael del. et lith.

Mintern Bros. imp.

STEPHANOCERAS.

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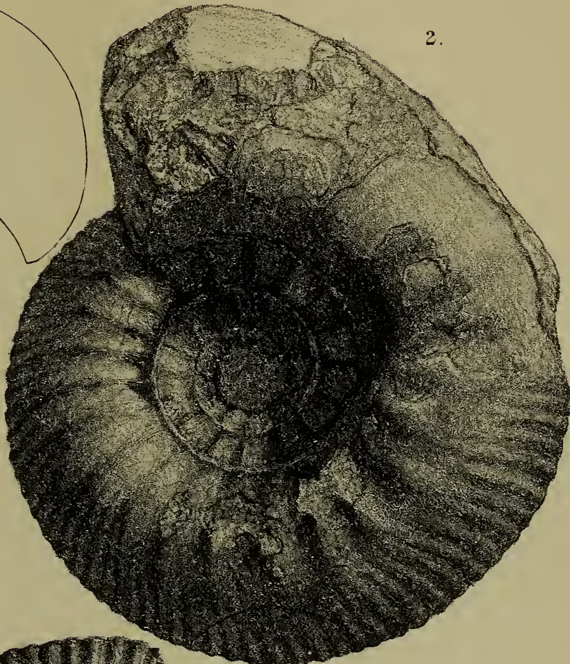

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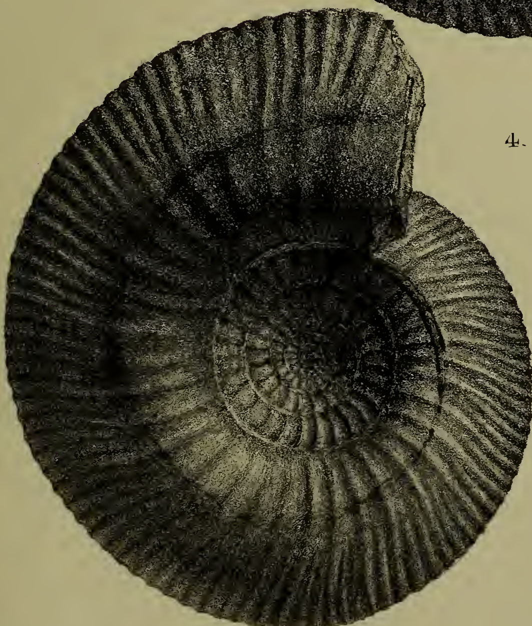

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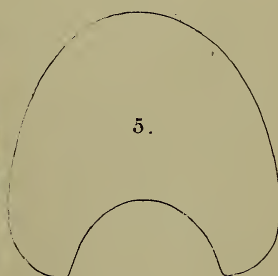

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F. H. Michael del. et lith.

Mintern Bros. imp.

STEPHANOCERAS.

30. *On the* Discovery *of* Mammoth *and* other Remains *in* Endsleigh Street *and on* Sections *exposed in* Endsleigh Gardens, Gordon Street, Gordon Square, *and* Tavistock Square, London. By Henry Hicks, M.D., F.R.S., Sec. Geol. Soc. (Read May 25th, 1892.)

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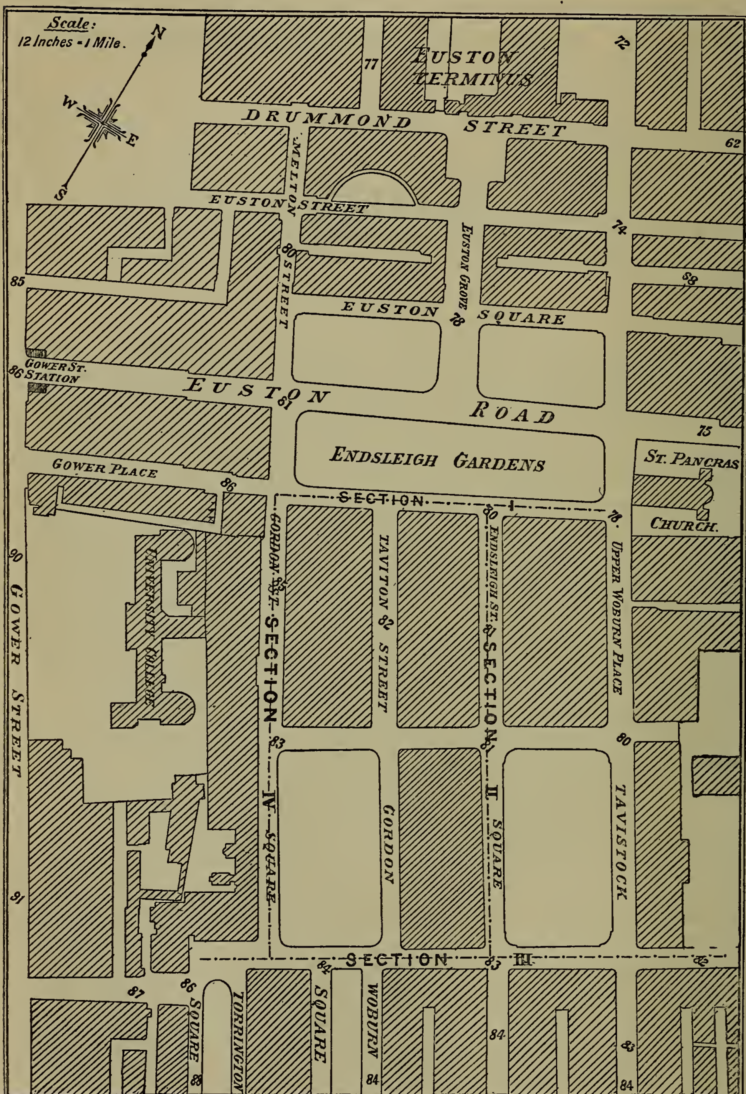
§ 1. Introduction.

On March 9th of the present year I received a communication from Mr. W. R. Bousfield, Q.C., M.P., in which he stated that his friend Mr. G. Hornblower, A.R.I.B.A., had two days before secured portions of a Mammoth tusk, which he had noticed lying on a heap of clay brought up from an excavation made for the purpose of deepening the sewer in Endsleigh Street, W.C. On March 14th I called at Mr. Hornblower's office to see the portions of tusk, and I found that he had in his possession about 3 feet 6 inches of the base of a large tusk, some fragments, and about 2 feet of the anterior portion. It was clear that it had only recently been broken, and that all the fragments belonged to the same tusk. Its circumference at the thickest part was $22\frac{1}{2}$ inches. I then visited the spot in Endsleigh Street whence it had been obtained, and found there several fragments which had been left behind, and also a portion of a rib which was lying on the clay. In course of conversation with the workmen I was informed that the tusk, which was evidently quite complete when first seen, had been found near the northern end of the street, at a depth of about 22 feet from the surface, and that they had left in the cutting another tusk of the same size. The tusks were near together, and doubtless belonged to the same animal, but the one left behind reached along the side of the cutting only, and therefore it was not necessary to remove it. The exposed portion of it was, however, measured, and this was found to be over 7 feet in length. No attempt to obtain it was made, and as that part of the sewer had been bricked up before I visited the place I was unable to secure the specimen. From the clay which had been brought up from the excavation, in addition to the rib mentioned, I obtained afterwards a broken vertebra of the Mammoth, and also a vertebra of Deer. On the same day I called at the office of the contractor, Mr. J. H. Neave, and asked that I might be informed of any further discoveries which might be made. I also called at the office of the Geological Survey in Jermyn Street, and Mr. Clement Reid afterwards accompanied

Map [based on that of the Ordnance Survey]

showing the localities where Mammoth Remains were found and sections of Glacial Deposits exposed in N.W. London.



me to Endsleigh Street for the purpose of securing some of the clay in which the bones had been embedded, in the hope of discovering in it evidences of the contemporaneous flora.

From that time to May 23rd I regularly visited the excavations as they were being made in this and the adjoining roadways, and, thanks to the kindness of Mr. Neave, I have been able to record carefully the facts obtained, and also to secure all the bones which have been found. Fortunately very little of the main sewer had been completed when I first visited the excavations, and as at those points the connecting-drains from the houses had still to be joined on to the main sewer these smaller excavations enabled me personally to record even there the nature of the deposits, to within a very few feet of the depth touched in laying the main sewer.

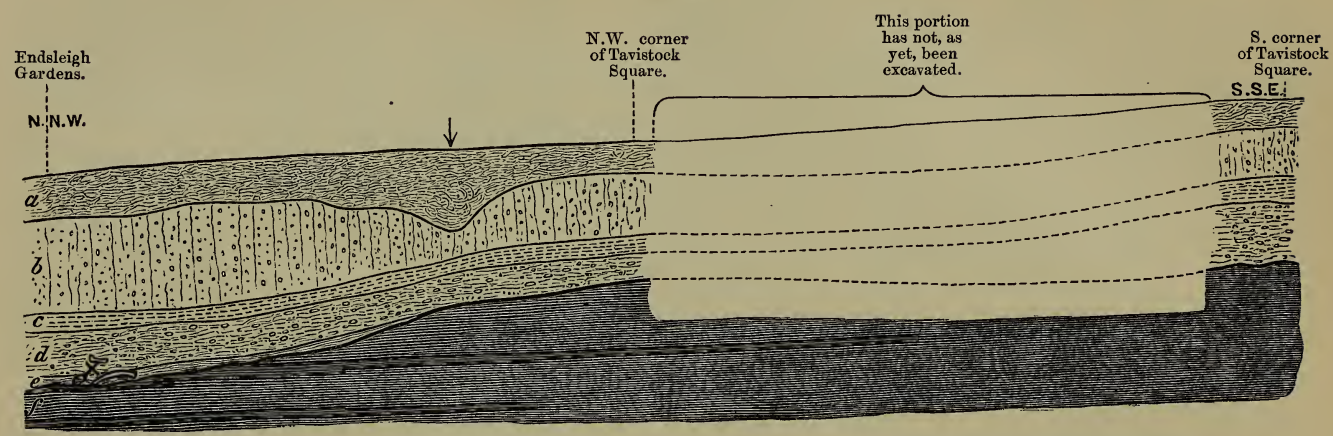
Up to the present time the excavations have been carried along the southern side of Endsleigh Gardens (Euston Square), Upper Woburn Place, the eastern and southern sides of Tavistock Square, the southern and western sides of Gordon Square, Gordon Street, and Endsleigh Street. The foregoing are all the thoroughfares included in the 'first contract,' but I understand that it is the intention of the St. Pancras Vestry, who are carrying out the work, to make new sewers also in Taviton Street, and along the northern and eastern sides of Gordon Square, and the northern and western sides of Tavistock Square, so that the whole of the area included within the boundaries referred to above may be drained at the same depth.

§ 2. Endsleigh Street.

This thoroughfare extends from Endsleigh Gardens to Tavistock Square in a direction from N.N.W. to S.S.E. At the northern end it is 80 feet above Ordnance datum and at the southern end 81, so that at present the fall is slightly towards Euston Square. It will be seen farther on that there is a much more decided fall in the underlying surface of London Clay in the same direction, therefore the present inclination of the surface follows in the main that which was marked out before the overlying deposits had been accumulated. The sewer in this street was carried down to a depth of about 25 feet, and though it was, in part, laid in tunnels, the excavations open to the surface were so extensive that it was quite easy to make out the features of the surface of London Clay below the newer deposits.

The section on the following page (fig. 1, II. on the Map) shows that there is a fall in this surface of no less than 6 feet from the southern to the northern end of the street, *i. e.* to where the Mammoth tusks were found. Except in the neighbourhood of the old sewer, which at the lowest part of the invert reached to a depth of 12 feet, the 'made' or disturbed ground extended only to a depth of from 5 to 6 feet; under this was found about 2 feet of a dark loamy clay which rested on a yellowish-brown clay, and sometimes

Fig. 1.—*Section through Endsleigh Street, and along the western side of Tavistock Square.* No. II. on the Map, p. 454.



[Length of section = about 950 feet. Vertical scale much exaggerated.]

a. Disturbed ground; ↓ points to the line of an old ditch, in which many bones of recent animals were found. Thickness = 6 to 10 feet.

b. Yellowish-brown clay, with much ' race,' flints, &c., thickening towards the northern end of the section, 4 to 10 feet.

c. Loamy sand, thickening towards the southern end of the section, 1 to 3 feet.

d. Yellowish sandy gravel, containing remains of Red Deer and Horse near the base, 4 to 6 feet.

e. Dark clayey loam, with seeds, &c. The Mammoth remains were almost buried in this deposit, at the spot marked ×.

f. London Clay, generally of a dark blue colour.

on a bluish-grey clay, containing a few flints and much 'race.' The yellowish clay varied from 6 to 10 feet in thickness, and it was quite undisturbed. Under the 'race'-clay was found some yellow sand, and below that sandy gravel. Lower down was a coarser gravel through which water flowed very freely. This rested on a dark clayey loam which appeared to pass almost insensibly into what was clearly deeply-stained London Clay with septaria. It was in the dark loam that the Mammoth tusks were found, and it was this also that yielded the seeds which will be referred to farther on.

On March 18th, in an excavation on the western side of the street, and very nearly opposite the spot where the tusks were met with, a portion of the antler of a red deer (*Cervus elaphus*) and two cannon-bones evidently belonging to two horses (*Equus caballus*) were discovered in yellow gravel about 20 feet from the surface. As the surface of the London Clay seems to rise rather sharply on the western side of the street, these bones were very nearly on the old land-surface, though not actually embedded in the dark loam.

On March 29th I found that the workmen, in excavating for a connecting-drain on the eastern side of Endsleigh Street, opposite the last house on that side of the street, and about 15 feet north of the position where the large tusks were discovered, had come upon several bones of a comparatively young Mammoth at a depth of 22 feet from the surface. These were in an excellent state of preservation, and had been embedded almost completely in the dark loam above the London Clay. The manner in which the bones were found, lying at the bottom of the excavation, here only about 6 feet in length, and less than 3 feet across, would indicate that there must have been a complete skeleton of the animal at this spot. I obtained possession of the bones and took them direct to the Museum of Practical Geology in Jermyn Street, where they were carefully examined, along with others which I secured afterwards from the same excavation, by Mr. E. T. Newton, F.G.S., who has kindly furnished me with the following list:—

1. Lowest Bed, with seeds.

Cervus. Axis vertebra.

Elephas primigenius.

Portions of a large tusk, part of a vertebra and part of a rib of a large animal.

The following bones, apparently belonging to one individual, about half grown, as shown by the teeth and by the epiphyses of the bones not being fixed:—

Lower Jaw, with the last milk molar much worn and the first true molar just coming into use.

Jugal arch. Atlas vertebra.

Scapula (28 inches long).

Humerus (31 inches long).

Ulna, without distal epiphysis (23 inches long).

Femur (37 inches long).

Many pieces of ribs.

Arvicola. A portion of a cheek-tooth of a small species.

2. Gravel above No. 1.

Cervus elaphus. Proximal part of a large antler.
Equus caballus. Two cannon-bones differing in size.

In the loam in which the bones were embedded Mr. Clement Reid, F.L.S., F.G.S., has recognized the seeds, &c., of the following plants, which he says are usually found in marshy places or ponds :—

Ranunculus aquatilis, Linn.
—— *sceleratus*, Linn.
—— *repens*, Linn.
Stellaria media, Cyr.
Geranium, sp.
Potentilla Tormentilla, Neck.
Hippuris vulgaris, Linn.
Myriophyllum spicatum, Linn.
Polygonum aviculare, Linn.
—— *Persicaria*, Linn.
Rumex obtusifolius, Linn.
Luzula ? maxima ?, De C.
Potamogeton obtusifolius.
Potamogeton crispus, Linn.
Zannichellia palustris, Linn.
Eleocharis palustris, Br.
Carex dioica, Linn.
——, sp.
——, sp.
Chara, sp.
Mosses.

Two land-shells also have been identified:
Planorbis nautileus.
Limnæa peregra.

It will be observed that there are no typically Arctic plants, but they are such as extend at the present time from the Arctic Circle to the South of Europe. That the climate, even in the Thames Valley, was then cold there cannot, in my opinion, be any doubt, and it is more than probable that farther north the conditions were such as are considered to have been in part, at least, characteristic of the Glacial period.

§ 3. Endsleigh Gardens.

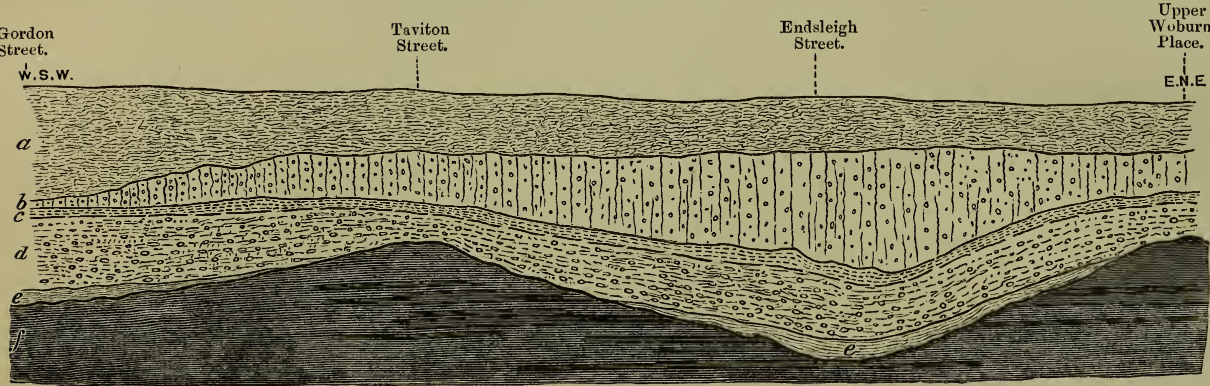
The section facing this page (fig. 2, I. on the Map) was compiled from observations made by myself in the portion between Endsleigh Street and Gordon Street, and from facts communicated to me by Mr. Neave and the clerk of the works with regard to the part between Endsleigh Street and Upper Woburn Place which had been, in the main, completed before my examination of the excavations commenced.

Opposite Upper Woburn Place the sewer has been carried down to a depth of about 28 feet, and I was informed that three separate layers of septaria were met with in the London Clay, which here reached upwards to within 12 feet of the surface of the street. Some excavations made subsequently in Upper Woburn Place, for connecting the drains with the houses, enabled me to verify this in part, and they also proved that the London Clay approached gradually nearer the surface eastwards.

The following section, exposed in making the Metropolitan Railway, which I quote from Mr. Whitaker's Memoir, 'The Geology of London,' vol. ii. p. 321, is interesting as showing that the ridge of London Clay extends northwards for some distance :—

"Euston Square (something doubtful near eastern side).
Made ground, 7 to 4.
Gravel and sand up to 8.
London Clay, within 10 feet of the surface near E. (? only 7 at E.)."

Fig. 2.—*Section along the southern side of Endsleigh Gardens (Euston Square).* No. I. on the Map, p. 454.



[Length of section = about 750 feet. Vertical scale much exaggerated.]

a. Disturbed ground, 6 to 10 feet.

b. Yellowish-brown clay, with much 'race,' flints, &c., 2 to 10 feet.

c. Loamy sand, 1 to 2 feet.

d. Yellowish sandy gravel, 3 to 6 feet.

e. Dark clayey loam with seeds, &c.

f. London Clay, usually of a dark blue colour. Sometimes, immediately under the gravel, it is of a yellowish-brown colour to a depth varying between 6 inches and 1 foot.

In the district directly north of Euston Square, in all the geological maps hitherto published, London Clay is shown to reach to the surface, but I am doubtful whether this is the case over all that area, for it is quite possible to mistake the brown clay which overlies the gravel, where it happens to be free from stones, for weathered London Clay. Over some parts of this district northwards, especially in the neighbourhood of Regent's Park and in St. John's Wood, I have recognized this clay with 'race,' containing included patches of gravel, in cuttings of several feet in depth. The presence of the gravel-patches clearly proves that it is not London Clay, but a redeposited clay derived mainly from the denudation of the London Clay. This re-deposited clay can usually be differentiated from the London Clay, not only because it frequently contains 'race' and patches of sand, and shows bluish streaks due to the percolation of water saturated with carbonate of lime; but also because of the manner in which it crumbles, when dry, into irregular fragments. London Clay, even when much weathered, still retains evidences of lamination, and is easily split along well-defined lines. With the re-made clay, on the other hand, unless near the base, where it is usually more or less sandy, there is very little evidence of lamination. The London Clay, excepting for a foot or two under the gravel (where it was usually found to be of a brown colour on account of decomposition by percolating waters), was of a dark bluish tint, and varied but little in any of the excavations.

The valley scooped out of the London Clay, nearly in a line with Endsleigh Street, as shown in figs. 1 and 2, seems to cut across Endsleigh Gardens in a northerly direction, evidently towards the comparatively low ground between Euston Road and Old St. Pancras Church, where at one point in the Old St. Pancras Road the present height is given as 57 feet only above O.D. against 75 in the Euston Road, and 85 in Upper Bedford Place. It is, of course, quite possible that the London Clay may reach almost or quite to the surface immediately north of Euston Square, but even then it will be seen that the inclination of the old valley must have been in the direction indicated, for the floor of London Clay exposed under the newer deposits reaches to a height of 68 feet in Upper Bedford Place, that is, 9 feet higher than the present level of the road-surface in Old St. Pancras Road. In an easterly direction, between Endsleigh Gardens and the Fleet Valley, London Clay is shown in the Geological Survey Map to reach to the surface at heights of 75 and 80 feet above O.D., and therefore the Endsleigh Valley must have been separated here from the Fleet by an important ridge, narrowing gradually towards the north. On the western side of Endsleigh Gardens the evidence points to another depression towards Gower Street, for a section exposed in Gower Place, beyond, but in a line with, the section reproduced in fig. 2, showed an increase in the thickness of the deposits. It also proved that beyond the 'made ground' in fig. 1 the yellowish clay again covered the sand and gravel. This valley also seems to run in a northerly direction.

The nearest section to that in Gower Place which has yet been described is the following at Gower Street Station, given by Mr. Whitaker (*op. cit.* vol. ii. p. 321):—

"Made ground, 4 to 5 [feet].
Sand and gravel, with yellow clay, 13 to 17 [feet].
London Clay, yellow at top, up to 5 feet, or above the line (rises eastward)".

The amount of yellow clay is not stated, but it is interesting to note that it extends northwards in that direction. The London Clay, which is stated to rise eastwards, evidently bounds the valley which crosses Gower Place in a northerly direction.

§ 4. Upper Woburn Place and the Eastern side of Tavistock Square.

From the south-eastern corner of Tavistock Square to the northern end of Upper Woburn Place there is a fall towards the north in the present surface of about 5 feet, and the excavations which have been made show a fall in the London Clay, in the same direction, of about 3 feet. The excavations were not opened out to the surface continuously along this line, but tunnels were made, in places, between the openings. The materials removed from the tunnels which were brought to the surface consisted of dark blue clay, with numerous septaria, fragments of iron pyrites, &c. The tunnels here, being nowhere nearer than about 20 feet to the surface, were well in the London Clay and below all the newer deposits, which did not in any part reach downwards to more than about 14 feet from the surface of the road.

At the corners of Tavistock Square very wide excavations were made, and excellent sections of the deposits were exposed, of which the following are the details:—

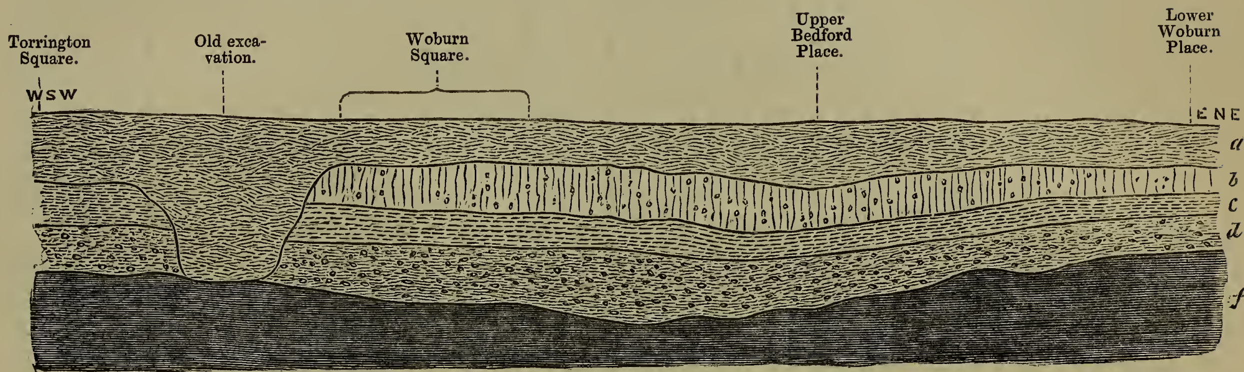
(*a*) North-eastern end of Tavistock Square, and extending into Upper Woburn Place.
Made ground, with stained clay at the lower part, 7 feet.
Yellowish clay, 1 foot.
Sand and sandy gravel, 5 feet.
London Clay.

(*b*) South-eastern corner of Tavistock Square, and extending into Tavistock Street.
Made ground, 6 feet.
Yellow clay, 2 feet.
Yellow loamy sand, 1 foot.
Sandy gravel, 5 feet.
London Clay.

§ 5. Southern sides of Tavistock and Gordon Squares.

The excavations along this line were carried to depths from the surface varying from 17 feet, at the south-western corner of Gordon Square, to 25 feet at the south-eastern corner of Tavistock Square. In Tavistock Square tunnels were made to connect the openings, but in Gordon Square the excavations were carried along continuously.

Fig. 3.—*Section along the southern sides of Tavistock and Gordon Squares.* No. III. on the Map, p. 454.



[Length of section = about 900 feet. Vertical scale much exaggerated.]

a. Disturbed ground, in one part reaching down to the London Clay (evidently filling up an old excavation made for the purpose of obtaining sand and gravel), 5 to 16 feet.

b. Yellowish-brown clay, with 'race,' flints, &c., 3 to 6 feet.

c. Loamy sand, 2 to 3 feet.

d. Yellowish sandy gravel, increasing in thickness towards the centre of the section, 5 to 7 feet.

f. London Clay. The upper surface was of a yellowish-brown colour along this line. There was no loam here between it and the gravel.

The fall in the present surface of the ground along this line is from the western to the eastern side, the height opposite Torrington Square being 86 feet compared with 82 opposite Lower Woburn Place. In the London Clay floor as seen in the section facing this page (fig. 3, III. on the Map) there is a wide but shallow valley, which is deepest at the south-eastern corner of Gordon Square, with a fall apparently in the direction of the Endsleigh Street valley. The deposits along this line showed very little variability, but the sand and gravel attained a greater thickness at the south-eastern corner of Gordon Square. Here also there were many streaks of a bluish clay in the sand (*c*). Sometimes the upper part of the clay (*b*) was deeply stained from percolation through the 'made ground'; but all along its position was well-marked.

Towards the south-western side of Gordon Square it was found that previous excavations had been made, and all the sand and gravel removed for a space of about 150 feet, for nothing but brick-rubbish and refuse-material rested here on the London Clay floor. Beyond this, towards Torrington Street, the usual succession showing clay, sand, and gravel was again met with, and in an opening in Torrington Street (beyond, but in a line with the section) the yellow clay attained a thickness of about 7 feet, and yellow sand and gravel were brought up from below. The London Clay comes within 16 feet of the surface at the south-eastern corner of Gordon Square, and the deepest part of the excavation there was $17\frac{1}{2}$ feet. Between this point and Torrington Street is the shallowest part, in which the new sewer has been laid, and the fall is directed eastwards along the line of the section (fig. 3).

§ 6. Gordon Street and the Western side of Gordon Square.

The excavations along this line were the last made and are only just completed. In the deepest part, down the length of Gordon Street, tunnels were bored to connect the openings, but in Gordon Square one continuous opening was made. The fall in the present surface is slightly northward, but the underlying floor of London Clay exhibited a somewhat irregular surface, with a more marked depression, reaching to a depth of 21 feet, at the north-western corner of Gordon Square.

Near the southern end of Gordon Street, in a loamy clay brought up from below the gravel, at a depth of about 18 feet from the surface, the seeds of *Ranunculus repens*, *Rumex*, and *Polygonum Persicaria* were recognized by Mr. Clement Reid. The great amount of water here prevented me from obtaining good samples of the loam, otherwise a more complete flora could doubtless have been made out. It will be noticed that the seeds recognized are those of plants found also in Endsleigh Street, in association with the mammalian remains (see p. 458). In these two places we have therefore evidence of the flora which grew on this old land-surface when the great herbivorous mammals roamed over it.

In the main excavation at the north-western corner of Gordon

Square the gravel attained a thickness of 9 feet, the overlying sand about 2 feet, and the yellow clay over 4 feet. The 'made ground' here averaged about 6 feet in thickness. The lower part of the clay (*b*) in the section facing this page (fig. 4, IV. on the Map) was very calcareous here, and continued so for some distance southwards in Gordon Square. Between the loamy sand and the clay, and in places in the latter, there was also a gravelly clay; in this I found many fragments and several well-preserved specimens of shells which had evidently been derived from the London Clay. This find is important, not only as proving that much of this yellow clay must have been derived from the London Clay, but also as showing, from the condition in which the specimens were found, their occurrence at one place only, and at that place in fair abundance, that they must have been transported to this spot by ice.

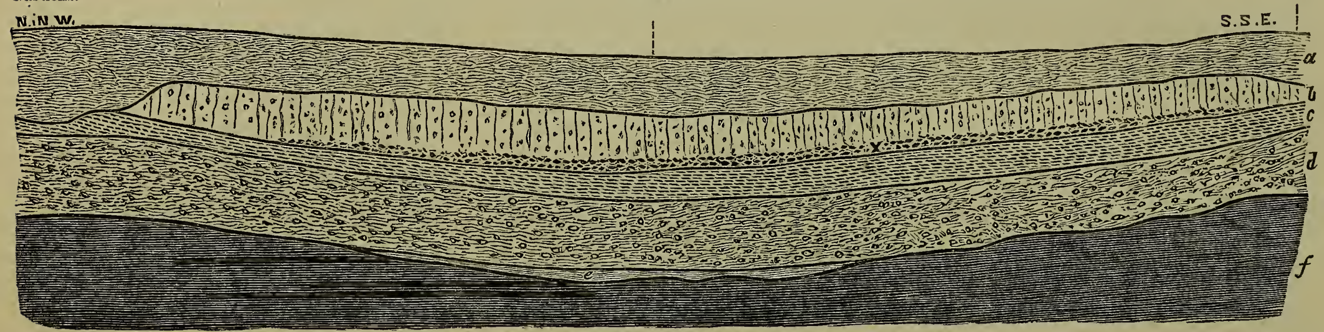
An examination of the fragments and pebbles in the gravelly clay in which the shells were found leads to the conclusion that they might have been derived from the combined denudation of Chalk, London Clay, and a deposit resembling in a marked degree the gravel described by Prof. Hughes in Hertfordshire as the 'gravel of the Upper Plain.'[1] Quartz-pebbles are unusually plentiful in it, generally small, but frequently from half an inch to an inch across. There are also quartzite pebbles, and worn fragments of chert, ragstone, &c.

The marked resemblance between the gravelly part of this deposit and the gravel occurring as enclosed patches in the brown clay with 'race' at Finchley and Hendon presented itself very forcibly to my mind, and a careful comparison made since has proved that they are almost identical in composition. The patches in the brown clay at Finchley and Hendon could hardly have been deposited otherwise than as frozen masses, and I think the evidence here points to the means of transport as having been ice, with a subsequent slight readjustment of the materials by water-action. The presence of so much calcareous matter, of so many quartz-pebbles, and of many unbroken shells would indicate the direct transport to this spot of the material.

The shell most plentifully found is a *Pectunculus*, derived from one of the basement-beds of the London Clay, and as these beds are nowhere exposed in the immediate neighbourhood, but occur on the Hertfordshire plateau, in places, under the Plateau Gravel, it seems reasonable to suppose that the shells were transported directly with the gravel to the spot in Gordon Square where they are now found. It is well known that they are very brittle, even in the original bed, hence a very slight amount of water-action would have entirely shattered them, and no complete valves could have been found at any distance from the parent bed. Some of the 'race' found so abundantly in parts of the clay is probably due to the decomposition of septaria from the London Clay, but it seems equally probable that it has in part been derived from dissolved Chalk.

[1] Quart. Journ. Geol. Soc. vol. xxiv. (1868) p. 284.

Fig. 4.—*Section through Gordon Street, and along the western side of Gordon Square.* No. IV. on the Map, p. 454.



[Length of section = about 950 feet. Vertical scale much exaggerated.]

a. Disturbed ground, 6 to 10 feet.

b. Yellowish-brown clay, with much 'race' in places, 4 to 6 feet.

At the spot marked × derivative shells were found in a very calcareous sandy clay, with subangular flints, quartz-pebbles, &c.

c. Loamy sand, thickening towards the southern end of the section, 1 to 3 feet.

d. Yellowish sandy gravel, 6 to 9 feet.

e. Clayey loam, with seeds.

f. London Clay, with septaria, &c.

The sands and gravels below the clay in these sections are usually of a bright yellow colour, but in places they are more deeply iron-stained. Large flints and masses of sarsen-stones were occasionally found in the gravel, though on the whole the pebbles and fragments were rather small. There were many well-rounded pebbles from the Tertiary beds, but the majority of the flints were subangular. A few pebbles of quartz and quartzite were found, and also fragments derived from the Lower Greensand. There appeared to be few, if any, very far-travelled rocks, such as are present in the uppermost Boulder Clay, a few miles to the north.

On the other hand, the materials resemble in a marked manner those which occur in the sands and gravels which at Finchley and Hendon underlie the brown clay with 'race.' This brown clay occurs below the Upper Boulder Clay, which contains large fragments of chalk, large unworn flints, and numerous northern erratics, and there is usually a varying thickness of unstratified gravel separating the clays.

§ 7. Conclusions.

The old land-surface under Endsleigh Street, on which the Mammoth died, is almost exactly 60 feet above the present sea-level.

The deposits which subsequently accumulated over the remains were evidently laid down in moderately tranquil water, otherwise the bones, especially those of the young Mammoth, would not have remained so near together. The epiphyses of the long bones were found close to the shafts, and unless the animal was suddenly buried in sediments accumulated in fairly quiet waters such as those of a lake, the epiphyses would have been readily moved as soon as the soft tissues and cartilage decayed. Except in caverns, where the bones in their fresh state must have been carried in by hyænas and other beasts of prey, it has been difficult in many cases to determine the exact horizon at which the Mammoth lived, since the bones have as a rule been removed from the spot where the animal died, and re-deposited in newer sediments. Here, however, we have the old land-surface, and evidence of the contemporaneous flora in the loam in which the bones were embedded.

An examination of the sections in this area, and also in adjoining areas, shows that there is a well-marked sequence in the deposits. Immediately over the bones there was, first, a fairly rough gravel; this was followed by a sandy gravel with smaller pebbles, and the latter was overlain by a fine, somewhat loamy sand with occasional seams of clay. Above this came the yellowish clay containing 'race,' derived shells, and here and there patches of gravel and scattered flints. It would appear from some of the sections that there might also have been some sand and gravel, in places, over the clay; but as this sand and gravel was everywhere much stained by percolation of water through the 'made ground,' I have preferred not to mark it as distinct from the disturbed material.

The following, in my opinion, are the main changes which may be deduced from a study of the sediments, &c.:—

(i) An uneven land-surface with a flora indicative of a climate that was gradually becoming colder.
(ii) Migration of the Mammoth and other northern animals southwards in advance of an ice-sheet, or of glaciers radiating from various northern and north-western centres.
(iii) Accumulation of materials on plains and in valleys, conveyed by water derived from melting ice and snow passing over soft deposits. The mammalian remains on the old land-surface would, at this time, be either covered over or transported from higher to lower ground.
(iv) A further advance of the ice reaching to within a short distance of this area, and the deposition at Finchley, &c., of the Upper Boulder Clay with many northern and far-travelled erratics.
(v) Retreat of the ice, and the accumulation of the more recent Thames Valley gravels, and of some surface-deposits.

Discussion.

The President congratulated the Author on his good fortune in finding these magnificent specimens in London. It was remarkable that no remains of Mammoth had been found in the $7\frac{1}{2}$ acres of gravel turned over in digging the foundations of the new Law-Courts. But there was no doubt a difference between the 80-feet plateau at Endsleigh Gardens, and the sloping surface between the 40- and 60-feet contour on which the gravel of the Law-Courts occurred. It must be remembered that the discovery, though interesting, was not absolutely new, for so long ago as 1715 the Mammoth was found in deposits on the same plateau (at Gray's Inn Lane) along with a Palæolithic implement.

Mr. Monckton remarked that the clay with flints and 'race' was very unlike the Chalky Boulder Clay; even at Hornchurch the Boulder Clay was full of lumps of chalk, and yet that place was much farther from the Chalk outcrop than Euston Station. He looked upon the Endsleigh Gardens deposit as newer than the Chalky Boulder Clay, and thought the materials of the sands and gravels might have come from older gravels, and the *Pectunculus* from London Clay of the neighbourhood. He did not consider 'race' evidence of Glacial age. He was very glad to find that the Author did not suggest a submergence or marine agency in connexion with the sands, gravels, &c., described in the paper.

Sir Henry Howorth also spoke.

The Author thought that Sir Henry Howorth had met the case exactly by emphasizing the fact that the bones, when undisturbed, always occurred under the whole of the deposits. The latter cannot be correlated with the low-lying river-gravels, but they resemble in a marked manner the Glacial deposits at Finchley and Hendon. The clay with 'race' is very widespread, and is met with at different levels over most of the undulating plain of North-west Middlesex. At Finchley it underlies a great thickness of Chalky Boulder Clay, with northern erratics.

In reply to Mr. Monckton, the Author said that the Hampstead and Highgate Hills would not, in any way, interfere with the outspreading of this material from a north-western area to the district referred to in this paper, as the inclination of the surface was more or less gradual from the Hertfordshire Upper Plain to this point.

The Author had been informed by Mr. H. B. Woodward that in a cutting made, near Wembley Park, for a new railway-station on the Metropolitan extension line, 3 miles south-west of Hendon, some Pleistocene mammalian remains were found in October 1890.[1] They occurred in the brown clay with 'race,' therefore they had evidently been transported from higher ground. During the present year, at Finchley, fragments of bone belonging, as the Author believes, to the Mammoth, were found in the lowest gravel. This proves that the animals must have died before any of the Glacial deposits which now occur at Finchley had accumulated.

[1] [The following are the particulars communicated to the Author by Mr. H. B. Woodward:—In a cutting made near Wembley Park for a new railway-station on the Metropolitan extension line, there was opened up, in October 1890, a deposit consisting mainly of re-constructed London Clay. In this clay there was a band of gravel, about one foot in thickness, having a clayey matrix, and containing flint-pebbles and fragments of septaria. The disposition of the gravel indicated a basin-shaped arrangement of the deposit, but it is possible that the accumulation may have been disturbed by local slipping of the strata. The section showed altogether about 10 feet of clay with the gravel band near the base, and remains of Hippopotamus, &c., were obtained from the gravel and also from the portions of clay exposed just beneath it. The deposit occurs on the slope of a hill, in the higher portion of the Brent Valley, away from the main stream.]

31. *On* Delphinognathus conocephalus (Seeley) *from the* Middle Karoo Beds, Cape Colony, *preserved in the South African Museum, Capetown.* By H. G. Seeley, Esq., F.R.S., F.G.S., Professor of Geography and Lecturer on Geology in King's College, London. (Read May 25th, 1892.)

The skull herein described is the only portion of the animal collected. No locality for it is recorded in the South African Museum, but Mr. Thomas Bain, the Government geologist in Cape Colony, believes it to have been collected by himself from near Beaufort West. It is slightly distorted with the folding of the strata. The preservation of the specimen leaves something to be desired, for the pre-orbital region is more or less obscured by weathering, which has destroyed the superior contour of the snout, the alveolar border, and the anterior extremity of the jaws. The occipital condyle and much of the occipital plate from the back of the skull are also lost. But, notwithstanding these defects, the skull is the most interesting Anomodont preserved in Cape Colony, and indicates a new family of fossil Reptilia.

The head is characterized by its broad, high, vertical occipital plate. The broad subpentagonal roof to the brain-case (fig. 2) ascends laterally from the inclined temporal region, and is elevated in a cone, which terminates in a large, circular, crater-like parietal foramen. The skull has large sub-circular vertical orbits, placed far backward above the hinder extremity of the lower jaw, so as to converge forward. The temporal fossæ are short and small, owing to the position of the orbits and the width of the cerebral region. The quadrato-squamosal region is directed obliquely forward, and forms a vertical articular surface to articulate with the lower jaw, which is singularly deep posteriorly, and suggests the jaw of a porpoise in its form.

The skull is now 31 centim. long, but was probably somewhat longer. The occipital plate was higher than wide. It extends 24 centim. above the inferior margin of the mandible. The bones which compose the plate lie in a vertical plane, and are conditioned as in *Dicynodon* and its allies, but their several limits cannot be traced. The transverse measurement of the back of the head over the foramen magnum is 20 centim., and at the lateral borders the squamosal bones are prominent. Those bones make the external narrow, vertical borders of the small temporal vacuities. The vertical measurement from the base of the occipital condyle to the summit of the occipital plate is 16 centim.; the superior lateral contours of the plate converge upward in half an ellipse. Inferiorly, there is only a slight narrowing caused by a slight approximation of the squamosal bones in the region of the condyles for the lower jaw. The foramen magnum is not clearly evidenced, but appears to have been small, narrow, and vertical, not more than 2·7

Fig. 1.—Skull of Delphinognathus conocephalus (Seeley).

Explanation.

$\frac{1}{3}$ nat. size.

pf=post-frontal bone.
p=parietal bone.
sq=squamosal bone.
m=malar bone.
f f=fractured surfaces.

centim. high by 1·3 centim. wide. The occipital condyle is inferred from the fracture to have been fully 4 centim. wide. The exoccipital bones as preserved are large and extend outward and slightly upward. On their infero-lateral borders they receive the quadrate bones, which lie internal to and behind the squamosal bones. The quadrate bones extend below the occipital condyle; their posterior surfaces are flattened, inclined somewhat forward, and vertical when seen from behind. Each quadrate bone terminates in a pedicle, with a vertical condyle which looks forward (fig. 1), is saddle-shaped, 4 centim. wide, and relatively shallow, concave transversely and convex from front to back. The transverse width of the interspace between the condyles of the quadrate bones is 6 centimetres. The supra-occipital bone is a sub-quadrate ossification above the foramen magnum, which lies between the exoccipital bones. The details of these elements of the occipital plate are lost, and its lateral margin is injured by fracture.

The interparietal bone appears to form the summit of the occipital plate as in Dicynodonts. It is of transversely oblong form, has a squamous union with the supra-occipital, and lies in front of that bone so that it is partly overlapped by it. It shows a slight median vertical ridge.

The superior surface of the skull comprises a long, narrow, triangular pre-orbital portion which is badly preserved; and a remarkably wide sub-pentagonal supra-cerebral region behind, which is defined by the occipital plate behind, and laterally by the borders of the temporal vacuities, and by the orbits. The transverse width of the post-orbital mass is about 11·5 centim. It rises in the form of a cone to a height of several centimetres above the level of the frontal margin of the orbit, and terminates superiorly in a large circular parietal foramen which is nearly 2 centim. in diameter. The middle of this foramen is situate vertically above the posterior border of the orbit. The external surface of the cone is smooth, and furrowed with vascular impressions which radiate in every direction. If the foramen were fancifully compared to the crater of the cone, these markings would simulate the irregularities of lava-streams.

This conical crown to the head descends posteriorly and laterally into the temporal vacuities, which are convex from above downward, concave from back to front, and marked with longitudinal ridges. The antero-posterior measurement of the vacuity is 5 centim.; and the measurement is 11 centim. from the summit of the parietal cone to the superior margin of the squamosal bone, which defines the temporal fossa. That vacuity is limited in front by the post-frontal bone, which forms the posterior border of the orbit. The malar bone may be excluded from the zygoma, which descends as a nearly vertical curved bar extending from the frontal to the squamosal.

The orbit of the eye is 7 centim. in diameter, nearly circular, vertical, and looks outward and forward. The frontal bone which presumably forms its upper border is thickened, rounded, and marked with small vascular impressions. This inflated superior margin is prolonged downward by the post-frontal bone which forms the hinder border to the orbit. The bone twists as it descends, so that its lower extremity, which has lost the inflation of its upper part, is nearly in the same plane with the squamosal bone. It is from 2 to 2·5 centim. wide. There is an excavation behind its posterior angle,

Fig. 2.— *View of upper portion of Skull of* Delphinognathus.

$\frac{1}{3}$ nat. size.

o = occipital margin.	*f* = frontal bone.
s = squamosal bone.	*t* = temporal vacuity.
pt = post-frontal bone.	*p* = parietal foramen.
or = margin of orbit.	

where it meets the squamosal bone, and this gives a sharp posterior margin to the post-frontal bone. The squamosal bone contributes to the hinder part of the inferior border of the orbit; while the malar bone forms a narrow bar on the antero-inferior border of the orbit. It meets the squamosal behind, and is prolonged downward and backward below the squamosal, terminating above the supra-condyloid notch; anteriorly it presumably meets the maxillary bone, but the suture is not evident. The squamosal bone, which is imperfect posteriorly, is of a sub-rhomboid form as preserved, with a talon extending downward and forward to cover the condyle formed by the quadrate bone. It is flattened on the vertical external surface. The infero-posterior outline is nearly straight, becoming concave towards the quadrate condyle, and, as preserved, is about 11 centim. long. The oblique transverse measurement from that border, which is rounded from within outward, to the orbital margin is about 7·5 centimetres.

The condyle is about 4 centim. deep, but behind the vertical articular surface the bone is a little constricted from above downward. This is partly due to a remarkable sub-ovate notch, between 2 and 3 centim. wide and deep, which excavates the bone above it in front. The upper border of the excavation is made by the malar bone. I am not aware of a similar excavation in any other animal, though the quadrate bone is similarly inclined forward in some Ornithosaurs and some Lacertilians.

As the malar bone extends forward its contour ascends, so that the hinder margin of the jaw forms a concave arch, the summit of which, as preserved, is elevated above the inferior border of the orbit. The state of preservation does not demonstrate the characters of the anterior maxillary alveolar border, but the jaw was probably straight and not concave in the dentary region as in the present state of the specimen.

The frontal bones appear to be paired at their anterior extremities. The nasal region is compressed, and prolonged the elevated frontal area forward for some distance, before the jaw descended towards its anterior extremity.

The exact position of the anterior nares is not quite manifest, though they appear to be some distance in front of the orbits and close together. The bones in the median line of the snout only show that the jaw becomes much depressed in front. No teeth are seen at its anterior extremity; on the right side the alveolar border is not preserved, and on the left side it is covered by the displaced lower jaw. The maxillary teeth have mostly disappeared, and the few which remain, imperfectly preserved, show a cylindrical type not altogether unlike that of *Procolophon*, only the crowns are more inflated.

The lower jaw is short and remarkably deep behind the teeth. Owing to the quadrato-squamosal articulation of the skull being below the middle of the orbit, and the circumstance that the lower jaw is not prolonged backward behind the condyle, it is much shorter than the skull. Its coronoid region forms a sort of coronoid process which exactly corresponds with and fits into the concavity in the palatal contour in front of the orbit, formed by the malar and squamosal bones. The hinder portion of this outline is long, straight, oblique, and connects the rounded coronoid eminence with the vertical articulation of the lower jaw. The inferior outline of the lower jaw, convex behind, concave in the middle, is necessarily developed downward as it extends backward; so that, though the total length of the mandible as preserved is only 20 centim., the depth below and behind the coronoid is about 13 centimetres. Hence the posterior half of the jaw has the aspect of being bent downward at an angle of 45° with the dentary part, while its form is obliquely oblong, and nearly twice as deep as is the dentary region. The articular condylar surface is vertical, and so situate on the infero-posterior extremity of the bone as to give the impression that the larger part of the jaw is superior in position to the articulation. The inferior border of the dentigerous region would about pass through the middle of the condyle. It is therefore manifest that, as the jaw extends forward, its vertical depth contracts, chiefly owing to the concavity of the inferior border; by this contraction it is diminished to about 6 centim. behind the last tooth, and not more than 5 centim. at the anterior extremity of the jaw, which is manifestly imperfect. The external layer of bone is lost in the alveolar region, but about half-a-dozen closely-set cylindrical teeth with conical crowns are preserved. The interspaces between the teeth are narrow. A slight cinguloid constriction defines the crown of the tooth, which is convex, and inflated as far as it is exposed, but the summit of the crown is not seen. The cylindrical roots are about 5 or 6 millim. in diameter. Successional teeth rise within the sockets on the inner side. On the left side the traces of the teeth are less satisfactory.

The lower jaw is composite and appears to show on the external surface the dentary, coronoid, angular, surangular, and articular elements, though their limits are indefinite. The jaw is flat externally, like that of a porpoise, and the rami similarly converge forward, but no trace of a symphysis is to be seen. There is a vascular foramen above the condyle, about midway between its upper margin and the summit of the coronoid process.

In the general form of the skull there is some resemblance to an Artiodactylate mammal in the large size and backward position of the vertical orbit, with its posterior boundary, and in the elongated form of the pre-orbital region, though the arch which supports the lower jaw is unlike that in any mammal. The lower jaw can only be compared to that of the Dolphin tribe in form and in dentition, as preserved. These superficial resemblances are the more interesting because the characters of the occiput, in so far as they are preserved, so closely conform to the Anomodont type of the Dicynodontia as to leave no ground for reasonable doubt that the genus must be included in the Anomodont order. The characters of the post-orbital region, however, are all different from those of every type hitherto comprised in that order. The differences appear to be more than those of a family; they are especially the forward direction of the quadrate bone, the excavation above the condyle which it forms, the short post-orbital region, and the depth of the zygomatic bar, relatively to its short length. The teeth are quite consistent with reference to the Theriodontia, though there is no evidence preserved of incisors or canines; for I conceive that Theriodonts may develop dental modifications as varied as those of Mammals. *Ælurosaurus* has the orbit large, sub-circular, placed far backward, with a short post-orbital region, and the quadrate bone directed downward beneath the orbit so as to form an articulation which faces forward.[1] The lower jaw in *Ælurosaurus* similarly increases in depth as it extends backward. Consideration of these facts, which are so dissimilar to the corresponding conditions in the type of the Theriodontia, *Galesaurus planiceps*, led me to regard *Ælurosaurus felinus*, *Lycosaurus curvimola*, and their allies as referable to a sub-order Gennetotheria, which is nearly related apparently to the Pelycosauria, and lies midway between the typical

[1] Owen, Quart. Journ. Geol. Soc. vol. xxxvii. (1881) pl. ix. fig. 1.

Theriodontia and the Dicynodontia. It is to this sub-order that *Delphinognathus* may be referred, though it forms a family type distinct from the Ælurosauridæ, distinguished by the conical parietal with a large foramen, the supra-condylar notch, and other modifications of the skull and the teeth.

I would in conclusion express my grateful thanks to the trustees of the South African Museum, Capetown, for the opportunity of describing this remarkable type.

32. *On* Further Evidence *of* Endothiodon bathystoma (*Owen*) *from* Oude Kloof *in the* Nieuwveldt Mountains, Cape Colony.

By H. G. Seeley, Esq., F.R.S., F.G.S., Professor of Geography and Lecturer on Geology in King's College, London. (Read May 25th, 1892.)

I am indebted to Mr. Thomas Bain, Geologist and Irrigation Officer to the Government of Cape Colony, for two bones collected by him in the Oude Kloof, a picturesque mountain-valley which traverses the Nieuwveldt range north of Tamboer, on the road towards Fraserburg.

The remains consist of the left ramus of the mandible, which is almost complete, and what I regard as the left squamosal bone underlapped by the malar in front, but fractured at both ends, so that only the external zygomatic bar is preserved. Small as the cranial fragment is, it is important as showing that the back of the head probably conformed to the type of skull seen in some of the Dicynodonts. The skull was as large as that of *Dicynodon leoniceps.*

The Zygomatic Bar.

The longitudinal squamosal bar is 20 centim. long, compressed from side to side and flattened, with the superior border convex in length. The convexity is most marked in the hinder part, where the edge of the bone is about 0·75 centim. thick and rounded, and the depth of the bone in front of its hinder termination is 6·25 centim. A wide shallow concavity extends along the external surface, and appears to be defined inferiorly by a rugose condition of the bone. Anteriorly the depth of the bar is a little less, but its thickness augments; this is due to the strong malar bone, 2·5 centim. thick, which forms its infero-anterior border, and extends behind the thin, external, zygomatic prolongation forward of the squamosal.

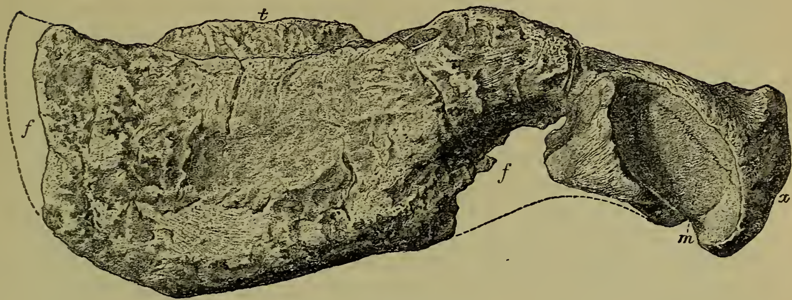
The inferior margin of the bar appears to be concave in length to the abrupt angle where the descending bar (if it was developed) is broken away, so that the bone has a depth of only $8\frac{1}{8}$ centim. from the superior border. This descending bar, so characteristic of all Dicynodonts and absent from Theriodonts and the Placodontia, if present would support Sir Richard Owen's judgment in regarding *Endothiodon* as affiliated to *Oudenodon.*[1]

The Lower Jaw.

The left ramus of the mandible, as preserved, is 30 centim. long, but has apparently lost about 2·5 centim. from the anterior extremity. It is nearly straight, with a slight inward inflection at

[1] Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 557.

Fig. 1.—*Left ramus of mandible of* Endothiodon bathystoma.

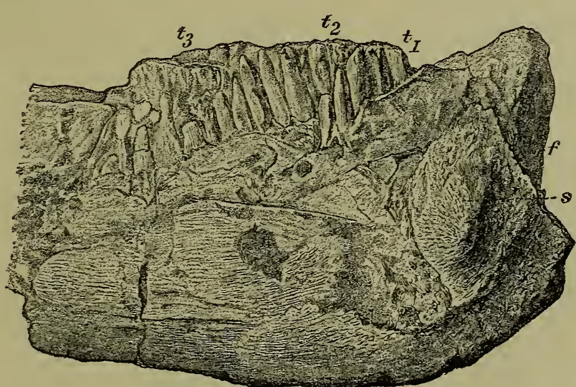


$\frac{1}{3}$ nat. size.

t = teeth.
ff = fractured portions.

m = muscular excavation, crossed by suture.
a = articulation.

Fig. 2.—*Portion of the above, showing position of teeth.*



$\frac{1}{2}$ nat. size.

f = fractured portion.
s = symphysis.

t_1–t_3 = teeth in parallel rows.

the posterior extremity, which is broken. It is deepest in front, below the commencement of the teeth, where the vertical measurement is about 10 centim. In the middle length, behind the teeth, the depth is about $8\frac{1}{8}$ centim. and at the posterior extremity the depth is 7 centim. The superior or buccal margin, which is sharp externally, is concave in length to behind the teeth; but the posterior half of this contour is convex in length, with the bone flattened above, slightly rounded from side to side, and 3 centim. wide. The inferior contour is convex in front and concave behind, though the thin inferior part of the bone beneath the superior coronoid convexity is broken away.

The vertical external surface converges forward to the symphysis, is flattened at the side, with a slight shallow longitudinal concavity in the middle, which increases in depth beneath the coronoid convexity, where it appears to become a narrow lateral perforation through the jaw about 10 centim. from the posterior extremity. The hinder end of the jaw is the condylar articulation. It is terminal, vertical, convex from above downward, wider above than below, and deeper than wide; it measures 7 centim. deep by 4 centim. wide as preserved, but may have been heart-shaped, with a concavity indenting the superior border. Its lateral and inferior margin is rounded.

Immediately in front of the condyle is a transversely ovate excavation in the external side of the jaw, with its posterior extremity inclined downward. It is fully 7 centim. wide, measured downward and backward, and 3·75 centim. wide measured upward and backward. Its outline is almost that of a perfect egg, with the wide end in front. The floor of this cavity is absolutely flat and vertical, with the elevated margin rising all round it. The articular surface of the condyle forms this margin behind; the upper surface of the jaw makes the superior margin; and at the supero-anterior angle the elevation is least. The infero-anterior border is most elevated, rising fully 2·25 centim., extending outward to a sharp crest, in front of which the thickness of the bone diminishes towards the sub-coronoid perforation. This cavity may have given attachment to the masseter muscle, and may be compared with the excavation below the condylar region in the Lion and many mammalia.

The jaw is about 3·75 centim. thick in its anterior half. Not more than 5 centim. of the symphysis between the rami is preserved. It was vertical, and its posterior margin, about 10 centim. deep, is convex from above downward.

The internal surface of the ramus is flattened in front, with a posterior longitudinal concavity in the region of the foramen. The base is rounded, but its median line is a sharp longitudinal ridge.

The mode of arrangement of the teeth has been described by Sir Richard Owen [1] as consisting of three parallel rows, extending successively within and behind each other, but the nature of their

[1] *Op. cit.* pl. xxxvii.

crowns was not shown. From the forms of their bases it seemed not improbable that they might resemble the teeth of *Placodus*. The present specimen has the crowns perfectly preserved. The longest are more than 2·5 centim. high. They are compressed from side to side, of a long lanceolate form, with strong transverse serrations on the anterior and posterior margins.

The dentigerous area is obliquely inclined on the Lacertilian plan, and the different groups of teeth, instead of being arranged from the front backward, as in Theriodonts, succeed each other in the opposite or transverse direction. In front and external to the teeth is a concave area 2·25 centim. wide anteriorly, limited by the buccal margin of the bone externally, and bordered internally by a short sharp longitudinal ridge, which prolongs the line of the dentigerous area forward. The concave space between these ridges is prolonged backward external to the teeth, becoming narrower. The first or external row of teeth, which may be incisors, are apparently six in number ; the crowns are compressed from side to side, rather wider and shorter than in the other parts of the series. The second or premolar series is counted with difficulty, but appears to number 10 teeth. In no case is the summit of the crown preserved, but the anterior teeth have been worn obliquely on the external side by the teeth in the upper jaw. This condition is well shown in three anterior crowns. The third or molar row apparently includes 15 teeth. In this series the serration of the crown is seen. It has been observed in nearly all the crowns, but from the nature of the matrix it becomes removed in process of development. There is no evidence that it extended below the upper half of the crown.

Fig. 3.—*Teeth (enlarged) showing serrations.*

$\frac{3}{2}$ nat. size.

There is a fourth row of six teeth developed on the inner anterior border. These teeth descend in position, as do the hinder molars, as they extend backward. The two middle series are between and behind the short internal and external series, which converge forward ; it is possible that this anterior inner group may represent a series of canines, more perfectly developed than among lizards. There is remarkably little variation in the forms and characters of the teeth in the several rows ; so that if the tooth-rows bear the interpretation suggested for them, it must rest upon their grouping, and not upon differentiation. The roots of the teeth are in sockets, embedded deep in the jaw.

In no Anomodont or other reptile has a jaw been described which in any way resembles this in form, muscular attachment, position of the articulation, and form and arrangement of the teeth.

Like so many of the South African fossil bones, this jaw is invested with a layer which seems to me to be the remains of the original skin. This layer has been left upon the bone.

The form of the articular condyle indicates a difference from *Dicynodontia* and all other *Anomodontia* hitherto described, which implies that the quadrate bone was inclined obliquely forward. This character is probably as important in defining the sub-order *Endothiodontia* as the condition of the teeth, which may only distinguish the family *Endothiodontidæ*. But all the characters of the dentition suggest near affinity with the *Theriodontia*.

Discussion.

Mr. Hulke bore testimony to the great value of Prof. Seeley's two communications. The skull, so far as shown by the present form, appeared distinct from all South African forms yet known to him; but he would speak with diffidence as to its generic distinctness, because the frontal plate and snout, and also the occipital region, were mutilated, and the specimen had suffered from wear, weathering, and compression. As the Author had noticed, the very large size of the parietal foramen was remarkable. The defective condition of the surface made it difficult to trace the sutures, and thus there must be uncertainty respecting the form and relation of the several anatomical elements constituting the skull, and yet in these lie the characters which determine the affinities and zoological position of the animal.

The lower jaw referred to *Endothiodon* was also extremely interesting. The teeth were more perfect than any before known to the speaker. There was one small matter to which he would direct attention: the upper teeth occur in rows, separated by rather wide intervals; in the lower jaw the several rows of teeth occur in closely ranged series, not separated by intervals corresponding to those between the upper teeth.

The Author said he was unable to detect any evidence of crushing or distortion of the occipital region of the skull of *Delphinognathus*, and he believed the state of the specimen warranted the interpretation which had been given in the paper.

He accepted the association of the lower jaw with the skull of *Endothiodon*, figured by Sir R. Owen in his South African Catalogue, on the testimony of the gentleman who collected the specimens, and was aware of a degree of difference in the superior and inferior dentition.

33. Notes *on the* Geology *of the* Nile Valley. By E. A. Johnson Pasha, Chief Inspector of Egyptian Police, *and* H. Droop Richmond, Esq., F.I.C., late Second Chemist to the Egyptian Government. (Communicated by A. Norman Tate, Esq., F.G.S. Read June 8th, 1892.)

These notes refer to some observations on the geology of the Nile, during journeys from Cairo to Wady Halfa.

The rocks on both sides of the Nile are, speaking generally, Eocene (and ? Cretaceous) from Cairo to Esneh; at Esneh, or about five miles south, we enter a sandstone region, which continues to near Assouan, where it meets the granite and basalt. A few miles south of Assouan the sandstone recommences and continues to Wady Halfa, broken only by enormous dykes of granite, which occur at Bab-el-Kalabsha and one or two other localities.

The following points are worth noticing as we follow the Nile from Cairo to Wady Halfa:—

(i) The saturation with silica of the old sand-and-gravel beds overlying the Nummulitic Limestone near Cairo, forming sandstones of all qualities from an extremely hard stone to one that can be rubbed down to powder between the fingers.

A similar saturation, apparently from water containing silica in solution, is visible in the beds overlying the Nummulitic Limestone in Biluchistan.

(ii) The fact that these old sands and gravels are formed from very old rocks, principally granitic. They contain great quantities of the Assouan pebbles, brown and red, wholly or semi-transparent, which were so largely used by the Romans to cut cameos and intaglios. Some minerals are found in these gravels, notably cobalt, the source of which is unknown.

(iii) The petrified forests of the same region.

(iv) The occurrence in greater or less quantity of titaniferous magnetic oxide of iron in the beds forming the Nile Valley; above Assiout this forms roughly $\frac{1}{10}$ of the total bank section, and is mixed with silicates of iron in a more or less advanced stage of oxidation.

The clays containing it are darker than the rest, and have a tendency to break away in perpendicular prisms which in appearance recall those of basalt. These banks assume a red coloration when exposed to the air.

The ironsand is carried down by the Nile despite its weight, and careful dredging of the bottom of the river has revealed its presence (about 1 °/₀) as far down as Cairo; this sand probably plays a very important part in the remarkable process by which the natural purification of the Nile is effected. It occurs in greatest quantity at Jebel Tarif, near Fashoda, and in the plain of Koos.[1]

[1] [For a discussion of the purification of the Nile water, see 'Report to the Egyptian Government on the River Nile,' which the writer hopes to publish in a forthcoming number of the 'Journal of the Society of Chemical Industry.'—H. D. R.]

Between Cairo and Assouan the first geological feature of importance is the great fault at Maghagha, where the whole mass of strata south of the dividing-line has been depressed some 500 feet and tilted at an angle of 30°. The rocks at the water's edge on the southern side of the fault correspond with the summit of the hills on the north. The fault brings to light great beds of dark grey and green clays beneath the limestones and the hard chalk which underlies these, and it seems possible that the collapse of the strata may be due to the action of the water on these clays. The fault runs nearly due E. and W. and seems to extend to a considerable distance into the desert. It is remarkable that those rocks on the southern side which have sunk to the water's edge are less water-worn than similarly situated rocks throughout the length of the river; this perhaps may indicate that the faulting has occurred in comparatively recent times.

The next peculiar feature is the limestone on the eastern bank from Kolosna to Sheikh Abadeh, which presents a vast field of 'hummocks' consisting of highly crystalline limestone full of small holes.

From near Minieh to Assiout and for some distance south the most striking feature is the increased number of pockets, hollows, and fissures existing in the limestone-rocks; and the fact that these are filled with, or have been for the most part filled with, clay strongly impregnated with iron, and containing numerous small streaks and patches of dioxide of manganese in a very fine state of division, or a mixture of dioxide of manganese with clay, &c., and carbonate of lime, also finely divided, and averaging 40 °/₀ dioxide of manganese, 20 °/₀ carbonate of lime, and 40 °/₀ of clay. The chemical evidence points to this partaking somewhat of the character of a calcium manganite, and it has possibly been formed by the percolation through the limestone of water containing manganese salts in solution. At some distance from the Nile manganese alums abound, and these may possibly have formed the dioxide, or a common source may perhaps be ascribed to both. Many of the tombs in the rock have been pockets of manganese, and in one set at Assiout blocks of this manganese were found piled up in a corner, suggesting that it had been used for an unknown purpose by the ancient Egyptians.

In Jebel Abou Fouda there are disturbances apparently due to the collapse of underlying strata.

From a point near Keneh to Luxor and thence to Esneh we find a limestone which is practically chalk-with-flints, forming the lower of the limestone beds; and below this are grey and green clays from 200 to 300 feet thick, full of nodules of hæmatite, the smaller nodules being of great purity, and apparently often used by the ancient Egyptians to cut scarabs. The larger nodules are in general less pure, and are in great part reduced to ochre, often of a very beautiful colour. The fossils of these clays, which are Cretaceous, are impregnated with iron and are dark brown in colour. A thickness of fully 300 feet of these beds is exposed in the high hills about

10 miles east of Luxor; they are also visible in a little-frequented locality near Deir-el-Bahri and more prominently near Nagada. The hæmatite nodules lie here in thick beds, having apparently been left by the degradation of the clays exposed on the faces of the hills.

About 15 miles north of Esneh, at Jebel Ain, the river passes between the upturned limestone-beds, which here have again subsided, the fault being this time parallel to the river. The calcareous strata here seem to be much thicker than at Luxor, if one may judge by the number of successive limestone-beds appearing above the plain and lying at an angle of about 30°. Possibly, however, these outcrops may be due to a succession of faults repeating the beds.

About 5 miles south of Esneh, after passing through about 1 mile of very broken and confused clays and sand-beds full of ochre and ochreous nodules, we come to the sandstone. This is chiefly interesting from the fact that it is carbonaceous and that it may be of Carboniferous age.[1] A shaft, 296 metres deep, still exists at Redesieh, in the hills near Edfoo on the eastern bank, dug 40 years back in searching for coal. We took out of the pit-heap near this shaft carbonaceous shale which would burn if placed in a fire; the mass of the strata in the pit is pale blue clay. In the desert west of Edfoo are a series of clays of all colours and thick seams of impure hæmatite.

A possible indication of carbonaceous matter lies in the fact that sulphur in the form of sulphates occurs in many beds where its presence can only be explained on the assumption that the beds themselves were attacked by sulphur acids (sulphurous ?). As examples we may quote the occurrence of calcium (and strontium) sulphates in the limestone-beds forming the Mokattam Hills between Cairo and Helouan, and the basic iron sulphates among the hæmatite of Luxor; these last have exactly the appearance of native sulphur; acid waters have also been found, notably at Bahnesa.

Just before reaching the Assouan granite-formation the Nile crosses a very ancient river-bed, running from W. to E. near Komombo. The deposits of this river form the western bank of the Nile for nearly a mile at Komombo.

The Nubian hills above Assouan are nearly all sandstone, except where the granite breaks through at Kalabsheh, and we believe that the granite is intrusive, the sandstone at the line of junction having been apparently altered by heat for 50 feet or more.[2]

Some rocks which have been described as volcanic are not volcanic at all. They are merely a silicate coating over the sandstone, formed by water impregnated with silica, iron, and manganese.

[1] [The sandstone (Nubian Sandstone) is generally regarded as Cretaceous. The lower portions, however, may be Carboniferous; see Sir J. W. Dawson's 'Egypt and Syria,' 2nd ed. p. 32, 1887.—Ed.]

[2] [Mr. J. C. Hawkshaw (Quart. Journ. Geol. Soc. vol. xxiii. 1867, p. 115) describes and maps the sandstones as resting upon the granite. Sir J. W. Dawson (*op. supra cit.* p. 32) says that the sandstones are 'very much newer than the crystalline rocks, and are derived from their waste.' The crystalline rocks are generally regarded as Archæan.—Ed.]

Above Abou Simbel this overlies the sandstone in curious forms, simulating black coral or sponge.

Unmistakable lavas, however, do occur in the desert within one day's journey of the Nile, both east of Minieh and west of Assiout. There is then some real evidence of volcanic action in this region, and the occurrence of sulphates mentioned above may be thus explained.

The sandstone has been deposited over the basalt at Abou Sir, near Wady Halfa, and the river has worn it away again, leaving the basalt bare; in several places the basalt is seen sticking up through the sandstone.

The principal lines of junction of all the main formations appear to run from S.S.E. to N.N.W.

Discussion.

The President observed that Englishmen in Egypt enjoyed at present very good opportunities of doing geological work, but it was a matter of regret that they did not pay more attention to the literature. Many of the facts noted in the present paper had been mentioned in the appendix to Sir William Dawson's 'Modern Science in Bible-lands,' and the silicated deposits had been discussed by Zittel and others and ascribed by Zittel to the action of fumaroles. Sir W. Dawson referred to the sandstones, which though *carbonaceous* are not *Carboniferous*. The Authors raised many chemical points of interest, and one of the Authors was a chemist who, he believed, had recently described a new element discovered by the other Author in one of the dry valleys dealt with in the present communication. The information concerning the region south of Assouan was of considerable interest, though the statement that the granite was intrusive in the sandstone was open to doubt.

Mr. Topley and Mr. Rutley also spoke.

34. *The* Bagshot Beds *of* Bagshot Heath (*a* Rejoinder). By the Rev. A. Irving, B.A., D.Sc., F.G.S. (Read June 8th, 1892.)

[Abridged.]

The Author maintains that the northerly attenuation of the Lower Sands and of the 'green-earth series' between the two principal brick-clays of the district is an established fact.[1] He insists on the value of the Wellington College well-section[2] as a vertical datum-line, on account of its proximity to the northern outcrop (which is not the case with the Goldsworthy section), and criticizes the arguments recently put forward in favour of an alternative and very doubtful sectional reading. But it does not stand alone, for the well-section at the Bagshot Orphan Asylum[3] gives practically the same sequence, and affords strong evidence of the thinning northward of the above-named deposits. (Other instances cited by the Author in 'Recent Contributions,'[4] &c., corroborate the reading he has adopted.) The Goldsworthy section itself lends strong corroborative evidence as to the value of the College well-section. The evidence of attenuation in the direction of Bracknell the Author reserves for the present. In his paper published in the February number of the Society's Journal for the current year, Mr. Monckton ignores the determinative value of stratigraphical alignment of the clays claimed as the basal clays of the Middle group with clays of the same character seen cropping out from below the 'green-earth series' at no great distance.[5] This evidence of stratigraphical alignment must be allowed due weight when set against evidence derived from such lithological characters as the presence of pipe-clay, mica, and false-bedding.[6] The Author considers that the argument as to the fossil evidence is over-stated in the above-mentioned paper.[7]

After criticizing some of the remarks in Mr. Monckton's paper,

[1] See 'Recent Contributions to the Stratigraphy of the Later Eocenes of the London Basin': Wellington College (Bishop, 1891).

[2] *Ibid.*, also App. Note A, p. 11; Quart. Journ. Geol. Soc. vol. xli. (1885) p. 494; Mem. Geol. Surv. vol. iv. (App.) p. 425.

[3] See Mem. Geol. Surv. vol. iv. (App.) p. 537.

[4] *Op. cit.*, Well-sections, cited in the Appendix, Note C, pp. 14, 15. See also, for comparison, Sections K (p. 165), L (p. 165), M (p. 166), N (p. 166), O (p. 171), P (p. 172), Q (p. 172), S (p. 174) of the Author's 1888 paper, in Quart. Journ. Geol. Soc. vol. xliv.; and fuller details of Sections P and Q in Geol. Mag. for 1888, p. 411.

[Extensive land-drainage works carried out by Rogers Field, Esq., C.E., on the College Estate during the early part of this year (particulars reserved for the present) furnish further confirmation for certain horizons.—July 1892.]

[5] See the Author's 1888 paper (*loc. cit.*), p. 164 (footnote), p. 167 (Sunningdale), pp. 174, 176, 183 (Additional Note on the Green-earth Series); also Geol. Mag. for 1888, p. 413.

[6] See the Author's 'Recent Contributions, &c.,' Appendix, Note C (1), pp. 13, 14.

[7] See Geol. Mag. for 1891, pp. 361, 362.

the Author adds the following notes on sections at Farley Hill which want of space had compelled him to omit from his 1888 paper :—

" *Farley Hill*, January 20th, 1888.

" Sandpit No. 1.

" Sand exposed beneath the gravel, about 6 feet in irregular layers; thin white sand-partings (occasionally an inch thick), thin laminated pipe-clay in several of these; some of these layers in the upper 2 feet coloured by carbonized stuff. The whole character of the section is that of later reconstructed Bagshot material below the gravel. It admits, however, of very fair lithological comparison with bed No. 4 of the Wellington College section. *No oblique lamination seen.*

" Sandpit No. 2.

" Disused gravel-pit, levelled and planted over quite recently. Sand exposed in three places, with all the signs of being *in situ.* Two of these exposures apparently fox-burrows. Upper Bagshot character very strong."

The Author adds here that in the unpublished MS. of his 1890 paper it will be found stated that microscopic examination brings out a *lithological identity* between these sands at Farley Hill and sands of the undoubted Upper Bagshot Beds of the North Court cutting on Finchampstead Ridges.

He also criticizes the remarks in the paper referred to on the Pearwood district and about Wokingham, and challenges Mr. Monckton to produce any direct evidence of such a *dip* as his reading of the country requires.

Discussion.

The President thought that perhaps the Author was wise in allowing one of the Officers to read this most controversial paper. Some years ago Dr. Irving did valuable service by his observations on the district to which the present paper referred, but it was difficult to understand what were his present aims. He (the President) would express his own conviction that the subject was worn threadbare. There was possibly some truth in the assertion that the Lower Bagshots and 'green-earth series' became attenuated in a northerly direction; but two sections quoted in the paper—viz. those of Goldsworthy Hill and the Wellington College Well—were diametrically opposed to this conclusion *qua* the 'green-earth series.' Anyone interested in the Bagshot Beds knew how very variable they were. Dr. Irving had apparently determined originally that the Upper Bagshot Beds should overlap on to the London Clay, and this supposition appeared to have affected all his subsequent work.

Mr. Monckton referred to the papers by the Author in the Quarterly Journal for 1887 and 1888, and to the folding plate by which they were illustrated. He was not clear whether the Author still adhered to the conclusion that an overlap of the Upper or of the Middle Bagshot Beds exists in the Bagshot country, or that there is Upper Bagshot at Farley Hill, Bearwood, Coppid Beach Lane, Bracknell, or Ascot. As, however, the present communication was only a reply to a small portion of the speaker's criticism in the February number of the Quarterly Journal, he (Mr. Monckton) reserved his defence until the remainder of the Author's reply should appear. He wished to take the opportunity of recording the discovery of a band crowded with casts of marine shells in the Lower Bagshot near Goldsworthy Hill.

Mr. R. S. Herries could not follow Dr. Irving's reasoning in this paper. He did not consider that the northerly attenuation of such variable beds as the green sands had been shown to be was proved; nor did he see that, if it were, it involved the thinning-out of the underlying clays and Lower Bagshot Beds. He drew attention to the fossils from the Lower Bagshot Beds of Goldsworthy which he had exhibited. The bed in which they occur is obviously marine, and the fact that it is intercalated in what is generally regarded as a freshwater deposit favoured the double classification of the Bagshot Beds lately proposed by Dr. Irving; but at the same time he did not consider the facts were of sufficient importance to warrant observers in setting aside the classification originally proposed by Prof. Prestwich.

35. Notes *on* Recent Borings *for* Salt *and* Coal *in the* Tees District. By Thomas Tate, Esq., F.G.S. (Read June 22nd, 1892.)

Since the publication of Mr. E. Wilson's exhaustive paper on the Durham Salt-district,[1] commercial enterprise has given an impulse to exploration, so that now the number of boreholes is over sixty. Most of these simply emphasize the knowledge derived from earlier work, with which they coincide. Three or four, however, may possibly contribute a few geological facts of interest, in relation to (*a*) the area of the Tees Salt-field and (*b*) the determination of the southern limit of the Durham Coal-basin.

1. *Whitehouse, Norton, No.* 1 *borehole.*—This borehole is 3¼ miles due west of Messrs. Watson and Scrafton's Stone Marsh borehole, the most westerly boring shown on Mr. Wilson's map.[2] Its site is 76 feet above sea-level, as proved by a neighbouring bench-mark. Full details of the strata bored through will be found in the Appendix to the present communication. The horizon of the rock-salt in this district lies at the base of the Saliferous Marls, and the layer of salt invariably has above it a bed of anhydrite, usually underlain by a stratum of red marl left in a rotten state by the dissolving out of some constituent: this is the 'rotten marl' of the workmen, to the presence of which is due the collapse of many brine-wells. Below the beds of pure and impure rock-salt comes the lower anhydrite, so that the salt-bearing stratum, wherever present, is sandwiched between two layers of anhydrite, and its horizon is never a matter of doubt for anyone practically acquainted therewith.

This boring, after piercing through 115 feet of Drift deposits and 151 feet of Red Sandstones and Marls, struck the Saliferous Marls, as follows:—

	ft.	in.
Red marls with gypsum	130	0
Anhydrite..............................	10	0
Red marl and gypsum (compact)	17	2
Horizon of rock-salt	—	—
Anhydrite................................	17	9
Gypsum	3	0
	177	11

The presence of the bed of compact red marl foreshadowed the absence of salt from this area.

It is sometimes suggested that percolating water may have removed the missing salt, but if a cavity had been so formed here the drilling tool would have 'dropped'; this, however, did not occur.

[1] 'The Durham Salt-district,' Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 761. [2] *Ibid.* p. 762.

On resuming the boring, the Magnesian Limestone proved to be the thinnest complete section in Durham, namely 299 feet; it was also noticeable for the large proportion of gypsum and anhydrite contained therein (see Appendix, p. 493). In boring bed No. 73 a small feeder of brine was cut, as is often the case when drainage from the salt-rock above—perhaps several miles away—flowing through the underlying beds is tapped, and liberated by pumping.

On analysis it was found to be a weak 6 % solution, of no commercial value, though it continued to flow so long as the pumps were kept going. A little later petroleum welled up continuously as a black liquid; and in addition to this, early in July, when the boring went through the beds of bituminous shale with ironstone nodules, Nos. 88 to 90, the amount of hydrogen sulphide that was set free was quite overpowering.

The presence of bitumen, rock-oil, inflammable gases, or hydrogen sulphide in the beds below the salt is often assumed to indicate underlying Coal Measures from which they are supposed to be derived. But this inference has proved erroneous again and again on Tees-side, where the possibility of obtaining petroleum and natural gas in paying quantities has been repeatedly discussed in commercial circles.[1]

The nearest coal-workings to this borehole are Rodridge Colliery, South Wingate, 7½ miles due north, and Bishop Middleham Colliery, about 7¾ miles north-west. Prof. Hull adopts, as the southern margin of the Durham Coal-basin, a line which Sir Andrew Ramsay[2] considered might be drawn from Seaton Carew westward to Middridge Grange. "To the south of this line, the Permian and Triassic strata would be found to overlie only Millstone Grit and Yoredale rocks."[3]

A boring near Spiceley, half a mile south-east of Bishop Middleham Colliery, after passing through 284 feet of surface-deposits and Magnesian Limestone, struck Millstone Grits which were followed for 107 feet. Discussing its bearings on the Coal-area, Sir Lowthian Bell suggested that "an anticlinal axis might, however, restore the coal under the Magnesian Limestone."[4] At Bradbury Carr a borehole penetrated surface-drift 125 feet thick, Magnesian Limestone 200 feet, and Yoredale Rocks 225 feet. The nearest borehole to this is at Elstob, 5½ miles west of Whitehouse: thickness of surface-deposits 125 feet, Magnesian Limestone 225 feet, Yoredales 550 feet.[5]

The Seaton Carew boring reported by Mr. Wilson down to 1761 feet, August 16th, 1888, was finally abandoned in the October following, at a depth of 1815 feet, having added 54 feet of grey

[1] 'Colliery Guardian' for 1891, p. 523; 'Northern Echo,' March, 1890.

[2] Ramsay, Rep. R. Coal Commission (1870), p. 139; based upon evidence supplied by Mr. H. H. Howell.

[3] 'Coal-Fields of Great Britain,' 3rd ed. p. 254.

[4] Proc. Inst. Civ. Eng. vol. xc. (1887) p. 133.

[5] Geol. Surv., Horizontal Section, Sheet 133, and Vertical, Sheet 65. The writer has to thank Mr. H. H. Howell, of the Geol. Survey, for kindly directing his attention to this information.

sandstones and black shales belonging to the Millstone Grits.[1] Notwithstanding this discouraging outlook, boring operations were persevered in, until, 336 feet of Carboniferous strata having been proved, without a trace of coal remunerative or otherwise, the borehole was closed.

To return to the Whitehouse No. 1 boring: the Magnesian Limestone was succeeded by grey sandstones, rich in calcite, probably due to infiltration. The lithological composition of the strata below these—alternating carbonaceous shales, ironstone nodules, and sandstones with bands of encrinital limestone—warrants us in assigning them to the Carboniferous Limestone Series (Yoredale Beds). The fossils observed also support this identification.[2]

The chief results of this boring may be summed up thus:—

(i) The Upper Keuper Red Marls are wanting, as is the case in every borehole north of the Tees, excepting the outlying patch on Haverton foreshore.
(ii) The Salt-rock is absent, and the Red Marl above that horizon is not 'rotten marl,' but compact.
(iii) The Bunter Series has no representative.
(iv) The Magnesian Limestone gives the thinnest complete section in Durham, namely 299 feet.
(v) No coal-seams are present.
(vi) The Yoredale Rocks are represented by encrinital limestones, carbonaceous shales, and sandstones.

2. *Whitehouse, Norton, No. 2 borehole.*—The site of this borehole is 750 feet north-west of No. 1 borehole and 100 feet above Ordnance datum.

	Borehole No. 2.		Borehole No. 1.	
	ft.	in.	ft.	in.
Surface-deposits	134	6	115	0
Red Sandstones and Marls...	157	0	151	0
Saliferous Marls	172	9	177	11
Magnesian Limestones	55	9+	299	0
Yoredale Rocks	—	—	336	7
	520	0	1079	6

[1] W. J. Bird, Trans. North of Eng. Inst. Min. and Mech. Eng. vol. xxxviii. (1889) p. 21. To the courtesy of C. T. Casebourne, Esq., C.E., the writer is indebted for the opportunity of inspecting these cores. Two borings north-west of Seaton Carew are now in progress, but for obvious reasons the information already obtained is not as yet available for publication.

[2] Since the above was written, Mr. J. G. Goodchild, Curator of the collection of the Geological Survey of Scotland, in the Edinburgh Museum of Science and Art, has kindly determined the following fossils, from cores submitted to him:—

No. 90. *Orthoceras cylindraceum*; *Streptorhynchus crenistria*; *Leaia* (?); *Aviculopecten*, two species; *Cypricardites parallela*; *Anthracomya*; *Athyris*; *Productus*; *Lingula mytiloides*; Pygidium of *Phillipsia* (4 specimens).
No. 112. Fucoid (?) or worm-tube (?).
No. 113. *Spirifer trigonalis*; *Productus fimbriatus*; *Productus*, sp.; *Athyris*; *Aviculopecten*; Encrinital stems.
No. 115. *Lingula mytiloides*; *Bellerophon Urei* (?).

Comparing the two borings as above, and especially the details given in the Appendix (p. 492 *et seqq.*), it will be seen that, allowing 24 feet for difference in altitude, the results are practically identical. The Upper Keuper Red Marls with gypsum are absent from both, and in neither is any salt met with. The Magnesian Limestone lies 4 feet lower in No. 1 than in No. 2: that is, in the direction of dip. The prevailing opinion regarding the horizon of the salt-rock in Durham no longer needs defence, but it may be well to remark in passing that the cores brought up from near the bottom of Messrs. Bell Brothers' trial-boring in 1876 presented a very different aspect from those obtained from Magnesian Limestone in these Whitehouse borings, as well as from that proved at Seaton Carew, where it was at its best—878 feet, the thickest section in County Durham.

3. Eight miles due east of Whitehouse boreholes, on the opposite margin of the Tees Salt-field, a borehole was being drilled at about the same time, and should be noticed here. It was put down on Lackenby foreshore, about 1 mile (6000 feet) north-east of Eston borehole, the most easterly shown on Mr. Wilson's map.[1] A vertical section has already appeared,[2] but as no cores were brought out by the method employed, the Red rocks have to be apportioned so as to approximate most nearly to contiguous borings executed with the diamond rock-borer. The following abstract may suffice for our purpose :—

	ft.	in.
Surface-deposits	13	0
Upper Keuper Red Marls	495	0
Red Sandstones and Marls	869	0
Saliferous Marls	266	0
Anhydrite	29	0
'Rotten Marl'	13	0
Rock-salt	119	0
Anhydrite	2	0
	1806	0

This borehole is important as adding 1 mile to the width of the Tees Salt-area. The upper surface of the salt here is 116 feet lower than it is in the Eston borehole : the salt-bed also is thicker, thus confirming previous anticipations as to both these items increasing with the south-easterly dip.[3] Every one of the fifteen boreholes or wells situated south of the River Tees passes through the Upper Gypseous Marls, *i. e.* the Upper Keuper Red Marls with gypsum (at Linthorpe the gypsum bed, five feet in thickness, was reached at about 350 feet); and all have proved the salt-seam in good workable thickness. But while they agree in indicating a

[1] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 762.
[2] Brit. Assoc. Report (Leeds Meeting), 1890, p. 367.
[3] Quart. Journ. Geol. Soc. vol. xliv. (1888) p. 775. The above figures exceed somewhat the depth and thickness of salt estimated by the writer in 1880, but the ground was not then so well-known as now.

uniform dip of its surface to the south-east, they by no means exhibit any like uniformity as to increase in its thickness. On the contrary, they confirm our general experience of the variable and uncertain possibilities, as the following table will show :—

Borings.	Salt. Depth. ft.	Salt. Thickness. ft.	
N. Ormesby (4)...	1350	90	
Middlesbrough ...	1206	100	Due north of the next preceding.
Imperial.............	1586	86	Due east ,, (Bored 20 ft. of made ground).
Tees Tilery	1562	90	Due east of the next preceding.
Eston (4)	1569	82	North-east ,,
Lackenby (3)......	1685	119	North-east ,,

Appendix.

Whitehouse, Norton, No. 1 *borehole.*

[Altitude 76 feet above sea-level. Depth 1079½ feet. Begun Feb. 13th and closed Sept. 17th, 1889.]

			Thickness of each bed. ft.	in.	Depth of each bed from surface. ft.	in.
Post-Tertiary = 115 feet.	1	Brown clay, sandy	8	0		
	2	Blue clay	7	0	15	0
	3	Red clay	10	0	25	0
	4	Brown clay, stiff	21	0	46	0
	5	Muddy sand	2	0	48	0
	6	Brown clay, sandy	2	0	50	0
	7	Grey 'pinnel and stones'	2	0	52	0
	8	Stiff brown clay with stones	2	0	54	0
	9	Stiff brown clay	14	0	68	0
	10	Sand	1	0	69	0
	11	Sandy clay	1	0	70	0
	12	Strong brown 'pinnel'	7	0	77	0
	13	Strong brown clay	1	0	78	0
	14	Strong 'pinnel and cobbles'	6	0	84	0
	15	Brown 'pinnel'	1	0	85	0
	16	Sand	0	6	85	6
	17	Dark gravelly 'pinnel'	2	0	87	6
	18	Grey 'pinnel and cobbles'	2	0	89	6
	19	Brown 'pinnel'	2	10	92	4
	20	Sandstone	0	4	92	8
	21	Dark brown 'pinnel'	13	4	106	0
	22	Dark red 'pinnel and cobbles'	1	6	107	6
	23	Grey 'pinnel'	7	0	114	6
	24	Dark red 'pinnel'	0	6	115	0

Whitehouse, Norton, No. 1 borehole (continued).

Formation	Division	No.	Bed	Thickness of each bed. ft.	in.	Depth of each bed from surface. ft.	in.
Upper Keuper (Waterstones?)=328 ft. 11 in.	Red Sandstone=151 ft.	25	Red sandstone	19	0	134	0
		26	Red sandy marl	9	0	143	0
		27	Red marl	1	7	144	7
		28	Red sandstone	9	4	153	11
		29	Red marl	2	0	155	11
		30	Red sandstone	4	2	160	1
		31	Red marl	22	0	182	1
		32	Red sandstone	7	8	189	9
		33	Red marl	21	7	211	4
		34	Red marl with blue joints	13	8	225	0
		35	Red marl	41	0	266	0
	Saliferous Marls =177 ft. 11 in.	36	Red marl with veins of gypsum	8	3	274	3
		37	Red marl	10	0	284	3
		38	Red marl with veins of gypsum	12	5	296	8
		39	Red marl	22	2	318	10
		40	Red marl with veins of gypsum	77	2	396	0
		41	Anhydrite	10	0	406	0
		42	Red marl and gypsum (compact)	17	2	423	2
		43	Anhydrite	17	9	440	11
		44	Gypsum	3	0	443	11
Permian (Magnesian Limestone)=299 ft.		45	Magnesian Limestone with veins of gypsum	13	8	457	7
		46	Magnesian Limestone	55	4	512	11
		47	Blue shale with veins of gypsum	11	11	524	10
		48	Dark limestone and gypsum	1	0	525	10
		49	Red shale and gypsum	3	0	528	10
		50	Anhydrite	4	0	532	10
		51	Red and blue shale with veins of gypsum	5	0	537	10
		52	Anhydrite	1	0	538	10
		53	Red and blue shale	2	7	541	5
		54	Anhydrite, limestone, and red shale	2	9	544	2
		55	Anhydrite with brown joints	21	5	565	7
		56	Anhydrite	10	0	575	7
		57	Anhydrite with black joints	2	5	578	0
		58	Magnesian Limestone	13	11	591	11
		59	Anhydrite with veins of gypsum	7	0	598	11
		60	Anhydrite	14	3	613	2
		61	Anhydrite with gypsum	15	10	629	0
		62	Blue marl	8	0	637	0
		63	Anhydrite with gypsum	1	6	638	6
		64	Red marl with veins of gypsum	7	7	646	1
		65	Anhydrite with gypsum	2	0	648	1
		66	Red marl with gypsum	11	8	659	9
		67	Red and blue marl	8	6	668	3
		68	Anhydrite containing spar	2	2	670	5
		69	Magnesian Limestone	8	10	679	3
		70	Red and blue marl	4	3	683	6
		71	Red sandy gritstone	3	4	686	10
		72	Red and blue marl	6	3	693	1
		73	Magnesian Limestone	49	10	742	11

Whitehouse, Norton, No. 1 borehole (continued).

			Thickness of each bed.		Depth of each bed from surface.	
			ft.	in.	ft.	in.
Carboniferous (Yoredale Rocks) = 336 ft. 7 in.	74	Grey gritstone with calcite	4	9	747	8
	75	Grey sandstone with calcite	1	0	748	8
	76	White crystalline limestone	6	0	754	8
	77	Fine grey sandstone with calcite	6	0	760	8
	78	Dark blue shale	5	2	765	10
	79	Light-grey sandstone	8	2	774	0
	80	Dark sandy shale	6	0	780	0
	81	Light-grey sandstone with rootlets	7	3	787	3
	82	Dark sandy shale	9	9	797	0
	83	Dark shale	16	5	813	5
	84	White sandstone, 'gannister'	4	0	817	5
	85	Light-grey sandstone	7	2	824	7
	86	Coarse light-grey sandstone	3	11	828	6
	87	Dark shale	2	0	830	6
	88	Black shale with ironstone nodules	23	7	854	1
	89	Black shale with bands and nodules of ironstone	8	3	862	4
	90	Black shale (fossiliferous)	10	8	873	0
	91	Black shale with veins of calcite	4	0	877	0
	92	Grey encrinital limestone	3	7	880	7
	93	Black shale	13	6	894	1
	94	Grey encrinital limestone	5	11	900	0
	95	Dark encrinital limestone	5	11	905	11
	96	Dark impure limestone	6	8	912	7
	97	Dark limestone	3	0	915	7
	98	Dark-grey sandy shale	10	0	925	7
	99	Light-grey siliceous shale	16	9	942	4
	100	Grey micaceous sandstone	3	0	945	4
	101	Black shale	7	6	952	10
	102	Grey micaceous sandstone	3	0	955	10
	103	Black shale	8	0	963	10
	104	Dark-grey sandstone with black streaks	0	6	964	4
	105	Dark shaly sandstone	13	0	977	4
	106	Coarse grey sandstone	18	0	995	4
	107	Dark-grey sandy shale	2	8	998	0
	108	Black shale with ironstone nodules	3	4	1001	4
	109	Dark-grey sandy shale	1	3	1002	7
	110	Black shale with ironstone nodules	5	3	1007	10
	111	Dark-grey sandy shale	3	0	1010	10
	112	Dark calcareous shale with concretions	16	0	1026	10
	113	Calcareous shale, very fossiliferous	10	4	1037	2
	114	Black shale	1	1	1038	3
	115	Blue shale	5	8	1043	11
	116	Grey sandy shale	7	6	1051	5
	117	Grey micaceous shale with calcite joints	18	0	1069	5
	118	Dark-grey sandy shale	9	0	1078	5
	119	Black micaceous shale	1	1	1079	6

Whitehouse, Norton, No. 2 borehole.

[Altitude, 100 feet above sea-level. Depth, 520 feet.
Begun March 29th, and closed May 23rd, 1889.]

Division		No.	Bed	Thickness of each bed. ft.	in.	Depth of each bed from surface. ft.	in.
Post-Tertiary = 134 ft. 6 in.		1	Soil	1	0		
		2	Red sandy clay	4	0	5	0
		3	Blue clay	15	2	20	2
		4	Sand	1	4	21	6
		5	Sand and gravel	1	6	23	0
		6	Sand	5	1	28	1
		7	Red clay	15	5	43	6
		8	Dark brown sandy clay[1]	30	3	73	9
		9	Soft brown clay and sand mixed	4	0	77	9
		10	Brown 'pinnel'	16	1	93	10
		11	Red loamy sand	4	0	97	10
		12	Brown 'pinnel'	5	10	103	8
		13	Grey sandstone	0	3	103	11
		14	Brown 'pinnel'	10	11	114	10
		15	Grey loamy sand	2	0	116	10
		16	Dark brown 'pinnel'	2	11	119	9
		17	Dark brown 'pinnel and cobbles'	14	9	134	6
Upper Keuper (Waterstones ?).	Red Sandstone = 157 ft.	18	Red sandstone	24	8	159	2
		19	Red marl	1	0	160	2
		20	Red sandstone	23	10	184	0
		21	Red marl	14	7	198	7
		22	Red sandstone	9	2	207	9
		23	Red marl	7	0	214	9
		24	Red sandstone	3	6	218	3
		25	Red sandy marl	40	0	258	3
		26	Red sandstone	5	6	263	9
		27	Red sandy marl	6	6	270	3
		28	Red marly sandstone	21	3	291	6
	Saliferous Marls = 172 ft. 9 in.	29	Red marl with gypsum and blue joints	1	7	293	1
		30	Red marl with blue joints and gypsum	6	0	299	1
		31	Red marl with veins of gypsum	13	8	312	9
		32	Red marl with blue joints and gypsum	11	0	323	9
		33	Red marl with veins of gypsum	49	5	373	2
		34	Red marl with blue joints	11	0	384	2
		35	Red marl with blue spots	17	1	401	3
		36	Red sandy marl	10	7	411	10
		37	Red marl with veins of gypsum	6	0	417	10
		38	Anhydrite	6	3	424	1
		39	Red marl with blue spots and gypsum	3	0	427	1
		40	Red marl with gypsum (compact)	16	8	443	9
		41	Anhydrite	20	6	464	3
		42	Magnesian Limestone	55	9	520	0

36. *On the* Basalts *and* Andesites *of* Devonshire, *known as* 'Felspathic Traps.' By Bernard Hobson, Esq., M.Sc., F.G.S., Lecturer in Geology in the Victoria University, Owens College, Manchester. (Read June 22nd, 1892.)

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I. Previous Literature.

1797. W. G. Maton. Observations relative chiefly to the Natural History, Picturesque Scenery, and Antiquities of the Western Counties of England. Salisbury, vol. i. pp. 95–97 (describes the Thorverton stone).

1811. J. F. Berger. Observations on the Physical Structure of Devonshire and Cornwall. Trans. Geol. Soc. vol. i. pp. 100–102 (describes the amygdaloid of Poucham [probably Pocombe], Upton Pyne,[1] and Thorverton).

1821. Rev. J. J. Conybeare. On the Geology of the neighbourhood of Okehampton, Devon ("memoranda on the Red Marle" at end); Annals of Philosophy, new series, vol. ii. pp. 165, 166 (describes the amygdaloid of Thorverton, Silverton, and Radden [Raddon Court] quarries).

1835. Sir H. T. De la Beche. "Note on the Trappean Rocks associated with the (New) Red Sandstone of Devonshire," Proc. Geol. Soc. vol. ii. (1833–8) pp. 196–8 (mentions the trappean rocks "near Tiverton, Thorverton, Silverton, Kellerton Park, Crediton, and Exeter," and gives the geological history of those at Washfield, near Tiverton.

1839. Sir H. T. De la Beche. Report on the Geology of Cornwall, Devon, and West Somerset (Geol. Survey Memoir) pp. 199–204, 211, 212, 215, 216, 489.

1839 ? (no date). One-inch Geological Survey Maps, Sheets 21, 22, 24, 26 (almost all the important exposures are included in Sheets 21 and 22).

[1] Later observers do not mention Upton Pyne. I have not visited the locality.

1865. W. Vicary, F.G.S. On the Feldspathic Traps of Devonshire. Trans. Devon. Assoc. vol. i. pt. iv. pp. 43–49 (gives additional localities and fuller details of the macroscopical characters of the rocks).

1890. R. N. Worth, F.G.S. The Igneous Constituents of the Triassic Breccias and Conglomerates of South Devon. Quart. Journ. Geol. Soc. vol. xlvi. pp. 69–83.

1892. W. A. E. Ussher, F.G.S. Permian in Devonshire. Geol. Mag. pp. 247–250.

The present paper is the result of a visit to the localities in July 1890.

The most satisfactory accounts of the Devon 'felspathic traps' are contained in the above-cited report of De la Beche, in Mr. Vicary's paper, and in Dr. Hatch's notes to Mr. Ussher's paper. As is well known, they are a series of volcanic rocks, of post-Carboniferous age, which are exposed at numerous localities in the south of the county. All those *microscopically* described in the present paper, except the rock of Killerton, N.E. of Exeter, are olivine-basalts.

II. Evidence of the Contemporaneous (non-Intrusive) Character of the Rocks.

Sir Henry De la Beche held them to be "sections of erupted igneous matter contemporaneously intermingled with the red sandstones and conglomerates with which they are associated."[1] Mr. Vicary, on the contrary, states that they "commonly appear as dikes, filling fissures in the earlier rocks."[2] The following considerations lead me to take De la Beche's view rather than Vicary's.

1. At Washfield the rock is, as Mr. Vicary himself states, "vesicular throughout." I observed vesicles over 2 inches long, and the whole rock is as full of cavities as a sponge. At "Beere, Thorverton, Rew, and the neighbourhood of Silverton" the rock is, as Mr. Vicary says, "more or less vesicular from top to bottom of the present workings." In almost every other case the top or bottom of the lava or both are vesicular.

2. In some cases, as at Pocombe, and, according to De la Beche,[3] between Ide and Dunchideock, the basalt intervenes between the underlying Carboniferous and the overlying Permian (or Triassic) rocks. This is most naturally explained by supposing it to have been erupted to the (probably sub-aqueous) surface in the interval between the deposit of the under- and the overlying rocks.

3. The lavas usually form horizontal or nearly horizontal beds, not vertical or highly inclined dykes. At Killerton, Dunchideock, and Posbury these beds are in each case many acres in extent, and at Western Town Mr. Vicary "caused a pit to be dug in the trappean floor of the quarry and beneath it found a layer of hard sandstone."

4. According to De la Beche,[4] "along the range of the igneous rocks, particularly on the north, a sand occurs, here and there

[1] Report, p. 201.
[2] *Op. supra cit.* p. 46.
[3] *Ibid.* p. 203.
[4] Report, p. 200.

mingled with the more common red sandstone, which bears a very great resemblance to a volcanic product."

The Rev. A. Irving [1] says:—"What I have seen in the field, particularly in the Crediton Valley, referred to in my 1888 paper (p. 159), points to the existence of true volcanic agglomerates forming locally integral portions of the Breccia series." Tuff is mentioned by Prof. Bücking, in Mr. Ussher's paper, as occurring at Yeoton, near Crediton. I was unfortunately prevented by the bad weather from properly examining the quarry there.

5. There is a very close agreement in mineral composition and both macroscopic and microscopic characters between the rocks of all the localities, except Killerton and Long Lane, Loxbear, so that, as many of the rocks are clearly contemporaneous, the probabilities are all in favour of the rest being so.

I therefore feel no doubt of the contemporaneous nature of the lavas exposed in all the localities visited, without for a moment denying the probability that the necks by which they ascended may be hidden beneath the surface-flows; indeed, De la Beche [2] figures dykes of 'felspathic trap' at Cawsand in Plymouth Sound intrusive in Devonian rocks, though the evidence that the trap there is of Permian (or Triassic) age is not quite conclusive, and I agree with the opinion expressed to me personally by Mr. Worth that the schistose dyke figured by De la Beche on p. 279 of the Report is most probably of much earlier age than, and quite distinct in character from, the main mass of the Cawsand 'trap.'

As mentioned by Mr. Vicary, "it is a fact of large generality that the strikes of the two formations [trap and Trias (or Permian)] coincide in direction." Examples of this occur at Silverton, Thorverton, Pocombe, &c. The greatest length of outcrop also usually coincides with the direction of strike, but this does not seem to me to be any reason for doubting the contemporaneous nature of the 'trap.' It appears to me that whether a rock be sedimentary (*e.g.* the Millstone Grit 'edges' of Derbyshire), contemporaneously interbedded igneous rock, or igneous rock intruded along bedding-planes, it will naturally tend to have its greatest length of outcrop in the direction of strike, as soon as it is tilted out of the horizontal and denudation sets in.

III. Improbability of the Former Existence of these Lavas in the Area of the Dartmoor Granite.

Mr. R. N. Worth, having adopted the theory that the granite of Dartmoor and the elvans in its neighbourhood are the relics of the base of a gigantic volcano, argues [3] in favour of the previous existence

[1] 'Suppl. Note to Paper on the Red Rocks of the Devon Coast Section (Quart. Journ. Geol. Soc. 1888),' Quart. Journ. Geol. Soc. vol. xlviii. (1892) p. 76.

[2] Report, p. 212; see also R. N. Worth, Trans. Roy. Geol. Soc. Cornw. 1886, p. 228, &c.

[3] Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 80.

of 'felspathic traps' in the Dartmoor granite area from the fact that in the Triassic (or Permian) breccias near "Dawlish and Teignmouth and thence to the southward" fragments known to be of Dartmoor origin are associated with undoubted 'felspathic-trap' fragments. He says, "The fact that these fragments came from the direction of Dartmoor, coupled with the absence of any locality between Teignmouth and Dawlish and their vicinities and Dartmoor whence they can have come, thus points directly to Dartmoor itself as their source."

The objections to this view appear to me very strong, namely:—

1. It seems to be a *non sequitur*, as there is no necessity for believing that the granitoid and 'felspathic-trap' fragments came from one and the same area; and there is plenty of 'felspathic trap' in place near Dunchideock, 7½ miles north-west of Dawlish.

2. Almost all the 'felspathic traps' being olivine-basalts, they cannot be the effusive equivalents of granite.

3. No necks or dykes of 'felspathic trap' are known to penetrate the Dartmoor granite.

4. It is highly improbable that the granite of the core and the lavas of the surface of the supposed volcano were simultaneously exposed to denudation.

5. The alleged facts with regard to the existence of quartz-porphyries among and also intrusive in the 'felspathic traps' of *undoubted* Permian (or Triassic) age will be shown in a subsequent part of the present paper to be at least very doubtful.

It is true that Mr. Ussher mentions a "quartz-porphyry giving place upwards and outwards to a rock resembling a mica andesite"[1] associated with the Thurlstone New Red outlier, and Mr. Worth himself describes a "trachytic quartz-felsite" passing into a "rhyolitic pitchstone" as occurring at Withnoe, in Whitesand Bay, and "undoubtedly continuing to a junction in depth with the main mass"[2] of the 'trap' of the Cawsand New Red outlier, but the evidence that these rocks belong to the same series as the 'felspathic traps' is not quite conclusive.

IV. Intrusive Dykes in supposed New Red Trap near Plymouth.

[Since the present paper was read, the writer has visited the Plymouth district, and hopes shortly to be able to publish more precise information on the subject.]

Meanwhile the following notes, based on field observation only, may be of interest. The main mass of the Cawsand rock is red or pinkish, and contains a good deal of brown mica. The evidence in favour of its Permian (or Triassic) age is its macroscopical resemblance to some of the weathered olivine-basalts of that age (this is not worth much) and the occurrence at Sandway Point (6-inch map,

[1] *Op. supra cit.* p. 249.

[2] 'Additional Notes on the Cornish Trias,' Trans. Roy. Geol. Soc. Cornw. 1891, p. 338.

Cornwall, 55 N.W.), a few yards north of the Cawsand rock, of an outlier of New Red breccia.[1]

One of the most remarkable points about the Cawsand rock is the presence everywhere in it of macroscopically evident flow-structure. The Withnoe rock, described by Mr. Worth, is exposed in a small quarry on the east side of Cliff Lane, leading southwards from Withnoe to the cliffs of Whitesand Bay (6-inch map, Cornwall, 54 N.E.). It certainly resembles the Cawsand rock macroscopically, and shows the same evident flow-structure, which is vertical or highly inclined. The same Withnoe rock is much better exposed in a quarry 450 yards S. 35° W. of the five cross-roads at Withnoe, a few yards north of the "Old Quarry" on the 6-inch map, on the N.E. side of the military road running along the cliffs. Here it is seen to be intrusive in the Devonian slates, but the most interesting point is the occurrence in this quarry of four dykes (perhaps not all separate) from 1 to 4 feet wide, of *apparently* quartz-porphyry intrusive in the Withnoe rock, cutting across the almost vertical flow-structure. The quartz-porphyry is pinkish grey to purplish, with phenocrysts of sanidine-like felspar (measuring as much as $1 \times \frac{1}{2}$ inch), kaolinized felspar, dark mica, and quartz in a compact groundmass.

V. Other Alleged Intrusive Dykes in the Lavas.

Mr. R. N. Worth remarks with regard to the 'felspathic traps,' "They are traversed at so many points by felsitic dykes that this association has a constant and not a merely casual character. Mr. Vicary noticed these dykes and their strong resemblance to elvan courses, though, as 'a matter of convenience,' calling them sandstone."[2]

As a matter of fact, I believe that there are no felsitic dykes traversing the undoubtedly Permian (or Triassic) 'felspathic traps,' but I have not examined every exposure minutely enough to assert positively that there are none. The so-called felsitic dykes are nothing but exceedingly calcareous sandstone-veins, or veins of calcite stained red. Such veins are of common occurrence in rocks erupted sub-aqueously and overlain by sandstones.[3]

I observed these veins at Posbury, Raddon Court, Orchard Copse at Dunchideock, and at Pocombe. They vary from pink to brick-red in colour, and from a fraction of an inch to 3 inches in breadth. In some cases compact-looking, in others, *e. g.* at Posbury (No. 929 D), they show sand grains when examined with a lens. These grains

[1] W. Pengelly, Trans. Devon. Assoc. vol. ix. (1877) p. 418; R. N. Worth, Trans. Roy. Geol. Soc. Cornw. 1886, p. 231.

[2] 'The Igneous Constituents of the Triassic Breccias,' &c., Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 80.

[3] See A. Geikie, Explanation of Sheet 14 (p. 13) and Sheet 13 (par. 5), Geol. Surv. Scotland; also in Geol. Mag. for 1866, p. 244, Anniversary Address to Geol. Soc. 1892, p. 82 (p. 58 of separate copies), 'Text-book of Geol.' 1885, p. 549; and R. D. Irving, 'Copper-bearing Rocks of Lake Superior,' U. S. Geol. Survey Monograph, 1883, pp. 137–140.

were seen under the microscope to be chiefly angular quartz.[1] In order to make quite certain, a fragment of No. 929 D was roughly powdered, dissolved (with strong effervescence) in HCl, and the specific gravity of the isolated grains was determined. It agreed with that of quartz.

VI. List of Localities examined.

As many of the quarries in which the 'traps' are exposed are no longer worked, are much overgrown, and tend to become obliterated, I give a list of those examined by me, with exact indication of their position, premising that the numbers preceding each locality are firstly a number for reference in the subsequent petrographical description, and secondly, the number of the quarter-sheet of the 6-inch Ordnance Survey maps (pub. 1887–90) on which they are indicated.

No. 889 (34 S.W.). Washfield, 2⅛ miles N. 35° W. of Tiverton. Quarry in Mousebeare Lane, 383 yards west of church.

No. 891 (34 S.W.). Exposure in roadside, Long Lane, 1325 yards S. 28° E. of Loxbear Church, N.W. of Tiverton, and 392 yards west of lane turning down to Lurley.

Nos. 895 A, 895 B, 896, 897, 898 (56 S.W.). Raddon Quarry, 1733 yards S. 84° W. of St. Thomas à Becket's Church, Thorverton, 6 miles north of Exeter.

Nos. 899 A, B, C, & D (68 N.E.). Quarry in Quarry Lane, Lower Budlake, 6 miles N. 37° E. of Exeter, 667 yards east of Killerton (house).

No. 900 (68 N.E.). Killerton Park, 5½ miles N. 33° E. of Exeter. 'Old Quarry' on east side of park, 705 yards N. 25° E. of Killerton (house).

No. 901 (68 N.E.). Old quarry at 'Remains of Camp,' Dolbury, Killerton Park.

No. 902 (68 N.E.). Old quarry, 127 yards S. 61° W. of northern lodge, Killerton Park.

No. 903 (68 N.E.). Quarry at Dunsmoor (Densmoor), 1302 yards south of St. Mary's Church, Silverton (Silverton is 6⅝ miles N. 17° E. of Exeter).

No. 904 (68 N.E.). Quarry (Rew Quarry ?), on road from Silverton southward to Rew, 600 yards N. 81° W. of Heazille Barton.

Nos. 906, 906 A (68 N.E.). Quarry in Columbjohn Wood, 1008 yards N. 83° W. of Killerton.

No. 907 (68 N.E.). Moss-grown quarry, 195 yards N. 83° W. of Killerton.

No. 908 A (68 N.E.). Old quarry at Beare Farm, 1575 yards N. 58° E. of Killerton.

No. 909 (56 S.E.). Old quarry (now a pond) in the grounds of Silverton Park (Combe Sacheville), 195 yards west of house.

[1] The appearance of the section is quite like pl. xi. of R. D. Irving's monograph, 'The Copper-bearing Rocks of Lake Superior.'

No. 911 (80 S.W.). Old quarry, 108 yards west of Barley House, $1\frac{1}{5}$ mile S. 75° W. of Exeter.

Nos. 912 & 912 A, B, C (79 S.E.). Knowle Quarry, $3\frac{5}{8}$ miles S. 54° W. of Exeter, 1000 yards S. 75° E. of Darniford (house).

No. 913 (79 S.E.). West Town Quarry, 1245 yards S. 87° W. of St. Ida's Church, Ide, near Exeter.

Nos. 914, 914 A (91 N.E.). Quarry behind Webberton Cottages, 467 yards N. 81° W. of Haldon House, near Dunchideock, S.W. of Exeter.

No. 915 (91 N.E.). Old quarry by roadside in 'School Wood' or 'Great Plantation,' 703 yards N. 66° W. of Haldon House.

No. 916 (91 N.E.). Old quarry in Orchard Copse, 203 yards N. 62° W. of Holy Trinity Church, Dunchideock.

Nos. 918 A, B, C, D (80 S.W.). Large quarry at Pocombe, close to Crossmead, $1\frac{1}{2}$ mile S. 60° W. of Exeter (cathedral).

No. 919. Old quarry at West Clist ($3\frac{5}{8}$ miles N. 60° E. of Exeter), opposite road turning off to Poltimore Park.

Nos. 928 A & B (65 N.E.). 'Stone Quarry,' 545 yards N. 40° W. of Crooke, and about 1 mile E.S.E. of North Tawton.

Nos. 929 A, B, & C (67 S.W.). Large quarry, 220 yards N. 54° E. of St. Luke's Chapel, Posbury, near Crediton.

VII. Macroscopical and Microscopical Characters of the Rocks.

Most of the 'felspathic traps' examined by me are altered olivine-basalts, but the rock of Killerton (Nos. 900, 901, 902, 907) is an altered andesite, and appears to differ from that at Columbjohn Wood (No. 906) on the west and of Lower Budlake (No. 899 A, &c.) on the east of it, although the Geological Survey map makes of them all one continuous mass.

(a) *Altered Olivine-basalts.*

These would be termed melaphyres according to the nomenclature of Prof. Rosenbusch,[1] but since it is now pretty generally admitted that the pre-Tertiary geological age of an igneous rock is no sufficient reason for giving it a different name, and since the use of the term 'melaphyre' for an altered basalt[2] or olivine-basalt[3] only tends to conceal the relationship of basaltic rocks, I prefer to call them basalts.

Although on the whole there is a considerable resemblance between the macroscopical characters of the 'traps' from the different localities, yet the appearance of the rock varies so much even in one and the same quarry, according to whether the freshest non-vesicular or the most altered and amygdaloidal specimens are taken, that no one description will apply to all cases.

Type 1. Freshest non-vesicular rocks. Their colour varies from

[1] 'Mikr. Physiogr. d. Massig. Gest.' 2nd ed. 1887, pp. 484, 506.
[2] F. H. Hatch, 'Introduction to the Study of Petrology,' 1891, p. 112.
[3] G. A. J. Cole, 'Aids in Practical Geology,' 1891, p. 237.

dark reddish to bluish purple, frequently resembling that of some specimens of Cambrian slate from Penrhyn Quarry, North Wales. Texture almost compact, with here and there a porphyritic plagioclase (Nos. 912 A, 913, 914, 915, 928 A & B, 929 A & C). Quartz inclusions are abundant in some specimens, as in Nos. 912 A, 913, 928 A & B, and present in Nos. 914, 915, 929 A & C. In the case of the four rocks just mentioned, ferruginous pseudomorphs after olivine are visible.

Type 2. Light reddish or pinkish purple to brown weathered rocks, full of vesicles drawn out in the direction of flow. Specimen No. 889 is as vesicular as a sponge, and is crowded with small red or yellow pseudomorphs after olivine. Specimens No. 897 (from upper surface of bed) and No. 908 B do not contain such large vesicles as No. 889, and few pseudomorphs are visible in them.

Type 3. This includes the great majority of the specimens, which are evidently weathered rocks varying from dark purplish red to lilac or pinkish in colour, sometimes very amygdaloidal, as in No. 912 B (within 3 feet of the upper surface of the bed) and No. 904, but often with few or no amygdules. Reddish pseudomorphs after olivine are often visible, *e.g.* in Nos. 899 A & B, 916, 918 A, B, & D, 929 B.

As to the microscopical character of these rocks, their structure is porphyritic in the sense of Rosenbusch.[1]

Phenocrysts.—Olivine and in some cases plagioclase. Brown mica in No. 889.

Groundmass.—Plagioclase. Augite in Nos. 914, 915. Magnetite or ilmenite. Brown mica in No. 889.

(i) *Olivine Phenocrysts.*—Unaltered olivine, colourless in thin section, does not occur. The olivine has in most cases undergone the alteration described by Rosenbusch,[2] it is "changed to a red transparent substance of laminated structure and mica-like habit; the lamellæ appear to lie parallel to the brachypinacoidal (010) cleavage-cracks. The substance is very distinctly pleochroic, and absorbs rays vibrating parallel to the lamination much more strongly than those perpendicular to it. The colour of this substance is intermediate between that of specular iron ore and that of pseudobrookite" [translation]. The change just described is very well shown in Nos. 928 A, 914, and 929 A.

The pseudomorphs are often a dark reddish-brown in colour and semi-opaque. In some cases the margin consists of magnetite, as in Nos. 909, 911, 918 A. Sometimes almost the whole of the original crystal is replaced by a granular aggregate of a zeolite showing the grey interference-colour of the first order, as in No. 918 D, and accompanied by calcite in No. 929 A. The pseudomorphs in No. 928 A consist of calcite with a reddish-brown margin of the material before mentioned, described by Rosenbusch.

Section 929 A illustrates excellently every intermediate stage between forms 1·15 millim. in diameter with reddish-brown trans-

[1] *Op. supra cit.* p. 340. [2] *Ibid.* p. 489.

lucent margin and calcite centre (evidently pseudomorphs after idiomorphic olivine), and minute patches 0·09 millim. in diameter or less, with a black margin of magnetite, having sometimes the outline of an olivine crystal, but often irregular and occupied by calcite in the centre with irregular bands of magnetite across it. The same transition is visible in No. 916. These minute pseudomorphs are plentiful in Nos. 929 B, 912 A, 912 C, 913, 928 B, 895 B, &c.

The pseudomorphs after olivine are frequently corroded by the groundmass, and very irregular fantastic forms thus arise, as in Nos. 928 A and 916, so that almost all trace of idiomorphism may be lost. In nearly every case the pseudomorphs are fairly abundant, though, as their size is not generally large, they hardly make up a notable percentage of the rock. The maximum size observed was 3·97 millim. in diameter in No. 928 A, but the usual size is about 0·8 millim. × 0·4 millim. in the case of the more obvious pseudomorphs, and about 0·09 millim. diameter in the case of the numerous small magnetite pseudomorphs.

The only section in which olivine pseudomorphs were not made out was No. 906 A, and it is uncertain whether they are not present in that case as minute magnetite pseudomorphs, since they are present in No. 906.

(ii) *Plagioclase phenocrysts* are present in Nos. 912 A, B, & C, 913, 914, 915, 928 A & B, 929 A & B. They give in general nearly square sections, but are never abundant. Though they are idiomorphic, they have been both corroded by the groundmass so as to alter their external contours and minutely honeycombed by the interstitial matter. In some cases the whole interior is honeycombed, in others a central patch remains free from attack, but in nearly all examples there is a narrow outer margin free from honeycombing. I take the explanation of this to be that the crystals were formed in the intratelluric period, that owing to the relief of pressure upon the rise of the rock to the surface they were corroded and honeycombed (as relief of pressure acts like increase of temperature), and lastly, as the rock cooled slowly the crystals renewed their growth, though not vigorously enough to obliterate the traces of the corrosion of their contours.

Brown mica occurs sparingly in No. 889. It is corroded and surrounded by hæmatite grains (probably altered magnetite due to resorption).

Groundmass.—Plagioclase is by far the most important constituent of the groundmass. It occurs in forms giving mostly lath-shaped sections. The largest average size of the crystals observed was in No. 904, namely, ·43 millim. × ·09 millim.

The only sections (except Nos. 928 A & B) in which augite occurs in the groundmass are Nos. 914 and 915. In both cases it is distinctly ophitic, but on a very microscopic scale, the allotriomorphic crystals having an average diameter of 0·08 millim. and being usually penetrated by only a single felspar. Traces of augite are seen in Nos. 928 A & B. Calcite, most probably replacing augite, occurs in Nos. 896, 918 A, 928 A & B, 929 A & B. It is accompanied by chlorite in No. 909, and chlorite, probably replacing augite, occurs in Nos. 903, 904, 906, 919.

Brown mica occurs in the groundmass of No. 889.

Magnetite is very abundant; indeed, it often occupies the greater part of the angular spaces between the felspars, especially in the less crystalline portions of the rocks, usually near the upper or lower surface, *e. g.* in Nos. 897, 906 A, 908 A, 911, 918 D. It is very generally altered to reddish ferruginous matter, which gives most of the rocks a reddish colour even in the thinnest sections.

Bronzite is mentioned by Prof. Bücking[1] as a constituent of the rock of Dunchideock (locality not more precisely given). I have not observed it in any of the specimens that I have examined.

Amygdules are very common. They are most frequently occupied by calcite or by zeolites (showing a grey interference-colour of the first order) or by both.[2]

(b) *Quartz Inclusions.*

As already mentioned, these occur in Nos. 912 A, 913, 914, 915, 928 A & B, 929 A & C, also in 912 B. They vary in size, from 2 to 3 millim. diameter and less, are usually of a rounded form, and are encircled by a rim of small augite-crystals, often obscured by secondary calcite. Each inclusion consists as a rule of a single individual, but aggregates of numerous individuals with interlocking margins, as in a quartzite, occur, *e. g.* in No. 912 C. The evidence in favour of regarding these quartz-crystals as inclusions is :—

1. The basic nature of the rock, shown by the presence of olivine and plagioclase.
2. The rounded form of the crystals.
3. The presence of reactionary rims of augite-crystals.
4. The complete want of any uniformity in the distribution of the quartz-crystals throughout the rock, which is in some places rich in them, in others free from them.
5. The fact that the rocks are interbedded with sandstones, whence the quartz could be obtained when the rock was erupted through the underlying beds.
6. The most convincing proof is the presence at Knowle Quarry (No. 912) of an oblong eye of quartz about 3×1 inch embedded in the rock. I have the specimen in my possession.

I am aware that Mr. J. S. Diller does not regard points 1 to 3 as proof that quartz is not (in some cases) an original constituent of basalt; indeed, they are all present in the case of the quartz-basalt of Cinder Cone, 10 miles N.E. of Lassen's Peak, California, which he describes,[3] and with a section of which I have compared the Devon basalts, but when combined with points 3 to 6 the evidence appears convincing.

[1] In Mr. Ussher's paper, p. 248.

[2] In the 'Challenger' Report, Deep-sea Deposits, 1891, pl. xviii. fig. 4 gives a good idea of the zeolites in No. 928 B, and figs. 2 and 3 of those in No. 929 A.

[3] 'A late Volcanic Eruption in Northern California and its peculiar Lava,' Bulletin U.S. Geol. Survey, No. 79 (1891), pp. 24–28.

The presence of quartz (or 'glassy feldspar') in the rocks of Stone, Knowle, and Western Town is mentioned by Mr. Etheridge in Mr. Vicary's paper before cited. It was previously noticed by De la Beche as follows[1]:—"Above Ideston and Knole we find porphyries sometimes containing crystals of quartz, at others of felspar, and occasionally of both together—a very interesting fact, inasmuch as it is the only locality with which we are acquainted where any portion of those quartziferous porphyries, of which fragments are so commonly found in the red conglomerate between Exeter and Teignmouth, occurs in place;" and again (p. 217) "the quartziferous porphyry near Dunchideock." I hold that De la Beche was misled by the quartz inclusions in these basalts into regarding them as quartz-porphyries.

A mass of genuine quartz-porphyry measuring about 4 feet × 1 foot is exposed on the west side of the road opposite to the entrance-gate of Dunchideock House, but it appears to belong to the New Red Breccia.

Dr. Hatch has described[2] some of the rocks which I term olivine-basalts as porphyrites (andesites), viz., Western Town, Ide (his No. 943 = my No. 913), Quarry N.E. of Knowle, N.E. of Holcombe-Burnell (his No. 946), and Knowle Quarry, W. of Dunchideock (his No. 949). It is difficult to identify the localities of Nos. 946 and 949. If the Geological Survey and 6-inch Ordnance maps are to be trusted, there is no 'trap' N.E. of Holcombe-Burnell. Probably S.E. of Holcombe-Burnell is meant, in which case Dr. Hatch's No. 946 is probably the same as my No. 912. No 'Knowle Quarry' is shown on the maps W. of Dunchideock. Probably that at Orchard Copse (my No. 916) is meant.

Obvious pseudomorphs after olivine phenocrysts are plentiful in No. 916, but in No. 913 only one *red* pseudomorph 0·47 millim. in diameter and in No. 912 B only two above 0·3 millim. in diameter are present, though smaller ones are numerous in No. 912 B; but in Nos. 912 A, B, C, and 913 magnetite pseudomorphs about 0·09 millim. in diameter, which I take to be after olivine (as previously described), are abundant.

The rock of Long Lane, Loxbear (No. 891), differs so much from the rest as to deserve separate description. The hand-specimen is whitish and very micaceous. Microscopically the rock is seen to contain pseudomorphs after idiomorphic olivine, consisting of brownish alteration-products outlined by black opaque iron ore; brown mica (very abundant), apatite in short prisms, much opaque iron ore, and felspar. The mica is often allotriomorphic towards the felspar, but sometimes the reverse relation appears to obtain. It is very full of inclusions of hæmatite, black as seen under a low, but red translucent under a high power, often arranged in a series of lines crossing one another at about 60° as seen in a basal pinacoid section. These are probably pseudomorphs after magnetite, as

[1] Report, pp. 203, 204.
[2] Notes to Mr. Ussher's paper, Geol. Mag. for 1892, p. 250.

is much of the iron ore in the rest of the rock. Although some of the felspar is undoubtedly plagioclase, I am uncertain whether it is all so.

(c) *Mica-augite-andesite of Killerton.*

This rock would be termed mica-augite-porphyrite by Rosenbusch. I can hardly describe it better than by saying that it looks like a minette, but is lighter in colour than most minettes. Specimen No. 907 is very micaceous, and the abundant small glistening flakes of mica have the same brown colour as the compact groundmass. Specimens Nos. 900, 901 are bluish to purplish grey and contain the same brown mica much less abundantly. Specimen No. 902 is light purplish grey, with comparatively few visible flakes of mica and numerous small narrow elongated cavities. Sp. gr. 2·57.

Phenocrysts occur of augite, brown mica, apatite, and iron ores. Groundmass of felspar.

The augite phenocrysts are almost colourless or faintly greenish, 0·5 millim. in diameter or smaller, and are often partly altered to calcite. Brown mica is abundant. In one case it was included in the augite. On the other hand it frequently contains apatite and iron-ore inclusions. Apatite occurs in numerous small crystals, and iron ore is generally distributed.

Mr. Edward Haworth has kindly made for me in the Chemical Laboratory of Owens College the following analysis (A) of the rock, No. 900:—

	A.	B.
SiO_2	48·37	51·20
Al_2O_3	20·74	20·03
Fe_2O_3	6·56	7·57
FeO	·63	
MgO	6·35	6·75
CaO	7·77	10·52
Na_2O	1·70	1·71
K_2O	—	0·51
H_2O	1·60	1·70
P_2O_5	·94	—
CO_2	6·00	—
	100·66	99·99

It is evident from analysis (A) that the felspar of the groundmass is plagioclase. The analysis (B) is that of the Morpeth dyke, Morpeth, Northumberland, by Mr. Stead, of Middlesbrough, quoted from Teall, 'British Petrography,' 1888, p. 206, for comparison.

37. *The* Dioritic Picrite *of* White Hause *and* Great Cockup. By J. Postlethwaite, Esq., F.G.S. (Read June 22nd, 1892.)

This rock is exposed on both sides of Hause Gill, which separates White Hause from Great Cockup; the exposure on the former measures from 12 to 15 yards square, that on the latter mountain being somewhat smaller. The two masses are about $\frac{1}{3}$ mile apart, and are doubtless connected beneath the till which forms the floor of the little valley, the only visible connecting-link being a group of blocks jutting out on the northern bank of the stream, which may or may not be in place. The area here indicated is shown in J. Clifton Ward's 6-inch 'Geological Map of the Lake District' (now in the Keswick Museum of Local Natural History) and coloured as diorite; it is also shown as diorite in 'Section I. through Skiddaw,' in Ward's 'Physical History of the English Lake District;'[1] but, so far as I have been able to ascertain, there is no description of the rock in any of his published works, owing in all probability to the fact that it lies a little to the north of Quarter Sheet 101 S.E., which embraces the area treated of in 'The Geology of the Northern Part of the English Lake District.' The area is shown in the accompanying map, which is based on that of the Ordnance Survey, Sheet 23 (formerly 101 N.E.).

My first visit to White Hause took place in the spring of 1890, when I was engaged in the preparation of a paper on 'The Deposits of Metallic and other Minerals surrounding the Skiddaw Granite,'[2] and I was then struck by the close resemblance existing between the rock at that place and the hornblende-picrite at Little Knott, which lies about 2 miles south-west; indeed, the resemblance is so marked that in the above-mentioned paper I referred to the rock at White Hause as "a large mass of hornblende-picrite of like nature." I re-visited the place in the autumn of 1891, and again in the spring of the present year. I obtained specimens from various parts of the mass, and also from the surrounding rocks, and had slides prepared from some of the specimens. The slides, together with the fragments of rock from which they were taken, were submitted to Prof. Bonney, F.R.S., for examination, and he kindly gave me permission to incorporate his notes in my paper, want of time having prevented him from making them sufficiently elaborate to be printed separately.

The dioritic picrite is a coarsely crystalline rock of a dark olive-green colour, consisting of several varieties of hornblende, also quartz, felspar, calcite, serpentine, iron peroxide, and probably a little apatite, ilmenite, and viridite. On White Hause the rock is very coarse, some of the crystals being nearly $\frac{1}{4}$ inch in diameter; the exposure on Great Cockup is somewhat finer, but the mineral con-

[1] Geol. Mag. for 1879, p. 54.

[2] Trans. Cumb. & Westm. Assoc. no. 15 (1889–90), p. 75.


Map of
PART of
BASSENTHWAITE
and PART of
SKIDDAW FOREST
Scale:
1 Inch = 1 Mile
References:
Unaltered Skiddaw Slate.
Chiastolite Slate
Spotted Schist
Dioritic Hornblende } Picrite
Grit
Granite
Bassenthwaite Lake
N
Dash
Beck
Hause Gill
White Hause
Dolerite
Great Cockup
Great Calva
Wiley Gill
River Caldew
Skiddaw
Southern Dale
Little Knott
Syning Gill

stituents are alike in both. There is a large boulder of the rock in the bed of the stream, about 200 yards below the masses *in situ*, in which some of the crystals are ½ inch in diameter. This variation in crystalline structure is a feature which appears to be rather common in rocks like picrite. The boulders scattered along the bed of the stream, together with those used in the construction of boundary walls, show that a large quantity of picrite has been removed by the denuding agents that have scooped out the valley to its present depth.

Two slides, one prepared from the fine-grained picrite on Great Cockup, and the other from the coarser rock on White Hause, were amongst those examined by Prof. Bonney, and the following are his notes on the slides and on the hand-specimens from which they were taken :—

"The specimens numbered 1 and 2 present a general resemblance to those which I have from Little Knott, and I may refer to my description already published [1] for the principal features, such as the different varieties of hornblende, and their relations one to another. In the new specimens it is more difficult to prove that olivine has been a constituent of the rock, though I think it is represented by some of the serpentinous aggregates; also there seems to me a slightly larger proportion of felspar; the rock, therefore, is rather farther away from a typical picrite than the Little Knott rock, to which, however, it is closely related, and so it may be regarded as one of the transitional forms between normal picrite and normal diorite."

About 300 yards east of the dioritic picrite, Hause Gill bends to the north-east, and at this point, on the eastern side of the stream, there is an exposure of rock, the true nature of which can hardly be determined without the aid of the microscope. In hand-specimens it exhibits many of the characteristic features of a quartz-felsite, but in other respects it is not very dissimilar from some of the grit which occurs in that locality. The outer surface is much decomposed. Prof. Bonney has made the following notes on a slide prepared from this rock :—

"This rock has undergone so much secondary change that it is difficult to speak positively as to the exact nature of the original constituents. It is, however, undoubtedly igneous. The chief constituent has been a felspar, which is now almost wholly replaced by secondary products, the more abundant being rather fibrous microliths, which give, with crossed nicols, fairly bright colours; with them are occasional spots and small patches of a clear mineral, which gives low polarization-tints. It may be a secondary quartz, or possibly a mineral allied to felspar; occasionally it is a crystalline grain or a small cluster of grains, resembling dolomite. Moreover there are some patches, in fair quantity, of a browner colour and 'dusty' aspect, which are imperfectly translucent, but also indicate the presence of secondary microliths,

[1] Quart. Journ. Geol. Soc. vol. xli. (1885) p. 511.

somewhat similar to those mentioned above; two or three of the same are much stained with clotted limonite, or contain small crystals of iron oxide.[1] Next in quantity to the felspar is a mineral of rather irregular, but sometimes rectilinear outline; most of it shows one strong parallel cleavage; occasionally, however, there is more than one direction of cleavage, neither being so distinct. Much of the mineral is rendered opaque by brown dust; in the clearer part this has a very feeble depolarizing effect, or is wholly inert. The cleavage-planes in the former examples are sometimes separated by a narrow lenticular space (as occasionally seen in mica), occupied by microliths, bright tinted with crossed nicols. It is almost impossible to determine the relation of the extinction to the cleavage-planes, because so little light passes through in any position, but I think it is *not* parallel with them. On the whole I feel certain the mineral was not mica, but augite (chiefly diallage).

"Hence the rock originally, in all probability, was a variety of dolerite, and, so far as I can judge, not a very basic variety—certainly not a picrite. I should have said there are some grains of iron oxide, now probably limonite, and perhaps a little apatite."

This mass of altered dolerite very probably issued originally from the same vent as that which at a later period discharged the dioritic picrite; the intense alteration that has taken place in the former being due in all probability to contact with the latter.

The exposures of dioritic picrite are too small to admit of any difference being traced between the outer margins and the central portions of the two masses, but a considerable amount of change has been produced in the surrounding rocks. On White Hause the dioritic picrite is succeeded on the eastern side by a schistose rock, which has clearly at one time been sedimentary, but is now almost crystalline in its nature. This schist is light grey in colour, moderately hard, and splits without much difficulty. In some places the surface is much weathered. A slide, No. 3, was cut from this rock, but unfortunately it is too thick, and Prof. Bonney was unable to make much of it; he states, however, that "there is a structure resembling incipient foliation or fluxion; there are also small patches of rather peculiar structure composed of some carbonate (probably calcite), some crystals of oblong form, now almost opaque, and probably some hornblende."

White Hause is on the margin of the area affected by the influence of the Skiddaw Granite. and crystals of chiastolite make their appearance in the Skiddaw Slate about 200 yards south of the dioritic picrite; proceeding 400 yards farther in the same direction, Dash Waterfall may be seen plunging over an escarpment of spotted schist. It is difficult to say, however, how much, if any, of this change may be due to contact with the picrite, or whether it is due solely to contact with the Skiddaw Granite.

On the north-eastern, northern, and north-western sides of the dioritic picrite on Great Cockup, a bed of grit which marks one of the

[1] These may possibly represent another mineral.

proposed subdivisions of the Skiddaw Slate Series [1] crops out to the surface, and near the picrite it shows distinct traces of contact-metamorphism. The grit is a coarsely granular rock composed chiefly of rounded grains, varying in size from $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter; amongst them are a large number of quartz and felspar-grains, derived apparently from the waste of a granite or granitoid rock. Skiddaw Slate is also represented by grains of both the smooth black and light-grey varieties. In this rock, at a distance of about 300 yards from the picrite, on the north-western side, there are traces of secondary change. Two slides prepared from the grit at this point are described by Prof. Bonney as follows:—"No. 4. A fairly coarse grit, consisting of quartz (apparently from a granitoid rock), some felspar, in certain of which is a curious 'dendritic' structure, probably due to secondary change, bits of volcanic rock of a fairly acid type, of grit, and of slate or phyllite. Some signs, but not conspicuous, of contact-metamorphism." The above notes refer to a slide taken from the upper surface of the grit, at its junction with the overlying soft slate. No. 5 is taken from grit of the normal type. "This is certainly a fragmental rock, the constituents not very dissimilar to those of the last (No. 4), but there are rather more numerous fragments of acid lavas, and there is no well-marked phyllite; perhaps fewer quartz-grains. One fragment exhibits a well-defined micrographic structure."

I also had a slide prepared from a rather gritty slate which occurs in the same locality, on which Prof. Bonney has written the following note:—"No. 6 is a rather gritty slate, containing a fair amount of small grains of quartz and flakes of mica (both fragmentary) mixed up with the usual earthy material, like numbers of other not very smooth-cleaving slates; possibly a little affected by contact-metamorphism."

The last three slides all show traces of secondary change, due to contact with the dioritic picrite on Great Cockup. Some of the soft smooth Skiddaw Slate on the north-western side of this exposure of dioritic picrite also shows signs of contact-metamorphism, in the form of alternating bands of light and darker colour.

The amount of alteration observable in the rocks surrounding the dioritic picrite, as the result of contact with it while in a molten state, and during the process of cooling, is considerably larger than that observable at Little Knott, although the amount of picrite exposed in the latter locality is probably quite as large as in the united areas on opposite sides of Hause Gill. We may infer, therefore, that there is probably, at a moderate depth beneath the surface, a much larger mass of dioritic picrite than that now exposed on the sides of Hause Gill. There is good reason for supposing that the picrites at Little Knott and on the sides of Hause Gill are of the same age, and, as Prof. Bonney suggests, probably came from the same 'pot,' notwithstanding the distance by which they are separated (2 miles); the trifling difference there is between the

[1] Ward's 'Physical History of the English Lake District,' Geol. Mag. for 1879, p. 122.

mineral constituents of the two rocks is unimportant, being no more than has been shown to exist in different portions of the Little Knott exposure.

My best thanks are due to Prof. Bonney for his kind help with the rock-sections, without which my paper would have been of no value.

Discussion.

The President remarked that the rock described by the Author appeared to verge on a diorite, and commented on the comparative rarity in the Lake District of rocks containing minerals rich in magnesia.

Mr. Rutley remarked that although the rock from Little Knott was a picrite, as already stated by Prof. Bonney, it was remarkably rich in hornblende, and resembled a diorite in external appearance. He had not examined sections from the other exposures mentioned by the Author.

Mr. Marr also spoke.

38. MICROZOA *from the* PHOSPHATIC CHALK *of* TAPLOW. By F. CHAPMAN, Esq., F.R.M.S. (Communicated by Prof. T. RUPERT JONES, F.R.S., F.G.S. Read June 22nd, 1892.)

[PLATE XV.]

THE present paper is the result of an examination of some material kindly sent me by Mr. Llewellyn Treacher, who obtained it from about the middle of the phosphatic band at Taplow.

A short list of the foraminifera of the Taplow Chalk has already been given by A. Strahan, Esq., M.A., F.G.S., of H.M. Geological Survey, with the assistance of Prof. T. Rupert Jones, F.R.S., F.G.S.,[1] and I wish at this point to express my obligation to the latter for help and advice in preparing these notes.

The material used was excessively rich in well-preserved specimens of foraminifera, forming perhaps 75 per cent. of the whole; and a series selected from it proving so extensive and interesting, there seemed good cause to communicate a list of them.

On treating the disintegrated chalk with a weak solution of hydrochloric acid, the most perfect casts in phosphate of lime are obtained, the Rotaline forms being especially noteworthy.

The total number of species and varieties of foraminifera found is 98; and to these must be added 5 species and varieties of ostracoda, represented by 11 specimens.

All the forms of ostracoda herein noted have been previously found in the Chalk. They are:—*Pontocypris triquetra*, Jones, sp., 2 specimens; *Bythocypris silicula*, Jones, sp., 1 specimen; *Cythereis auriculata*, Cornuel, sp., 1 specimen; *C. Wrightii*, Jones and Hinde, 6 specimens; and *Cytherella Williamsoniana*, var. *granulosa*, Jones, 1 specimen.

Of the 98 varieties of foraminifera, 5 appear to be entirely new to science, whilst altogether 30 are new to the Chalk fauna, and these are marked on the list by an asterisk. Of those new to the Chalk, 2 have been known from recent deposits only, namely, *Bulimina elegans*, D'Orb., and *Cristellaria gemmata*, Brady.

Of the remainder, 20 are recorded from the Tertiaries, and the rest from deposits older than the Chalk.

The following descriptions relate to those forms which are apparently new to science:—

(i) *Nubecularia Jonesiana*, sp. nov. Pl. XV. fig. 2.

Test porcellanous, free, consisting of a single flask-shaped chamber with a simple circular aperture; the surface of the test uneven and

[1] Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 357. The forms mentioned in this earlier list are included in that given at the end of the present paper, with the exception of *Globigerina Linnæana*, which I have not met with.

irregularly pitted. Length $\frac{1}{60}$ in. (0·42 millim.). Two specimens only were found.

(ii) *Textularia decurrens*, sp. nov. Pl. XV. fig. 6.

Amongst a large number of the globulose-chambered *Textulariæ* so abundant in the Taplow Chalk were noticed several specimens more or less inclined to depart, in the latest growth of the shell, from the bi-serial or Textularian type and to become spirally uni-serial, showing in fact the reverse of the essential character of the genus *Spiroplecta*. The specimen figured represents this abnormal growth in perhaps its best development. It is only another instance of the readiness with which a form will depart from its type, serving perhaps as a link not only between species, but it may be between genera also. Length $\frac{1}{45}$ in. (0·56 millim.).

(iii) *Textularia serrata*, sp. nov. Pl. XV. fig. 7.

This is a somewhat elongate form resembling, by the hollowed faces of the shell, *T. concava* of Karrer; but the species is distinctly separable from the latter by the attenuated form and the constrictions between the pairs of chambers. *T. serrata* generally possesses a single terminal chamber, probably an indication of age; and in some specimens a slit-like aperture can be seen disposed horizontally at its base. Length $\frac{1}{45}$ in. (0·56 millim.). Common in the Taplow Chalk.

(iv) *Bulimina trigona*, sp. nov. Pl. XV. fig. 8.

Test subconical, three-sided, slightly twisted, and with the aboral end thickly granulated, or studded with short prickles. This form resembles one variety of *B. elegans* in the three-sided disposition of the series of segments, but is much stouter and more angular. Length $\frac{1}{50}$ in. (0·5 millim.). Frequent in the Taplow Chalk.

(v) *Bolivina strigillata*, sp. nov. Pl. XV. fig. 10.

Test compressed, triangular, and elongate, tapering gradually to the commencement of the shell. The surface of the test bears oblique raised ridges, sometimes broken into tubercles. The ornamentation of the shell somewhat resembles that of *B. decorata*, Jones, recorded by Mr. Joseph Wright, F.G.S., from the Chalk of Keady Hill, in the North of Ireland,[1] but differs from the latter in the lengthened, rather than dilated, form of the shell. Length $\frac{1}{40}$ in. (0·63 millim.). Common in the Taplow Chalk.

[1] Proc. Belfast Nat. Field Club, Appendix ix. (1884–85), p. 330.

List of the Foraminifera from the Taplow Chalk.

	Name.	Remarks.
1.	**Nubecularia tibia*, Jones & Parker	This, the only specimen found, is attached to a fish-scale fragment.
2.	*—— *Jonesiana*, sp. nov.	2 specimens.
3.	*—— *novorossica*, Karrer & Sinzow	1 specimen.
4.	**Spiroloculina limbata*, D'Orb.	1 „
5.	**Miliolina trigonula*, Lam., sp.	2 specimens.
6.	*—— *oblonga*, Mont., sp.	Rare.
7.	*——*venusta*, Karrer, sp.	1 specimen.
8.	*Textularia globulosa*, Ehr.	Very common.
9.	—— ——, var. *striata*, Ehr., var. ...	„ „
10.	*—— *decurrens*, sp. nov.	Rare.
11.	*—— *quadrilatera*, Schwager	Common.
12.	—— *anceps*, Reuss	Frequent.
13.	*—— *conica*, D'Orb.	1 specimen.
14.	—— *trochus*, D'Orb.	Rare.
15.	*—— *concava*, Karrer, sp.	2 specimens.
16.	*—— *serrata*, sp. nov.	Common.
17.	—— *sagittula*, Defrance	1 specimen.
18.	*Verneuilina triquetra*, Münst., sp.	Common.
19.	—— *spinulosa*, Reuss	Frequent.
20.	—— *pygmæa*, Egger, sp.	Rare.
21.	*Tritaxia tricarinata*, Reuss	Common.
22.	*Spiroplecta annectens*, Parker & Jones, sp.	Frequent.
23.	—— *biformis*, Parker & Jones, sp. ...	Rare.
24.	*Gaudryina rugosa*, D'Orb.	Common.
25.	—— *Jonesiana*, Wright	1 specimen.
26.	*Bulimina obliqua*, D'Orb.	Common (neat var.).
27.	—— *affinis*, D'Orb.	„ „
28.	*—— *ovata*, D'Orb.	Rare.
29.	—— *subsphærica*, Reuss	Frequent.
30.	—— *brevis*, D'Orb.	„
31.	*—— *elegans*, D'Orb.	„
32.	—— *obtusa*, D'Orb.	2 specimens.
33.	—— *variabilis*, D'Orb.	1 specimen.
34.	*—— *trigona*, sp. nov.	Frequent.
35.	—— *Murchisoniana*, D'Orb.	Common.
36.	**Virgulina Schreibersiana*, Czjzek	2 specimens.
37.	*—— *subsquamosa*, Egger	2 „
38.	**Bolivina dilatata*, Reuss	Frequent.
39.	*—— *strigillata*, sp. nov.	Common.
40.	*—— *punctata*, D'Orb.	2 specimens.
41.	—— *textularioides*, Reuss	1 specimen.
42.	*—— *nobilis*, Hantken	1 „
43.	*Pleurostomella subnodosa*, Reuss	1 „
44.	*Lagena sulcata*, Walker & Jacob	Frequent.
45.	—— *globosa*, Mont., sp.	1 specimen.
46.	*—— *striatopunctata*, Parker & Jones .	1 „ (fragment).
47.	*Nodosaria tenuicosta*, Reuss	2 specimens.
48.	—— *obscura*, Reuss	1 specimen.
49.	—— *radicula*, Linn., sp.	1 „
50.	—— *consobrina*, D'Orb., sp.	1 „
51.	—— *hispida*, D'Orb.	1 „

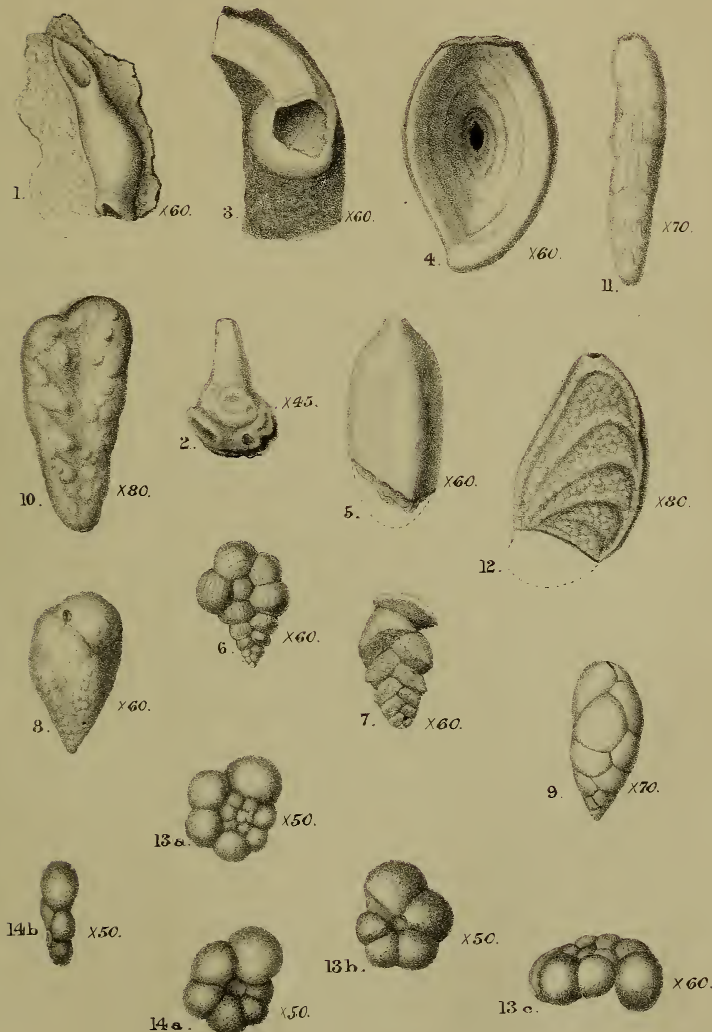
List of Foraminifera (continued).

	Name.	Remarks.
52.	*Nodosaria(Dentalina)communis*, D'Orb.	2 specimens.
53.	—— (——) *Roemeri*, Neug.	1 specimen.
54.	—— (——) *aculeata*, D'Orb.	2 specimens.
55.	—— (——) *pauperata*, D'Orb.	1 specimen.
56.	—— (——) *nodosa*, D'Orb.	1 „
57.	*Lingulina carinata*, D'Orb.	1 „
58.	*Frondicularia Archiaciana*, D'Orb. ...	Rare.
59.	—— *angulosa*, D'Orb.	2 specimens.
60.	—— *angustata*, Nilsson	2 „
61.	*Marginulina glabra*, D'Orb.	1 specimen.
62.	—— *elongata*, D'Orb.	1 „
63.	*Cristellaria cultrata*, Mont., sp.	1 „
64.	—— *rotulata*, Lam.	1 „
65.	—— *navicula*, D'Orb.	1 „
66.	—— *triangularis*, D'Orb.	1 „
67.	*—— *gemmata*, Brady	1 „ (fragment).
68.	*—— *convergens*, Born	1 „
69.	—— *Gaudryana*, D'Orb.	1 „
70.	*Flabellina rugosa*, D'Orb.	Frequent.
71.	—— *ornata*, Reuss	„
72.	—— *Baudouiniana*, D'Orb.	2 specimens.
73.	**Polymorphina sororia*, Reuss	1 specimen.
74.	—— *gibba*, D'Orb.	Frequent.
75.	—— *acuminata*, D'Orb., sp.	1 specimen.
76.	**Uvigerina canariensis*, D'Orb.	2 specimens.
77.	*Ramulina aculeata*, D'Orb., sp.	Frequent.
78.	*Globigerina cretacea*, D'Orb.	Very common.
79.	—— *bulloides*, D'Orb.	Rare.
80.	—— *marginata*, Reuss	Very common.
81.	—— *æquilateralis*, Brady	Frequent.
82.	*Planorbulina Clementiana*, D'Orb., sp. .	„
83.	—— *Lorneiana*, D'Orb., sp.	1 specimen.
84.	*Truncatulina lobatula*, Walker & Jacob, sp.	2 specimens.
85.	—— *variabilis*, D'Orb.	2 „
86.	*Anomalina ammonoides*, Reuss, sp. ...	Very common.
87.	—— *ariminensis*, D'Orb., sp.	2 specimens.
88.	*—— *grosserugosa*, Gümbel, sp.	1 specimen.
89.	—— *rotula*, D'Orb., sp.	Rare.
90.	*Pulvinulina elegans*, D'Orb.	Very common.
91.	—— *Karsteni*, Reuss	Frequent.
92.	—— *Micheliniana*, D'Orb.	Very common.
93.	*—— *punctulata*, D'Orb., sp.	1 specimen.
94.	*—— *repanda*, Fichtel & Moll, sp. ...	Frequent.
95.	*——, var. *concamerata*, Mont., var.	1 specimen.
96.	*Rotalia exsculpta*, Reuss	Very common.
97.	—— *Soldanii*, D'Orb. = *R. umbilicata*, D'Orb.	Frequent.
98.	—— *Beccarii*, Linn., sp.	2 specimens.

EXPLANATION OF PLATE XV.

Fig. 1. *Nubecularia tibia*, P. & J. (attached var.). × 60.
2. —— *Jonesiana*, sp. nov. × 45.
3. —— *novorossica*, Karrer & Sinzow. × 60.
4. *Spiroloculina limbata*, D'Orb. × 60.
5. *Miliolina oblonga*, Montagu, sp. × 60.
6. *Textularia decurrens*, sp. nov. × 60.
7. —— *serrata*, sp. nov. × 60.
8. *Bulimina trigona*, sp. nov. × 60.
9. —— *elegans*, D'Orb. × 70.
10. *Bolivina strigillata*, sp. nov. × 80.
11. —— *nobilis*, Hantken. × 70.
12. *Cristellaria gemmata*, Brady. × 80.
13, *a, b, c*. *Globigerina cretacea*, D'Orb. × 50, × 50, × 60.
14, *a, b*. —— *æquilateralis*, Brady. × 50.

Quart. Journ. Geol. Soc. Vol. XLVIII. Pl. XV.



F. Chapman del.
A. T. Hollick lith.

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FORAMINIFERA FROM THE TAPLOW CHALK

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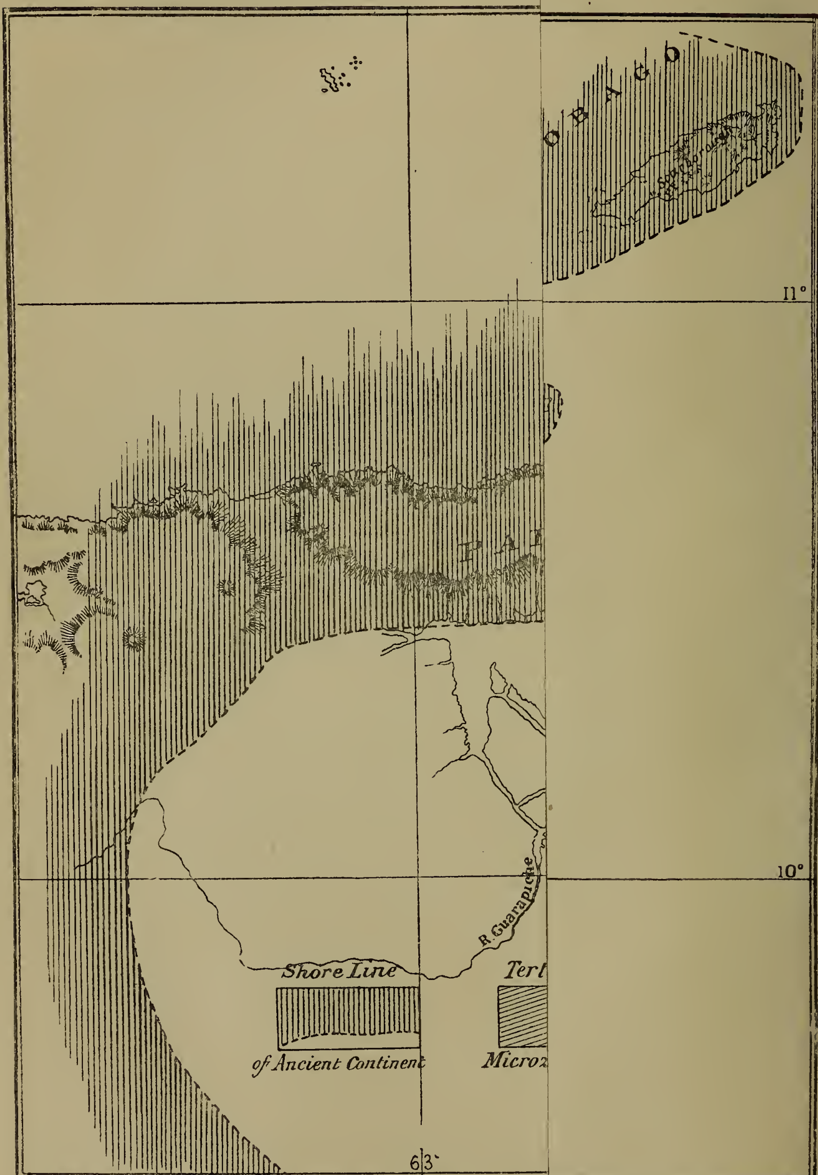

39. *The* Tertiary Microzoic Formations *of* Trinidad, West Indies.

By R. J. Lechmere Guppy, Esq. (Communicated by Dr. H. Woodward, F.R.S., F.G.S. Read June 8th, 1892.)

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§ 1. Introduction.

The island of Trinidad is separated from Venezuela and the great delta of the Orinoco by the Gulf of Paria, which stretches for 100 miles from east to west, and opens northward into the Caribean Sea by the Bocas del Drago (Dragon's Mouths), and southward into the Atlantic Ocean by the Serpent's Mouth.

The Microzoic Deposits of Trinidad form a zone 10 miles broad from N. to S., and about 35 miles long from E. to W. Whether they occur or not on the mainland of South America is not known, but from considerations which will appear in the course of this paper I think it probable that they do not.

The strike of the beds varies between N.E. & S.W. and E. & W. It will be noticed that, on the whole, it corresponds with the trend of the coast of the Gulf of Paria south-westward from Sipero Creek, near San Fernando. On the east the microzoic formations rise out of the swamps that fringe that shore of the island, while westward they sink below sea-level in the Oropuch Lagoon. They are bounded to the north by strata presumed to be of Cretaceous age, and to the south by Miocene and Pliocene rocks of mainly arenaceous character.

The sketch-map facing this page exhibits the relationship of the Microzoic Deposits to the chief physical features of the region, and indicates the shore-line of the supposed ancient continent.

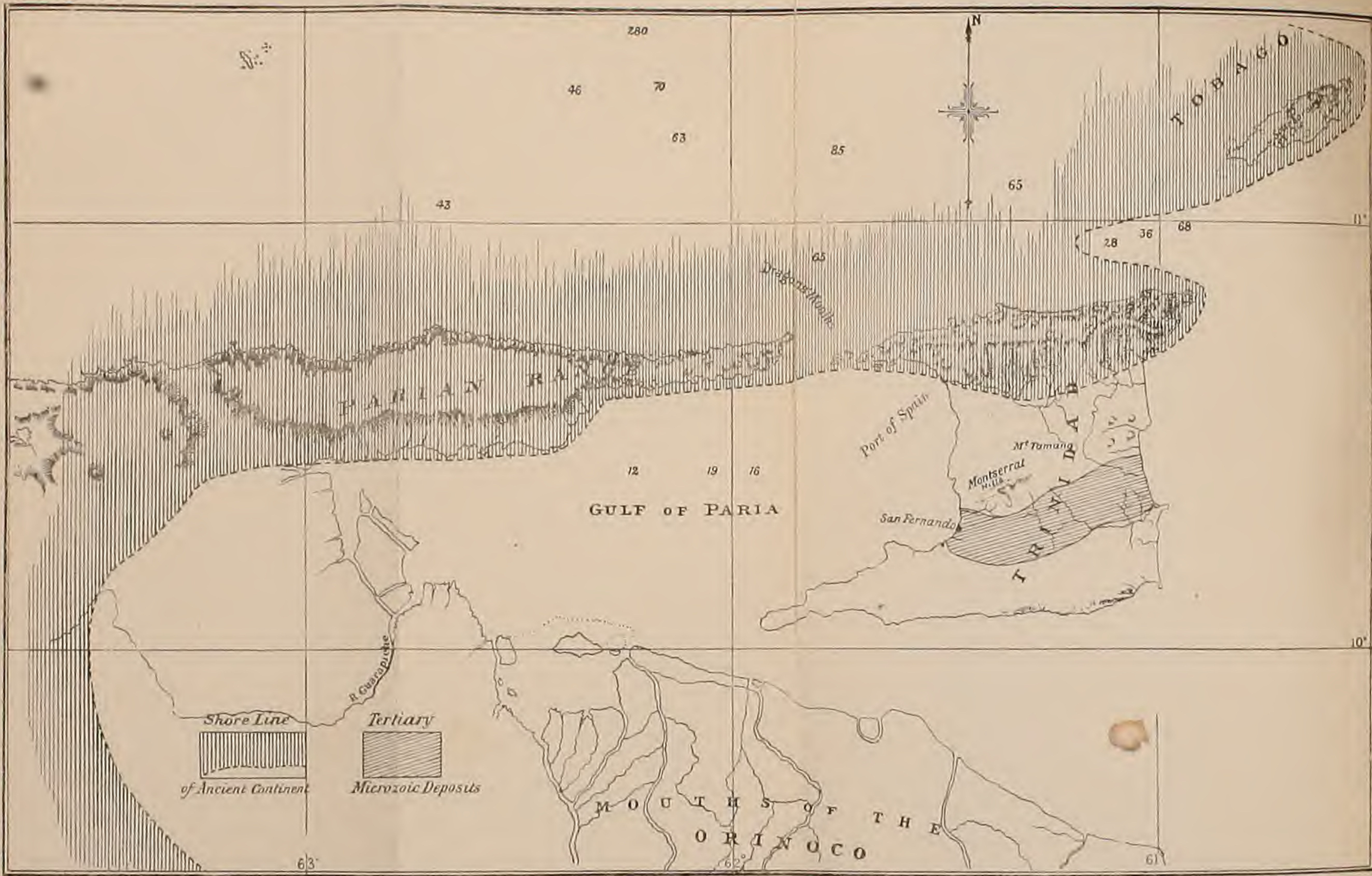
As regards the literature of the subject, the reader may consult Messrs. G. P. Wall and J. G. Sawkins's 'Report on the Geology of Trinidad,' published in 1860. The practical difficulties with which those surveyors had to contend were such as to prevent their Report from being more than a general outline.

The Naparima Marls, mentioned in that Report as exposed for some distance in the cliffs north and south of San Fernando, were treated of three years later by the present writer in a communication to the Scientific Association of Trinidad,[1] and again in 1866.[2]

[1] Reprinted in the 'Geologist' for 1864, p. 159.
[2] Quart. Journ. Geol. Soc. vol. xxii. (1866) p. 571.

SKETCH-MAP OF THE ISLAND OF TRINIDAD AND THE NEIGHBOURING MAINLAND

(showing the extent of the known Tertiary Microzoic Deposits and the probable Shore-line of the ancient Continent).



Note.—The numbers on the Map indicate depths in fathoms.

One bed was described as consisting entirely of the tests of *Orbitoides* and *Nummulina*, while other beds were described as unfossiliferous. But in 1872 I was able to announce that what up to that time had been considered to be oolitic grains in certain of the "unfossiliferous" Naparima Beds were really minute organisms, chiefly foraminifera.[1]

In the following year I gave a further account of the West Indian Tertiary fossils,[2] with lists of all the species of invertebrates (corals excepted) known up to that date from those rocks. Further information on the palæontology will be found in Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 516; W. M. Gabb, Trans. Am. Phil. Soc. vol. xv. p. 49; and Proc. Acad. Nat. Sci. Philad. 1872, p. 270.

Sufficient evidence had meanwhile accumulated to show that, while the Caroni Series of Trinidad might be correlated with the Miocene formation of Haiti, Jamaica, and Cumana, the fossiliferous deposits of Naparima and Manzanilla were of older date, probably Eocene. In this connexion I would refer the reader to the rough diagram of the succession in Trinidad which I published in Proc. Sci. Assoc. (of that island) for December, 1877.

But I had had since 1874 no opportunities of going again over the ground in the Naparima district, until at the end of 1890 and in the beginning of 1891 I undertook a re-examination of the beds, the results of which are summed up in the following pages. It should be premised, however, that the work of exploration is extremely arduous, and the difficulties of every kind which confront the observer are such as to preclude a thoroughly exhaustive investigation.

§ 2. The Stratigraphy of the Naparima Beds.

The diagram on p. 522 is the result of an examination of the coast-line from near the northern limit of the known Tertiary rocks of Naparima to the Oropuch Lagoon, the southern limit of the Microzoic Beds. The series of beds marked 1 and 2 appear to belong to the "Nariva Series" of the Geological Report, supposed to be inferior in position to the Naparima Marls of that Report. I am doubtful on this point, not having met with any evidence of superposition. The rocks themselves, as exposed on the shore and in railway-cuttings, consist chiefly of impure ferruginous and gypseous marls of various colours, containing in places thin veins of sandstone with particles of mica. Large blocks of crystalline gypsum occur abundantly in some parts of this formation. The less impure beds contain *Globigerina* and other foraminifera, but not very abundantly. These rocks present, in my opinion, a very close resemblance to the deposits derived from the denudation of the Naparima (Foraminiferal) Marls now being laid down in the Gulf of Paria, between San Fernando and Oropuch. Some seams of a substance resembling coal have been found in this formation; but no such

[1] See Geol. Mag. for 1873, p. 362.
[2] *Ibid.* for 1874, pp. 404, 433.

thing is known in those deposits that we regard as Eocene. Lignite and other varieties of carbonaceous matter are abundant in the recognized Miocene rocks of Trinidad, and the asphalt (though found infiltrated into the Eocene deposits) is probably of Pliocene date. I should not be surprised, then, if this Nariva Series proved to be of Miocene age, and therefore younger than the Eocene Naparima Marls. I think it probable that it was merely the position of these beds between the Cretaceous rocks of the Pointapier district and the Tertiary marls of Naparima that induced the Geological Surveyors to assign to them an age earlier than that of the Naparima Marls.[1]

I find that in 1877 I arrived, as regards the age of these beds, at the same conclusion as that expressed above, and stated it in a paper read before the Scientific Association of Trinidad 'On the Discovery of Tertiary Coal at Williamsville, Savana Grande,' printed in the Proceedings of that Association, part xi. p. 110. I think, therefore, that (unless evidence to the contrary is forthcoming) this Nariva Series is not inferior to the Eocene marls of Naparima, but superior to them, being Miocene in date and partly the equivalent, on the southern side, of the Secondary rocks of the Caroni Series on the northern.

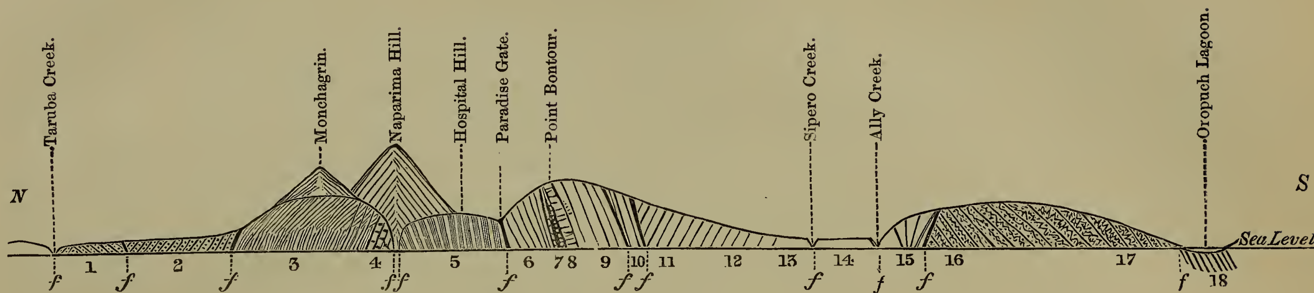
No. 3 is a series of red, black, and variegated marls, seemingly much dislocated. These pass into No. 4, beds which are very similar but contain bands, strings, and masses of limestone, not now visible, for they have been hidden by the building of the railway-station and works. These limestone veins, &c., contain fossil mollusca similar to those in No. 7. I have hitherto been unable to describe or identify these fossils on account of the impossibility of developing them or extracting them from the rock; but I believe them to be for the most part of undescribed and extinct species. These beds I am inclined to think are a repetition of those on the southern side of San Fernando, namely at Bontour Point.

The foregoing portion of the section is on the northern side of the wharf at San Fernando. The following portion is on the southern side.

No. 5 is a series of grey marls passing under the Hospital Hill. These marls contain *Globigerina* and other foraminifera, and are occasionally interbedded with darker shaly layers. Their strike is approximately W.N.W.; like all the beds exposed in this section, they are inclined at a high angle, often approaching the vertical. To the north they are terminated by the great fault or series of faults surrounding the Naparima Hill, and to the south by another

[1] The Eocene series of Manzanilla, whose fauna has little in common with that of the Naparima Marls, was deposited on the northern side of the ridge of Secondary strata crossing the middle of the island, and probably in shallow water, since the fauna so far as known would suit a depth of less than 50 fathoms. On the other hand, the Naparima Marls were thrown down on the southern side of the Secondary ridge, in water gradually deepening from the beginning of the Eocene period to the close, perhaps, of the Miocene period.

Fig. 1.—*Sketch-section from Taruba Creek to the Oropuch Lagoon.*



Height much exaggerated. Length about five miles.

f = Faults.
1, 2. Impure ferruginous and gypseous marls of various colours, containing in places thin veins of sandstone with particles of mica.
3. Red to black marls and shales; bedding confused.
4. (Railway Station). Rocks similar to No. 3, but containing bands, strings, and masses of limestone, with remains of mollusca, etc.
5. Grey marls (*Globigerina*) with dark shaly layers.
6. Alternating pale greenish-grey and blackish beds (*Globigerina*, etc.).
7. Hard beds, containing fossil mollusca, echinoderms, *Spirorbis*, *Nummulina*, *Tinoporus*, etc.
8. *Orbitoides*-beds and *Amphistegina*-beds.
9. *Nucula*-beds, passing upwards into *Globigerina* marls similar to No. 6.
10, 11, 12. *Globigerina* marls. At 13 and 14 the strata are hidden by swamps, etc.
15. Shell-bed, containing large foraminifera and mollusca.
16, 17. *Globigerina*-marls of less uniform composition than Nos. 6, 9, 10, and 11.
18. Polycystinous and diatomaceous beds of South Naparima, thrown down below the Oropuch Lagoon.

*** Nos. 6 to 9 represent the beds shown in the writer's diagram, Quart. Journ. Geol. Soc. vol. xxii. (1866) p. 571.

fault bringing up (as I believe) the lowest beds of the Naparima Series, Nos. 6, 7, and 8. Some of these appear to have been deposited in shallow water, and contain compact dark-coloured limestone in irregular masses. Such rocks occur at the railway-station as well as at Bontour Point, as already observed. Though they are full of fossils, I have not found it possible to obtain any in a condition for specific identification. The generic position of some can be made out, and it is not unlikely that one or more may be identical with Manzanilla fossils. The more resisting nature of these harder beds has given rise to the protruding bluff of Bontour Point, and their extension westward into the Gulf is marked by rocks standing out of water to a height of several feet. The most prominent of these is a small islet called Farallon, composed of a fossiliferous limestone, the chief contents of which are *Amphistegina*, *Nummulina*, *Spirorbis* (*Rotularia*) *clymenioides*, and Nullipores. At the time I first knew it (1859) this islet was a pinnacle nearly sixty feet high, but it was cut down to less than half by a gentleman who intended to build a house on it, a purpose frustrated by his death. In this series (No. 7) and perhaps inferior to the *Amphistegina*-rock comes the *Orbitoides* (asphaltic)-bed which was figured in the 'Geological Report,' and described by me in 1863 and 1866. Since then I have met with some interesting specimens showing the probability that the asphaltic matter with which this bed and the neighbouring ones are impregnated was introduced after their deposition and consolidation. These specimens consist of indurated portions of the *Orbitoides*-bed, composed almost entirely of *Orbitoides*, *Nummulina*, and *Tinoporus*, identical in fact with the other and more friable portions of the bed, but without any contained asphalt. These are indeed portions of the *Orbitoides*-bed in which induration has preceded and excluded the asphalt.

This series of beds (Nos. 6, 7, and 8 of the section) has supplied several fairly preserved fossils, of which I gave a list in this Journal, vol. xxii. (1866) p. 572. Of these *Echinolampas ovumserpentis*, *Ranina porifera*, and *Terebratula carneoides* have recurred in the Eocene limestone of St. Barts, one of the north-eastern West India Islands,[1] while a specimen of *Rotularia* (*Spirorbis*) *clymenioides* has been given to me as coming from the argiline of Naparima Hill, and another as having been found in the Pointapier cutting, both Cretaceous according to the Geological Survey. I have already noted that the *Rotularia* is abundant in the *Amphistegina*-rock. These lower shallow-water beds of the Naparima Series are probably brought up here by the fault shown in the section under the heading 'Paradise Gate,' and they may be, as I have already observed, a continuation of the somewhat similar beds near the railway-station, the rocks under Hospital Hill being *Globigerina*-marls like those between Bontour Point and Sipero Creek. I may note that none of the limestone-beds retain their characters for any great distance.

[1] Duncan, Quart. Journ. Geol. Soc. vol. xxix. (1873) p. 548. See also Davidson, Geol. Mag. for 1874, p. 158.

Next to the *Orbitoides* and *Amphistegina*-rocks come the deeper water beds in which I found *Nucula Schomburgki*, *Leda Packeri*, and *Stomatia eidolon*. The *Nucula* and the *Leda* were originally described by Forbes in Schomburgk's 'History of Barbados,' from specimens found in Barbados. The *Nucula* is very nearly allied to *N. bivirgata* Sow., of the Gault, and also to *N. Cobboldiæ* Sow., of the Crag, but it is nearer to the former than to the latter.[1] The *Nucula*-beds are made up of a fine-grained grey rock with a greenish tinge and a conchoidal fracture. They are more coherent and tougher than the *Globigerina*-beds generally, and in external appearance resemble some of the radiolarian marls (especially No. 2). The tail of a fish was found in a nodule in these beds. Foraminifera (*Globigerina*, *Nodosaria*, &c.) occur plentifully. It is here chiefly that *Trochammina coronata*, *T. conglobata*, and *Spiroloculina* abound; these are generally rare in, or altogether absent from, most of the other beds.

This portion of the section (from Nos. 6 to 9 inclusive) was given in greater detail and upon a different scale in my 1866 paper in this Journal. The strike is somewhat south of west and the beds are nearly vertical.

Next following are the beds 10, 11, 12, 13, in which the dip is reversed, changing from S.W. to N.E. The organic contents are deep-sea foraminifera, *Globigerina*-forms largely predominating, with a few ostracoda, some small fishes' teeth and otolites, and echinoderm spines. At the southern end of these and near Sipero Creek are quantities of boulders of a hard material. These appear to have been included in the 'Geological Report' under the term "indurated sandstone." A microscopic examination of these boulders reveals a structure similar to the argiline of Naparima Hill. They are also of a similar but variable and much darker colour. I have not found any such rock in place. Probably it exists in nodular and lenticular masses in the softer strata, whose decay and denudation leave the hard portions to accumulate on the beach.

From the mouth of Sipero Creek to Ally Creek the strata are not exposed, being covered by swamp and mud-flats. Two or more faults occur here. At No. 15 there is a shell-bed containing *Nummulina*, *Cristellaria*, *Nodosaria* (*raphanistrum*), and a few other foraminifera, some mollusca, and also fishes' teeth and otolites. This shell-bed is a reddish-brown ferruginous rock with large green grains. The latter often predominate, so that the rock shows green when broken across the planes of deposition, the reddish-brown colour being apparent only when the fracture is coincident with those planes. As the land where this stratum is exposed has slipped very considerably I could not ascertain the true dip or strike, or the relations to the other beds. I am inclined to think, however, that this bed together with the next strata (16, 17) are possibly an extension of Nos. 6, 7, 8, 9, and 10 brought up by the Sipero and Ally Creek faults. Foraminifera-beds now come in again, Nos. 16

[1] See Proc. Scient. Assoc. Trinidad, 1881, p. 170.

and 17 (*Globigerina*, &c.), and then the section is terminated on the south and west by the swamps and mud-flats of the Oropuch Lagoon, beneath which lies the extension of the radiolarian marls of South Naparima.

Mr. Louis de Verteuil, the manager of Mr. Lamont's sugar plantations in South Naparima, very kindly gave me his assistance in examining the rocks of that district. He accompanied me to the several excavations and cuttings made in the marls for railway and agricultural purposes. From these in several instances I obtained evidence of the dip and strike of the rocks; and I believe there is little doubt that the radiolarian beds are thrown down below the Oropuch Lagoon and thus do not appear in the coast-section. No clear case of the junction of these beds with the foraminiferal beds has been observed, and I think, for reasons I will now state, that it is unlikely—save under exceptional conditions—that any such case will be found.

The faults marked in the diagram (p. 522) are inserted, generally speaking, from inference only. The nature and constitution of the Naparima rocks (as will be described in the course of this paper) are such that wherever a fault occurs the adjacent rock is shattered and broken up and thus easily disintegrated and removed. A ravine or valley is almost always the result. The rivers or creeks called Taruba, Sipero, and Ally are each probably caused by two or three contiguous faults. Wherever these or similar ravines come out on the coast-line they are worn down by denudation below high-water level and thus pass into the state of tidal swamps. Consequently no section is visible.

§ 3. Physical and other Characters of some of the Naparima Microzoic Rocks.

The following analyses of the argiline of Naparima Hill and of the white (radiolarian) marl of South Naparima are given at page 132 of the Geological Report on Trinidad:—

		Argiline.		*White Marl.*
Hygroscopic Water		2·00		1·80
Combined Water and Organic Matter		4·50		7·50
Soluble in Acid.				
Silica	0·39		0·62	
Oxide of Iron, &c.	8·80	14·16	2·30	22·77
Carbonate of Lime	3·75		18·65	
Carbonate of Magnesia	1·22		1·20	
Insoluble.				
Silica	68·00		57·91	
Alumina, &c.	8·54	77·86	4·28	68·16
Lime	1·32		0·72	
Magnesia		1·15	5·25	
Loss		·13		
		99·80		100,23

The proportion of lime in the argiline is greater than is here shown. The report states that the portion selected for analysis was free from calcspar. But this mineral exists in minute veins traversing the rock, and is derived from the solution and redeposition of the calcareous matter of contained organisms. The above analyses show much resemblance in the composition of the two rocks.

Now, as to the argiline,[1] considerable variation exists in different specimens of it, but the following characters apply generally:—It is extremely fine-grained and readily abrades the teeth of a file. While chiefly a siliceous rock, it contains a notable quantity of lime and a certain proportion of alumina. The calcareous matter is either disseminated through the rock (probably its original condition) or it exists in the form of minute veins of calcite as above mentioned. The rock has a lamination resembling cleavage, but this is crossed again by joints approximately at right angles to the planes of lamination and to each other, so that it breaks up into irregular prismoidal masses, varying much in size in different beds, but ranging generally from 1 inch in length by $\frac{1}{2}$ inch in breadth and thickness to three or four times those dimensions. The fragments are often nearly white or of a pale buff externally, but on being fractured they are found to be of a deeper colour internally. The paler external colour is due to the dissolution of the iron by water. Water percolating through the joints slightly softens the surface of each prismoidal piece and removes some of its constituents, but penetrates only to a very slight distance. Nevertheless, a gradual disintegration takes place in the outer and more exposed portions of the rock. The lime and iron are carried off in solution, and partly re-deposited in the joints as fine veins of calcite and black films and dendritic markings of iron. The prismoidal pieces into which the rock separates are hard and tough and require a smart blow of the hammer to break them. The material is largely used for road and railway metal. For the first-named purpose it is not so good as some varieties of limestone; for it rapidly crumbles into dust under the ordinary road traffic. But for railway purposes it is probably unsurpassable.

The origin and nature of this argiline are somewhat problematical. No distinct traces of organisms are visible in it. Washing reveals no foraminifera or other fossils. Unlike the South Naparima marl no radiolaria or diatoms are developed by treatment with acid or otherwise. Thin slices, however, show the existence of minute cavities which are the casts of fossils the original matter of whose

[1] In the Geological Report on Trinidad (p. 33) the name 'argiline' was applied to the rock of Naparima Hill and other localities. The definition given was as follows:—"Strata composed of an argillaceous base, with small equivalents of carbonate of lime and free silica." This account by itself alone is scarcely satisfactory. The additional particulars now furnished will aid in giving an idea of the nature of the rock. One use of the material will no doubt be for polishing purposes.

shells has been altered or removed. The exact nature of the bodies which have thus disappeared is not clear; but it may be inferred that they were foraminifera, radiolaria, and other small organisms. I have noticed one more definite fossil, apparently the spine of an *Ophiura*.

It seems then that we have here a deep-water deposit very similar in its origin to the radiolarian beds of Naparima and elsewhere. But what are its relations to the Naparima Marls? Though no existing sections show those relations, it is probable that it is of more ancient date. It is true that direct evidence of superposition is wanting, but there can be little doubt on this point. Naparima Hill is higher than any other ground within several miles, rising as it does to 500 feet above sea-level, while the general surface of the country is under 200 feet.[1] Is this superior height due chiefly to the elevation of the beds forming the hill by subterranean forces, or entirely to the degradation of the more decomposable Naparima marls? Viewed from the Gulf the hill seems to rise out of a crater-like depression. This appearance is caused by the large ravine which separates it from the neighbouring but lower hill of Monchagrin. This large ravine has its origin in two great faults, which run approximately N.E. and S.E. respectively and meet near the mouth of the ravine somewhat inland from the position occupied by the wharf at San Fernando. The hill itself is certainly an anticline, as shown in the diagram-section (p. 522); for on the northern

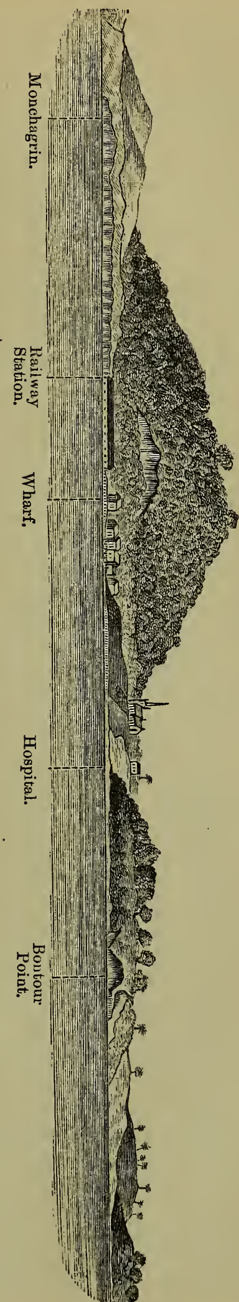


Fig. 2.—View of Naparima Hill and San Fernando, from the Gulf.

[1] The height of Naparima Hill is stated in old documents at 670 feet. The Geological Survey put it at 590 feet. I have failed to make it exceed 500 feet. On this point see the remark of Orton (quoted in Ann. & Mag. Nat. Hist. 4 ser. vol. xvi. p. 361) that every successive measurement of the Andes gives a reduced elevation.

side the strata dip to the north, while on the southern side they dip to the south; the strike being about E.N.E. and W.S.W., coinciding with the longest diameter of the hill.

The foraminiferal rocks of Naparima consist of marls containing 80 to 90 per cent. of calcareous matter. Some of the beds contain gypsum, but not to the extent or in the large-sized masses occurring in the Nariva (Miocene) Series. When subjected to washing, about one-half of the material passes off as fine mud containing minute foraminifera (*Globigerina*, *Textularia*, &c.) such as those found in the white Chalk of England, also *Calcaromma* and coccoliths. Of the remainder, one-half consists of indeterminable and amorphous particles, bits of pumice, iron pyrites, &c. There are a number of rod-like forms of a black colour and more or less glistening or metallic subgranular texture. These may possibly be *Lituolidæ* or similar foraminifera and perhaps echinoderm spines and pteropod shells impregnated with a compound of iron. The remaining half ($=\frac{1}{4}$ of the original material) is chiefly made up of shells of *Globigerina*, from among which the other foraminifera may be picked. This is a true solidified *Globigerina*-ooze, corresponding in essential features with that now found in the abysmal depths of the ocean.

Under treatment with acid a specimen of this rock lost about 90 per cent. The residue was of a brown colour and showed little else but amorphous particles. Here and there traces of fossils were visible, probably fragments of radiolaria and sponge-spicules. In other samples I have demonstrated clearly the presence of radiolaria and other siliceous organisms.

The "infusorial" character of the marls of South Naparima was referred to at pages 86 and 116 of the Geological Report on Trinidad. There is as much variation in the physical properties and composition and in the organic contents of different samples of these marls as in those of the foraminiferal beds. Nevertheless, many characters are common to all of them. They differ from the foraminiferal marls in the large proportion of silica that they contain. This silica is due to the presence of so-called infusorial fossils, the remains of radiolaria and diatomaceæ. The diatomaceæ were described by Greville in the fifth volume of the Journal of the Microscopical Society. The polycystinæ are similar to those of the Barbados rocks described by Ehrenberg in the 'Mikrogeologie' and elsewhere.

For purposes of a brief description I will select two samples of the radiolarian marls. Of sample No. 1 from 30 to 40 per cent. is removed by treatment with acid. The portion thus removed is chiefly made up of foraminifera, the remainder consisting of radiolaria, &c., and of iridescent scales and lumps of a whitish substance. The simple washing and drying of a sample of this rock, without the use of reagents, furnishes a material strongly resembling steatite (French chalk). It might indeed be applied to the same purposes as the latter is. This material consists of small scales and lumps of a pearly grey colour and iridescent surface, and these form about one-half of the rock, the remainder being fine siliceous particles (radiolaria, &c.) and foraminifera. The latter are present in noticeable quantity, though they do not form so large a proportion of the rock as they do in the foraminiferal beds.

Sample No. 2 is a much harder, tougher, and more coherent rock than the foregoing. Its tinge is slightly more of a greenish-grey and it is less chalky in appearance. Its fracture is more decidedly conchoidal. Radiolaria and diatomaceæ abound in this rock, but foraminifera are not so evident, partly no doubt from its state of aggregation. Coccoliths occur plentifully, and so do the minute stars of *Calcaromma calcarea.* This rock loses one-half its weight by treatment with acid.[1]

To the account just given of the composition of the microzoic rocks of Naparima, I may add a brief description of some of their physical properties. The soil derived from their decomposition is exceedingly rich and easily worked. As some drawback to this they present difficulties to the road-maker and to the engineer whose business is water-supply.

[Part of the following is taken from a paper of mine, 'On the Water-bearing capacities of some of the Rock-formations of Trinidad,' published in the Trinidad Agricultural Record for 1891.] When a piece of the foraminiferal rock is placed in water it absorbs it rapidly and soon falls asunder. This substance is capable of union with a large quantity of water, and the water which enters into union with it is given up only to evaporation. Hence springs or streams are never found in these rocks. That portion of the rain which does not penetrate the soil flows off at once as flood water, and that part which does penetrate is only removable by the sun's heat. From these properties it follows that the natural soil-roads passing over these rocks become in the wet season the worst quagmires it is possible to imagine.

Another property of these rocks is attributable to the same facts of physical constitution. During the wet season they become saturated with moisture. This effect is greatest at the surface and diminishes downwards. An increase of bulk is the result of the absorption of so much water. In the dry season the heat of the sun carries off a considerable part of the water. Hence the soil contracts, producing numerous and extensive cracks. These cracks are often several inches wide and run for long distances. It is somewhat difficult to ascertain their depth, but in some cases at least it is 20 feet or more at the end of a long and severe dry season. These cracks get partly filled with fragments broken and detached from the sides. Then, when the wet season comes on again, the rainwater flows freely into the cracks, washing down the débris of the surface and uniting with the loosened and fallen fragments and with the sides of the cavities. The saturated materials now expand and act as wedges, riving and breaking up the rock to a depth of 20 feet more or less according to circumstances. The repetition of this action year after year causes such

[1] For complete analyses of these Trinidad rocks, the reader should consult the valuable paper published by Messrs. Jukes-Browne and Harrison in the May number of the present volume of this Journal, p. 219.

an entire disintegration of the rock that its original texture can nowhere be seen except in deep cuttings. All traces of fossils are obliterated.

The radiolarian marls differ from the foraminiferal marls in some respects. Some of them are equally incoherent when exposed to water and have an equal power of absorption. But the mud they produce is not quite so tenacious; this is due to the presence of silica in fine division. Other varieties are more coherent and have a larger proportion of radiolaria and a smaller proportion of amorphous silica (or silicate of magnesia). But from the point of view from which we are now looking at them, all these marls, whether derived from the radiolarian or from the foraminiferal deposits, act much in the same manner.

The marls of the Nariva Series furnish a less fertile soil. But as regards adaptability for road-making they are little, if any, better than the marls of the Naparima Series.

I think it highly probable that in some of the marls we have a material suitable for the manufacture of cement, though which of them will prove best adapted for the purpose is matter for experiment. Possibly those of the Nariva Series, such as are found in the neighbourhood of Vistabella and Ne-plus-ultra, may be found to possess good qualities. On the other hand some of those on Paradise and Les Efforts may be better in some respects.

By way of parenthesis I may refer here to a question that has more than once been put to me, that is, as to the nature and origin of the shells found scattered over the surface of the soil in Naparima and other parts of Trinidad. These are generally recent shells and have no connexion with the formations on which they are found. Mollusca taken on or near the shore have been carried up the country for food and the shells have been thrown about. In a few cases fossil shells are found on the surface, but this occurs only where there is some exposure of a shell-bearing stratum. And this is not very common in Trinidad, especially in the Naparima district.

§ 4. The Pointapier Section.

Our section of the Naparima deposits ends northward at Taruba Creek. Little can be made of the stratigraphy of the next two miles until we come to the coast-section at Pointapier. A diagram of this was given in the Geological Report on Trinidad (sheet No. 2, fig. 2). The details were very imperfectly rendered, and it was scarcely possible that it should be otherwise. Since the time of the Geological Survey a railway-cutting has been made a short distance inland from this shore-section. But even with the aid of this, little additional light can be thrown upon the age and relations of the rocks named by the Geological Survey 'Older Parian' and considered to be of Lower Cretaceous (Neocomian) age.

What further information I have gleaned shall be briefly stated here. For, although the object of this paper is more particularly the microzoic marls of Naparima, I believe, from palæontological and stratigraphical considerations, that there was no real break in the series of deposits from the Cretaceous to the Eocene in the Parian area. Oscillations of level there probably were, and movements of the earth's crust appear to have been frequent; but sea prevailed in this region throughout the period and the fauna of the Cretaceous is perhaps more intimately linked with the Eocene than that of the latter is with the Miocene.

In 1863 I contributed to the 'Geologist' (pp. 204 and 363) a notice of some fossils that I had found at Pointapier. These included a belemnite, a *Trigonia*, and some other mollusca considered to be identical with species found in Lower Cretaceous rocks in South America. I have lately been led to suspect that these fossils came from a bed of shaly conglomerate in which the shaly material is the matrix, while the fossils and pebbles are derived from a pre-existing rock.

On my last visit to this locality I found exposed a bed I had never seen before. It is a very fine-grained material containing small shells, of which the most abundant is a *Ditrupa*. There are some pteropods and other mollusca. In the presence of water this rock is the most incoherent of any I have ever met with. It falls into powder at the mere contact of water, and for the most part the fossils disintegrate likewise, so that there is a difficulty in getting anything like perfect specimens. Careful washing brings to light a considerable number of extremely minute foraminifera.

A few foraminifera may be obtained of ordinary size, but large specimens generally go to pieces. There then remain the far more numerous minute forms, together with spicules of *Tethya*, *Halichondria*, *Gorgonia*, &c., and amorphous particles. The most abundant foraminifera in this rock (after *Globigerina*) are *Bolivinæ* of many varieties and some *Miliolinæ*. *Bolivinæ* are rather rare comparatively in the Naparima foraminiferal marls, and *Miliolinæ* are not common in them. In the next portion of this paper I give lists of the foraminifera from the Pointapier microzoic rock and from the radiolarian marls. A thorough exploration of these rocks will yield many more forms. Of the few I have isolated some have been left unnamed, including a *Pulvinulina* (*P. canariensis* possibly), a *Truncatulina*, and a *Rotalia*. So far as revealed, the foraminiferal fauna of the *Ditrupa*-bed resembles that of the radiolarian marls of South Naparima in the characteristic *Globigerinæ*, in the small size of the generality of the species, and in the abundance of minute *Bolivinæ*. On the other hand calcareous (*Gorgonia*) spicules are rare or wanting in the radiolarian marls, and I have not detected *Miliolinæ* in them. And, moreover, the last mentioned rocks are distinguished by the abundance of radiolaria in them and by the occurrence in large quantity of silicate of magnesia.

§ 5. The Foraminiferal Fauna.

In determining the foraminifera Mr. C. Davies Sherborn, F.G.S., was good enough to offer me his assistance, and he began the examination of my specimens. But unfortunately his sight became affected, and I was thus thrown back upon my own resources. But I have since had the help of Mr. Joseph Wright, F.G.S., of Belfast, and, thanks to his aid in the correction of names and the identification of forms, I trust that errors are not numerous in the lists which follow. Although Mr. Wright assisted me in the naming of the foraminifera, I am solely responsible for the lists.

Notes and observations are appended to the lists. The relative frequency of occurrence of the different forms is expressed by the appended letters as follows:—

I	signifies that from	1 to 5	specimens	have been	obtained.
V	„ „ „	5 to 10	„	„	„
X	„ „ „	10 to 50	„	„	„
L	„ „ „	50 to 100	„	„	„
C	„ „	100 or more	„	„	„
D	„ „	many	„	„	„
M	„ „	very many	„	„	„

These indications must be taken as applicable only to the whole series of beds comprised under each division of the list, especially as regards the *Globigerina*-beds. Certain species are only found in particular beds. *Bigenerina*, *Glandulina*, and *Polymorphina* are wanting in several beds. *Miliolina* may be said to be abundant in one bed only, while in another scarcely anything but *Globigerina* is to be found.

A. Foraminifera from the Orbitoides and Amphistegina-beds.

(Nos. 7 & 8 of Section.)

Nonionina depressula, W. & J. I
Nummulina Ramondi, Defr. ... M
Orbitoides Mantelli, Mort. ...... M
—— *dispansa.*
—— *papyracea.*
—— *media.*
—— *Forbesi.*
} =Varieties of *Mantelli.*

Discorbina Bertheloti, Orb. I
Tinoporus asteriscus, Guppy ... M
—— *globulus*, Reuss I
Amphistegina Lessoni, Orb. ...... M
Nodosaria raphanistrum, Linn. . V
Ammodiscus incertus, Orb. I

B. Foraminifera from the Shell-bed, Ally Creek.

(No. 15 of Section.)

Nodosaria raphanistrum, Linn. . X
Cristellaria cultrata, Mont. X
—— *papillosa*, F. & M. X
Planorbulina larvata, P. & J. ... I

Heterostegina depressa, Orb. X
Nummulina radiata, Orb. L
Miliolina trigonula, Lam. V
Spiroloculina alata, Terq. I

C. Foraminifera from the Globigerina-beds.

(Nos. 9 to 17 of Section.)

Rotalia Soldanii, Orb.	M
—— *orbicularis*, Orb.	D
—— *Broeckiana*, Karr.	C
Nonionina exponens, Brady	I
—— *pompilioides*, F. & M.	I
Pulvinulina favus, Brady	X
—— *pauperata*, P. & J.	D
Truncatulina Haidingeri, Orb.	D
—— *culter*, P. & J.	D
—— *tenuimargo*, Brady	C
—— *tenera*, Brady	L
—— *Akneriana*, Orb.	X
Anomalina Wullerstorfi, Schw.	M
—— *grosserugosa*, Gumb.	D
Pullenia sphæroides, Orb.	L
Sphæroidina bulloides, Orb.	L
Globigerina bulloides, Orb.	M
—— *digitata*, Brady	X
—— *pachyderma*, Ehr.	M
—— *conglobata*, Brady	M
—— *Dutertrei*, Orb.	M
Orbulina universa, Orb.	D
Sagrina striata, Schw.	I
—— *virgula*, Brady	I
Uvigerina pygmæa, Orb.	L
—— *tenuistriata*, Reuss	X
—— *asperula*, Czjz.	L
—— *canariensis*, Orb.	V
—— *brunnensis*, Karr.	V
Polymorphina lactea, W. & J.	L
—— *gibba*, Orb.	V
—— *gutta*, Orb.	X
—— *rotundata*, Born	X
—— *lanceolata*, Reuss	I
—— *elegantissima*, P. & J.	V
—— *horrida*, Reuss	I
—— *Orbignyi*, Zbor.	I
Cristellaria cultrata, Mont.	L
—— *orbicularis*, Orb.	I
—— *rotulata*, Lam.	V
—— *cassis*, F. & M.	I
—— *nitida*, Orb.	I
—— *gibba*, Orb.	V
—— *reniformis*, Orb.	I
—— *crepidula*, F. & M.	V
—— *compressa*, Orb.	X
—— *obtusata*, Reuss	X
—— *italica*, Defr.	V
Vaginulina legumen, Linn.	V
Marginulina glabra, Orb.	I
—— *costata*, Batsch	I
Glandulina rotundata, Reuss	V
—— *obtusissima*, Reuss	V
—— *æqualis*, Reuss	V
—— *lævigata*, Orb.	X
Nodosaria raphanistrum, Linn.	V
—— *bacillum*, Defr.	X
—— *raphanus*, Linn.	X
Nodosaria obliquata, Batsch	V
—— *abyssorum*, Brady	X
—— *costulata*, Reuss	V
—— *vertebralis*, Batsch	V
—— *catenulata*, Brady	V
—— *rudis*, Orb.	L
—— *pyrula*, Orb.	V
—— *hispida*, Orb.	L
—— *nitida*, Orb.	V
—— *radicula*, Linn.	L
—— *ovicula*, Orb.	X
—— *calomorpha*, Reuss	X
—— *glabra*, Orb.	X
—— *semistriata*, Orb.	X
—— *rugosa*, Orb.	V
—— *simplex*, Silvestri	V
—— *scalaris*, Batsch	X
—— *consobrina*, Orb.	C
—— *pauperata*, Orb.	X
—— *obliqua*, Linn.	X
—— *filiformis*, Orb.	X
—— *communis*, Orb.	X
—— *Roemeri*, Neug.	X
—— *mucronata*, Neug.	X
—— *longiscata*, Orb.	X
Lagena elongata, Ehr.	I
—— *gracillima*, Seg.	I
—— *apiculata*, Reuss	X
—— *distoma*, P. & J.	I
—— *lævis*, Mont.	I
—— *squamosomarginata*, P. & J.	X
—— *marginata*, W. & B.	X
—— *aspera*, Reuss	I
—— *hispida*, Reuss	X
—— *sulcata*, W. & J.	I
Frondicularia pupa, Orb.	V
—— *interrupta*, Karr.	V
—— *inæqualis*, Costa	X
Cassidulina lævigata, Orb.	I
—— *subglobosa*, Brady	C
Bolivina pusilla, Schwager	V
Chilostomella ovoidea, Reuss	I
Pleurostomella brevis, Schw.	X
—— *rapa*, Gumb.	V
—— *alternans*, Schw.	X
Bulimina elegans, Orb.	V
—— *affinis*, Orb.	V
—— *pupoides*, Orb.	V
—— *Buchiana*, Orb.	I
Gaudryina pupoides, Orb.	X
Textularia agglutinans, Orb.	X
—— *porrecta*, Brady	V
—— *trochus*, Orb.	V
—— *Barreti*, P. & J.	V
Spiroplecta americana, Ehr.	V
—— *annectens*, P. & J.	I
Pavonina flabelliformis, Orb.	I
Bigenerina capreolus, Orb.	D

C. Foraminifera from the Globigerina-beds (*continued*).

Bigenerina pennatula, Batsch ...	C
Tritaxia tricarinata, Reuss	I
Verneuilina pygmæa, Egg.	X
—— *propinqua*, Brady	X
Clavulina communis, Orb.	X
—— *parisiensis*, Orb.	X
—— *clavulus*, *Lam.*	V
Reophax pilulifera, Brady	X
—— *nodulosa*, Brady	V
Haplophragmium agglutinans, Orb.	V
—— *glomeratum*, Brady	V
—— *emaciatum*, Brady	X
Cyclammina cancellata, Brady...	L
—— *pusilla*, Brady	X
—— *orbicularis*, Brady	X
Ammodiscus incertus, Orb.	D
—— *tenuis*, Brady	C
Ammodiscus Shoneanus, Sidd....	X
Hormosina globulifera, Brady ...	X
Webbina clavata, J. & P.	X
Trochammina coronata, Brady .	X
—— *conglobata*, Brady	X
—— *lituiformis*, Brady	I
Planispirina celata, Costa	L
Spiroloculina tenuis, Czjz.	I
—— *limbata*, Orb.	V
Miliolina trigonula, Lam.	I
—— *pygmæa*, Reuss...............	X
Biloculina depressa, Orb.	X
—— *lævis*, Defr.	I

Calcaromma calcarea, Thomps.
Coccoliths,

D. Foraminifera from the Pointapier Ditrupa-bed.

Anomalina ammonoides, Reuss.
Truncatulina reticulata, Czjz.
Orbulina universa, Orb.
Globigerina bulloides, Orb.
—— *triloba*, Orb.
—— *quadrilobata*, Orb.
Lagena marginata, W. & B.
—— *gracillima*, Seg.
Nodosaria vertebralis, Batsch.
—— *obliqua*, Linn.
—— *pyrula*, Orb.
—— *raphanus*, Linn.
Cristellaria cultrata, Mont.
—— *echinata*, Orb.
—— *aculeata*, Orb.
Cristellaria calcar, Linn.
Bolivina alata, Seg.
—— *ænariensis*, Costa.
Uvigerina porrecta, Brady.
Spiroloculina excavata, Orb.
Miliolina oblonga, Mont.
—— *venusta*, Karr.
—— *bicornis*, W. & J.
—— *Auberiana*, Orb.
—— *seminulum*, Linn.
Verneuilina polystropha, Reuss.
Gaudryina, n. sp.

Calcaromma calcarea, Thomps.

E. Foraminifera from the Radiolarian Beds.
(No. 18 of Section.)

Anomalina Wullerstorfi, Schw.
Nodosaria hispida, Orb.
—— *globosa*, Orb.
—— *pyrula*, Orb.
—— *radicula*, Linn.
Polymorphina gutta, Orb.
Frondicularia pupa, Orb.
Bolivina robusta, Brady.
Gaudryina pupoides, Orb.
Globigerina bulloides, Orb.
—— *conglobata*, Brady.
—— *pachyderma*, Ehr.
Sphæroidina bulloides, Orb.

Calcaromma calcarea, Thomps.
Coccoliths.

Notes on the Lists of Species.

Tinoporus asteriscus.—Described by me in Quart. Journ. Geol. Soc. vol. xxii. (1866) p. 584, pl. xxvi. fig. 19, as *Cisseis asterisca*. I noted the resemblance to *Sparsispongia*; but is it certain that *Sparsispongia* is not a relation of *Tinoporus*?

Tinoporus asteriscus differs in several characters from *T. baculatus*, to which I referred it in a paper published in 1890. It is usually more flattened and more like a small *Goniaster* in shape. Both surfaces are alike. The number of rays is usually four or five, very rarely six, and there is no obvious external difference in structure between the rays and the centre of the disc. The internal structure as shown by sections is similar to that of other species of *Tinoporus*, but recalls that of *Orbitoides* also.

Nodosaria raphanistrum.—The specimens from the *Orbitoides*-bed and the Ally Creek shell-bed are well-grown, large, strong, and closely-ribbed. They are seldom procured entire owing to the nature of the matrix. The examples from the *Globigerina*-beds are rare and much smaller and weaker.

Orbulina.—I have opened several specimens and have in nearly all cases found them to contain the internal polythalamous skeleton.

Webbina.—The specimens of *Webbina clavata* are usually found adherent to *Ammodiscus incertus* and other foraminifera.

Spiroplecta americana.—The few examples of this species which have been found are black, except on the prominent parts which are white, as if the specimens had been plunged into ink and quickly withdrawn. This coloration is no doubt due to infiltration by iron.

Many of the foraminifera are tinged with colour. Some, no doubt, retain a trace of their original hue. Such, for example, as *Bigenerina*, which is usually brown, but sometimes (especially *B. capreolus*) grey.

Globigerina is usually of a brilliant white, and so are the *Nodosariæ*, both being rarely brown or black. Many of the arenaceous forms are often of some shade of brown. Black glistening specimens are occasionally seen.

The Pointapier species are for the most part minute, the *Globigerinæ* being almost the only forms of full size, and these are usually white, the other foraminifera being mostly tinged with a deep red colour or filled with matter of that hue. Some, however, are bright and polished and retain their original structure very perfectly. The minute *Bolivinæ*, which are numerous, appear to show a spiral commencement like *Spiroplecta*. When mounted in Canada balsam it is difficult to distinguish these from the minute *Textulariæ* of the Chalk or of the Naparima rocks.

§ 6. General Conclusions.

The Eocene molluscan faunas of Trinidad show no near alliances with any other known faunas. In this they differ from the well-known and easily recognized Miocene fauna found in Haiti, Jamaica, Cuba, Cumana, Trinidad (Caroni Series), and other localities. Nevertheless a few of the forms have been found elsewhere. The *Echinolampas ovumserpentis*, *Terebratula carneoides*, and *Ranina porifera* of the Naparima Beds recur in the Eocene of St. Bartholomew's (north-eastern West Indies), and I have already noted that the same beds have a *Nucula* and a *Leda* in common with Barbados. It is only with doubt that the name of *Natica phasianelloides*, a Miocene fossil of Cuba and Jamaica, can be assigned to the imperfect casts found near San Fernando in Trinidad. Of these casts some are fully 6 inches long. Some *Pinna*-like shells, also in the state of casts, found in these beds are still larger than this. *Erycina tensa*, a near ally of *E. obliqua*, Caillat, of the Paris Eocene, was described by me from the Manzanilla Beds in Trinidad. Gabb included the name in his list of the Miocene fossils of Haiti. When dealing with the fossils of that island I passed over this observation, but I have since seen reason to believe that Gabb's shell was not *Erycina tensa*, but the flatter valve of a species of *Corbula*. These corrections leave us with a single molluscan species (*Corbula vieta*) in common between the Eocene and the Miocene of the West Indies. The foraminifera of the shallow-water beds (*Orbitoides*, *Nummulina*, and *Amphistegina*) are found in Miocene as well as in Eocene formations, while the foraminifera of the deep-water beds are nearly all of existing species. Deep-water foraminifera are scarcely available as a guide to the age of the deposits in which they are found; but they are valuable indications of the depth of water in which those deposits were formed. Among the characteristics of the foraminiferal fauna of the Naparima marls are the following:—

1st. Absence or great rarity of shallow-water forms (except in the admittedly shallow-water beds, namely the *Orbitoides*-, *Amphistegina*-, and Shell-beds).

2nd. Absence or rarity of pelagic forms, such as *Pulvinulina Menardi* and *P. Micheliniana*. *Sphæroidina* and *Pullenia* are rare. In some beds *Orbulina* is rather abundant.

3rd. Abundance of certain deep-water forms, as *Pulvinulina pauperata*.

It appears from the evidence derived from the nature of the Naparima rocks, their fossil contents, and the movements which have affected them and the other formations of Trinidad, that during the Cretaceous and Eocene periods there was a sea having a considerable but variable depth of water, say up to 1000 fathoms and more, in the region now occupied by the microzoic rocks of Trinidad. It is probable that this sea extended on the north to the base of the northern range of hills, a distance of some 20 or 25 miles from the northern limit of the Naparima deposits. During the Cretaceo-Eocene period the northern mountains probably formed an unbroken chain with the littoral cordillera of Venezuela. This chain may be called the "Parian Range." According to abundantly clear evidence adduced by me in 1877, in a paper on the 'Physical Geography and Fossils of the Older Rocks of Trinidad',[1] the great chasms between Trinidad and Venezuela called the Bocas del Drago were produced by subsidence. Previous to this the Parian Range probably formed the southern boundary of the Caribbean continent, and was a barrier through which no large river found its way, and down the flanks of which only minor streams flowed, so that the clearness of the oceanic water at the distance of 20 miles or so from land was not seriously interfered with. The Parian Range may be

[1] Proc. Scient. Assoc. Trinidad, December 1877, p. 103.

regarded as one of those "stable areas" which have never been submerged since Palæozoic times. Volcanic action seems to have been limited to the northern side of it, for volcanic matter only appears in minute quantity in the Trinidad deposits. The area south of the Parian Range, including Trinidad and the Gulf of Paria, has never at any time been a volcanic area nor have any volcanic or plutonic rocks been discovered therein. Beyond the minute quantity of volcanic débris just referred to, the only substance attributable to a volcanic origin I have met with has been a pebble or two of a trap-like rock in one of the ancient river-beds of the island.

To the westward the Cretaceo-Eocene sea probably extended as far as the present low-lying alluvial plains of Venezuela. In this direction it was no doubt bounded by the high land now forming the Pico de Cumanacoa and the Cerro del Bergantin, ranges at present twice as high as any in Trinidad. Its southern extension went presumably near to the granitic and gneissic ranges and plateaux of Guiana. The Orinoco was at this time in existence, but although its waters flowed over and modified the tinge of the upper strata of the ocean, keeping out some of the pelagic forms of life, as is now the case to the north of Trinidad as far as Tobago and Grenada, yet they brought no appreciable sediment so far from what was then the mouth of the river. The main current must then have run more directly towards the east in the line of what is still the principal channel of the river, 100 miles or more south of Trinidad. The intermediate sea acted as a settling-pond, as the Gulf of Paria does now for those branches of the Orinoco which pour their turbid waters into it. Eastward the Cretaceo-Eocene sea was fully open to the Atlantic.

To what distance northward our supposed continent extended it is not easy to deduce from the facts now at hand, or what connexion it had with the existing islands. Along the northern coast of Venezuela there is a considerable belt of shallow water not exceeding a depth of about 50 fathoms. And this shallow sea is full of rocks, shoals, and islands. But beyond this the depth of water increases greatly, and hence the difficulty of accepting what, at first glance, appeared a likely conclusion, namely, that the Caribean Sea was formerly the site of a continent of which the former margins are in part indicated by the islands of the Antilles.

After the close of the Miocene period there was probably in the region south of the Parian Range a slow and gradual upheaval which brought the oceanic deposits above the level of the sea, during which process they suffered great denudation. The Gulf of Paria was then land, and Trinidad was united to the mainland. At that time the river Guarapiche probably flowed across Trinidad from Venezuela, while the Orinoco continued to pour its waters into the ocean at some distance southward. The disruption of the Parian Range and the formation of the Bocas and the Gulf of Paria probably followed; and these events may have been contemporaneous with the submergence of the Caribean land. There are palæontological reasons for believing that this submergence did not take place until a late geological epoch.[1]

The following provisional arrangement of the Cretaceo-Eocene deposits of Trinidad described in this paper may be suggested :—

Miocene	Radiolarian Beds.	Deep-water Deposits.
Eocene	*Globigerina* and *Nodosaria*-beds.	
	Nucula-beds.	
	Orbitoides and *Amphistegina*-beds.	Shallow-water Deposits.
	Spirorbis and *Echinolampas*-beds.	
	Mollusca-beds.	
Cretaceous	Argiline of Naparima Hill, &c.	Deep-water Deposits.
	Ditrupa-bed of Pointapier.	
	Shaly Conglomerate, &c.	Shallow-water Deposits.
	Limestone with Shells.	
	Trigonia and *Ostrea*-beds.	

Appendix.

The Microscopic Structure of some Trinidad Rocks.

By J. W. Gregory, Esq., B.Sc., F.G.S.

Some specimens of rocks from Trinidad were submitted to me by Mr. Guppy, who asked me for a few notes on their microscopic structure. He gave me no information as to the horizon or stratigraphical position of the specimens, as he wished merely to have a quite independent description of them.

The rocks belong to four different types :—(1) Radiolarian Marls, (2) a rock called by Mr. Guppy 'argiline,' (3) Foraminiferal Marls, and (4) a greensand shell-bed.

(1) *The Radiolarian Marl of South Naparima.*—This is a white, soft, chalky rock, closely resembling that of the lower beds at Castle Grant, Barbados, though it is whiter and the radiolaria are in better preservation than is the case with the last-named. The rock effervesces briskly with acid, and contains numerous foraminifera (chiefly small *Globigerinæ*). Nevertheless, radiolaria, sponge-spicules,

[1] Proc. Acad. Nat. Sci. Philad. 1868, p. 313. See Ann. & Mag. Nat. Hist. 4 ser. vol. viii. (1871) p. 305.

and fragments of these, form so large a proportion of the rock that it may be included among the siliceo-calcareous earths.

If a little of the dust of the rock be examined with the microscope under a $\frac{1}{5}$-inch objective, it is seen to consist mainly of fragments of radiolaria, sponge-spicules, and some indefinite argillaceous substance. The radiolaria are similar to those from Barbados. Podocyrtoid forms are numerous: well-preserved specimens are not uncommon. There are a few diatoms. Calcareous organisms are represented by numerous small foraminifera and peculiar stellate bodies similar to those from Barbados described and figured by Mr. W. Hill.[1]

The inorganic material forms but a small proportion of the rock; it is an amorphous argillaceous substance, often flaky. It varies in colour from a reddish or pale-yellow colour to clear and colourless; it is slowly bleached in strong hydrochloric acid. It agrees in general character with the "argillaceous matter" of modern deep-sea deposits described by Dr. J. Murray and Prof. Renard.[2] Grains of sand and other clastic material are absent.

Pumiceous Radiolarian Marl.—A second specimen from South Naparima agrees in general characters with that previously described; the matrix, however, contains a large proportion of pumice of the filamentous acid type.

(2) '*Argiline*'—a tough chocolate-coloured clay.—The specimens of this rock are all tough and indurated rather than hard, and they can easily be scratched with a knife. They do not effervesce with acid. The rock consists mainly of fragments of an amorphous argillaceous substance which varies in colour from brownish-red or light-yellow to colourless and transparent. Minute granules of peroxide of manganese are scattered throughout. The materials in the rock are stratified.

Fragments of radiolaria are not uncommon, but they are generally indeterminable.

Ordinary clastic material is absent, and the rock appears to be a true representative of one of the chocolate-coloured varieties of red clays.

In lithological character and the condition of the radiolaria this resembles an impure Ordovician chert, for a sample of which I am indebted to Prof. H. A. Nicholson. The rock is, however, not siliceous enough to be included among even the most impure cherts. The examination of microscopic sections suggests that the proportion of manganese in the rock is rather high, and it may be regarded as a kind of bole.

(3) *Foraminiferal Marls of Naparima.*—The finest material obtained from this by washing agrees with that of the radiolarian marls, but it is associated with coarser constituents. The radiolarian fragments are rare, but foraminifera are larger and more

[1] See this Journal, vol. xlviii. (1892) pp. 177–178; Mr. Guppy refers these stellate bodies to *Calcaromma calcarea*, Wyville Thomson (see 'The Atlantic,' vol. i. p. 233).

[2] 'Challenger' Report on Deep-sea Deposits, 1891, pp. 24–25.

numerous than in the South Naparima rock. The stellate bodies are also very abundant. The indefinite light-coloured argillaceous substance is present, and the fragments of this contain numerous small, opaque, black specks, which are doubtless peroxide of manganese. Sand grains are fairly abundant, and one slide contained a small angular crystal of brown hornblende.

(4) *Greensand Shell-bed*—Ally Creek, South Naparima. — The matrix of this rock is almost entirely composed of glauconite in the form of irregular grains and dust. These are mostly of the pale-green variety; the largest grains are dark green; the brown type is rarer. A few sand-grains and some argillaceous material are also present. The glauconite seem to show but little evidence of organic origin. A fragment, probably of a tubulated brachiopod shell, is infiltrated with brown glauconite.

This specimen appears to belong to the sub-littoral zone.

Microscopic examination suggests that the last-described rock is an ordinary sub-littoral greensand, and that the foraminiferal marls were formed in deeper water, but sufficiently near land to receive mechanical derived débris. The 'argiline,' which appears to be an indurated red clay, and the radiolarian marls have all the characters of deep-water and pelagic deposits.

[Mr. Guppy has since sent me a specimen of the '*Ditrupa*-rock,' and asked me to examine it. It consists mainly of indefinite argillaceous substance, and contains a few foraminifera and sponge-spicules. Coccoliths and fragments of radiolaria also occur. A feature which separates this rock from the radiolarian and foraminiferal marls and 'argiline' is the abundance of very fine rounded grains of quartz.—3rd Aug.]

Discussion.

The President felt sure the Society would welcome once more a paper by an Author whose writings on the molluscan faunas of Trinidad and Haiti were of much value. Those papers were written before the exploration of the deep-sea faunas had been carried out.

The Society had lately heard the paper by Messrs. Jukes-Browne and Harrison on the deep-sea deposits of Barbados, and the present paper would be useful for comparison with the results of those Authors. It was difficult to understand the conclusions arrived at as to the molluscan fauna after the description of the microzoic fauna, but perhaps some of the Fellows present might throw light on this point.

Dr. H. Woodward regretted the absence of the Author of this communication, the more so as he was prevented from attending by severe illness. Although he had been unable to visit Mr. Guppy, and so learn his views upon the subject of his paper, he was greatly indebted to Dr. G. J. Hinde for having examined Mr. Guppy's specimens so carefully, and for having prepared and exhibited a series of slides of radiolarian and foraminiferal deposits from the Naparima Beds of Trinidad to illustrate Mr. Guppy's paper, from materials furnished to him by Mr. J. W. Gregory.

Mr. J. W. GREGORY stated that the conclusions as to the truly deep-sea origin of some of the Trinidad rocks stated in an appendix to the paper agreed with those just announced by Dr. Hinde. He remarked on the great interest of the geology of Trinidad, as that island occurs at the intersection of the two main Caribbean lines of movement, viz., that along the Cordillera of Venezuela, and the later one along the Antillean chain. It was from Trinidad that evidence as to the exact correlation of the Cainozoic deposits of this area might be expected, for a series of shallow-water beds containing mollusca there occurred below deep-sea beds almost identical in character with those of the Oceanic series of Barbados. The speaker expressed doubts as to the value of the evidence on which some beds both in Trinidad and St. Bartholomew were assigned to the Eocene.

Mr. VAUGHAN JENNINGS said that, as regards the value of foraminifera in determining the age of West Indian beds, specimens had been sent over to this country containing *Orbitoides* of Eocene facies (*Orthophragmium*, Mun.-Chal.) associated with *Gypsina globulus*, *Patellina* (=*Orbitolina*) *concava*, and *Haplostiche Soldanii*. Of the last two species, the former was regarded by European geologists as Cretaceous only; the latter as a type in the 'Pteropod Marls,' probably Miocene. The difficulty was probably only due to the deficiency of accurately localized specimens and stratigraphical horizon, but it was worth mentioning as showing the difficulties which attend the work of 'microzoic' palæontologists at home.

Dr. HINDE also spoke.

40. *On the* Structure *of the* American Pteraspidian, Palæaspis (Claypole); *with* Remarks *on the* Family. By Prof. E. W. Claypole, B.A., D.Sc. (Lond.), F.G.S. (Read June 22nd, 1892.)

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I. Review of the Discovery of Palæaspis.

In the volume of this Journal for 1885[1] the present writer published a description of the first specimens of Pteraspidian fishes that had come to light in the New World. They were discovered in the autumn of 1883 in a bed of variegated marl, and later in a bed of red and green sandstone enclosed in the marl and belonging to the Onondaga or Salina Group of the Upper Silurian formation. The fossils were found in Perry Co., Pennsylvania, in the survey of which the writer was at that time engaged. The sandstone and shale pass under the town of New Bloomfield, and for this reason the stratum has received the name of the 'Bloomfield Sandstone.' The horizon of these beds corresponds with that of the English Lower Ludlow, or with the interval between that and the Wenlock, inasmuch as the Lower Helderberg Limestone which overlies it is unquestionably the palæontological equivalent of the English Ludlow, and the Niagara Limestone which lies next beneath it is as certainly the counterpart of the English Wenlock. The whole mass of the Salina Shale is, in Perry Co., about 1500 feet in thickness, and for the most part, with the exception now noted, is entirely unfossiliferous. This mass is but slightly represented in the English series.

The fossils consisted of the usual shields resembling those so long known from the rocks of nearly corresponding age in Herefordshire, and occurred in great abundance, but were for the most part broken or in the form of casts. Good representative shields are very scarce, partly no doubt because all the material accessible on the several exposures was considerably weathered and deep quarrying was not practicable.

Two forms were observed among these fossils, and they were

[1] Vol. xli. pp. 48–63.

taken to represent as many species, to which respectively the names *Palæaspis americana* and *P. bitruncata* were applied. The former was usually rather the larger of the two and was rounded at one end, if not also at the other. The latter, as the name implies, was bitruncate and especially square-cut at one extremity.

The microscopic structure of these shields, which was fully described in the original paper above referred to, sufficiently proved the affinity of the specimens, agreeing as it did in every respect with that of the shield of *Pteraspis* as described by Huxley in his memoir on the subject in this Journal,[1] and by Lankester in his monograph on the fishes of the Old Red Sandstone, published by the Palæontographical Society.[2]

The above-mentioned papers constituted the bulk of what was accessible to the writer at the time of publishing his original description, now seven years ago. The papers of Kunth and of Schmidt had, it is true, appeared, but they were not at the time accessible to him, and no other data available for the purpose were within his reach. During this interval our acquaintance with the family has considerably advanced, especially with regard to the American forms. Sufficient time has been given for working out some more of the old Pennsylvanian material, and also for obtaining a certain amount of new specimens. In addition to this, at least one new species has been described on the American continent and the epoch-making paper of Von Alth has appeared in Austria-Hungary. By these various additions to the literature of the subject we are placed in a position to better understand the structure and economy of the strange fishes of the early seas.

II. Kunth's Discovery of Pteraspis integra.

It will be desirable before proceeding farther with our subject to pass briefly in review the progress of our knowledge concerning this ancient ichthyic fauna. Twenty years ago three forms of Pteraspidian fishes had been recognized in Europe. These were first clearly defined as genera by Lankester in the monograph already cited. For one of these he retained the original name *Pteraspis*, given by Kner to his specimen, though in misapprehension of its real affinity. To the other two he applied the names *Cyathaspis* and *Scaphaspis*, suggested by their forms. This was the commencement of real progress in the systematic arrangement of these fossils.

The minute structure of these shields had been studied some years previously by Huxley in the memoir already alluded to, and this structure has been ever since the crucial test, by which almost the very smallest fragment of a Pteraspidian may infallibly be recognized.

All these three fossils were considered by Lankester in his monograph as representing the dorsal plates of as many distinct genera

[1] Quart. Journ. Geol. Soc. vol. xiv. (1858) p. 274, &c.
[2] Palæontogr. Soc. Monogr. 1868.

of fishes of Silurian and Devonian age. As defined by him, they were distinguished by the number of pieces composing the shield, which in *Pteraspis* was seven or perhaps eight, in *Cyathaspis* four, and in *Scaphaspis* only one.

The dawn of new light on this subject came in the year 1872, four years after the appearance of Lankester's masterly monograph. In that year and in the 'Zeitschrift der Deutschen geologischen Gesellschaft' (Band xxiv. p. 1) was published a posthumous paper of Dr. Kunth's containing a description of a specimen which he had been fortunate enough to obtain in a block of Silurian limestone in a railway-cutting near Berlin. The fossil consisted of a shield of *Cyathaspis* (Lk.) and one of *Scaphaspis* (Lk.) facing it, both with the convex sides outwards, indicating that they retained the positions in which they had been situated during life, and at once suggesting the inference that the latter was not an independent species, but only a portion of the defensive armour of the animal represented by the former. This was the first published announcement of any such relationship between these fossils which rested on a base better than suspicion, if, indeed, it may not be considered absolutely the earliest guess of such relationship. Lankester, it is true, in his monograph called attention to the fact that certain species of the two genera *Cyathaspis* and *Pteraspis* are frequently found associated with certain species of *Scaphaspis*, but failed to draw the inference of their organic connexion, and, indeed, later he opposed the view when brought forward by Kunth.

For this there was some justification in the peculiar use which Kunth made of his discovery. After he had, by most careful working-out of the specimen from the matrix, convinced himself beyond all reasonable doubt that the two shields really belonged to one another, and held in the fossil the relative positions which they had held in the living fish, he abandoned the safe ground on which he had thus far travelled, and, led astray by what was little better than a fancy, he wandered into regions in which he soon lost his way. Failing to rely confidently, as he should have done, on the strong evidence afforded by the microscopic structure of the plates, he adopted the notion that they represented the head-shield and pygidium of a rolled-up trilobite or trilobitic crustacean belonging to a family not yet recognized by palæontologists. He likened it to a *Calymene* or *Asaphus*,—genera often found in this folded condition. This view he confirmed by imagining that he saw in some loose fragments on the slab the disjointed body-rings of the same animal. Of course this opinion compelled him to reverse the direction of the Scaphaspid shield, and make what was considered by Lankester the front to be really the back, but as the true nature and position of *Scaphaspis* in the fish was unknown he encountered no logical obstacle in so doing. We will return to this matter later.

III. Controversy and Results.—Holaspis, Lankester.

The very peculiar view advanced by Kunth found, as might have been expected, no favour at the hands of palæontologists, and on the opposite side the field was at once taken, in the 'Geological Magazine' and in the 'Transactions of the Imperial Russian Mineralogical Society,' by Magister Fr. Schmidt, of St. Petersburg,[1] who with much acuteness saw immediately the strength and the weakness of Kunth's position, and, while denying the crustacean affinity of his fossil as altogether untenable, maintained and extended his conclusion that the two shields found in juxtaposition really belonged to the same animal, and that this animal was no other than *Cyathaspis*, as indicated by the dorsal plate. He therefore fully agreed with Kunth in denying the independent existence of *Scaphaspis* as a genus, and followed him in assigning its various forms to the different species of *Pteraspis* and of *Cyathaspis* with which it was usually found in company. He thus took ground considerably in advance of all previous writers on these fishes, and to him is fairly due the honour of first announcing what is doubtless the true nature of these peculiar fossils. Instead of the rolled-up trilobite of Kunth, Schmidt presented us with an armour-clad fish possessing both dorsal and ventral plates, whereas previously these creatures had been supposed to be protected only above and to be defenceless below. Schmidt further pointed out, in confirmation of his view, the fact that the Devonian fishes were doubly armed in the same manner as his Pteraspidians, and adduced *Coccosteus* as an example in support. The value of this argument was great, and must be felt by every student of these ancient fossils. But it should, at the same time, be borne in mind that among all the thousands of specimens that had come to light, Kunth's *Cyathaspis integer* (*integra*)[2] alone suggested and supported the new view, and had it not been for the excellent state of its preservation, in a smooth hard shale, palæontologists would have been slow to admit so large a conclusion from so small a premiss. But the evidence was so clear and strong that, as Schmidt says, it was useless to attempt to invalidate it.[3]

[1] Geol. Mag. for 1873, pp. 152, 330, and Verhandl. der k. russisch. mineralog. Gesellsch. für 1873, p. 132, &c.

[2] It is worthy of remark how uniformly writers on this subject have followed the earlier authors in the error of using these generic terms as masculine nouns. Agassiz seems to have led the way; consequently nearly all the specific names have been wrongly formed. A few only have appeared in the feminine gender. After remaining in this confusion and error for half a century, it is refreshing to a classical eye to see the needed amendments introduced in the Brit. Mus. 'Catalogue of Fossil Fishes' by Mr. A. Smith Woodward.

[3] With regard to the statement of Magister Schmidt, that he has discovered true bone lacunæ in the superficial layer of *Pteraspis Kneri* (Geol. Mag. for 1873, p. 330), thereby breaking down the distinction drawn by Lankester between his Osteostracans and Heterostracans, I can only remark that, after the most careful examination of my slides, I have been quite unable to find anything resembling them in *Palæaspis*, whose shield consists outwardly of a uniformly dense layer of calcareous material enclosing the tubules, but nothing else.

Against the new view originated by Kunth, and amended and extended by Schmidt, Lankester, in 1873, protested energetically.[1] In a short paper, in which he described a new genus, *Holaspis*, the shield of which consists of a single plate, he asserted that in the specimens described by Kunth the two shields were only in accidental juxtaposition, and that the fossil could not therefore prove anything in regard to their arrangement during life. He even pushed his argument so far as to reason from analogy that, as *Holaspis* was intermediate in structure between *Cyathaspis* and *Scaphaspis*, it represented one term in a series of which *Scaphaspis* was the simplest and *Pteraspis* the most complex form. There is no reason for doubting that *Holaspis* is a new Pteraspidian, but when this is granted it by no means follows logically that *Scaphaspis* was its analogue. Differences had long been noted between this last-named form and the rest of the group; but these had never been put into any definite shape before the appearance of Kunth's paper. On examination of his figure it is, however, impossible to agree with Lankester that the position of the shields is accidental, or in any way to be compared with the packing of shells one within another, which constantly occurs, says Lankester, in Herefordshire and in Galicia, and, I may add, in Pennsylvania.

Lankester's position is strong in defending the ichthyic nature of *Cyathaspis*, and, consequently, of *Scaphaspis*, but it becomes weak when he goes beyond this, and denies the co-existence of the two as parts of the same animal. Altogether, judging from the figures, Kunth's work deserved more consideration than it received from Lankester.

It is not necessary to do more than allude to the revival, by Roemer and Eichwald, of Kner's original view of the cephalopodian affinity of the Pteraspids, inasmuch as it was afterwards abandoned by the former, and the specimen on which the latter relied is said by Schmidt, who has seen it, and at Eichwald's request carefully examined it, to be of quite different structure, and to belong to some, at present undeterminable, but totally distinct group.

IV. Discovery of Diplaspis (Matthew) in Canada.

Thus the matter remained for some years. No more illustrative and critical specimens came to light in Europe, and the belief, if such it could be called, in the ventral position of *Scaphaspis* rested on the excellent but ill-interpreted example of Kunth. In 1885, however, the writer published (as already mentioned) his description of the first Pteraspidian fishes that had been discovered in the New World. Beyond adding a single new species, or, as was then supposed, two new species, to the list of the family, these fossils threw no additional light on the structure of the fishes. Dismissing this subject for more complete discussion in a subsequent part of this paper, we will pass on to note the next contribution to the history of the Pteraspids.

[1] 'Academy' for 1873, p. 11, and Geol. Mag. for 1873, pp. 190, 241, 478.

In 1886, Mr. G. F. Matthew, of St. John, New Brunswick, discovered near that town, in rocks of Upper Silurian age, a new species of the family. In his paper on the subject, presented to the New Brunswick Academy of Science, he published details regarding it, making, among others, the important announcement that in his opinion it was armour-clad ventrally as well as dorsally, and giving satisfactory evidence in favour of this belief. This species of Matthew's, named *Diplaspis acadica* from the character above emphasized, which he then supposed to be peculiar to it, is at present represented only by the single specimen in his own possession—the basis of the original description. It was undoubtedly the first instance on the American continent in which the existence of a ventral as well as a dorsal armour on the Pteraspids was announced.

Mr. Matthew's fossil showed what he considered to be the fragments of the dorsal and ventral shields of the fish, with a rostral piece and two antero-lateral plates attached to the former and two others (postero-lateral ?) attached to the latter. If Mr. Matthew's interpretation of his specimen is correct, instead of the two 'cornua' of Lankester's *Cyathaspis*, *Diplaspis* had four of these side-pieces in its armour. Besides these, there was a separate small plate, which its discoverer regarded as the eye-plate, and which must in that case correspond to the eye-plate of *Pteraspis*, as that genus is described by Lankester. In spite, however, of the resemblances, the fossil, judging from Mr. Matthew's description and figures, which are, it is true, merely outlines, cannot be placed in either of Lankester's three genera (really two), but must stand alone, at least for the present. It may be well to observe that all doubt and uncertainty respecting the correctness of the reference of this fossil to the family of Pteraspidians is removed by the presence on the shields of the peculiar and very characteristic striation, whereby the smallest fragments of the defensive armour of these fishes may be recognized with certainty whenever it is visible.

Unfortunately, in this case the last crucial link in the argument is imperfect. The two shields were not, as in Kunth's specimen, found in position, and if the fossils were as abundant as they are in many places in Europe and in Pennsylvania, this gap would be serious. But in the circumstances obtaining in New Brunswick the objection has but little weight. Only this one specimen has ever been described from the Dominion of Canada, and the fragments were found close together, so that Mr. Matthew's inference that they belonged to one another cannot be refuted, or, indeed, with good reason attacked.

At the time of publishing his description of *Diplaspis*, Mr. Matthew was evidently not acquainted with the latest results of discovery in Europe on this subject, or with the papers above quoted on the Pteraspidians. He consequently had not learned that they were more than suspected to have been armour-clad above and below. What doubt remained may be ascribed to the fact that a new and unexpected discovery, and especially one which contravenes the opinion that has previously been universally held, is always regarded with a certain measure of doubt till confirmed by the finding of further specimens by other workers. In his own words, as printed in the 'Canadian Record of Science' for 1886, we read: "The author is not aware that the existence of a ventral shield has hitherto been observed in any Pteraspidian fish, although it is well known to exist in the large Devonian Placoderms." Mr. Matthew here uses the same argument as that employed by Schmidt (which indeed must have occurred to the mind of any palæontologist) in order to render more probable, or, we may rather say, less abnormal, the new view concerning the defensive armour of the Pteraspids.

V. Von Alth's Specimen and Interpretation.

We come now to the paper of Von Alth published in 1886, the same year in which Matthew announced his *Diplaspis*, but neither author was aware of the work of the other. This writer had already in 1874 published descriptions of ten species, belonging to the genera *Pteraspis*, *Cyathaspis*, and *Scaphaspis*, from the Upper Silurian strata of Podolia. But in 1883, during an expedition in search of fossils, he came upon a specimen of so peculiar a character, that after careful removal of as much of the matrix as was possible, he could reach no other conclusion than that it showed a *Pteraspis* and a *Scaphaspis* together exactly as in Kunth's specimen, and afforded fresh and incontrovertible proof of their relationship. This fossil he made the subject of a communication (in Polish) to the Cracow Academy of Natural Sciences,[1] and of another (in German) to the 'Beiträge zur Palaeont. Oesterr.-Ung.'[2]

The evidence of this new find, as developed and set forth by Von Alth, was so convincing, when added to the previous discovery of Kunth, that it may fairly be said to have established an epoch in the history of these fossils, for it was scarcely possible that any doubt could longer remain in an unbiassed mind.

Von Alth candidly acknowledged in his paper that he had till the discovery of this specimen strongly opposed, with Lankester, the new view put forward by Kunth and defended by Schmidt:— "In meiner oben erwähnten Arbeit über die palaeontologischen Gebilde Podoliens und deren Versteinerungen habe ich ebenfalls die Ansicht vertheidigt dass *Pteraspis* und *Scaphaspis* ganz verschiedenen Thierformen angehörten." But he frankly avowed the change of front caused by his own discovery, and was quickly followed in the same movement by Lankester,[3] who wrote: "The specimen described and figured by Von Alth leaves no doubt in my mind as to the interpretation of *Scaphaspis* adopted by him."

The results of Von Alth's paper may also be seen in Mr. Smith Woodward's new 'Catalogue of the Fossil Fishes in the British

[1] Verhandl. d. Krakauer Akadem. d. Wissensch. vol. xi. p. 160, &c.
[2] *Op. cit.* Band v. (1887) p. 61.
[3] See 'Nature,' vol. xliii. p. 578, April 23rd, 1891.

Museum.' This palæontologist has there figured *Pteraspis*, armour-clad both above and below.

It is not yet possible to refer all the different species of *Scaphaspis* directly to the several species of *Pteraspis* and *Cyathaspis* to which they must severally belong, and probably the line of argument indicated by Lankester will be the only available one until some geologist is fortunate enough to discover the various species of *Scaphaspis* in juxtaposition with their corresponding species of *Pteraspis* and of *Cyathaspis*.

VI. The two Shields of Palæaspis.

Repeated and careful study of my specimens, both new and old, since 1883, has from time to time led to new observations regarding them, but it was not until I had seen the paper by Von Alth, quoted above, that I examined them in the light of this new theory of their structure. Considering that almost all my fossils are preserved in a sandstone-matrix, I was not sanguine of finding any confirmation of his view among them. The total result of the studies that I have made since the publication of the original description it is the purpose of the present paper to set forth.

Among the mass of material in my possession I have discovered two specimens in which the same relative position of the shields may be observed as that which was noted by Kunth and Von Alth. This had not altogether escaped my notice when several years ago I first extracted the specimens from their matrix. But the fact, to which Lankester, with wise caution, alludes in his tract on *Holaspis*, that the shields of these fishes are frequently found packed together as so many shells, had so often come to my notice in Pennsylvania that I naturally attributed this fact also to the same cause. In this I was somewhat hasty, as it now appears, inasmuch as I did not lay due stress on the circumstance that in these two cases the relative position of the shields was contrary to that of the great majority. Though nothing could be more natural than that a number of saucer-shaped shells should pack themselves together just as a pile of plates is packed, yet it was far less likely that any two of these should come to rest with the concave sides facing each other and with great exactness. Moreover, at that time I had not had an opportunity of reading Kunth's paper, which, in spite of his erroneous interpretation, might have raised a suspicion of the true significance of these two specimens. But, considering the sandstone-matrix and the scattered position of the great majority of the specimens, were it not for the confidence afforded by the two already-mentioned fossils, I should even now hesitate to put forward my own as evidence. However otherwise doubtful, the occurrence of the shields of *Palæaspis* in the same relative position serves now only to bring the American species into line with their co-ordinates in Europe, and so to lend confirmation and to gain probability at the same time. I feel therefore that no reasonable doubt can be entertained regarding the original position of the two shells above described. They are represented in the accompanying figures.

Fig. 1.—*First specimen, showing both shields in exact juxtaposition.*

[Section in front of laterals.]

As will be seen from a careful examination of the figures, there is not here even the slight lateral slip which has, to a small extent, displaced the plates in Von Alth's *Pteraspis*. The two shields fit accurately and closely one upon the other. Nor do they show any trace of the flange or outspread margin which is represented in the section by Von Alth; but the edges, which in the dorsal plate at least are somewhat thickened, fit exactly on to each other as a lid on a box. So close an accuracy of fit may be quoted as a further argument in favour of the belief that this was their position during the life of the fish, as it is exceedingly improbable that after being once shifted they would ever come again into juxtaposition so precise.

Fig. 2. — *Second specimen, showing both shields in juxtaposition.*

[Place of section uncertain.]

It then follows that *Palæaspis bitruncata* ceases to exist as a specific individuality, and becomes, as *Scaphaspis* has already become, only the name of the ventral plate of *Palæaspis americana.*[1] The absence of any notch for the eye, previously attributed to an imperfection of the specimen, and the usually rather smaller size are thus at once explicable.

When I described *Palæaspis* in 1884 I was unaware of the

[1] Since the above was written, I have received Mr. A. Smith Woodward' 'Catalogue of the Fossil Fishes in the British Museum,' and notice that he has made a suggestion to the same effect, and has in consequence treated one of these fossils as the ventral armour of the other. His foresight thus proves entirely just.

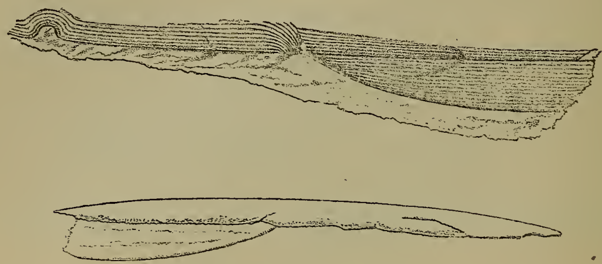
existence of the genus *Holaspis,* though it had been described in 1873 by Prof. Lankester, who kindly called my attention to it by sending me a copy of his paper. Had I known this earlier I should certainly have referred my species to his genus instead of coining a new term. However, as it has since proved that Prof. Lankester's name was pre-occupied, my own has precedence, and *Holaspis* has consequently been referred to *Palæaspis* by Mr. Smith Woodward in his Catalogue. But *Holaspis* can only remain a congener of *Palæaspis* on the supposition that it possessed a yet-to-be-discovered ventral armour. In the present state of our knowledge it is scarcely possible to doubt that this was the case and that one day it will be found. Only one or two specimens are yet known, and in this respect the fossil resembles those species of *Pteraspis* and *Cyathaspis* that are not yet known to have had a second plate. Doubtless time and search will in all cases bring these to light.

VII. The Lateral Plates of Palæaspis.

Among the material in my possession, I from time to time observed fragments which obviously could not belong to either of the two large shields of the fish. As the number of these fragments increased a general resemblance became apparent, and though I have not yet obtained a single perfect specimen in place, yet the supposition that occurred to me has proved well grounded, and scarcely a doubt remains that the fragments represent lateral plates corresponding to the 'cornua' of *Cyathaspis.* I had not previously suspected the existence of such plates. Their presence, however, brings *Palæaspis* yet more closely into connexion with the rest of the Pteraspidian family as now understood. At the same time the most careful examination fails to remove a peculiarity in which this genus differs at present from all other known Pteraspids, except perhaps *Diplaspis.* Instead of extending along the whole side of the fish they were apparently limited to the posterior half, and ended forward in points. They thus fill what would be otherwise a narrow wedge-shaped opening between the dorsal and ventral shields. I at first not unnaturally regarded this hitherto unnoted and abnormal feature with much suspicion, but the concurrent testimony of numerous specimens, combined with a few lateral plates which gave more or less distinct evidence of their position, have led me to regard it with confidence as the actual arrangement and form of these plates. The significance of this fact, then, is that the dorsal and ventral shields nearly met or possibly were in actual contact (on this point see later) from the front backward to about the middle, where the point of the lateral plate came in; and this gradually widened out to the hinder margin, where it came to an end with the two shields. This arrangement is shown in the lateral view of the type-specimen (fig. 3), so far as it is perfect, and in fig. 4 (see p. 552).

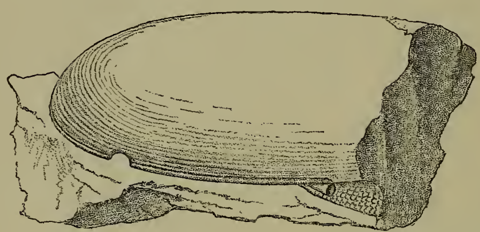
I have used the words "nearly met" above because there is some reason for thinking that the two large plates were not in actual contact, still less in sutural union, along their fore halves. The sculpture of the dorsal shield is on this point very peculiar and significant. I have represented it imperfectly in the figure, the scale being too small to do full justice to this feature. The marginal

Fig. 3.—*Side-view of type-specimen, right side.*



[Showing dorsal plate with orbit, medio-lateral striation, and lateral plate in place, but broken off behind. Cast of the same in outline.]

Fig. 4.—*Specimen showing front half of a dorsal shield.*



[With point of lateral plate and a small object, apparently the base of a 'fin,' in the angle.]

'ridglets,' which are coarser than those of the general surface, after curving round the orbit run backward along the outer margin to about the middle of the shield, where they swerve yet closer to a point on the very edge which is also a sort of focus for all the other striation on that section of the fore part of the shield. Behind this point the 'ridglets,' which are here smaller, resume their rudely parallel course to the end of the plate. This singular convergence of the superficial markings to a point near the middle of the outer edge of the shield is evidently an indication of some character at that point. There is no trace of any spine, nor is there any probability that such an appendage existed there. But the plate shows a constant disposition to break across just at the point of convergence of these lines, thereby indicating a weakness in that region. All these facts bear out the inference above expressed that the lateral plates reached no farther forward than I have stated, and in this case they would cease to strengthen the dorsal shield just at the point where fracture so frequently takes place.

The presence of the lateral plates brings *Palæaspis* into very close relationship with *Cyathaspis*, and unless similar parts should be found in *Holaspis* it will form a character of generic distinction between these, in which case the last-named can no longer be included in the American genus. It is, however, possible that further search may prove that *Holaspis* did possess such parts, and the question must therefore not be prejudged. Lankester's figure and description certainly indicate no 'cornua,' and his explicit statement that the fossil is intermediate between the more complex Pteraspids and *Scaphaspis* sufficiently indicates his opinion on this point.

Of the remarkable canal-system of *Holaspis* so clearly shown in Lankester's figure I have found no trace in *Palæaspis*, nor yet of the 'pores' accompanying the canals.

Fig. 5.—*Outline of ventral shield, from several specimens.*

[Outer view, right side, showing obtuse angle.]

In another point, however, the two fossils are in agreement. There is in both a total absence of a separate rostral plate. Not the slightest sign of division is shown in any of my specimens, and in the representation of *Holaspis* accompanying Prof. Lankester's paper the place of junction of such a plate with the dorsal shield is equally unmarked. In both the striation flows on uninterruptedly over the surface, and thus affords a distinctive character from *Cyathaspis*. Moreover the fore margin is in both well rounded and complete, giving assurance that no such plate is missing.

In no one of the many specimens that I have examined have I seen the slightest indication of a medial posterior spine on the dorsal shield, so that we may be quite confident that no such appendage existed. There is moreover no thickening of the material, no converging or change in the direction of the striæ towards the hinder end, and no sign of a furrow or groove for its insertion, such as might have been looked for had *Palæaspis* possessed the spinous process that characterizes *Pteraspis* and *Cyathaspis*.

VIII. The Lateral Organs, 'Fins,' of Palæaspis.

In addition to the above-mentioned new characters of *Palæaspis* there is another point on which I am at present unable to speak with certainty, but the interest of it is too great to allow of its omission.

I have from time to time detected on the slabs containing the specimens small objects in some respects resembling spines, for which indeed I at first mistook them. But, as above said, no indication of such parts can be anywhere found; hence this opinion was untenable. An increased number of specimens and closer examination revealed several facts: first, that these apparent spines were margined with what appeared to be a flat fringe around their smaller and pointed ends and nearly to their bases; secondly, that the rounded conical parts were filled with matrix and had therefore not originally consisted of hard material; thirdly, that this central spine-like portion was covered with a layer of the same tissue as that of which the shield was composed; and fourthly, that the fringe around the conical central portion was distinctly striate in a direction approximately parallel to its axis. The resemblance of this structure to a Crossopterygian fin was now obvious, yet as no such organ had been found with any Pteraspid I was unwilling to attach much value to this resemblance until a single specimen showed the organ so close to the side of the dorsal shield as irresistibly to suggest a connexion. Unfortunately the matrix here obscures the possible contact. and adheres so firmly that separation is impossible without destroying whatever evidence may exist. This, however, is scarcely to be counted an objection to the view above suggested, inasmuch as actual connexion may have been severed before fossilization took place by the decay of the soft parts through which union with the body must have been effected in order to allow of movement.

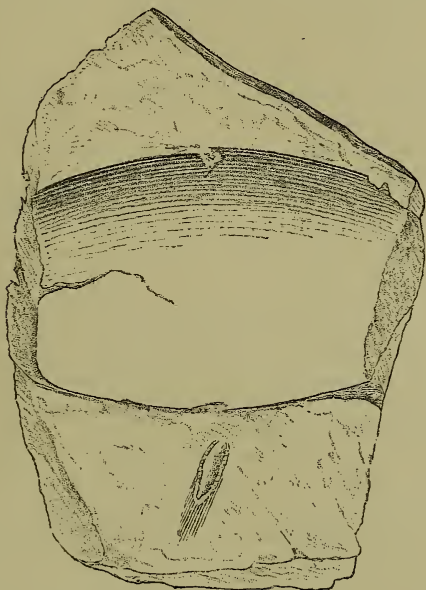
I have represented the three specimens of this singular fossil in fig. 6, wherein are shown the slight differences that exist in size, proportion, and detail. In fig. 7 (p. 555) I have also represented the one specimen showing the organ in the position in which I have written of it above. Four of these 'fins,' if I may venture to so name them, are in my possession, and I have seen indications and imperfect traces of others.

Fig. 6.—*Three 'fins,' showing differences of form and size.*

Without seeming too positive on this question, I may further remark that there is no antecedent improbability in this view and no real ground for scepticism. Though we know that the hinder end of *Pteraspis* was not clad in armour but in scales, so that the caudal and dorsal fins would, if present, fall to pieces on the decay of the soft retaining-parts, yet we have no reason to assume that the same was true of the anterior limbs, hitherto altogether unknown. They might naturally be clad in the same protective armour as the rest of the fore body, though movable as the spine of *Pterichthys*. True, it is not usual to find the fins of fishes severed from the body and yet remaining tolerably entire as in the present case, but in creatures so anomalous as these such a state seems possible. The conical hollow was in that case the lodgment of the motor muscle on whose decay its place was filled, as that of the other soft parts, with mud.

The resemblance of these 'fins' to those of Huxley's Crossopterygians was noted above, and I may add that two forms appear to prevail, one broad and the other narrow. This difference may indicate that more than one pair belonged to the same individual as pectorals and ventrals, or it may be of slighter import.

Fig. 7.—*Shield with 'fin' lying by its side—in life-position?*



A somewhat curious specimen which is in my possession gives us a little more information concerning the organ above described. It is at present quite unique, and was employed to illustrate the lateral plates. By turning back to fig. 4 (p. 552) and closely examining the lateral plate which is partly shown in its cast, there may be seen in the very angle a small roundish object looking extremely like what the base of such a fin would show if preserved in place. I am unable to interpret it in any other way than by regarding it as the actual inner extremity of an organ such as I have above described. This specimen must therefore be regarded as strongly confirming the opinion that we have here a real lateral organ—one of a pair of fins, pectoral or ventral or the two combined—whereby *Palæaspis* balanced itself in the water. Unfortunately I do not possess the cast of this specimen, which might have afforded yet more testimony in the same direction, and the above is all the evidence that I can offer in support of the opinion herein expressed.

In opposition to this view may be adduced the structure of *Cephalaspis*, which, so far as we yet know, was possessed of no organ similar to that above described. The appendages to the cephalic plate of which traces are so frequently seen in the fossils, but which has been so rarely preserved in a satisfactory state, have been regarded (as, for example, by Lankester) as pectoral fins, or as doing a double duty (1) as fins and (2) as accessory breathing-organs, resembling in this latter respect the 'gill-scoops' or scaphognathites of the Lobster and the Crayfish. But in these parts of *Cephalaspis*, as Lankester says, there is no trace of fin-rays, they being simply elliptical expanses. On the other hand, these organs in *Palæaspis* do show what may be regarded as rays and what indeed cannot but suggest fin-rays to the eyes of the ichthyologist. In size also they correspond with what might be expected, so that all considerations lead us to the conclusion above stated. But, at the same time, as no specimen has yet shown them indisputably in place, we must suspend our final decision until some happy accident shall, as in the case of Kunth and Von Alth, bring forward absolute and incontrovertible proof either for or against this view. At present the Cephalaspids and the Pteraspids stand alone in the vertebrate sub-kingdom in not possessing or being known to possess paired limbs, unless the low, existing Lancelet (*Amphioxus*) be set down in the same category. I make no mention of the Serpents, because they are without doubt descended from limbed ancestors, a conclusion which may indeed be true of the Lancelet, but cannot be predicated of the Silurian fishes.

Though no specimen (as aforesaid) actually shows this organ in position, yet I am induced to believe that it was attached to the body at the critical point already mentioned, where the lateral plate ends forwardly, and where the remarkable change of direction is to be seen in the striation; and if from this point towards the head the dorsal and ventral plates were not in actual contact there would be here ample opportunity for attachment to the soft parts of the body within, as is the case with the Trunk-fishes or Ostracionts of to-day.

It is fitting here to allude to the fact that Kunth, in his paper already more than once referred to, makes mention of some such organ, and I was at first inclined to hope that a confirmation of my theory of the fin-structure of *Palæaspis* might be derived from the remarkable specimen which this palæontologist so clearly but mistakenly described. He writes distinctly of an organ which it seemed to him might be regarded as a means of locomotion or, he adds, of getting food.[1] But a short examination of his figure

[1] 'Auf der linken Seite befindet sich zwischen den beiden Schildern noch ein Schalstück von stumpf spindelförmiger Gestalt, welches etwas länger ist als die oben erwähnten Segmente und längs der Ränder der Schilder gelagert ist. Es mag dasselbe irgend welchen Bewegungs- oder Ernährungswerkzeugen angehört haben; seine Erklärung muss glücklicheren Findern vorbehalten bleiben.'—Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxiv. (1872) p. 5.

dispels all such expectation, and shows in a moment that this statement is only another of the misapprehensions into which this writer was led in consequence of his mistaken view of the fossil. Regarding it as a rolled-up trilobite he was puzzled to explain the side-pieces which were visible on his slab between the head- and tail-shields of his 'crustacean.' He could not compare it with any known part of any known species, nor was it probable that any unknown form would differ very widely from these. He consequently was driven to the view that his fossil represented some not yet discovered family, and that these side-pieces were the remains of locomotive or feeding organs. But in the light of the now known structure of *Palæaspis* it is evident that Kunth was dealing with a somewhat similar form, wherein the side-pieces being rather loosely anchylosed to the dorsal shield fell away when the soft retaining-parts decayed. The close correspondence of these parts with the 'cornua' of *Cyathaspis* should, one would think, have almost sufficed to prevent the complete misinterpretation which led Kunth astray in regard to his fossil. The insertion of such organs in a crustacean of trilobitic affinity is hardly less foreign to what we know of the structure of the group than would have been the addition of lateral pieces, and scarcely aided the case or lessened the difficulty.

IX. Comparison of Palæaspis with other Pteraspids.

One difference, however, between Kunth's fossil and *Palæaspis* is obvious from an examination of his figures. It is that in the former the side-pieces lie in front of the mid-point, whereas in the latter they lie behind it. There is no possibility of otherwise explaining either Kunth's figure or my specimens. This may of course be due simply to difference of species or rather of genus, for so great a variation must be more than specific. But our present knowledge scarcely warrants a definite resort to this explanation. If, however, the side-pieces in Kunth's specimen really lay in life as represented in his figure, and of this I can see no reasonable doubt, then it would not be possible to include it in my genus. But there is a possibility which may one day remove this existing discrepancy. Though no specimen in my possession shows an antero-lateral plate in position, or any convincing traces of such an arrangement, yet from some indications I should not be surprised if such a case should come to light and the species should be found to have had side-pieces in front similar to those of Kunth's figure. This would render the armour of the animal more symmetrical and in harmony with that of some other members of the family, notably *Cyathaspis*, in which, however, the two plates are represented by a single one, and the critical point where a fin may have been attached in *Palæaspis* is not apparent. Moreover, the hinder part of Kunth's specimen is so badly broken that it is in my opinion impossible to say that it did not originally possess a postero-lateral plate resembling that of *Palæaspis*, and lying in a corresponding position. Should this prove to be the case, the two would very closely correspond in structure, and both would most likely fall into the genus *Palæaspis* as here amended, no very important difference then remaining so far as they are yet understood.

Yet farther in this direction may be quoted the *Diplaspis* of Mr. Matthew, in which he represents in his figure what appear to be two such lateral plates on each side of his fish. His specimen is so dam aged that this point is left doubtful, and Mr. A. Smith Woodward says in his 'Catalogue' that he prefers to consider them as the result of fracture till further evidence is forthcoming. But if in reality *Diplaspis* possessed both an antero- and a postero-lateral plate, this fact would greatly strengthen the argument that such a structure was not uncommon in the family. The place of meeting of these three plates would then furnish a critical point to which an organ of motion, if one existed, might naturally be attached.

It may further possibly turn out that this division of the single lateral plate of *Cyathaspis* of Europe into two may be a character of all the American Pteraspidians, and the different genera (if more than one exist) must be characterized by other features. We are unable on this point to form an opinion regarding Kunth's specimen.

Recurring for a moment to Kunth's figures, it is not easy to understand the relations of the other parts of the fossil there represented. But the fragment shown crosswise and behind the dorsal plate is certainly sufficient to justify the above suggestion. Evidently the dorsal shield extended farther, and possibly much farther, backward than the fragment shown in the figure indicates; while the lateral plate shown out of position may readily be supposed to have extended from the bevelled edge of the Scaphaspid plate backward, and to have gradually tapered off at the end of the Pteraspid shield.

It is not a little surprising that in his attempted restoration Dr. Kunth has entirely omitted this lateral plate. He evidently regarded it as belonging elsewhere than between the two main shields, and hence, though it is represented in the end view, it is not shown in his fig. 5.

Regarding the medley of fragments lying behind the large shield, we cannot from Kunth's figure form any definite idea of their nature and relations. Such fragments are always difficult of interpretation, and the pencil of the learned author may have been unconsciously swayed by his belief that he was representing a trilobitic crustacean.[1] Whatever their appearance may be they

[1] That Dr. Kunth was somewhat biassed by his prejudice in favour of a crustacean affinity for his fossil appears almost certain when we read his remarks on the wider bearings of his subject towards the end of his paper. He saw of course that his conclusions regarding his own species, which he named *Cyathaspis integer*, would logically be applied to *Pteraspis* in consequence of their manifest affinity. But Lankester had figured a *Pteraspis* with a few evident scales behind the dorsal shield. This specimen, the only one yet known showing any similar parts, established of course the ichthyic nature of *Pteraspis*. With a view of invalidating the strength of this opposing testimony Dr. Kunth remarks:—" Schwer zu entscheiden ist es, ob die Gattung *Pteraspis* im Sinne Lankester's hierher zu stellen ist. Lankester hat ein Stück Schild von *Pteraspis*

probably represent the fragments of the missing portion of the dorsal shield, the hinder part of which was in all probability ridged or fluted as the ventral shield, and therefore has been broken up into the linear pieces which he has figured and imagined to be the detached rings of a trilobite.

X. Attempted Restoration of Palæaspis.

With regard to the attempted restoration in fig. 8 (p. 560), I do not of course attach too much value to it as a whole. The following points may, however, be fully relied upon:—the form of the dorsal shield, the total absence of a spine, the presence of orbital notches, the singular striation at the mid-edge, and the nearly straight lateral margin; also the general form of the ventral shield, the obtuse angle near but rather in front of the middle, the truncate termination, and the general convexity. As to the lateral plates, several specimens show the same form and position as that represented in fig. 8 (p. 560); but it seemed unnecessary to repeat the illustration.

On the other hand, I am not quite certain regarding the exact position of the ventral in relation to the dorsal shield. No specimen yet found shows the two so perfectly as to enable me confidently to adjust them to each other. Possibly the ventral plate lay farther forward, but I incline towards the view that its actual position, if not as represented, was somewhat farther backward.

Of course, as Von Alth has pointed out, the position of the mouth represented by Lankester cannot now be accepted as correct. It must be removed far enough forward to lie in front of the fore edge of the ventral shield. But exactly how great a removal this would mean is, in *Palæaspis* as in *Pteraspis*, at present uncertain. In Von Alth's specimen some slip has occurred. In mine the ends are incomplete in both cases where the shields are together. I am therefore uncertain whether or not the ventral plate fell short of, or extended beyond, the dorsal backward.

The exact form of its termination I have also been unable to ascertain. Several specimens show a serrate edge at what appears to be the hinder end of the ventral shield; but these are fragments showing only the internal face of the plate, and other specimens

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mit daran hängenden 'Schuppen' abgebildet. Dass die abgebildeten rhombischen Gebilde Schuppen seien erscheint allerdings sehr wahrscheinlich; weniger überzeugend wirkt die Abbildung bei der Frage, ob das daran hängende Schildfragment zu *Pteraspis* gehöre."—*Op. supra cit.* p. 6.

But the presence of the peculiar and fine striation on the fragment (which is fortunately well preserved) of this unique and invaluable specimen from Herefordshire, to which Lankester calls special attention, should have been amply sufficient to convince anyone of the Pteraspidian nature of the fossil beyond all doubt or misgiving.

Thus did Kunth narrowly miss the honour of first publishing the real nature of the genus *Scaphaspis*, and its true relationship to *Pteraspis* and to *Cyathaspis*.

rather encourage the belief that the outer layer had an even edge. In this case the row of tubercles forming the serration probably indicates the points of attachment of muscles.

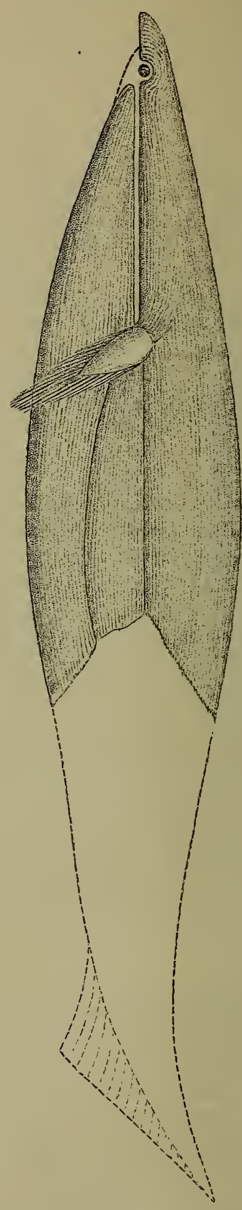
It is a little remarkable, and to me unexpected, that in no specimen yet found have I seen any indication of the canal-system so clearly apparent in the plates of *Holaspis* as represented in Lankester's figures and also in the shields of other Pteraspids. It is scarcely likely that the canals were altogether wanting, and the absence may be due to the mode of fossilization. Neither on the casts of the outer surface nor on the surface itself when preserved, though showing the most delicate striation, have I found the least trace of such structure.

Nor have I seen in any of the lateral plates any sign of the (so-called) branchial tubes or holes found in the laterals of *Pteraspis*. These do not occur in *Cyathaspis*, and this fact, no less than the structure of the shield, indicates a closer relationship with that genus than with the former.

In addition to the specimen herein described I have among the material in hand several very small shields much more convex than those of *Palæaspis*, and not exceeding 1 inch in length. They suggest very strongly by their outline a relation to *Cyathaspis*, but they may be merely young specimens of the larger genus. Some of the stones also abound with coprolitic matter, which is mostly of a lighter colour than the rock.

A comparison of my restored figure with that of *Pteraspis* as given by Mr. A. Smith Woodward shows that no very great modification of structure is necessary to bring it and *Palæaspis* into close resemblance. The curve there shown on the upper edge of the ventral plate might easily be so increased or developed as to result in two lines meeting at an obtuse angle, as seen in *Palæaspis*, and this change would convert the one lateral plate of *Pteraspis* into two by dividing it in the middle. This might result either in forming

Fig. 8.—*Attempted restoration of* P. americana.



[Showing details ascertained or rendered probable so far as at present known.]

two laterals, or the anterior might be suppressed or united with the dorsal. This change would bring *Diplaspis* as described by Mr. Matthew, and *Palœaspis* as figured here, into line with the older forms.

With the structure of *Pteraspis* as indicated it is, however, difficult to see any special place for the attachment of an organ of motion such as I have described in this paper, supposing its function to have been rightly interpreted, and I should like to at least throw out the suggestion that the openings in the 'cornua' or lateral plates which have somewhat puzzled authors on this subject may have answered this purpose, and may correspond with the 'critical point' on which I have laid some stress in my account of the genus. If I read Lankester's description aright (I have no critical specimen of *Pteraspis* for reference) there is a passage through these to the inside of the body. Indeed this must be the case in order to afford a foundation for the supposition that they are connected with the branchial organs, of which, however, we thus far know nothing.

XI. Amended Definition of Palæaspis.

In conclusion, I append amended descriptions of the genus and species as now known (March, 1892).

Palæaspis (Claypole), 1884.

Armour consisting of a dorsal, a ventral, and at least two (perhaps four) lateral plates.

Dorsal plate oval, nearly alike at both ends, not very convex, even-edged, and with rather shallow orbital notches in the margin.

Ventral (Scaphaspid) plate (the *Pteraspis bitruncata* of 1884) rather smaller than the dorsal, usually rather more convex, truncate; lateral edges not straight, but forming an obtuse angle about the middle.

Post-lateral plates elongate-triangular in outline, resting on the posterior slope of the edge of the ventral plate.

Antero-laterals suspected to exist, but not proved.

No rostral plate or indication of one by striation or otherwise.

Palæaspis americana.

Dorsal shield oval, about 3 to 4 inches in length.

Ventral bitruncate (*P. bitruncata* of 1884).

Post-laterals pointed in front and terminating with ventral behind.

Antero-laterals perhaps present.

"Fin," or some appendage resembling one, with fringed margin (Crossopterygian), and probably attached in front of the post-laterals.

41. NOTES *on some* NEW *and* LITTLE-KNOWN SPECIES *of* CARBONIFEROUS MURCHISONIA. By Miss JANE DONALD. (Communicated by J. G. GOODCHILD, Esq., F.G.S. Read June 22nd, 1892.)

[PLATES XVI. & XVII.]

EVERY student of the Carboniferous rocks must be struck by the number of keeled gasteropoda they contain, many of which are so small and also so strongly resemble one another that only the study and comparison of a large series can afford means for anything like an accurate determination of different species. As a help towards their elucidation, I am about to figure and define the characteristics of some of the more marked forms of *Murchisonia*. Several of these have been previously described, but I think it well to reproduce them with more detailed notes.

In a previous paper [1] the various sections into which it has been considered advisable to group different species of *Murchisonia* have been noticed. Of the species here described two alone can undoubtedly be referred to *Goniostropha*, Œhl., as possessing the characteristics of that section: namely, the turriculated form, angular whorls, and sinual band situated on the summit of the angle. In *M. quadricarinata*, *M. quinquecarinata*, *M. elongata*, *M. Kirkbyi*, *M. plana*, and *M. conula*, var. *convexa*, the sinus is situated above the angle; in other respects these shells resemble species of *Goniostropha*. It is therefore a question whether they should be referred to that section or whether the position of the sinual band be considered sufficiently distinctive to necessitate their being grouped together in a new section. In the latter alternative I should suggest the name *Hypergonia*, and take *M. quadricarinata* for the type.

With regard to *M. pentonensis*, it is somewhat difficult to decide whether the sinual band is actually on the summit of the angle or immediately above. I incline to the latter opinion, and should therefore group this species with *M. quadricarinata* and allied forms. *M. conula*, var. *convexa*, and *M. plana* differ from the other species of this group, and also from species of *Goniostropha*, in having the base of the shell flattened. *M. amœna*, De Kon., agrees with these two last-named species in having the sinus above the angle and also in the base being flattened. The possession of this flattened base is hardly a characteristic of such value as to render it necessary to separate these shells from those referred to *Hypergonia*. In addition to these keeled *Murchisoniæ*, I notice a new and interesting smooth form, probably belonging to the section *Cœlocaulus*, Œhl. I also give a fuller description of a fossil described in 1859 by Prof. Haughton [2] as *Cerithioides telescopium*,

[1] 'Descr. of some New Species of Carb. Gasteropoda,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 621.

[2] 'On some Fossil Pyramidellidæ from the Carb. Limestone of Cork and Clonmel,' Proc. Dublin University Zool. and Bot. Assoc. vol. i. pt. iii. p. 282, pl. xx. figs. 2–4.

which seems to have been overlooked, for it is not mentioned in any of the lists of fossils published since. Though he notes the existence of a band on the whorls, he does not observe its significance as indicating the possession of a sinus in the outer lip. He refers it to the *Pyramidellidæ*, and considers it closely allied to the recent *Cerithium telescopium*, Brug. The sinus in the outer lip is clearly shown to have been present by the lines of growth which curve backwards to the band above and forwards again below, thus proving that the shell is closely related to the *Murchisoniæ*. Of the sections into which that genus has been divided, this species has most in common with *Cœlocaulus*, but it differs from it in its remarkably flattened, grooved base and in the absence of an umbilicus. The mouth is imperfect in all the individuals I have seen, but from what is preserved I think it is highly improbable that the columella was vertical or the peristome reflected as in *Cœlocaulus*. It might therefore be well to retain the name *Cerithioides* for a section of *Murchisonia* in which this species might be placed until more is known of its affinities.

Section Goniostropha, Œhlert.

Murchisonia (Goniostropha) hibernica, sp. nov. (Pl. XVI. fig. 1.)

Shell elongated, turreted. Whorls angular, increasing very gradually, slightly concave both above and below the angle. Sinual band bounded by two strong keels situated near the middle of the body-whorl, and rather below it on the upper whorls. Ornamentation consisting of one keel a short distance below the band and another above, immediately below the suture. Sutures deep. Mouth unknown. Lines of growth not seen.

There is but one specimen of this species in the collection of the Geological Survey, Museum of Science and Art, Dublin. The apex is broken and only six whorls remain. Its surface is badly preserved, so that lines of growth indicating the possession of a sinus in the outer lip are not perceptible. Nevertheless its characteristics are sufficiently distinctive to warrant its being taken as the type of a new species of *Murchisonia*.

Length $12\frac{1}{2}$ millim.; width of body 5 millim.; height 4 millim.

Locality. Hook Point, Wexford.

Formation. Lower part of the Mountain Limestone.

Murchisonia (Goniostropha) Tatei, sp. nov. (Pl. XVI. fig. 2.)

Shell elongated, turreted. Whorls angular, numerous, increasing gradually. Sinual band bounded by two strong keels, situated near the middle of the body-whorl, and rather below the middle of the upper whorls. Ornamentation above the band variable, some specimens having two slight keels on the upper part of the whorl with one or two fine threads below, between the lower keel and the band, and occasionally another thread above at the suture; while others have only two keels, the additional threads being absent. Below the band are three keels somewhat less strong than those limiting the band; of these, only one or two are visible on the upper whorls. Lines of growth curving backwards to the band above and forwards again below. Mouth imperfectly preserved.

The shell figured is in the Tate Collection, Alnwick Museum, in which there are also fragments of other specimens referable to the same species. The surface of all is badly preserved, and the apex of the best specimen is embedded in the matrix, leaving only seven whorls visible.

It resembles *M. elongata*, Portl., more nearly than any other Carboniferous species; but may be distinguished from it by its much smaller spiral angle, by the greater strength of the keels above the band, as well as by the greater relative width of the band.

Length 23 millim.; width of body-whorl $7\frac{1}{2}$ millim.; width of penultimate whorl 6 millim.; height 4 millim.

Locality. Howick.

Formation. Upper part of the Yoredales.

Section Hypergonia.

Shell turriculated, composed of numerous angular whorls ornamented with keels. Sinual band situated above the angle, a characteristic which distinguishes it from *Goniostropha*, Œhl. It agrees with *Stegocelia* in the position of the sinus, but differs in not having the inner lip reflected on the columella, and in not being umbilicated.

Murchisonia (Hypergonia) quadricarinata, M'Coy. (Pl. XVI. figs. 3 to 6.)

Murchisonia quadricarinata, M'Coy, 1844, 'Syn. of the Char. of the Carb. Limest. Foss. of Ireland,' p. 42, pl. v. fig. 9; A. d'Orbigny, 1850, 'Prodr. de Paléont. stratigr.' t. i. p. 123.

Non *Murchisonia quadricarinata*, L. G. de Koninck, 1851, 'Descr. des Anim. foss. du terr. Carb. de la Belgique,' Supplément, p. 697, pl. lviii. fig. 15.

Murchisonia quadricarinata, Morris, 1854, Cat. of Brit. Foss. p. 259; F. M'Coy, 1855, 'System. Descr. of Brit. Pal. Foss.' p. 531; R. Griffith, 1860, Journ. Geol. Soc. Dublin, vol. ix. p. 90; J. Armstrong, J. Young, and D. Robertson, 1876, 'Cat. of the Western Scot. Foss.' p. 56; J. J. Bigsby, 1878, 'Thes. Devonico-Carboniferus,' p. 327.

Non *Murchisonia quadricarinata*, L. G. de Koninck, 1883, 'Faune du Calc. Carb. de la Belgique,' vol. viii. pt. 4, p. 20, pl. xxxiv. figs. 17, 18.

Murchisonia quadricarinata, R. Etheridge, 1888, 'Foss. of Brit. Islands,' vol. i. Pal. p. 301.

Shell elongated, turreted. Whorls angular, numerous, gradually increasing. Angle a little below the middle of the whorl, bearing a strong keel and having two slighter keels above and two below; of the latter that next below the angle is generally the stronger. The widest space is that between the keel on the angle and the lower of the two upper keels; it is occupied by the sinual band. Lines of growth curving backwards to the band above and forwards again below, arched upon the band itself. Base somewhat produced. Mouth longer than wide.

Several different forms having been erroneously named *M. quadricarinata*, I consider it advisable to give a fuller description and enlarged figure of the type of this species. It is unfortunate that there is only one specimen from the original locality, and that it is embedded in the matrix. Thus we cannot tell what amount of variation in the strength and position of the keels there might be if a large series were available for comparison. Also the exact spiral angle is not seen. The shell is, however, well preserved, and shows traces of the lines of growth. It is quite distinct from the form called *M. quadricarinata* by De Koninck: the whorls are more angular, the sutures deeper, there is also a difference in both the number and the position of the keels, and the base of the shell is more produced. It bears a great resemblance to *M. quinquecarinata*, De Kon.; but in that species the whorls are higher in proportion to the width, the angle being in the middle or above the middle of the whorl, and three keels being frequently visible below it on the lower whorls; the spaces between the keels are more nearly equal in width, and the sutures are more oblique. *M. quinquecarinata* may, however, prove to be merely a variety having the whorls less closely coiled.

The type (Pl. XVI. figs. 3, 3 *a*) which is in the Museum of Science and Art, Dublin, is embedded in the matrix, and only nine whorls are visible; these have a length of 11 millim. Width of portion of body-whorl seen 3 millim.; height $2\frac{1}{2}$ millim.

Locality and Formation. Upper (Carboniferous) Limestone of Blacklion, Enniskillen.

In the Woodwardian Museum there are two shells from the Carboniferous Limestone of Derbyshire referred, but with a query, to this species by M'Coy himself; I also doubt their identity with the Irish specimen. They are, however, so badly preserved that it is difficult to tell what they really are.

Four small shells from the Mountain Limestone of Settle appear to belong to this species. Three are in the Woodwardian Museum, and the other is in the York Museum. This last (Pl. XVI. figs. 4, 5) is remarkably well-preserved, showing the lines of growth very distinctly, and in the middle of the band there is a fine thread on the two lower whorls. The two keels below the band are about equal in strength instead of the upper being the stronger, as is the case in the type. Eight whorls are preserved, and there would probably be two or three more if the apex were entire.

Length $8\frac{1}{2}$ millim.; width of body-whorl $3\frac{1}{4}$ millim.; height $2\frac{1}{4}$ millim.

There is also, from the same locality, a fragment of a larger shell in the Woodwardian Museum which bears a great similarity to this species in the position of the angle and in ornamentation. The space above the angle is not quite so wide, and the dimensions are greater; in these points it resembles *M. quinquecarinata*, De Kon., so that it appears to be a connecting-link between the two forms. Only four and a half whorls are preserved, of which the length is 11 millim.

A shell in the Museum of the Geological Society of London, from the Carboniferous Limestone of the shores of Lough Gill, Co. Sligo, may be this species, though the space above the angle is not quite so great as in the type.

In the collection of Mr. Young, Hunterian Museum, Glasgow, there are several specimens which, though of much smaller dimensions, appear to agree with this species in general characteristics.

One (Pl. XVI. fig. 6) from the shales of the Lower Limestone Series[1] at Craigenglen, Campsie, has a length of 4½ millim. Others are from the shales of the Upper Limestone Series at Glencart, Dalry, and at Robroyston.

Some external casts in my own collection from the Yoredales of Widdle Fell, Wensleydale, may also be referred to this species.

MURCHISONIA (HYPERGONIA) QUINQUECARINATA, De Kon., var. PULCHELLA. (Pl. XVI. fig. 7.)

Murchisonia quinquecarinata, De Koninck, 1883, 'Faune du Calc. Carb. de la Belgique,' vol. viii. pt. 4, p. 23, pl. xxxiv. figs. 14–16.

Shell very elongated, turreted. Whorls angular, numerous. Angle situated rather above the middle of the whorl. Ornamentation consisting of a strong keel on the angle with two finer keels above and three below; these latter are all visible above the sutures on the five lower whorls, but the lowest keel is hidden on the upper part of the spire. Spaces between the keels about equal in width. Lines of growth not perceptible. Sinual band probably between the keel on the angle and that next above. Sutures deep and somewhat oblique. Mouth longer than wide. Base slightly produced. Columella rather arched.

I know of only one specimen, and this was given me by Mr. Young. The apex is broken, and only eight whorls remain.

Length 8½ millim.; width of lowest whorl 2¼ millim.

From the above description it may be seen how strongly this shell resembles *M. quinquecarinata*, De Kon., in every way except in size, for De Koninck gives 20 millim. as the length of his species and 5 millim. as the width. He only speaks of two keels below the angle on the whorls of the spire, and two additional keels on the body-whorl, but some of the specimens examined in the Brussels Museum show a third keel just above the suture on several of the lower whorls similar to the specimen under discussion. The angle is, however, placed high up the whorl on all the Belgian shells.

[1] The higher members of the Lower Carboniferous rocks which are known to Scottish geologists as the Lower Limestone Series, the Lower Coals and Ironstones, and the Upper Limestone Series, are now known to represent the upper part of the Mountain Limestone and the Yoredale rocks of English geologists.

The body-whorl of the Scottish shell is too imperfect to show whether there was an additional keel upon it. With regard to the remarkable difference in size, it has been previously observed that many Scottish fossils are dwarfed as compared with the same species from other localities, and this appears to be especially the case with those from Dalry. In a former paper I described a variety of *M. turriculata*, De Kon., from the shales of the Upper Limestone Series [1] (Dalry), differing as greatly in size from the type as the present form does. In the absence of specimens of intermediate dimensions, and considering that the Scottish shell is only about half the size of the Belgian one, it seems advisable, in the meanwhile at any rate, to let it constitute a distinct variety for which I should suggest the name *pulchella*.

This species bears a great resemblance to *M. quadricarinata*, M'Coy, from which it may be distinguished by the higher position of the angle, more oblique sutures, and also in its being of much greater size than the specimens of *M. quadricarinata* from the Scottish beds. It may, however, be an elongated variety of that species, but this could only be proved by the comparison of a large series of specimens which might show intermediate forms.

Locality and Formation. Law Quarry, Dalry, in the shales of the Lower Limestone Series.

Murchisonia (Hypergonia) conula, De Kon., var. convexa. (Pl. XVI. figs. 8, 9.)

Murchisonia conula, L. G. de Koninck, 1843, 'Précis élém. de Géologie' par J.-J. d'Omalius d'Halloy, p. 516.

Murchisonia abbreviata, L. G. de Koninck, 1843, 'Descr. des Anim. foss. du Terr. Carb. de la Belgique,' p. 415, pl. xxxviii. figs. 3 et 6.

Murchisonia angulata, L. G. de Koninck, 1843, *ibidem*, p. 412, pl. xxxviii. fig. 8 (synonymis et tab. xl. fig. 8 exclusis); H. G. Bronn, 1848, 'Index pal.' p. 747; A. d'Orbigny, 1850, 'Prodr. de Paléont. stratigr.' p. 122; J. J. Bigsby, 1878, 'Thes. Devonico-Carboniferus,' p. 325.

Murchisonia conula, L. G. de Koninck, 1883, 'Faune du Calc. Carb. de la Belgique,' vol. viii. pt. 4, p. 17, pl. xxxiv. figs. 9, 10.

? *Murchisonia quadricarinata*, L. G. de Koninck, *ibid.* p. 20, pl. xxxiv. figs. 17, 18.

Shell elongated, turriculated, somewhat convex in outline. Whorls from twelve to fifteen, very gradually increasing and but slightly angular. Ornamentation consisting of four keels; the keel on the angle and that next below strong and almost equally prominent, the uppermost and lowest keels much finer. The uppermost keel divides the space above the angle almost equally in two; the lowest keel appears immediately above the suture. Base flattened, having no additional keels, but having numerous fine spiral lines. Sinus situated between the keel on the angle and the upper-

[1] 'Descr. of some New Species of Carb. Gasteropoda,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 622.

most keel. Lines of growth distinct and slightly irregular in strength, curving backwards to the band above and forwards below; strongly arched on the band, the greatest convexity being nearer the upper keel than the lower. Sutures prominent. Mouth imperfectly preserved, probably somewhat rounded.

This shell bears so strong a resemblance to *M. conula*, De Kon., that I consider it a variety of that species. It agrees with it in the form of the whorls, the number and position of the keels and the flatness of the base. But it differs in having a smaller spiral angle than the specimen figured and described by De Koninck. De Koninck also states that the sinus is between the two strongest keels instead of above. On the specimens, however, that I have seen both in the Brussels Museum and in the British Museum (Natural History) from Visé the lines of growth appear to indicate the sinus as being above the angle, precisely as in the British shells. Most of the Belgian specimens are imperfect and compressed, so that it is difficult to ascertain the spiral angle with accuracy. The upper part of the spire increases more rapidly than the lower, and if that portion of the shell be taken alone the spiral angle of the whole may be represented as greater than it really is. There are two unnamed shells in the Brussels Museum from Visé which are identical with the British specimens, and the clearly-preserved lines of growth show the sinus to be in the same position. The *M. quadricarinata* of De Koninck appears to me to be a small variety of this species. *M. conula*, var. *convexa*, may be distinguished from *M. quadricarinata*, M'Coy, by its more prominent sutures, less angular whorls, fewer and differently disposed keels, and by its flattened base. It is like it, however, in having the sinus above the angle.

Locality and Formation. The variation in size of different individuals is somewhat remarkable. The largest English shell (Pl. XVI. figs. 8, 9) is from shales at the base of the Yoredales at Abbey Foss, Askrigg, Yorkshire. It consists of eleven whorls; the apex is broken, so there would probably be four or five more if entire. It is 34 millim. in length; the width of the body-whorl is $12\frac{1}{2}$ millim. None of the Scottish specimens equal this in dimensions. The largest that I have seen is in the collection of Mr. John Young, Hunterian Museum, Glasgow, from the shales of the Lower Limestone Series of Craigenglen, Campsie. It consists of twelve whorls; the apex is broken, but if the specimen were entire there would probably be two or three whorls more. The length is $16\frac{1}{2}$ millim.; width of body-whorl 5 millim.; height 4 millim. The larger of the two Belgian specimens referred to is from Visé. étage v 2; it is embedded in the matrix, and only shows nine whorls, which have a length of 17 millim. De Koninck gives 45 millim. as the length of the type. Other specimens from various localities in Yorkshire, Scotland, and Belgium vary in size from these dimensions down to shells which have as many as eleven or twelve whorls in a total length of 6 millim. Small, well-preserved external casts of this species are found in an impure limestone of Yoredale age at Mosedale, on the northern slopes of Widdle Fell.

Murchisonia (Hypergonia) pentonensis, sp. nov. (Pl. XVI. figs. 10–12.)

? *Turritella* ? *sulcifera*, J. E. Portlock, 1843, 'Geol. Rep. Londonderry,' p. 420, pl. xxxi. fig. 11; H. G. Bronn, 1848, 'Index Pal.' p. 1338.

Orthonema quinquecarinata, De Kon., 'Notes on some Carb. Gasteropoda from Penton and elsewhere,' Trans. Cumberl. & Westmorl. Assoc. No. ix. (1883–1884) p. 135, fig. 6.

Non *Murchisonia quinquecarinata*, De Kon., 1883, 'Faune du Calc. Carb. de la Belgique,' vol. viii. pt. 4, p. 23, pl. xxxiv. figs. 14–16.

? *Turritella* ? *sulcifera*, J. Donald, 1887, 'Notes upon some Carb. Species of *Murchisonia* in our Public Museums,' Quart. Journ. Geol. Soc. vol. xliii. p. 630, pl. xxiv. fig. 12; R. Etheridge, 1888, 'Foss. of Brit. Islands,' vol. i. Pal. p. 308.

Shell elongated, turreted, composed of about twelve angular whorls. Sinual band situated near the middle of the whorl, bounded by two strong keels. Ornamentation consisting above the band of one keel placed near the suture, below the band of three or four keels on the body-whorl, only two of these being visible on the upper whorls. These keels are not so strong as those limiting the band, the uppermost being generally the slightest of all, but occasionally the two next below the band are less developed. The widest space is that above the band, the spaces below being about equal. Lines of growth fine and rather irregular in strength, curving backwards to the band above and forwards again below, somewhat indistinct on the band itself. Mouth longer than wide. Columella simple. Base of the shell slightly produced.

In a previous paper I erroneously referred this shell to the genus *Orthonema*.[1] The examination of a large number of specimens both in my own and Mr. Young's collections, and especially the discovery of a well-preserved specimen upon which the lines of growth are very distinctly seen, have convinced me that this shell should be referred to *Murchisonia* instead of *Orthonema*. Many shells from the same beds have lines coming straight down the whorls which appear to be lines of growth, though they are not really so, but merely result from the substance and manner in which the shells are preserved. This is the case with an easily determined species of *Pleurotomaria*, some specimens of which exhibit these straight lines, while the best preserved show the true lines of growth. I also doubt the identification of the species under discussion with *M. quinquecarinata*, De Kon.; for I have lately compared some of my specimens with De Koninck's type-form at Brussels, and I consider the difference in characteristics such as to lead to their separation into two distinct species. That of De Koninck has a smaller spiral angle, there is a single strong keel on the angle of the whorl with two finer keels above and two or three below; also the angle is higher up the whorl, and the spaces between the keels are about equal in width. My specimens more nearly agree with seven unnamed shells on Tab. 933 in the Brussels Museum

[1] 'Notes on some Carb. Gasteropoda from Penton and elsewhere,' Trans. Cumb. & Westm. Assoc. No. ix. (1883–84) p. 135, fig. 6.

from Visé. The only difference lies in the uppermost keel bounding the band being somewhat finer on these.

Among shells belonging to the British Isles this form most nearly resembles *Turritella ? sulcifera*, Portlock, and may possibly be identical with it. The only known specimen of that species, however, is very small and imperfectly preserved, so it is impossible to identify others with it with any degree of certainty. It therefore hardly appears advisable to unite them as one species, but should the discovery of more and better specimens from Cullion prove them to be the same, the name *pentonensis* must be dropped or adopted as a variety of *sulcifera*. It also has some similarity to *M. quadricarinata*, M'Coy, but the sinual band is narrower, the keels bounding it are more nearly equal in strength, and the widest space is above the band instead of being occupied by the band itself. Length of specimen (Pl. XVI. fig. 10), composed of twelve whorls, 16 millim.; width of body-whorl 5 millim.; height of body-whorl 5 millim. A larger shell, of which only eight whorls are preserved, is 23 millim. in length; the body-whorl is crushed, so its exact dimensions cannot be given.

Locality and Formation. Fairly abundant in the Calciferous Sandstone Series at Penton. It occurs in the shales of the Lower Limestone Series at Law Quarry, Dalry, at Craigenglen, and at Hairmyres. There are also three specimens in the Museum of Practical Geology, London, from the Carboniferous Limestone of Halkin Mountain, Holywell.

MURCHISONIA (HYPERGONIA) KIRKBYI, sp. nov. (Pl. XVI. fig. 13.)

Shell conical, composed of eleven or twelve somewhat rounded whorls. Whorls ornamented with five keels, which, with the exception of the uppermost, are very strong in comparison with the size of the shell. Spaces between the keels pretty equal in width. Sinual band situated between the second and third keels. Lines of growth curving backwards to the band above and forwards below. Base slightly produced. Mouth rather longer than wide. Columella simple.

This shell may be distinguished from *M. pentonensis* by its greater spiral angle, stronger keels, and less angular whorls. It bears some resemblance to *M. nana*, De Kon.,[1] but the keels are much stronger and the whorls are not quite so rounded. It is very like *M. nebrascensis*,[2] Geinitz, but has not so great a spiral angle as that species is represented to have in the figure.

I am indebted to Mr. J. W. Kirkby for specimens of this species. Length of shell consisting of eleven whorls $8\frac{1}{2}$ millim.; width $3\frac{1}{4}$ millim.; height of two last whorls $3\frac{1}{2}$ millim.

Locality and Formation. Randerstone, Fife. Low down in the Calciferous Sandstone Series, about 3000 feet below the base of the Carboniferous Limestone Series, which there is equivalent to the Yoredales of the North of England.

[1] 'Faune du Calc. Carb. de la Belgique,' 1883, vol. viii. pt. 4, p. 20, pl. xxxiv. figs. 27, 28.

[2] 'Carbonformation und Dyas in Nebraska,' 1866, p. 12, pl. i. fig. 17.

Murchisonia (Hypergonia) plana, sp. nov. (Pl. XVI. figs. 14, 15.)

Shell elongated, turreted, composed of about thirteen very angular whorls. Angle considerably below the middle of the whorl, bearing a strong keel. Upper part of the whorl very flat, ornamented with two much finer keels, between which there is a wide space, as one keel is immediately below the suture and the other at a slight distance above the angle. Below the angle is another keel, not so strong as that on the angle, but stronger than those above it; this keel is visible just above the suture on the upper whorls. Sinus most probably situated between the strongest keel and that next above. Lines of growth not discernible. Base flattened. Columella simple.

The only shell to which this bears any resemblance is *M. amœna*, De Kon.,[1] from which it may be easily distinguished by its more elongated form and more angular whorls. The keels are also somewhat different, both in their form and their disposition. On this species the keels stand out clear and sharp, whilst on *M. amœna* they are so strong and rounded as to make the spaces between appear like grooves. On the base of *M. amœna* there is also an additional keel, and the uppermost one is absent.

Length of specimen figured 9 millim.; height of two lower whorls 3 millim.; width of penultimate whorl $2\frac{3}{4}$ millim.

Another shell, which is imperfectly preserved, and of which the apex is broken so that only eight whorls remain, measures 10 millim. in length.

Locality. Law Quarry, Dalry; Craigenglen, Campsie.

Formation. Shales in the Lower Limestone Series.

Murchisonia (Hypergonia) elongata, Portl. (Pl. XVII. figs. 2, 3.)

Murchisonia elongata, J. E. Portlock, 1843, 'Geol. Rep. on Londonderry,' p. 569, pl. xxxviii. fig. 10 *a*, *b*; F. M'Coy, 1844, 'Syn. Carb. Foss. Ireland,' p. 42; H. G. Bronn, 1848, 'Index Pal.' p. 747; J. Morris, 1854, 'Cat. Brit. Foss.' p. 259; R. Griffith, 1860, Journ. Geol. Soc. Dublin, vol. ix. p. 90; J. J. Bigsby, 1878, 'Thes. Dev.-Carb.' p. 325; R. Etheridge, 1888, 'Foss. of Brit. Islands,' vol. i. Pal. p. 301.

Shell elongated, turreted, composed of from ten to twelve whorls. Whorls angular; surface nearly flat, both above and below the angle. Sinual band situated about the middle of the body-whorl and a little below the middle of the upper whorls; it is narrow and bounded by two keels, generally about equal in strength, but sometimes the lower keel is more strongly developed on the anterior whorls. Ornamentation consisting of two fine keels above the band and two stronger ones below, with one or two finer additional keels on the body-whorl and occasionally a fine thread in the middle of the band. Sutures deep. Lines of growth fine, distinct, and slightly irregular, strongly arched on the band. Base convex. Mouth unseen.

[1] 'Faune du Calc. Carb. de la Belgique,' vol. viii. pt. 4, p. 22, pl. xxxiv. figs. 32–34.

This species has been erroneously identified by De Koninck with his *M. Archiaciana*,[1] from which it differs by its much smaller size, greater spiral angle, more angular form, the smaller number of its keels, and also their greater relative strength. He evidently confounds *M. angulata*, Portl., with *M. elongata*, Portl., shells which are not only distinct species, but which he also considers belong to different genera. On p. 67 he identifies the former with *Worthenia Waageni*. In his account of *M. Archiaciana* he refers to the figure of *M. elongata* and the description of *M. angulata*, Portl.

The largest specimen in the Museum of Practical Geology, London, is that figured by Portlock. There are only eight whorls, as the apex is imperfect. Length 19 millim.; width of body-whorl $8\frac{1}{2}$ millim.

Localities. Dromard, Draperstown; Ballynascreen, Londonderry.

Formation. Lower Carboniferous Shales, referred by Prof. Hull to the Upper Calciferous Series.

In the Museum of Practical Geology there is a shell (Pl. XVII. fig. 6) from the Calciferous Sandstone Series of Northumberland (marked R. 106 with a red line) which strongly resembles this and is probably identical with it. It differs slightly in ornamentation, having a fine thread between the sinual band and the lower of the keels on the upper surface of the whorl. Also the upper of the two keels bounding the sinual band appears to be more prominent than on the Irish specimens. The shell is embedded in the matrix and only about eight whorls are visible, of which the length is $21\frac{1}{2}$ millim.; width of penultimate whorl 8 millim.

Locality. River Tweed, a quarter of a mile below Coldstream Bridge.

Formation. Calciferous Sandstone Series.

Section Cœlocaulus, Œhl.

Shell elongated, whorls smooth, sinual band not prominent, sinus shallow. Distinguished from *Hormotoma* by its flattened whorls, sutures less impressed, and above all by the existence of a narrow but very deep umbilicus. Columella quite vertical, peristome reflected.

Murchisonia (Cœlocaulus ?) tuedia, sp. nov. (Pl. XVII. fig. 7.)

Shell elongated, conical, composed of more than ten compactly coiled whorls. Whorls smooth, somewhat flattened and separated by sutures, but slightly inclined from the horizontal. Sinual band nearer the anterior than the posterior suture, level with the surface of the whorls, and defined by a very fine thread on each side. Lines of growth strong, curving back to the band above and forwards again below, indistinct on the band, but sufficient to give evidence of a somewhat shallow sinus. Base probably flattened. Mouth unknown.

I refer this shell to the Section *Cœlocaulus*, Œhl., on account of its compressed whorls and flat sinual band. As the mouth and base

[1] 'Faune du Calc. Carb. de la Belgique,' vol. viii. pt. 4, p. 16.

are not well preserved, it is uncertain whether it possesses the other characteristics of *Cœlocaulus*—viz., the narrow umbilicus, vertical columella, and reflected peristome. Its compact flattened whorls distinguish it from *Hormotoma.*

It is quite distinct from any other Carboniferous species in Britain that I am acquainted with. But it bears a strong resemblance to the Silurian forms *Terebra* (?) *sinuosa*, Salter,[1] *Turritella cingulata*, Hisinger,[2] and *Murchisonia Anna*,[3] Billings. It is evidently closely allied to the Devonian shells described by D.-P. Œhlert, of which *M. Davidsoni*[4] is the type.

Length $11\frac{1}{2}$ millim.; width of penultimate whorl $4\frac{1}{2}$ millim.; height $2\frac{1}{2}$ millim.

Locality. There are only two specimens in the Tate Collection, Alnwick. That figured is from Lewis Burn, the other from Cawhope.

Formation. Calciferous Sandstone Series.

Section Cerithioides, Haughton.

Shell elongated, conical, whorls slightly convex, smooth, band not raised above the surface; base flat, grooved. No umbilicus. Mouth probably subrhomboidal.

Murchisonia (Cerithioides) telescopium, Haughton. (Pl. XVII. figs. 1, 4, 5, 8.)

Cerithioides telescopium, Rev. Prof. Haughton, 1859, 'On some Fossil Pyramidellidæ from the Carb. Limestone of Cork and Clonmel,' Proc. Dublin University Zool. & Bot. Assoc. vol. i. pt. iii. p. 282, pl. xx. figs. 2, 3, 4.

? *Murchisonia maxima*, L. G. De Koninck, 1883, 'Faune du Calc. Carb. de la Belgique,' vol. viii. pt. 4, p. 26, pl. viii. fig. 7.

? *Glyptobasis conica*, ibid. p. 92, pl. viii. figs. 4–6.

Shell large, conical, composed of more than nine whorls. Whorls smooth, flattened, slightly convex, the lower whorls becoming more convex in the larger specimens. Sinual band wide, situated below the centre of the whorl, very slightly sunk below the surface, bounded on each side by a shallow groove. Lines of growth curving backwards to the band above and forwards again below, obscure on the band itself. Base very flat, ornamented by numerous spiral lines alternately strong and fine, separated by grooves which become gradually wider towards the outer margin. Mouth imperfectly known, probably subrhomboidal. No umbilicus. Shell-structure thin.

This shell is quite distinct from any British species with which I am acquainted, but it bears a strong resemblance to two Belgian shells—namely, *Murchisonia maxima* and *Glyptobasis conica*, De Koninck. I have examined the specimens of these in the Brussels

[1] Mem. Geol. Surv. 1848, vol. ii. pt. i. p. 357, pl. xiv. fig. 2.
[2] 'Leth. Suecica,' 1837, p. 39, pl. xii. fig. 6.
[3] 'Canad. Nat. and Geologist,' vol. iv. 1859, p. 358, fig. 8.
[4] Bull. Soc. d'Etudes Scientifiques d'Angers, 1887, p. 20, pl. vii. figs. 4–4 *d.*

Museum, and they are so much alike that I think the discovery of better-preserved individuals would most probably prove them to be the same species. There is only one of *M. maxima*, the surface of which is very imperfect, and the shell is flattened by pressure. The band is obscure, but seems to be in the same position as in *Cerithioides telescopium*, and there are traces of grooves on the base. Of *Glyptobasis conica* there are two specimens, both badly preserved and more or less contorted by pressure. It agrees with *Cerithioides telescopium* in form and in having a grooved base, but there is no evidence of the existence of a sinual band; this band, however, is so superficial that it could only be visible on well-preserved shells.

I have met with eight specimens of this species, none of which are entire. Six of these are Irish, and they are all more or less compressed. I am indebted to Mr. J. Wright for the loan of three, two of which were figured by Prof. Haughton. The largest (Pl. XVII. fig. 5) consists of about five and a half whorls, the base is embedded in the matrix, and the apex is broken. Length about 94 millim.; width of body-whorl one way 47 millim., the other 40 millim. A smaller specimen (Pl. XVII. fig. 4) has ten whorls and the apex embedded in the matrix; it is figured by Prof. Haughton, and has a length of 67 millim., width 36 millim. The other figured by Prof. Haughton has only two and a quarter whorls in a length of 48 millim.

Locality. Near Cork.

In the Museum of Queen's College, Cork, there is a fragment consisting of two and a half whorls from Windmill Quarry, Cork.

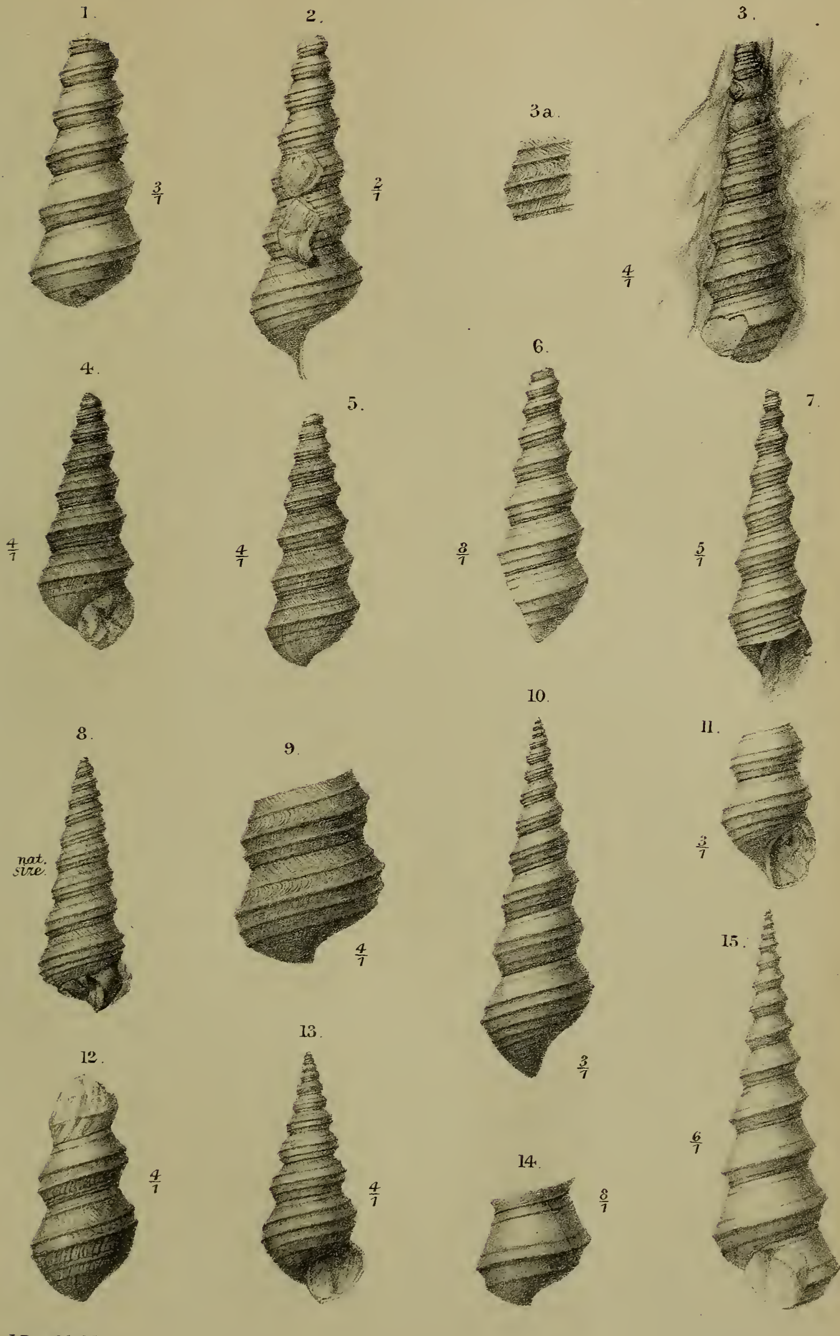
A specimen (Pl. XVII. fig. 1) in Trinity College Museum, Dublin, has eight whorls preserved; the apex is broken, and the shell is greatly compressed, so as to make the sutures appear much more oblique than they would be in the natural condition. Length 70 millim.; width of body-whorl about 40 millim.; height about 20 millim. *Locality.* Little Island, Cork.

There is a large specimen of about nine whorls in the collection of the Geological Survey, Dublin. Surface badly preserved. Length 87 millim. *Locality.* Kilgrogan, Limerick.

The British Museum (Natural History) possesses two specimens of this species which are not contorted by pressure, and the whorls are slightly more convex. They are both broken, but the surface of that in the Gilbertson Collection is well preserved, showing the lines of growth distinctly. Neither has the base entire, but one is so fractured across the top that the impression of some of the grooves on the base of a higher whorl is left on the upper part of the lower whorl. The shell (Pl. XVII. fig. 8) in the Gilbertson Collection has part of four whorls preserved, but only the second and third are entire. Length about 62 millim.

Locality. The specimen in the Gilbertson Collection is from Bolland; the locality of the other is unknown.

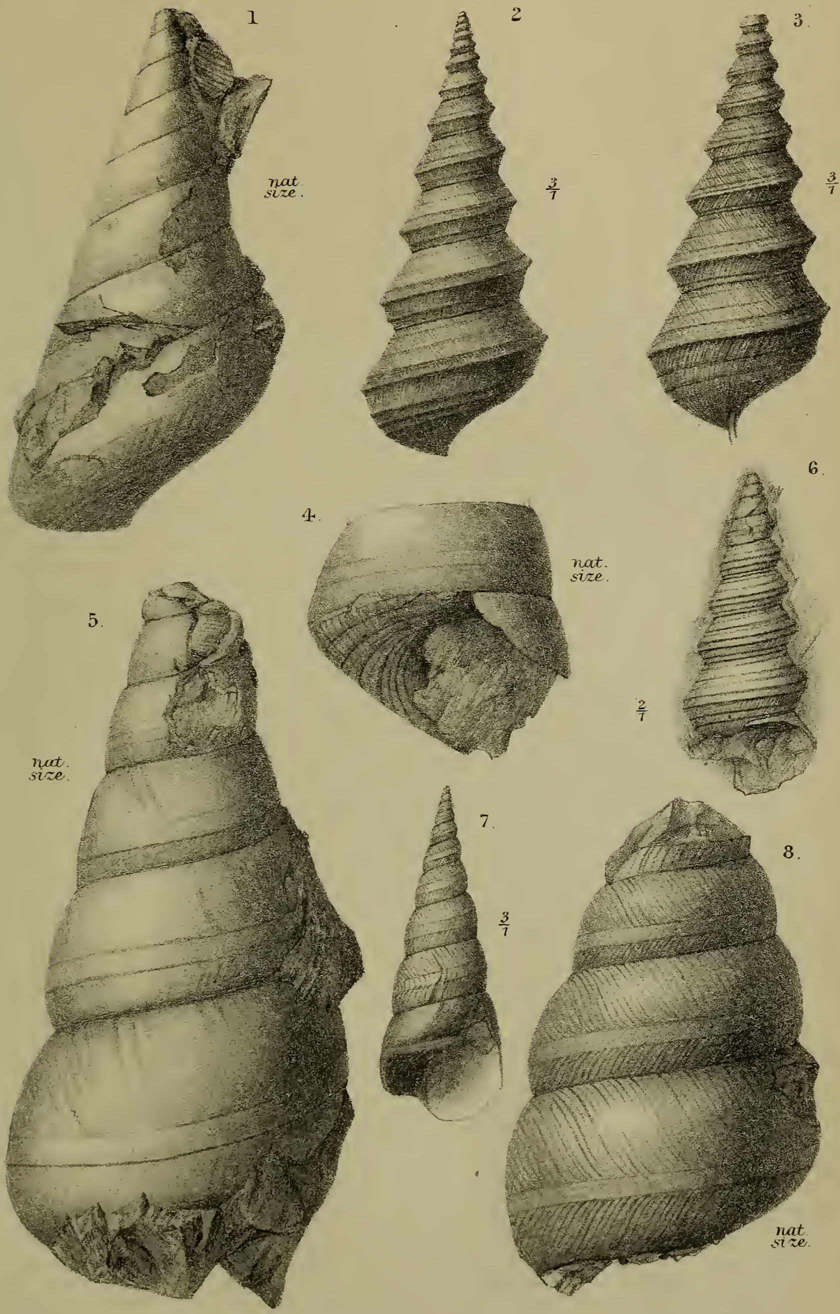
Formation. Carboniferous Limestone.



J. Donald del.
F. H. Michael lith.

Mintern Bros. imp.

MURCHISONIA.



J. Donald del.
F. H. Michael lith.

Mintern Bros. imp.

MURCHISONIA

EXPLANATION OF PLATES.

PLATE XVI.

Fig. 1. *Murchisonia* (*Goniostropha*) *hibernica*, sp. nov., × 3. Hook Point, Wexford. Museum of Science and Art, Dublin.

Fig. 2. *M.* (*G.*) *Tatei*, sp. nov., × 2. Howick. Alnwick Museum.

Figs. 3–6. *M.* (*Hypergonia*) *quadricarinata*, M'Coy. Fig. 3, type, × 4. Blacklion, Enniskillen. Museum of Science and Art, Dublin. Fig. 4, front view; fig. 5, back view, × 4. Settle. York Museum. Fig. 6, × 8. Craigenglen, Campsie. Collection of Mr. John Young, Glasgow.

Fig. 7. *M.* (*H.*) *quinquecarinata*, De Kon., var. *pulchella*, × 5. Law Quarry, Dalry. My own collection.

Figs. 8, 9. *M.* (*H.*) *conula*, De Kon., var. *convexa*. Fig. 8, nat. size; fig. 9, × 4. Abbey Foss, Askrigg. My own collection.

Figs. 10–12. *M.* (*H.*) *pentonensis*, sp. nov. Fig. 10, back view, × 3. Fig. 11, front view, × 3. Fig. 12, fragment showing lines of growth, × 4. Penton. My own collection.

Fig. 13. *M.* (*H.*) *Kirkbyi*, sp. nov., × 4. Randerstone, Fife. My own collection.

Figs. 14, 15. *M.* (*H.*) *plana*, sp. nov. Fig. 14, back view, × 8; fig. 15, front view, × 6. Law Quarry, Dalry. Collection of Mr. John Young.

PLATE XVII.

Figs. 1, 4, 5, 8. *Murchisonia* (*Cerithioides*) *telescopium*, Haughton. Fig. 1, back view, nat. size. Little Island, Cork. Trinity College Museum, Dublin. Fig. 4, portion of a shell showing mouth, nat. size. Fig. 5, back view, nat. size. Cork. Collection of Mr. Joseph Wright. Fig. 8, back view, nat. size. Bolland. Gilbertson Collection, British Museum (Natural History).

Figs. 2, 3. *M.* (*Hypergonia*) *elongata*, Portl. Fig. 2, back view, × 3. Trinity College Museum, Dublin. Fig. 3, front view of type, × 3. Dromard, Draperstown. Museum of Practical Geology, London.

Fig. 6. *M.* (*H.*) *elongata* ?, var., × 2. River Tweed. Museum of Practical Geology, London.

Fig. 7. *M.* (*Cœlocaulus* ?) *tuedia*, sp. nov., × 3. Lewis Burn. Alnwick Museum.

42. NOTES *on the* GEOLOGY *of the* NORTHERN ETBAI. Abridgment of a paper by ERNEST A. FLOYER, Esq., F.L.S., F.G.S. (Read April 27th, 1892.)

BY the scientific expedition despatched by H.H. the Khedive in the beginning of the year 1891 the whole country between the Red Sea and the Nile, and between Kos and Kosair on the north and Assuan and Berenice on the south, was examined and mapped out. Close attention was paid to the geology, for a study of which special preparation had been made, and the simplicity with which the formations are arranged enables a fairly correct picture to be drawn of an area of 2300 square miles, although the time given to its examination extended but little over three months.

The Map which accompanies the present abridgment shows the principal places mentioned in the text, and may be useful to any one who may have time and opportunity to visit the country.

§ 1. KINA-KOSAIR-BERENICE.

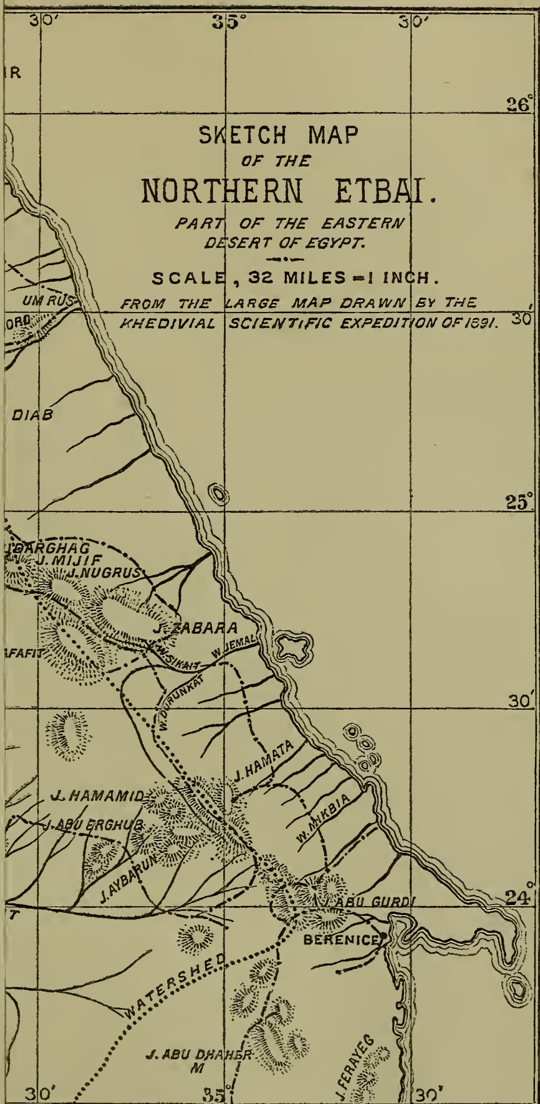
The principal feature is a long ridge of igneous rock running N.N.W. and S.S.E. In this ridge, porphyry at times rises up into lofty peaks. These are at Jebel Dukhan, where are the quarries of the 'imperial red porphyry' now worked by Mr. Brindley, F.G.S. Next southwards come the porphyry peaks of Hullus, and south again the peaks of Jebel Ferayeg, the πεντεδάκτυλον ὄρος of Ptolemy. Between these peaks the ridge is lower, granites and metamorphic rocks alone appearing. The ridge runs near the sea, and the valleys on the east are short, frequent, and deeply eroded, both from the more frequent rains consequent on the sea-moisture, and from the slopes being steeper on the eastern than on the western flank. West of the watershed are four main drainage-basins, the Zeidun, the Abbad, the Khareit, and the Allaki, which last reaches the Nile some 30 miles south of Assuan.

These run over a vast bed of sandstone which dips slightly to the west and to the north, when it sinks under limestone.[1] What may have been the original thickness of this sandstone it may be possible to conjecture from various circumstances which will be hereinafter detailed, but it would seem that there is now no great thickness of it left.

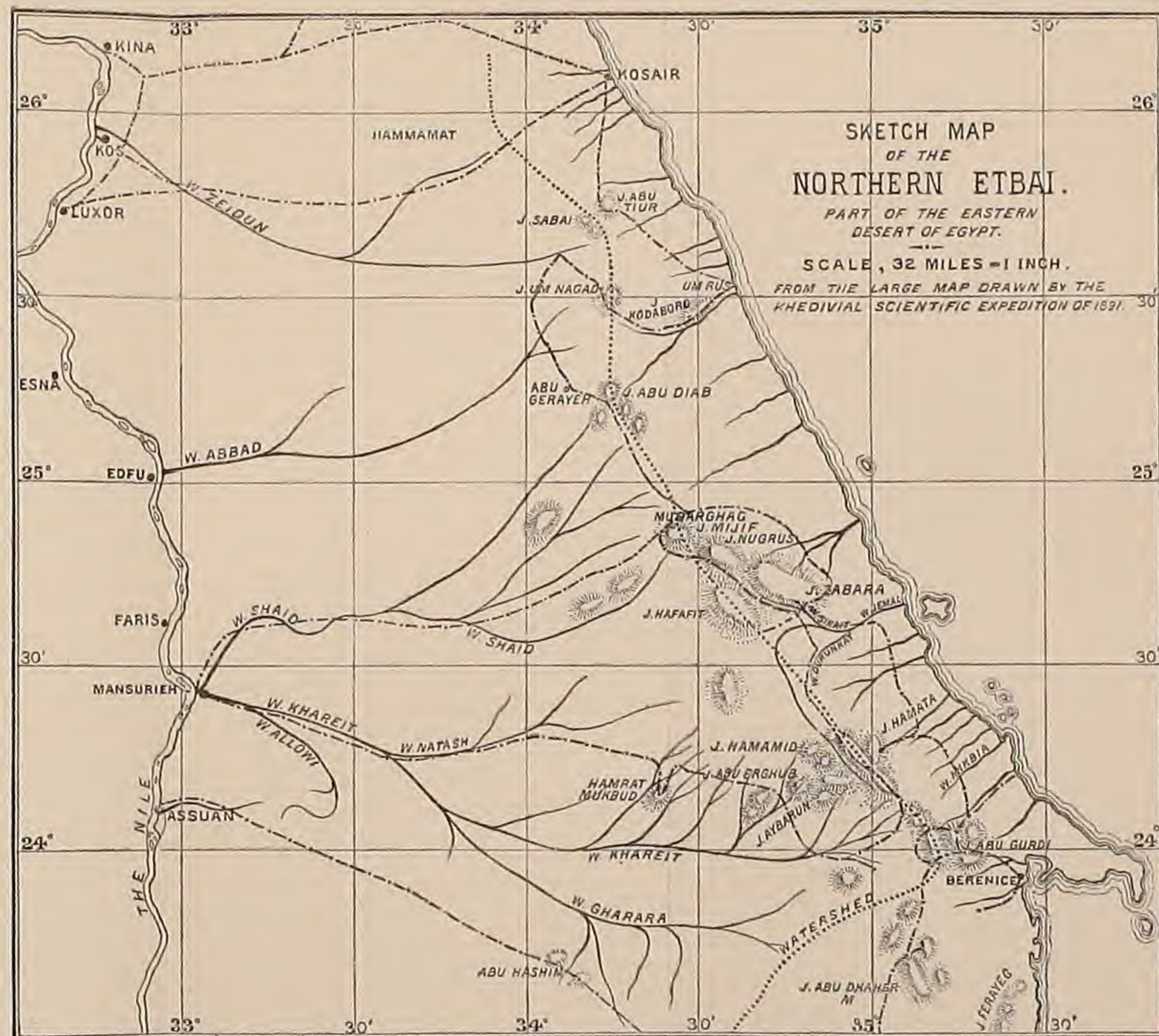
Under the sandstone comes a bed of blue clay, absent or very thin in the south, and increasing rapidly in thickness northwards. This blue clay may represent the mica-slate of Jebel Zabara and the slate-breccia of the Kina-Kosair road. Under the blue clay comes a grey granitic rock. It is very coarse-grained, and composed

[1] In the latitude of Kosair, on both sides of the watershed, is seen limestone bedded over sandstone over blue clay; nor was any difference observed in the sandstone or the limestone on either side of the watershed.

[*To face* p. 576.



outes traversed by the Author.



Note.—The broken lines —·— —· indicate the routes traversed by the Author.

almost wholly of felspar and mica, the latter mineral causing it to disintegrate rapidly. It shows often dark spots and patches which the Arabs call "leprous patches," and which are caused by a large proportion of hornblende. This rock forms a large part of the surface east of the watershed to the south, where it has been covered only by sandstone. It is worn into caverns and potholes and into large balls; it peels and blisters like a lump of dough. All authors who have written about this country have noticed it, from Strabo downwards, and it looks so much as if it had been subjected to the action of a rushing stream that Colston writes, "on seeing it one would say there had been a cataract here."[1]

The *lapis psaronius* quarried at Jebel Fatīrah is probably the same rock that has become brighter and more sparkling by a larger proportion of quartz and hornblende: it rises up into great pinnacles and bosses called 'Mudarghag,' some of them 1600 feet in relative height, and standing in a mass of their own scalings; grey, like those of Hamrat Mukbud, buff like Abu Diab, pink like Kodaboro, which is composed almost entirely of pink felspar, and down whose sides streams a gravel recalling in appearance pink snow. Where this 'cataract' rock touches the sandstone, the latter is metamorphosed into a brilliant green crystalline rock. This is a very handsome stone at the mines of Um Eleagher, near Jebel Abu Dhaher.

Below the 'cataract' rock is a very compact, hard granite, of apparently great thickness. This does not often come to the surface, but it forms the principal mountain-masses, such as Abu Erghūb, Aybarūn, Hamāta, Abu Gurdi, and the twin peaks of Hamamīd. It is close by the huge mass of Hamāta that the porphyry of Hullus appears; the rock is of various colours, but has chiefly a dark chocolate matrix with small quartz-grains. There are other colours: perhaps the most noticeable being a clear sea-green which, when weather-worn, has a purplish surface with yellow lights something like a starling's breast.

§ 2. Assuan to the Red Sea.

On leaving Assuan by the Bab el 'Ajjaj, the Pass of the Sand-driving Wind, one first crosses a mass of crystalline and schistose rock consisting of diorite, dolerite, and syenite. It rises gradually to a height of 900 feet, and then, at the Wadi Allowi (which drains into the Khareit), it falls a little to 700 feet, the level of the sandstone-plain.

Beyond this mass of rock the flat desert rises regularly and almost imperceptibly to the east. The surface is furrowed by long ridges of sandstone with horizontal bedding running from N.W. to S.E. and ranging from 200 to 600 feet of relative height. Here is petrified wood similar to that found outside Cairo.

Up the broad Khareit valley, at the foot of the Jebel Mikbīa, a cluster of 'cataract' boulders will be readily recognized by the name

[1] 'Reconnaissance from Berenice to Berber,' Bull. Soc. Khed. Geogr. 1878.

of 'Stonehenge' given them by the Expedition. Here, at 1550 feet above sea-level, is the edge of the sandstone-plain. The 'cataract' rock swells and bulges up through the rapidly-thinning metamorphosed edge of the sandstone.

The Mikbīa 'divide' is the 'cataract' formation, rising at a gradually increasing angle, till at 2450 feet it is perpendicular. Following the Wadi Mikbīa to the east, the line passes through a great variety of vertical schists, and finally a plain of 'cataract' rock slopes right down to the sea, where, just at the edge, are two recent sandstone and limestone banks, and, in the sea itself, coral supporting mangrove forests.

Abu Gurdi is a huge truncated cone of compact granite which deflects the eastward drainage to the north. It is surrounded by vertical schists and a mass of schistose rocks in thin layers inclined at every angle with the horizon. But seawards these schists give way to 'cataract' rock. East of the watershed for 60 miles to the north, 'cataract' rock, with ridges of vertical schists and a narrow fringe of recent limestones and sandstones, is a brief geological description of the country.

§ 3. The Wadi Jemal Area.

The catchment-basin of the Wadi Jemal is the next matter for description. Approaching from the sea the tall porphyry peaks of Hullus, the cliff is seen to rise steeply for 2000 feet and abruptly for 1000 feet more. Climbing (if it were possible) over these peaks, which rise to a height of 4500 feet, the traveller drops into a deep ravine running north-west, at the source of which are, since many generations of mankind, the broad shady trees and well-fed cattle of the patriarchs Abdullah and Koraim.

From east to west the ridge is only six miles across, and the descent from the western cliff by the Helgeit Pass is but little less steep than the eastern cliff. The ridge of igneous rock is, as has been said, hollow-backed between the porphyry peaks. The Arab simile is apt, —a camel-saddle. At Hullus, in the little craggy ravine from which arises the Wadi Jemal, are some highly picturesque caverns and clefts in the rugged cliffs.

The Wadi Jemal, a fissure between the porphyry on the east and the metamorphosed sandstone-edge on the west, runs north-west for the first six miles, curving round the broad base of the granite peak of Hamāta, known in A.D. 800 as the 'Karkashenda,' the huge mountain south of the Emerald Mines. It is here (in the Wadi Jemal) that sandstone metamorphosis can be seen in every stage. The Wadi Hullus, which becomes the Jemal in its lower course, bends to the west after running twenty miles. But the traveller mounts to his right (the porphyry wall has long disappeared) over a low 'divide' and enters the Wadi Durunkat, which forms a chord of the arc of the Jemal, into which it falls in latitude 24° 35′ N. Here it meets the Nugrus, Hafafit, and Sikait coming from the north-west, and all form a fine well-timbered valley, which has carried so much detritus in floods that at its mouth a considerable island has formed. For the Wadi Jemal forms a depression within a depression—a fold, as it were, in the hollow of the camel-saddle.

In the latitude of the Emerald Mines the ridge is very low. Consequently the westward dip of the sandstone is very slight. It is here that the sandstone lies over blue clay, and the slight angle formed with the horizon makes what is apparently a bed of great thickness spread out over some miles of surface from which the sandstone has been denuded. On this line may be seen every kind of change in the blue clay: from the blue clay full of ferruginous nodules which is seen in the cliffs of Natash and Shaid, it changes eastward into mounds of laminated clay or slate. Then follows the pistachio-breccia (described as a volcanic breccia) where the topazes are found, and then the mica-schist, mica-slate, and talcose blue clay of the mass of Zabara where the emeralds are found, while farther north it merges into the hard slate-breccia of the road between Kina and Kosair.

§ 4. The Wadis Abbad, Shaid, and Natash.

Between the 24th and 25th parallels the edge of the sandstone-plateau lies near the 34th meridian. On the east it stands 200–300 feet above the blue clay, and it slopes down rather rapidly to the west. The two Wadis, Shaid and Natash, which have cut through this edge, have clearly percolated through the blue clay which shows in the cliffs from 50 to 100 feet above the bed, generally obscured by great boulders of sandstone which have fallen from the cliffs on either side. The thickness of the blue clay, if it be not folded at Zabara, may be estimated by the height of that mountain, which seems to be formed of it from top to bottom, at about 1200 feet. Between the sandstone-edge on the 34th meridian and the mass of Zabara are two north-west and south-east ranges converging to the north, and called Nugrus and Hafafit. These seem to be the sandstone metamorphosed, and may indicate the thickness of that formation at 1000 feet.

These ranges at their northern end nearly join the metamorphic mass of Mijif in lat. 24° 50′. Hence northwards the crest is 'cataract' rock, and the characteristic feature of it is the great bosses, principally of felspar, which rise along it, as Abu Diab, Kodaboro, Um Nagad, Sabai, and Abu Tiur.

To the east the 'cataract' granite sinks under the blue clay, here found in every kind of metamorphosis from a dark grey or black schist to laminated clay and slate full of quartz-veins, which at Um Rus have been extensively worked for gold.

The Wadi Abbad was not followed to its junction with the Nile at Edfu, so the line where the sandstone sinks under or meets the limestone was not accurately determined. But at the Roman station of Abu Gerayeh (lat. 25° 18′ N., long. 34° 8′ W.) pockets or isolated outcrops of limestone occur in the sandstone, and have been used by the builders to cement the large burnt-brick tanks which collected water for the station. North of Abu Tiur the 'cataract' rock sinks below the metamorphosed blue clay which, between Kina and Kosair, is bare on the crest; rising from under sandstone under limestone on the west and sinking on the east under sandstone under limestone; nor is there any apparent difference in the sandstone on either side of the crest, though the samples have not yet been examined microscopically. The 'cataract' rock sinks at Abu Tiur, and it seems very probable that it reappears in the Jebel Fatīrah quarries in latitude 26° 50′ N. To the north of the east-and-west depression of Kina-Kosair the ridge rises from 1400 to 1800 feet, and the masses along the western portion of it are uniformly metamorphic sandstone. Nor does any igneous rock appear till the porphyry quarries of Mr. Brindley are reached in latitude 27° 20′ N., where are three parallel lines of upthrust, counting from the west: Um Sidra and Jebel Dukhan (*Mons Porphyritis*), Jebel Aish, and Jebel Zeit close to the sea, where petroleum pools are found in what is apparently a deposit of immense thickness of Miocene limestone.

§ 5. Points to be examined.

It is interesting to compare the sections west of the Red Sea with the geological map by Walther of the Sinai peninsula. A section drawn from Walther's map between the 28th and 29th parallels would give first the fringe of recent coral, then the 'stock-granit' which corresponds to the 'cataract' rock; over this comes the Nubian Sandstone, and over this the limestones.

Before quitting the general geological survey mention must be made of two points on which imperfect geological knowledge debars the Author from expressing an opinion, but which seem to be of considerable interest to geologists.

The first question relates to the great Eocene sea drawn by that eminent geologist Prof. Hull. It seems a most interesting matter for future travellers to examine whether the Eocene sea did not stretch across to Arabia. For, unless the observations are mistaken, the ridge has in latitude 23° N. been thrust through the sandstone which spreads both east and west of the watershed.

Another question of interest is what is the history of the blue clay which lies under the sandstone, and of which, so far as the Author has been able to ascertain, no mention has been made previously.

A Pluvial epoch is thought necessary by some to account for the erosion of the valleys, but from an examination of the valleys the Author inclines to the opinion of Prof. Schweinfurth that they do not require for their erosion more rain than falls to-day.

§ 6. The Emerald Mines.

The Emerald Mines cover some forty square miles of valley and mountain, and much resemble a large rabbit-warren. From countless holes in every dark hillside pour streams of silvery, powdered mica. The hills are some 1200 feet in relative height, and formed of talcose schist, tortuously bedded, with quartz and limestone-veins and masses of tuff. The principal old shafts are on the south, while the modern borings of 1820 are on the north. There are perhaps 500 to 800 shafts, and buildings still represent the various periods of working from B.C. 20, if not earlier, to A.D. 1526, when the emerald mines of South America outstripped those of Egypt in producing the gem.

Discussion.

The Chairman (Prof. Judd) expressed his regret at the absence of the Author, and invited discussion on the paper.

Prof. Hull observed that he felt great reluctance to criticize adversely a paper in the absence of its Author, but there were several points in Mr. Floyer's communication he could not agree with, the chief of which was the view of the Author that the Nubian Sandstone had been converted by a process of metamorphism into granite, owing to its contact with porphyry and with the igneous rocks of the ridge bordering the Red Sea coast. Nearly all observers were of opinion, in which he (Prof. Hull) concurred, that the igneous and granitoid rocks of this ridge were of immense geological antiquity, in all probability of Archæan age, and as the Nubian Sandstone was of Cretaceous age there could be no possible effect produced on the latter by contact with the former. The breccia and conglomerate found at the base of the Nubian Sandstone were in reality a littoral deposit—derived from the waste of the Archæan rocks.

Mr. Floyer's 'blue clay' the speaker regarded as probably decomposed schist of the Archæan series, and he could have wished that the Author had given more precise information concerning the occurrence of the emeralds than was given in his paper.

In conclusion, the speaker did not see any reason for abandoning the view which he had arrived at from his observations in Arabia Petræa and Southern Palestine, namely, that the formation of the remarkable dry valleys in this part of the world could only be accounted for on the supposition that at a former period the rainfall and resulting streams had been greatly in excess of those of the present day, and this Pluvial period he believed to have represented the Glacial period of more northern latitudes.

Prof. Le Neve Foster complained of the absence of specimens, and said that it was impossible to discuss the paper without them. He regretted that a paper on emerald mines contained so little information about the mode of occurrence of the mineral.

Mr. Rudler explained that, although no specimens were exhibited in illustration of the paper, he had had an opportunity, some time ago, of seeing the specimens brought from the Emerald Mines by Mr. Floyer. The rock representing the matrix of the emerald appeared to be a biotite-schist, more or less talcose. Mr. Floyer had obtained two crystals of emerald, which were attached to quartz, apparently from a vein in the mica-schist. The mode of occurrence of the emeralds of the Etbai was somewhat similar to that of the emeralds of Siberia and of Salzburg, where the mineral was associated with mica-schist, while it was entirely different from that of the South American emerald, which occurred in a bituminous limestone, supposed to be of Neocomian age.

Mr. J. W. Gregory said that Mr. Floyer was probably using the term 'Nubian Sandstone' in its old sense, including a series of sandstones from the Cenomanian to the Carboniferous. He suggested that it was possible that the rock which Mr. Floyer regarded as altered Nubian Sandstone might be much older than the base of that series in Prof. Hull's diagram, which possibly represented another tract of country.

Dr. Blanford also spoke.

43. *On a* NEW REPTILE *from* WELTE VREDEN (BEAUFORT WEST), EUNOTOSAURUS AFRICANUS (SEELEY). By H. G. SEELEY, Esq., F.R.S., F.L.S., F.G.S., Professor of Geography and Lecturer in Geology in King's College, London. (Read June 22nd, 1892.)

WHEN I visited Welte Vreden, near Beaufort West, Cape Colony, in August 1889, Mr. L. Pienaar gave me a small ovate concretion which contained the dorsal region of a new reptile. As preserved it is 7·5 centimetres long and 5·75 centimetres wide.

It shows on the ventral aspect the under surfaces of seven consecutive dorsal vertebræ. These centrums are more slender and elongated than in any South African fossil previously known. They decrease in length from front to back. The first (which may be the first dorsal) is fully 1·25 centim. long, while the seventh is 0·75 centim. long, and is probably the last dorsal or lumbar vertebra, since the pubis is found immediately behind it. These vertebræ in form and number suggest the Chelonian type. They are of an elongated hour-glass form, and relatively longer than in Teleosaurs. The centrum appears to be hollow, but this condition is probably the effect of deep penetration of the conical notochordal substance, as in *Mesosaurus*, and the vertebræ referred by Sir R. Owen to *Tapinocephalus*. A conical cavity penetrates the posterior end of the sixth centrum, and apparently the anterior end of the first, so that the constriction in the middle length of the centrum is due to the tapering away of these conical cups. The articular faces are not exposed, but are inferred to be approximately circular, and the under surface of the centrum is rounded from side to side. In the seventh vertebra a slight lateral widening is seen in front, towards the neural arch. (See fig. 1, p. 584.)

The neural canal is fairly large and rather wider than high, but is only exposed by fracture of the neural arch on the dorsal surface. There is no indication of such transverse expansion of the neural arch as is seen in the Pareiasauria and Mesosauria, so far as can be judged from the bony tissue preserved. The neural spine is compressed as shown in the first vertebra, but there is no evidence of its length. There is no satisfactory evidence that transverse processes were developed; and the ribs were certainly attached closely to the sides of the neural arches, much as in Chelonians, but apparently more widely along the side of the arch.

The ribs are remarkably massive. They are long and convexly curved, deep and convex from side to side in the proximal ventral portions, which are only exposed obliquely on the posterior aspect where the ribs are crushed downward and forward. Above this powerful support there is a thin plate which extends beyond the inflated inferior portion of the rib, so as to give an antero-posterior extent of about 1 centimetre. Hence the ribs appear to be as wide as the vertebræ are long. This expanded superior layer is broken

Fig. 1.—*Ventral aspect of* Eunotosaurus.

Natural size. *p*, os pubis; and vertebræ.

Fig 2.—*Dorsal aspect of* Eunotosaurus.

Natural size. Vertebræ and ribs.

away from the bone beneath in places, but there is no proof that it is a separate ossification. Some approach to this type of rib is seen in *Cratæomus* from the Gosau Beds.[1] Still, as the centrums have a Chelonian aspect, it is interesting that the ribs should also simulate the ribs and costal plates of Chelonians. But they were clearly free at their margins, and rather resembled the ribs of certain Edentata, like *Cyclothurus*, in their superior aspect. The ribs are about 5 centimetres long. There are one or two wide thin bones in the ventral cavity which have the aspect of being sternal ribs, or their representatives. And although there is no proof that they are correctly identified, the possibility of such ossifications being present is worth recording, as it might be a further approximation towards the Chelonian type. Nevertheless, too much importance may be attributed to such characters, unless it is remembered that the specimen affords no proof that the whole of the dorsal vertebræ are preserved.

At the posterior ventral extremity is the left os pubis (see fig. 1), a flattened bone of moderate size, thin, rather longer than wide, with a notch at the external posterior border, which recalls the condition of the bone in various Mesosauria. At the right hinder corner of the specimen are fragments of two parallel slender cylindroid bones which may be parts of the tibia and fibula.

From the fragmentary condition of the remains, it seems to me inexpedient to determine absolutely the systematic position of the genus. Every character preserved differs from those of South African fossils hitherto known, with the exception of the imperfect pubis. This bone strongly suggests that the specimen is referable to the Mesosauria, in which it is likely to be placed, in a division distinct from the Proganosauria.

In conclusion I would express my thanks to the Committee of the Government Grant Fund of the Royal Society, for assistance in making this investigation.

[1] Quart. Journ. Geol. Soc. vol. xxxvii. (1881) pl. xxvii. fig. 18.

44. *The* MESOSAURIA *of* SOUTH AFRICA. By H. G. SEELEY, Esq., F.R.S., F.L.S., F.G.S., Professor of Geography and Lecturer in Geology in King's College, London. (Read June 22nd, 1892.)

[PLATE XVIII.]

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§ 1. INTRODUCTION.

PROF. GERVAIS in 1865 described under the name *Mesosaurus tenuidens* the remains of a small reptile from Griqualand, South Africa, which had been brought to France more than thirty years before. It is preserved in a slab which shows the skull and anterior portion of the skeleton. As with other vertebrate remains from South Africa, its exact geological age is unknown. The author states [1] that the animal was a little larger than the Ocellated Lizard, and has many affinities; resembling in some characters terrestrial types of reptiles, while in other characters it approaches Simosaurians and Plesiosaurians. Its cervical vertebræ have some resemblance to those of Crocodiles. The lower jaw recalls in a general way Crocodiles and Plesiosaurs. The dorsal vertebræ are rather elongated and comparable to those of Homœosaurians and of Teleosaurs. The ribs are stronger than in any known reptile except *Pachypleura*, and are arranged as in that genus. They have much the same relation to the ribs of other reptiles that the ribs of Sirenians have to those of other mammals. The sternal ribs, identified by Cope, were regarded as annelid tracks. The scapular arch is compared to those of Crocodiles and Plesiosaurs; but the scapula and coracoid are anchylosed. The humerus is that of a Plesiosaur or Simosaur, with an ent-epicondylar perforation, like that seen in *Varanus* and certain mammals. The forearm and hand are of less aquatic type than in Plesiosaurs, and approach the terrestrial type; but the ulna, unlike that of terrestrial reptiles, has no olecranon. The animal is compared to *Lariosaurus*, *Machrimosaurus*, and *Pachypleura*, but is distinguished from them by the form of the head, the teeth (which are exceptionally long), and the number of cervical vertebræ, which were stated to be seven, with two which are intermediate in character between the cervical and dorsal.

[1] Gervais, 'Zoologie et Paléontologie Générales,' 1867–69, p. 223, pl. xlii.

§ 2. The Kimberley specimens of Mesosaurus pleurogaster.

Many years passed without further evidence of *Mesosaurus*. But about 1878 Mr. G. H. Lee, F.R.M.S., of Kimberley, obtained from the shale at the margin of the Kimberley Diamond Mine some specimens, which were partially figured by Mr. J. W. Matthews in his 'Incwadi Yami' in 1887. In 1878 these four specimens, which were all that were collected, were deposited in the British Museum. Two display the characters of the lower dorsal and lumbar vertebræ, the dorsal ribs and abdominal ribs; the third fragment shows some characters of early caudal vertebræ, and the hind foot, which lies towards them; the fourth specimen belongs to the middle region of the tail. There are slight differences in the relative sizes of the bones in the several slabs, and differences in the colour and hardness of the marly matrix, so that the remains may be portions of more than one individual, but I have no doubt that they are all referable to one species.

They show that *Mesosaurus* was a long-tailed reptile, with hind limbs well developed. The remains are not easily compared with the type in Paris, which is in a very dark hard matrix; but they add materially to our knowledge of the genus, and are now described under the numbers in the British Museum Catalogue.

No. 1.—49972. Presented by Wm. Benstead Smith, Esq., Registrar of Kimberley Mine. This specimen, found $\frac{1}{4}$ mile S.E. of Market Square, Kimberley, in January 1878, is a natural mould in pale whitish calcareous shale, from which the bones have disappeared. The late Mr. Wm. Davies placed with it a plaster-of-Paris impression which exhibits the forms of the bones in natural relief. It shows the ventral aspect of the bodies of eleven vertebræ, eight of which carry ribs; the last three show no trace of ribs, and may therefore be lumbar.

The bodies of the vertebræ are not in close contact, but separated by narrow intervertebral spaces. Each centrum is 6 millimetres long. Its form is semicylindrical, being convex from side to side, without the slightest concavity in length. On the contrary, the articular faces are a little contracted, and, on the evidence of one displaced centrum, are characterized by a subconical articular cavity penetrating into the centrum for fully a third of its length. The neural canal is wide, concave below, and angular above. The intervertebral perforations for the nerves are inferior in position to the transverse tubercles from the neural arch. These tubercles increase the width of the vertebræ, as exposed, to about 1 centimetre.

The ribs, 4 centimetres long, are strongly curved in the proximal part, and less curved distally, where they become cylindrical and thicker, being fully 3 millimetres wide. In the proximal third the rib is less than 2 millimetres thick, so that it is there flattened from below upward; and its small articular extremity bends a little forward. The measurement over the two extremities of the dorsal ribs is 3 centimetres. The length of the posterior ribs diminishes, so that the last is only 1·5 centimetre long, and the distal ends of the last four terminate in the same transverse line, showing that the vertebræ behind them are lumbar. The massive cylindrical character and small head are the most distinctive features of the rib.

Delicate, curved, flattened, fusiform ossifications extend transversely over the ventral interspaces between the ribs, as well as beneath some of the ribs, and beneath the centrums of some vertebræ. These are the abdominal ribs. They are five or six times as numerous as the costal ribs, and are composite, joining each other by squamous overlap or contact, so as to form a ventral armour like that seen in the abdominal ribs of certain Plesiosaurs, with a median riblet and two lateral elements on each side. The middle bones are 7 millim. long.

No. 2.—49971. Presented by Maurice Marcus, Esq., from Mining Board Cutting, 50 feet deep; 100 feet from the eastern margin of Kimberley Mine, March 1878.

This is a natural mould of the dorsal region which exposes the dorsal aspect of the corresponding portion of a similar but slightly larger animal; for while seven vertebræ in No. 1 measure 4·7 centimetres, seven vertebræ in this specimen measure 5·5 centimetres. But there is no difference in the character of the vertebræ and ribs.

Eight vertebræ with their ribs are exposed in sequence, and the flattened filamentous abdominal ribs are seen between the costal ribs, admirably preserved. This armour is quite unlike that attributed to *Mesosaurus tenuidens*, and may indicate another species.

The neural arch, seen from above, has a wide subquadrate form; it is 6 millimetres long and 1 centimetre wide, but the width becomes less in the hinder vertebræ. It is slightly wider in front than behind. The dorsal surface is divided into two lateral subhorizontal areas, which are convex from back to front, by a very thin neural spine, which was vertical, compressed to a sharp edge anteriorly and posteriorly, and appears to have been low.

Laterally the neural arch of each vertebra gives off a strong tubercle. It is subconical, compressed from above downward, placed well below the level of the neural platform, towards the anterior end rather than in the middle of the side of the vertebra. These tubercles extend the width of the arch for 2 or 3 millimetres on each side in the earlier vertebræ, but they appear to be slightly shorter and slightly lower in position in the last vertebræ preserved.

The dorsal ribs lie in natural sequence. At first sight they appear to be wider proximally than in the other specimen, because they are exposed so as to show the superior convex dorsal curvature; but enough of the margin is exposed to show that the proximal end was compressed from above downward, so that there is no difference of condition, though these ribs are uniformly wide from the proximal to the distal end.

At the hinder extremity of this slab are two early caudal vertebræ, isolated, and partly exposed; one showing the anterior, the other showing the posterior articular face.

The anterior aspect displays the relatively small size of the face of the centrum as compared with the neural arch, the width of the former being apparently about 5 millimetres, and of the latter about 11 mm. The prezygapophyses extend in advance of the face of the centrum, but are rather short, and look upward and inward. The sides of the neural arch are inclined obliquely outward, are convex from above downward, and look outward and upward. The transverse processes or caudal ribs are strong, subconical, almost horizontal processes, 9 millimetres long, compressed from above downward into a wedge-shape at the outer extremity; while they are flattened vertically in front at the base, which is 4 millimetres deep, where the process is given off from the conjoined centrum and neural arch. The processes are directed outward and a little downward. The neural spine is short, and in front it is sharp; the height from the base of the centrum to its summit is 1·5 centimetre.

The posterior aspect shows similar characters in the neural arch, except that the lateral convexity is rather greater, and the height is rather less. The posterior zygapophyses are compressed from above downward, and look obliquely downward and outward; the transverse width over them is about 7 millimetres, being apparently rather less than the anterior measurement. The neurapophyses do not extend to the hinder face of the centrum, but are notched out in the usual way to form the intervertebral foramen. The centrum is convex on the under side, as in the dorsal region, but its dimensions contract markedly towards the concave posterior articulation. The transverse process or caudal rib appears to be flattened on its under side; it is about 1·2 centimetre long.

No. 3.—49974. Presented by Captain Scott Helps; from the cutting at the east of Kimberley Mine, facing Claim ·018, 40 feet from the margin and 50 feet deep; January 1878. This specimen shows an impression of a few early caudal vertebræ, very imperfectly preserved; and an impression of the hind foot with the distal row of the tarsus, the metatarsus, and digits having the formula 2·3·4·5·4.

The inflated sides of the neural arches are shown in five vertebræ, and the stout, subconical, transverse caudal ribs attached to them diminish from a length of 1·5 centimetre in the earliest to about 4 millimetres. These processes are rounded; their shortening in these five vertebræ may be taken to indicate that they are speedily lost, and that the sides of the caudal vertebræ then become flattened.

The evidence concerning the hind limb, though fragmentary, is instructive. The distal row of the tarsus is preserved and consists of five subovate cuneiform bones, of which the fifth is very small.[1] One of these bones articulates with the proximal end of each metatarsal (as in *Cryptobranchus* and *Salamandra*). On the external side of the slab, above the small fifth cuneiform bone, is the large broadly wedge-shaped cuboid, and above the other bones a part only is preserved of a larger bone which the evidence does not enable me to identify.

The metatarsal bones progressively increase in length, and there

[1] This fifth bone is much smaller than in *Stereosternum.*

is a corresponding elongation of the phalanges of the digits, so that curves might be drawn through the articular ends of the bones which would diverge as they extend outward and forward. The first digit is the shortest and strongest; the two outer digits appear to be slightly the more slender. All the metatarsals and phalangeal bones are more or less contracted in the shaft and expanded at the ends, and the digits terminate in conical claws.

The first digit measures 1·7 centimetre in length, of which the metatarsal forms one centimetre; it is a stout bone with the extremities fully 4 millimetres wide. The first phalange is less than 4 millimetres long and the conical claw-phalange 3 millimetres long. The interspaces between the bones are small, showing that their extremities were well ossified.

The second digit is 2·6 centimetres long. The metatarsal bone measures 14 millimetres. The first phalange is 5 millimetres long, the second scarcely 4 mm., and the third 2 mm.

The third digit has a length of 3·2 centimetres. The metatarsal bone is 15 millimetres long. The first phalange is 7 mm., the second 4 mm., the third 3 mm., and the fourth 2 mm.

The fourth digit has a length of 4·8 centimetres. The metatarsal bone has a length of 1·7 centimetre. The first phalange measures 8 millimetres, the second 5 mm., the third 4 mm., the fourth 3 mm., and the fifth phalange has a length of 1 millimetre.

The fifth digit has a length of 4·1 centimetres. The metatarsal bone is 2 centimetres long. The first phalange is nearly 11 millimetres, the second fully 5 mm., the third 3 mm., and the fourth, which is very small, is about 1 millimetre long.

No. 4.—49973, was found at the same time and place as the specimen just described, and presented to the British Museum by the same gentleman. It may therefore be a portion of the same individual. It is a similar slab in soft shale exhibiting some characters of the middle caudal region. It includes 18 vertebræ. In the early vertebræ the length of a centrum is 9 millimetres, and as the series measures 15·5 centimetres, it is manifest that the decrease of the vertebræ in length, as they extend posteriorly, is slight. The subquadrate vertebral bodies are flat at the side, with the centrum scarcely defined from the neural arch, which contracts anteriorly and laterally, so as to form a sharp, strong, pointed neural spine, which is directed upward and backward. In the later vertebræ, the neural spine becomes at first more slender, and afterwards, in the hindermost vertebræ preserved, it is more depressed. Chevron bones are present in all the vertebræ which are sufficiently well preserved to show them. They appear to be attached in the usual way at the posterior angles of the centrums, are more slender than the neural spines, rather shorter, and directed backward at a sharper angle. They are 9 mm. long, 2 mm. wide, and terminate at first in a horizontally truncated surface, but afterwards they are more compressed distally. (See fig. 1, p. 591.)

This completes the evidence from the Kimberley specimens. It is impossible to say that they belong to *M. tenuidens*. The well-developed abdominal ribs, formed of flattened plates, give its most distinctive feature, and it is probable that the species is different from the slender delicate type-species, with elongated teeth. It makes known the remainder of the skeleton, with the exception of the pelvis and sacrum, the femur, tibia, and fibula, and the extremity of the tail.

Fig. 1.

ch = chevron bone.

There are some points in which it appears to me that the Mesosaurian shoulder-girdle figured by Gervais may be given a different contour, but the evidence in favour of this change in interpretation will be better appreciated after the discussion of a new specimen which is preserved in the South African Museum, Cape Town.

§ 3. The Mesosaurus tenuidens (Gervais) from Albania.

The Cape Town fossil was collected by David Arnott in the district of Albania in Griqualand West. It is in white fissile marl, and, as in all other similar specimens, the bones have disappeared and left an internal mould of the skeleton. The slab unfortunately only shows the ventral aspect of the anterior part of the skeleton. It appeared at first as though the skull had a short triangular form, but by careful development from the matrix it is proved to have had the same elongated form of head which characterizes the Paris type; and, indeed, it extended beyond the limit of the slab.

As preserved, the lower jaw is 5 centimetres long. The rami are narrow in the articular region, beyond which they are prolonged backward in a heel. The transverse width over the articular region is about 1·5 centimetre. The rami widen as they extend forward, though this condition may be, in part at least, the effect of compression, since a median channel extends along the symphysis, of which not more than 1 centimetre is preserved. The transverse width at the anterior fracture exceeds $\frac{1}{2}$ centimetre. The external surface of the bone is somewhat uneven and marked with longitudinal striations. Behind the acute anterior convergence of the rami the palate is exposed. It is completely closed, without indication of any vacuity. Two elevated ridges nearly parallel to each other and close together extend along its length and converge backward. There is a possibility that these ridges carried single rows of teeth like the teeth on the ridges on the palate of *Pareiasaurus*, as the impression from the cast shows at regular intervals a few white dots along each ridge. The ridges become more elevated at the back of the palate and diverge outward and backward in a V-shape to the articular region, which is strongly suggestive of the pterygoid bones abutting against the basi-sphenoid. It is possible that the palate-nares may be in the depression behind the posterior divergence of the pterygoid bones. On the hinder part of the pterygoid region are short slender rods which appear to be part of the hyoid.

The articulation with the vertebral column is not clearly shown, because the atlas is in close apposition with the back of the head. The teeth are few and imperfectly displayed; they are long, slender, and extend outwards at right angles to the jaw.

The palate closed in the median line is common to *Nothosaurus* and *Pareiasaurus*, and is seen in certain Amphibians, Chelonians, Crocodiles, and other orders, so that it gives no clear indication of affinities. Prof. Cope finds that the head of *Stereosternum* is also elongated, with slender teeth; but the details of the structure have not been determined.

The cervical vertebræ are short, narrow, wider in front than behind, in close contact, with a median ridge moderately elevated on the base of the centrum. On each side of the ridge the base of the centrum is concave, owing mainly to the development of a strong tubercle at the anterior angle of the side of the centrum. These tubercles are compressed from above downward, and each apparently gave attachment to a rib by a facet which is less than half as long as the centrum. Eight cervical vertebræ have a length of 3·25 centimetres. The first three are very short, the atlas shortest. It appears to terminate in front in a concave articular cup. The other centrums are rather less than ½ centimetre long.

The cervical ribs have large heads, which articulate with the lateral tubercles, but appear otherwise to be slender rods which lie near to the sides of the vertebræ and are about 1 centimetre long, which is unlike both the figure of the type of *Mesosaurus*, which has transversely expanded cervical ribs according to Gervais,[1] and the cast of the specimen, though these may be only the expanded heads of the ribs.

In the lateral aspect the cervical vertebræ are concave from above downward. The zygapophyses are well developed and strong; they lean a little forward. The foramen for the intervertebral nerve is developed vertically, and chiefly excavated at the posterior borders of the vertebræ.

Beyond the eighth centrum the vertebræ have a different form. The median ridge gives place to a convex base to the centrum, from the sides of which strong transverse processes are given off. No divisions can be seen between the centrums of the vertebræ 9–11, and they look as though anchylosed. But, since they are curved, that is impossible; and I suggest that the aspect is a delusive appearance which not improbably results from the presence of a thin osseous film which extends over the sutures. The position is that which would be occupied by the stalk of the interclavicle or forward prolongation of the precoracoid. Extending transversely outward from the suture between the eighth and ninth vertebræ are fragments of a transversely extended median bone. On the left side it extends outward and backward to the scapula, so that the bone has the relations of the clavicular mass in Plesiosaurs. The preservation is such that its nature cannot be determined with cer-

[1] The cast and the figure differ materially, especially in the structure of the skull; and I suppose the figure to be more accurate, since it corresponds better with this fossil.

tainty. On the right side are two bones a little displaced, which may be the remainder of the right clavicle and the transverse bar of the interclavicle. Both bones are wider than cervical ribs. There is nothing to show whether the clavicular arch resembled that of *Lariosaurus* and *Nothosaurus*, or that of *Pareiasaurus* and Anomodonts, but that it existed seems probable.

A pair of bony plates make the ventral part of the shoulder-girdle, and cover much of the two succeeding vertebræ so that their transverse processes are not seen. On both sides these bones are fissured and broken by pressure. On the left side a suture extends inward from near the acetabulum, which appears to have divided the mass into a posterior coracoid part and an anterior scapular part. On the right side the suture is not seen. There is a coracoid foramen, which is presumably in advance of the acetabulum. In some Anomodonts the coracoid foramen is situate at the junction of the scapula and precoracoid, in others at the meeting of the scapula, coracoid, and precoracoid; while it is entirely in the coracoid in Crocodiles and Dinosaurs. Hence it may be inferred that the part of the bone which thickens behind the foramen is the coracoid. The thinner plate in front is the scapula. The part of the bone which extends inward from the scapula towards the clavicle corresponds to the precoracoid region, though there is no suture to define it as a separate bone. The contour of the scapula is apparently not unlike that of the Muschelkalk fossil *Dactylosaurus gracilis*, but the coracoid is dissimilar.[1] The correspondence is close with the type *Mesosaurus tenuidens*. In that fossil the coracoids overlap, while in this specimen they are separated, probably by *post-mortem* pressure. On each side towards the median line there is a lunate plate. Its inner border is convex, very thin, and apparently adapted for squamous overlap. As it extends outward towards the coracoid foramen it contracts. There is a deep semi-ovate emargination of the posterior margin of the bone, external to which the posterior border of the coracoid terminates in a transverse line. In front of the emargination the bone thickens to an elevated band, which has the aspect of connecting the lunate mass with the external part of the coracoid and scapula, though there is no anterior emargination, but only a depression in which the coracoid foramen is placed. The external border of the scapula and coracoid is straight, with a tendency to concavity behind the humeri, which extend transversely outward from the middle of the border. In the impression from the natural mould the anterior border of the scapula appears to be rounded, but this may result from conditions of preservation.

A thin plate of bone, of which the outlines are imperfectly defined, extends laterally between the front of the scapula and the clavicle. It appears to be continuous with the inner lunate mass which rests on the 12th and 13th vertebræ, though it is not continuous with the anterior border of the scapula, but above it. It is obviously displaced, since the transverse process of the 10th vertebra extends

[1] Gürich, Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxxvi. (1884) p. 125, pl. ii.

in front of it. Its external border appears to be straight and directed forward. It cannot be determined with certainty, and may be part of the scapula or the epiclavicle or clavicle; most likely the latter, for it is improbable that the epiclavicle has a separate existence as a large bone in *Mesosaurus*, seeing that no trace of it is known in European allies of the type. There is every reason to look for the epiclavicle in such a position in animals of this type, but no specimen shows it. In 1865 [1] I suggested that the lateral plate of the Plesiosaurian scapula was the clavicle. This was corrected in 1874 [2] by finding the clavicles in association with the interclavicle. Mr. Hulke suggested in 1883,[3] that the antero-internal part of the bone which articulates with the coracoid to form the glenoid cavity, is the precoracoid; and that the thin lateral ascending plate which extends above the head of the humerus is a part of the scapula. While the body of this bone both in *Plesiosaurus* and *Mesosaurus* appears to me to be the scapula, there is some evidence to suggest that the ascending plate of that bone in *Plesiosaurus* is the epiclavicle. There is no evidence of any such structure in *Mesosaurus*, though the bone identified as a clavicle in *Dactylosaurus* and in *Stereosternum* is in a not dissimilar position with regard to the head of the humerus.

After the eleventh vertebra, dorsal ribs are developed. Seventeen dorsal vertebræ thus characterized are more or less perfectly preserved. The bodies of the vertebræ increase a little in depth as they extend backward, owing to the transverse process being inclined rather more upward.

The attachment of the rib is by a transversely ovate facet, which is placed *below the zygapophysis on the anterior face of the neurapophysis*, so as to look forward and slightly outward and downward. I am not aware of a similar mode of attachment for ribs in any other animal. When the ribs are *in situ*, their proximal ends, which are compressed, have the appearance of being wedged into the interspaces between the ascending processes of the vertebræ. The articular faces of the contiguous centrums are seen between the twenty-second and twenty-third vertebræ. The centrum contracts a little to its articular ends, which are small and circular, and conically cupped as in the Kimberley specimens. The ribs are cylindrical, strongly curved in a bow, a little compressed proximally, truncate distally, and stout like the ribs of *Lariosaurus*. The first pair, partly covered by the shoulder-girdle, is short and conspicuously slender. The others are of approximately uniform size, the earlier measuring 2·5 centimetres in length, and in the middle of the specimen 3 centimetres; they are about 0·375 centimetre in diameter, but the antero-posterior width rather exceeds the thickness. The interspaces between the ribs are wider than the ribs. This specimen shows no trace of abdominal ribs, unless one or two hair-like rods at the distal end of the right humerus should be of that nature.

[1] Ann. & Mag. Nat. Hist. ser. 3, vol. xvi. p. 358, pl. xv.
[2] Quart. Journ. Geol. Soc. vol. xxx. p. 444.
[3] *Ibid.* vol. xxxix. (Presid. Address), *Proc.* p. 46.

The anterior limbs are well preserved, and extended transversely. The measurement over them exceeds 15 centimetres, and each limb is $6\frac{1}{4}$ centimetres long.

The humerus is 2·625 centimetres long. It has the form of the bone in *Pliosaurus*, being deep at the proximal end, elongated, nearly straight on the anterior border, and concave on the posterior border in consequence of the distal expansion. In no way except as a genus does it differ in form from the humerus of the Edentate mammal *Megalonyx*, where that bone has lost its terminal epiphyses, thus showing a new example of evolution in ossification which is associated with transition from one vertebrate type to another. The bone is $\frac{1}{4}$ centimetre wide at the proximal end, and nearly 1 centimetre wide at the distal end. The anterior border is flattened proximally, but becomes compressed distally to a sharp edge ; the posterior border is modified in the same way. The under side of the bone is concave in length. The distal end is truncated, slightly convex from front to back. Its inferior margin is slightly thickened, and its articular surface shows two concavities which correspond in position with the heads of the ulna and radius, though those bones on both sides appear to be separated from the humerus by an interval of about $\frac{1}{8}$ centimetre. The bone has a comparatively large ent-epicondylar foramen which passes from the internal or posterior border obliquely downward and forward so as to open on the under side of the bone near to the posterior margin, above the ulnar articulation. It is vertically ovate and has not the narrow, elongate form figured by Gervais in the type of *Mesosaurus tenuidens*. This, with the slenderness of the humerus, supports the indication of the cervical ribs that the species may be distinct.

The ulna and radius are exceptionally slender in proportion to the size of the humerus. The radius is $1\frac{3}{8}$ centimetre long, straight, slightly enlarged at both extremities, with the distal end compressed so as to carry a median ridge on the under side, which may make the distal end triangular.

The ulna is a little shorter. It is very slightly curved, the proximal end being a little developed on its radial side, where the two bones of the forearm are in contact. And distally there is a corresponding development towards the carpal element which is wedged between the radius and ulna so as to separate their distal ends. The posterior outline of the ulna is very slightly convex, and its radial border is concave. In slender form it is the counterpart of the radius. The transverse measurement over the proximal ends of the two bones as they lie together is $\frac{1}{2}$ centimetre ; the transverse measurement over the distal ends as they lie is $\frac{3}{4}$ centimetre.

The carpus is remarkable for the large size and triangular arrangement of the three bones which form the proximal row, as compared with the small size and linear arrangement of the four bones in the distal row.

The proximal carpal, which alone gives attachment to the radius and ulna, may be regarded as the lunar bone. It is flattened, of irregular subquadrate outline, and has the border towards the ulna thickened; it is in close contact with the other two bones which are placed distally. On the ulnar side there is a foramen between this bone and the element which is above the fifth digit, and separated from it by a cartilaginous interspace. On the radial side there is a close sutural union with the bone, beneath which are placed the four carpals of the distal row. There is an interspace, which was presumably occupied by cartilage, between the distal end of the radius and the carpal above the first digit. The bone on the ulnar side is obviously the cuneiform. But that on the radial side may be either the scaphoid or centrale. From its holding a corresponding position to the naviculare of the tarsus in relation to the bones of the distal row, there is some evidence in support of its identification as the centrale, in which case the scaphoid is unossified, but the evidence is insufficient to determine the point, especially as there is an interspace between the distal carpal bones and this element. If the bone were identified as the scaphoid it would approximate the carpus towards such a mammalian type as *Cheiromys*; and the resemblance would be not less interesting if the scaphoid were supposed to be unossified on the radial side, and the pisiform unossified on the ulnar side. In any case the condition is unlike that of Plesiosaurs, in which the carpal bones of the proximal row have a transverse linear arrangement. *Lariosaurus* is figured by Zittel with two bones in the proximal row and two in the distal row, but the carpus is imperfectly known in *Neusticosaurus* and unknown in *Anarosaurus*.

The distal row of the carpus in *Mesosaurus* consists of four bones,[1] arranged like the corresponding bones in a mammal. They are identified as trapezium, trapezoid magnum, and unciform. The first of these is the smallest, and the unciform is the largest.

The metacarpus consists of five divergent bones which vary in length. The first is strong and short, $\frac{1}{2}$ centimetre long. The third, fourth, and fifth are about $\frac{5}{8}$ centimetre long, and the fifth (which is most slender) is only a little longer than the first. The transverse measurement over the distal ends of the metacarpal bones is fully $1\frac{3}{8}$ centimetre. The digits are moderately developed, the middle digit being the longest; and in every case the first phalange is the longest and strongest. The digits terminate in short conical claws. The number of phalangeal bones is $2 \cdot 3 \cdot 4 \cdot 3 + \cdot 3 +$. The fourth digit is imperfect; the fifth has three well-developed phalanges without a terminal claw, and a small ossification lies near its extremity which may represent the rudiment of a terminal phalange. The first digit, including the metatarsal, measures fully $\frac{3}{4}$ centimetre, and the third measures $1\frac{1}{4}$ centimetre in length.

There are obvious differences between this specimen and the type, but it is difficult to judge of their importance. In the Paris fossil the teeth appear to be more numerous, but in both they have

[1] Attention is subsequently drawn to the specimen of *Stereosternum* which may possibly show five bones in the distal row of the carpus.

an elongated slender cylindrical form. The cervical ribs in the Cape Town fossil are long and slender, and directed backward, close to the vertebræ; in the Paris specimen the cervical ribs have been figured with a considerable lateral expansion, which, however, is not present.[1] The shoulder-girdle is at first sight very dissimilar, but a mass of matrix appears to cover the hinder part of the coracoid plate in the Paris fossil and to hide the posterior emargination of the bone. The lateral pre-acetabular expansion seen in the Paris fossil is absent from the Cape Town specimen, but it may possibly be lost upon the upper slab. The humerus in the Paris specimen is more compressed distally and the foramen is longer. The evidence is insufficient to prove specific distinction.

§ 4. The Mesosaurus in the Albany Museum.

Another specimen of apparently the same genus, from near Burghersdorp, is contained in the Albany Museum at Grahamstown. It shows the dorsal aspect of dorsal vertebræ and ribs. The vertebræ are no wider than in the Cape Town fossil, but relatively longer. While in the latter seven vertebræ occupy a length of $4\frac{1}{4}$ centimetres, in this only five vertebræ are contained in that length, but the vertebræ are less closely articulated. The ribs are fully $\frac{1}{2}$ centimetre in diameter, so that the interspaces between them are only half as wide as the ribs. As they are preserved, inclined backward at an angle of 45°, they lie in close contact distally on the right side and overlap on the left side. They appear to be a little ovate in section, being wider than deep, so that this character is not peculiar to *Ditrochosaurus*. The proximal ends are compressed and recurved. They have a length of about $4\frac{1}{4}$ centimetres; and the transverse measurement over the body as preserved is 7 centimetres. They lie in natural connexion with the vertebræ. On the left side of the sixth vertebra, the cast shows an impress as of a flat transverse process. Apparently the anterior edge of the rib is in close contact with the concave posterior margin of the process. The contact is as close as though this relation were articular.

Thirteen vertebræ are preserved in the cast, with indications of one more at each end, imperfectly preserved, and on the left side there are thirteen ribs in sequence. The vertebræ seen from above are transversely oblong. They are narrowest in front, widest in the middle, and narrow again posteriorly. The greatest transverse measurement is $1\frac{1}{8}$ centimetre. The antero-posterior measurement increases a little from front to back, being less than $\frac{3}{4}$ centimetre anteriorly, and more posteriorly. The neural spines are compressed from side to side, moderately elevated, higher than in the impression from the cast, stronger behind than in front, and stronger in the later than in the earlier vertebræ. On each side of the neural spine the surface is convex from front to back and concave from side to side,

[1] I am indebted to Prof. Gaudry for evidence that the cervical ribs in the type of *Mesosaurus tenuidens* are essentially the same as in this fossil. The tenth vertebra of the type appears to have ribs with two distinct articular surfaces, and such ribs may be present in the ninth vertebra.

being margined by a longitudinal ridge, chiefly developed above the posterior zygapophyses. In the anterior half of the vertebræ these ridges converge forward above the pre-zygapophyses. The lateral contour of the neural arch is concave in length. The pre-zygapophysial facets are horizontal, transversely ovate facets, above which the neural arch rises abruptly.[1]

The entire length of the fragment of this skeleton preserved is 12½ centimetres. I have no doubt that it indicates a new species, but there is no character available for its definition except the unsatisfactory one of relatively stout ribs.

§ 5. The Relations of Mesosaurus with Stereosternum.

In 1886 Prof. Cope published his well-known description of *Stereosternum tumidum*.[2] He recognized the close general resemblance of that type to *Mesosaurus*; but since the Brazilian fossil which he figures represents the hinder half of the body, and the Paris specimen only shows the anterior half, no very close comparison could be made. The author observes, "As the dorsal vertebræ [of *Mesosaurus*] are obscured by matrix, the only point in which actual comparison can be made is the ribs. These are quite identical in the two types . . . The humerus is almost identical, and the carpus is nearly what one would expect to find in the Brazilian form." Shortly afterwards the British Museum acquired two skeletons of this animal from São Paulo, one of which is better preserved than that figured by Cope, in showing the entire dorsal region with the fore and hind limbs, as well as some indications of the shoulder-girdle, and important pelvic characters. Dr. Henry Woodward, F.R.S., had a cast taken from the better of the two slabs, and I studied the remains and found that comparison of the Kimberley and Brazilian specimens suggested the conclusion that *Stereosternum* was generically indistinguishable from *Mesosaurus*, unless the clavicular arch should be found to separate them. Mr. Lydekker, in his Catalogue of the Fossil Reptilia in the British Museum, Part ii. p. 302, referred the specimens to *Mesosaurus*, remarking that "there appear to be no characters by which *Stereosternum* can be specifically distinguished from the type-species [*Mesosaurus tenuidens*]." There are important regions of the skeleton which have not been compared, such as the pelvis, the shoulder-girdle, and the skull. The coracoid figured by Cope amply justifies specific separation, and makes generic distinction not improbable, though Mr. Lydekker would refer the coracoid to some other type of animal; but it has enough in common with the coracoid of *Mesosaurus* as now

[1] There are imperfectly preserved doubtful indications of transverse processes. In the Cape Town fossil these possible plates (if they are not division-planes in the matrix) are hidden beneath the ribs, but appear to be triangular and directed outward and backward for nearly half the length of the ribs. A similar appearance is seen in the Grahamstown specimen, where the transverse process appears to be broken. It is more slender than in the other example. These indications are imperfectly displayed, and better specimens must be obtained to show how far the indications may be relied upon.

[2] Proc. Am. Phil. Soc. vol. xxiii. p. 7.

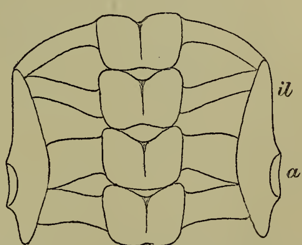
known to indicate that it is a fragment of the coracoid of an allied genus, in which there was no squamous overlap of the bones. The British Museum examples of *Stereosternum* show that the cervical vertebræ are very short. They are exposed laterally. The centrum is badly preserved. The neural spine is long, thin, flat; with the anterior and posterior borders sub-parallel, slightly converging superiorly. The extremity of the spine is truncated. The neural spines are inclined backward, and increase in length towards the dorsal region. The neurapophyses are constricted from back to front, so as to cause the anterior angle to extend forward as a pre-zygapophysis, and there is a strong post-zygapophysis with a semi-circular excavation beneath it for the intervertebral nerve. There are six vertebræ preserved anterior to the humerus. In the Cape Town *Mesosaurus* these would extend forward to the middle of the cervical region.[1]

The measurement from the humerus to the femur is 13·5 centimetres, and in this length are twenty vertebræ. The transverse measurement over the middle of the dorsal ribs is 4·2 centimetres. There are twenty pre-sacral vertebræ which bear dorsal ribs. The early vertebræ of the dorsal series have the centrum short, measuring ½ centimetre. The under side of the centrum is wide anteriorly, convex from side to side, and less convex from back to front. In the specimen R. 537, twenty dorsal vertebræ measure 16·2 centimetres; that example is therefore somewhat larger. There are no lumbar vertebræ in *Stereosternum*.

The early dorsal ribs are slender proximally, and, enlarged, they are club-shaped distally. In R. 537 the ribs appear to be flatter, but this may be the effect of compression.

In the specimen R. 536 there are four sacral vertebræ characterized by their sacral ribs, supporting the ilium. Probably only the last two are rightly accounted sacral, and the anterior, which have the ribs converging outward, may be sacro-lumbar. There is no reason for believing that any of the sacral vertebræ are anchylosed. In Gürich's *Ditrochosaurus* from Hope Town the sacral vertebræ appear to be scattered. The width of the stronger transverse processes which are opposite the acetabulum in *Stereosternum* is about ¾ centimetre.

Fig. 2.—*Sacrum and ilium of* Stereosternum.



Restored.

il, ilium; *a*, acetabulum.

The early caudal vertebræ of *Stereosternum* seen from above show the lateral notching behind the transverse processes, which defines the post-zygapophyses. The transverse processes of the caudal vertebræ

[1] Prof. Cope records nine cervical vertebræ besides the atlas, 'Am. Nat.' vol. xxi. p. 1109.

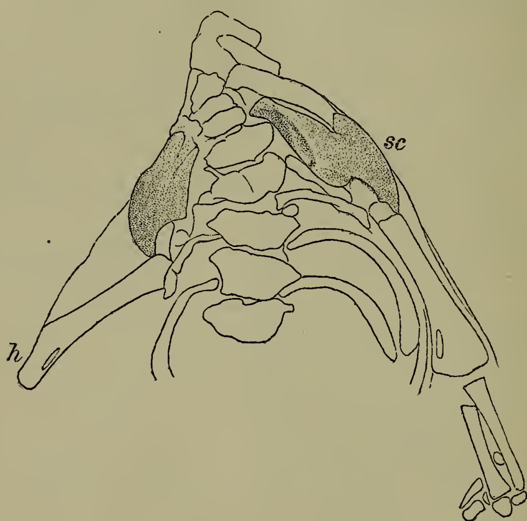
are somewhat similar to those in the Kimberley *Mesosaurus*, in which they decrease in length very rapidly and are thicker, so as to have a dissimilar aspect. Seventeen caudal vertebræ are preserved. In the first twelve the form is flattened, and they differ only by decreasing in size. In the later caudal vertebræ there may be a large intercentral ossicle, almost as large as the exposed part of the centrum. The chevron bones are attached to these ossifications. This suggests that chevron bones are the transverse processes or caudal ribs of the intercentrum. The chevron bones are a little longer than the centrum, and lie parallel to its base.

Fig. 3.—*Early caudal vertebra of* Stereosternum.

Natural size.

The shoulder-girdle is imperfectly preserved. The coracoid in

Fig. 4.—*Part of the shoulder-girdle of* Stereosternum tumidum.



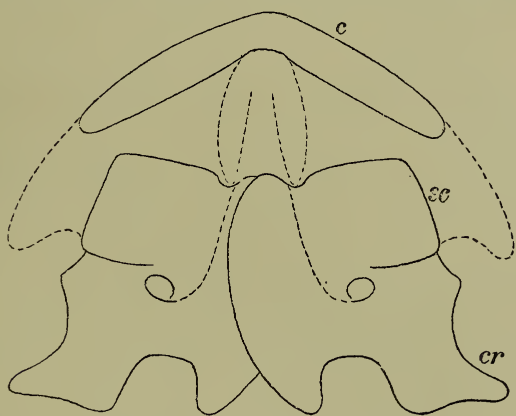
Natural size.

sc, scapula; *h*, humerus.

R. 537 is evidenced by an impression and some bone tissue, but its form is not defined. In R. 536, Brit. Mus., there are indications of a pair of wide, thin, crescentic bones in advance of the shoulder-girdle. In extending above the humeral articulation they correspond in position with the lateral plates of the Plesiosaurian scapula, and are of not dissimilar form. I cannot regard them as scapulæ because they do not enter into the glenoid cavity. Prof. Cope only records a large coracoid, and a transverse element anterior to it which he regards as either clavicle or interclavicle.[1] I regard the bone as either the episcapula if it is blended with the scapula, or clavicle if it is a distinct element (as appears more probable).

If the transverse expansion seen in the Paris type of *Mesosaurus* is the same bone, its form is imperfect, but it is in the same position as the lateral crescentic bone of *Stereosternum*. There is nothing in the Cape Town *Mesosaurus* which corresponds in form with these bones in *Stereosternum*. And the shoulder-girdle in the two types seems to be unlike, because the coracoids in the Brazilian genus met (as shown by the thickened margin) in the median line, while in *Mesosaurus* there seems to have been a squamous overlap as in Monotreme Mammals, and as the coracoid cartilages overlap in *Triton* and *Salamandra*. This condition, so far as I am aware, is not otherwise suggested by remains of fossil reptiles. There is also a possible resemblance to Salamanders in the fact that the scapula and coracoid are not separable, though the Cape Town *Mesosaurus* appears to indicate a suture.

Fig. 5.—*Restored outline of shoulder-girdle of* Mesosaurus.



c, clavicles; *sc*, scapula; *cr*, coracoid.

The British Museum specimen of *Stereosternum* (R. 536) has the humerus 2·6 centimetres long. In R. 537 it is 3·6 centimetres long. It is very like the humerus of *Mesosaurus*. In all these types the bone would be separable only by generic characters from the humerus of the Edentate Mammal *Megalonyx*, if the epiphyses in that genus were removed. The ulna is $1\frac{7}{8}$ centimetre long, and the radius a little shorter. The carpus is badly preserved. Prof. Cope states that it includes a radiale, a large intermedium, a small ulnare, a large centrale, and four distal carpals. The distal

[1] *Op. et loc. supra cit.*

row of the carpus is isolated in the British Museum specimen, but appears to include five small bones in linear series.

The femur is compressed in opposite directions at the two extremities, but the expansion in either direction is inconsiderable.

In the specimen R. 536 the tibia measures under 1·6 centimetre and the fibula over 1·8 centimetre long. Hence the bones of the hind limb are very little longer than those of the fore limb.

The Kimberley specimen of *Mesosaurus* has shown that in both genera the distal row of the tarsus includes five bones; but the fifth bone in *Mesosaurus* is a minute ossification compared with that in *Stereosternum*.

The presence of the fifth distal tarsal in *Stereosternum* induced Prof. George Baur to place the genus in a new order of reptiles under the name 'Proganosauria.' It seems to me probable that in most animals in which there are four distal tarsals the fourth is formed by blending of the fourth and fifth, since the fourth tarsal in them gives attachment to the fourth and fifth metatarsals. And if so, this tarsus is not necessarily so far removed from the mammalian type as might appear. Nor does the persistence of the fifth distal tarsal necessarily assume the importance assigned to it by Baur.

Prof. Cope remarks on *Stereosternum* :—" Its characters are only like those of some of the Urodele Batrachia and the Theromorphous [Anomodont] Reptilia. . . . The vertebræ might be those of a Theromorph reptile, and the pelvis also agrees with that of those animals. The abdominal rods are found in species of that order referred to the genus *Theropleura*. The ribs and tarsus are, however, of an entirely different type. The former would refer the genus to the Rhynchocephalia or the Sauropterygia, and there is nothing known in its structure which positively forbids either reference, unless it be the character of the pelvis . . . . . . The pubis is not so large as the ischium, and has a foramen near its posterior border."[1]

The abdominal rods have never been figured in any of the genera in which Prof. Cope has indicated their existence. They are dimly marked on the British Museum *Stereosternum*, with the same want of definition as the abdominal ribs of *Hyperodapedon*. They were presumably formed of fibro-cartilage, and not ossified in the same way as in the Kimberley *Mesosaurus*. The foramen in the pubis is interesting, as it appoximates in position to the notch in the hinder border of the pubis, which characterizes Nothosaurians.

From the sum of the characters it may be legitimate to include the group within the Anomodontia. But it differs in some remarkable characters which appear to be of sub-ordinal value. The most important of these are the mode of articulation of the dorsal ribs, seen in *Mesosaurus*; the Edentate form of the larger limb-bones; and the structure of the shoulder-girdle. For this small group thus defined the name 'Mesosauria' would be convenient, because distinctive.

These African Sauromorpha closely resemble some genera from the Trias of Europe in general form and in characters of the humerus.

[1] Proc. Am. Phil. Soc. vol. xxiii. (1886) p. 9.

The most remarkable of these is *Neusticosaurus*. When describing that type[1] I inferred from the shoulder-girdle that it should be affiliated to the Nothosauria. Now, however, I believe that too little importance was then given to the mode of attachment of the dorsal ribs. This character entirely separates *Neusticosaurus* from the Nothosauria, and approximates it to the Mesosauria. In all Nothosaurians the dorsal ribs are carried upon exceptionally stout transverse processes, which only differ from those of *Plesiosaurus* in being more massive and deeper; while in the Mesosauria there is no trace of this relation. In *Mesosaurus*, *Stereosternum*, and *Neusticosaurus* there is the same barrel-like contraction of the ends of each dorsal centrum, though this is but a family character. The articular faces of the centrum are conically cupped in the African and Brazilian types, but in *Neusticosaurus* this surface is flat, as in associated genera, although the neural arch is not anchylosed to the centrum. Indeed, the European Neusticosauridæ fall into a family which has the tail short and the neck long, and shows points of affinity to the Nothosauria; while the African Mesosauria have the neck short and the tail long, and show points of affinity to the Anomodontia. The Nothosauria are nearer in affinity to the Anomodontia than is consistent with their inclusion in the order Sauropterygia. The chief difficulty in recognizing this relation has been in the apparent differences of the shoulder-girdle.

In the shoulder-girdle referred to *Nothosaurus mirabilis* (Münster) figured by Von Meyer, a small notch is seen in the coracoid, between that bone and the scapula. Internal to the notch the coracoid develops a strong process which terminates abruptly forward in a transverse but oblique line. The notch is in the position of the foramen which in certain Anomodont types occurs at the junction of the precoracoid with the coracoid and scapula. Since an open angle stretches forward between the latter two bones, it is possible that it was occupied by a cartilaginous precoracoid during life, in contact with the internal border of the scapula and the anterior border of the coracoid, which have the aspect of being articular surfaces. Such a condition would make an approach towards the Anomodont type. But in *Neusticosaurus* there is no trace of the coracoid notch or foramen, and there are no internal articular surfaces in the scapular arch, like those seen in *Nothosaurus*.

The Lariosauridæ, according to Deecke,[2] have the vertebral characters of the Nothosauria. And although there is similarity in form in the humerus to that of the Mesosauria, there is no such entepicondylar foramen as characterizes the bone in the genera so grouped. It seems to be transitional between the Nothosauria and the Sauropterygia, and to have no near affinity with the Mesosauria, in so far as detailed comparison can be made. But the development of a sacrum of many vertebræ in *Lariosaurus*, as figured by Zittel,[3]

[1] Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 350.
[2] Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxxviii. (1886) p. 170.
[3] 'Handbuch der Palæontologie,' Bd. iii. p. 485.

makes a resemblance to *Stereosternum*. It is possible that the suborder Mesosauria may be enlarged hereafter, but at present it seems to me convenient to include in it two divisions, the Proganosauria of Baur and the Neusticosauria. These groups may be defined in the following classification:—

§ 6. Classification of the Mesosauria.

General Characters:—Palate closed in the median line. Teeth slender, prehensile. Cervical ribs with a single articulation. Dorsal ribs articulated to the anterior face of the neural arch. The shoulder-girdle formed of scapular and clavicular arches. Humerus expanded distally with an ent-epicondylar foramen. Digits terminating in claws.

Division I. Proganosauria.

Articular faces of centrum conically cupped. Coracoid and scapula anchylosed. A large clavicle [or separate episcapulæ]. A sacrum of four vertebræ. A foramen in the pubis. Five bones in the distal row of the tarsus. Neck short; tail long.

South Africa; South America.

Division II. Neusticosauria.

Articular faces of centrum flat. Coracoid and scapula separate. Clavicles relatively small [no separate episcapula]. Sacrum unknown. A notch instead of a foramen in the pubis. Neck long; tail short.

Europe.

I wish in conclusion to express my thanks, for the loan of specimens and for facilities in making these observations, to the Trustees of the South African Museum, Cape Town; to the Committee of the Albany Museum, Grahamstown; to Dr. Henry Woodward, F.R.S., and the Officers of the Geological Department of the British Museum (Natural History); and to the Government Grant Committee of the Royal Society for assistance.

EXPLANATION OF PLATE XVIII.

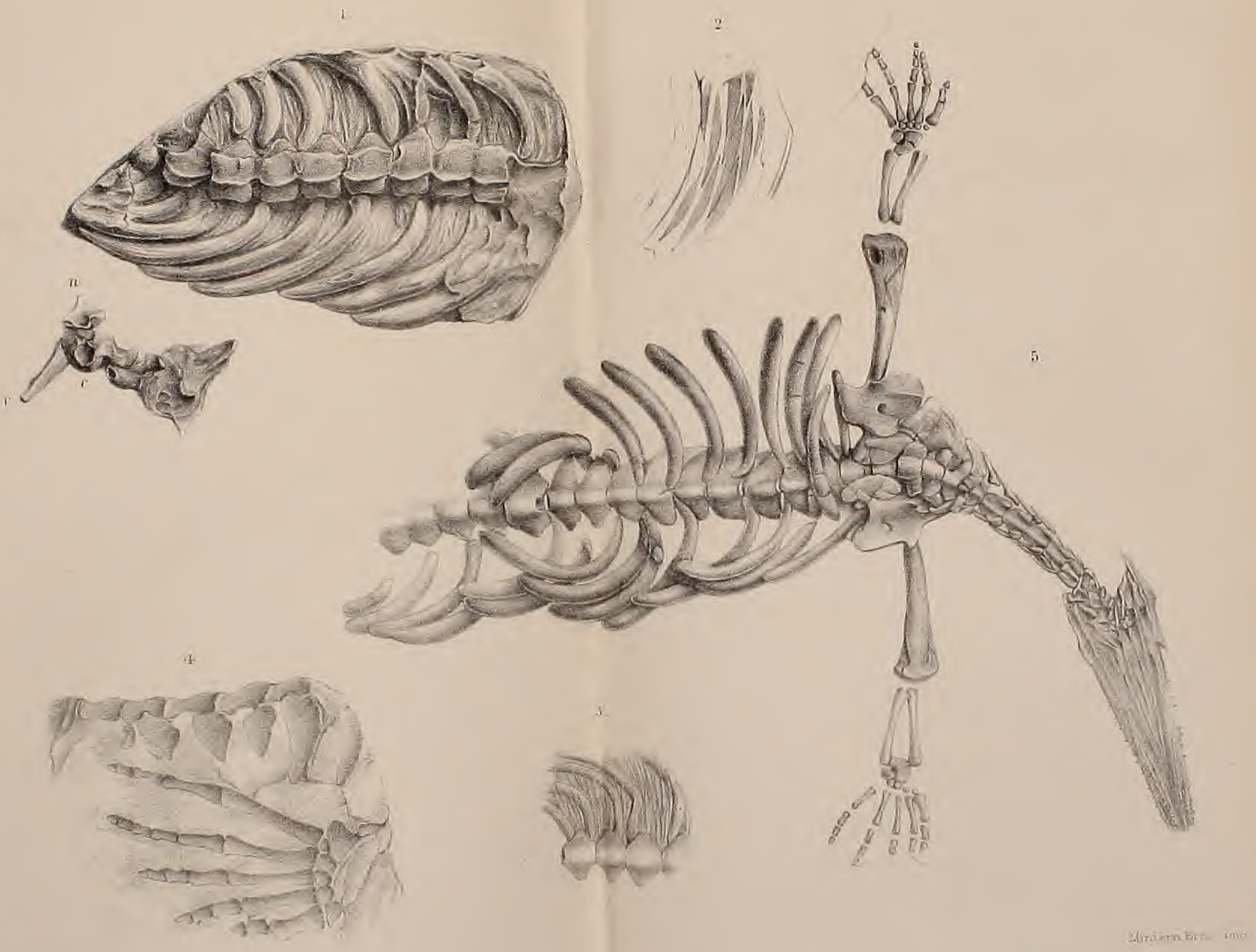
Fig. 1. Dorsal aspect of dorsal vertebræ and ribs of *Mesosaurus pleurogaster* (Brit. Mus., Nat. Hist.); *n* = neural arch; *v* = transverse process; *c* = centrum.

2. Portion of ventral armour of the same specimen. $\frac{2}{1}$

3. Ventral aspect of a specimen showing abdominal ribs.

4. Impressions of early caudal vertebræ; and hind foot of the same animal.

5. Ventral aspect of the anterior part of the skeleton of *Mesosaurus tenuidens* (South Afr. Mus., Cape Town).



Mintern Bros. imp.

MESOSAURUS.

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AND

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PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1891–92.

November 11, 1891.

Sir Archibald Geikie, D.Sc., LL.D., F.R.S., President, in the Chair.

The Rev. James Crossby Roberts, 41 Derby Road, East Park, Northampton, and John Whitehead, Esq., Esplanade, Guernsey, were elected Fellows; and M. Gustave H. Cotteau, Auxerre, France, was elected a Foreign Member of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On *Dacrytherium ovinum* from the Isle of Wight and Quercy." By R. Lydekker, Esq., B.A., F.G.S.

2. "Supplementary Remarks on Glen Roy." By T. F. Jamieson, Esq., F.G.S.

The following specimens were exhibited:—

Nodule of Malachite from South Australia, exhibited by E. Charlesworth, Esq., F.G.S.

Water-colour drawing and photographs of the Merjelen-See, Switzerland, showing Parallel Terraces, exhibited by H. M. Klaassen, Esq., F.G.S.

November 25, 1891.

Sir Archibald Geikie, D.Sc., LL.D., F.R.S., President, in the Chair.

Walter William Cheadle, Esq., B.A., Trinity College, Cambridge, and 19 Portman Street, W.; Alfred Harper Curtis, Esq., B.A., Assoc.M.Inst.C.E., 13 South Hill Park Gardens, Hampstead, N.W.; and William Bruce Dallas Edwards, Esq., Assoc.R.C.S., Geological Survey of India, Calcutta, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Os pubis of *Polacanthus Foxii*." By Prof. H. G. Seeley, F.R.S., F.G.S.

2. "A Comparison of the Red Rocks of the South Devon Coast with those of the Midland and Western Counties." By Prof. Edward Hull, LL.D., F.R.S., F.G.S.

3. "Supplementary Note to the Paper on the 'Red Rocks of the Devon Coast-section,' Q. J. G. S. 1888." By the Rev. A. Irving, D.Sc., B.A., F.G.S.

The following specimens were exhibited:—

Rock-specimens, exhibited by the Rev. A. Irving, D.Sc., B.A., F.G.S., in illustration of his paper.

December 9, 1891.

Sir Archibald Geikie, D.Sc., LL.D., F.R.S., President, in the Chair.

William Cheetham, Esq., Woodbottom Cottage, Horsforth, Leeds; Charles Chewings, Esq., Largs Bay, Adelaide, South Australia; John Rule Daniell, Esq., Polstrong, Camborne, Cornwall; Walter Burn Murdoch Davidson, Esq., Assoc.R.S.M., Pall Mall Club, S.W.; William Drummond, Esq., 4 Learmonth Terrace, Edinburgh; William Fox, Esq., M.Inst.C.E., 15 South Norwood Hill, S.E.; Henry William Ford, Esq., Cunninghame Street, Northcote, Victoria; Wheelton Hind, M.D., B.Sc., Stoke-on-Trent; George Anthony Lefroy, Esq., Chief Surveyor of Perâk, Assoc.M.Inst.C.E., Taipeng, Perâk, Straits Settlements; Ferdinand Joseph Maingot, Esq., 19 Lower Prince Street, Port of Spain, Trinidad; Frank Merricks, Esq., Assoc.M.Inst.C.E., 2 Edwardes Square, Kensington, W.; Edward Rochfort Pike, Esq., Government Inspector of Mines, State of Perâk, Kinta, Perâk, Straits Settlements; Charles Gordon Richardson, Esq., 180 Euclid Avenue, Toronto, Canada; and Charles Wilson, Esq., F.C.S., 19 Little Queen Street, Westminster, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Rocks mapped as Cambrian in Caernarvonshire." By the Rev. J. F. Blake, M.A., F.G.S.

2. "The Subterranean Denudation of the Glacial Drift, a probable cause of submerged Peat- and Forest-beds." By W. Shone, Esq., F.G.S.

3. "High-Level Glacial Gravels, Gloppa, Cyrn-y-bwch, near Oswestry." By A. C. Nicholson, Esq. Communicated by W. Shone, Esq., F.G.S.

The following specimens were exhibited:—

Rock-specimens, exhibited by the Rev. J. F. Blake, M.A., F.G.S., in illustration of his paper.

Specimens of fossils from High-level Glacial Gravels, exhibited by A. C. Nicholson, Esq., in illustration of his paper.

At a Special General Meeting, held at 7.45 P.M., before the Ordinary Meeting, the appointment of Mr. L. L. Belinfante as Assistant Secretary to the Society was confirmed by the Fellows.

December 23, 1891.

W. H. Hudleston, Esq., M.A., F.R.S., Vice-President, in the Chair.

Arthur Morley Davies, Esq., Assoc.R.C.S., Demonstrator of Geology at the Royal College of Science, London, 32 Delancy Street, N.W.; Matthew H. H. Habershon, Esq., 26 Newbould Lane, Sheffield; George Francis Hosking, Esq., Bendigo, Otago, New Zealand; Robert Paulin, Esq., St. Clair, Dunedin, New Zealand; Rev. William Robinson, Athlin, Thurlow Road, Torquay; Stephen Rogers, Esq., Ferris Town, Truro; William Sherwood, Esq., Eastbourne House, Sutton Coldfield; and Henry Gilbert Stokes, Esq., Albert Street, Brisbane, Queensland, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On Part of the Pelvis of *Polacanthus*." By R. Lydekker, Esq., B.A., F.G.S.

2. "On the Gravels south of the Thames from Guildford to Newbury." By Horace W. Monckton, Esq., F.G.S.

3. "The Bagshot Beds of Bagshot Heath." By Horace W. Monckton, Esq., F.G.S.

The following specimens were exhibited:—

Specimens exhibited by Messrs. Herries and Monckton in illustration of the papers by the latter.

January 6, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., Vice-President, in the Chair.

Ernest Sidney Berrie Biddell, Esq., B.A. Cantab., 32 The Grove, Boltons, S.W.; John Colley Smyth Burkitt, M.D., The Old Vicarage, Whitwick, Leicester; John Evans, Esq., Bulli, New South Wales; William John Rooke Cowell, Esq., B.A., 5 Atlantic Terrace West, Weston-super-Mare; Frederick McKnight, Esq., 179 Roden Street, West Melbourne, Victoria; Charles Parker, Esq., Assoc.M.Inst.C.E., St. George's Club, Hanover Square, W.; Thomas Arthur Rickard, Esq., Assoc.R.S.M., Allemont, Isère, France; Friend Edward Streeten, Esq., M.R.C.S., L.R.C.P., Swindon, Wiltshire, were elected Fellows; and Major J. W. Powell, United States Geological Survey, Washington, D.C., U.S.A., a Foreign Correspondent of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—F. W. Rudler, Esq.; John Hopkinson, Esq.

The List of Donations to the Library was read.

The following communications were read:—

1. "On a new Form of *Agelacrinites* (*Lepidodiscus Milleri*, n. sp.) from the Lower Carboniferous Limestone of Cumberland." By G. Sharman, Esq., and E. T. Newton, Esq., F.G.S.

2. "The Geology of Barbados.—Part II. The Oceanic Deposits." By A. J. Jukes-Browne, Esq., B.A., F.G.S., and Prof. J. B. Harrison, M.A., F.G.S.

3. "*Archæopneustes abruptus*, a new Genus and Species of Echinoid from the Oceanic Series in Barbados." By J. W. Gregory, Esq., B.Sc., F.G.S.

The following specimens were exhibited:—

Specimen of *Lepidodiscus Milleri*, n. sp., exhibited by G. Sharman, Esq., and E. T. Newton, Esq., F.G.S., in illustration of their paper, by permission of the Director-General of the Geological Survey.

Specimens of Barbados rocks, exhibited by A. J. Jukes-Browne, Esq., B.A., F.G.S., and Prof. J. B. Harrison, M.A., F.G.S., in illustration of their paper.

Microscopic slides of Oceanic Deposits, Barbados, exhibited by W. Hill, Esq., F.G.S.

Specimen of *Archæopneustes abruptus*, n. g. & sp., from the Oceanic Series in Barbados, and specimen and sections of Radiolarian Marl from Cuba, exhibited by J. W. Gregory, Esq., B.Sc., F.G.S.

Portion of Bone-bed from the Wadhurst Clay, Hastings, with a Mammalian Tooth (*Plagiaulax Dawsoni*, A. S. Woodw.), discovered and exhibited by Charles Dawson, Esq., F.G.S.

January 27th, 1892.

Dr. W. T. Blanford, F.R.S., Vice-President, in the Chair.

George W. Eustice, Esq., Frontino and Bolivia Mines, La Salada, care of Señores J. M. and E. Montoya, Puerto Berrio, Republic of Colombia, South America; F. T. Howard, Esq., B.A., Lecturer in Geology at University College, Cardiff; and Alexander Charles Nicholson, Esq., Bronderw, Oswestry, Shropshire, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Hornblende-schists, Gneisses, and other Crystalline Rocks of Sark." By the Rev. Edwin Hill, M.A., F.G.S., and Prof. T. G. Bonney, D.Sc., F.R.S., V.P.G.S.

2. "On the Plutonic Rocks of Garabal Hill and Meall Breac.' By J. R. Dakyns, Esq., M.A., and J. J. H. Teall, Esq., M.A., F.R.S. F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

3. "North Italian Bryozoa.—Part II. Cyclostomata." By Arthur Wm. Waters, Esq., F.L.S., F.G.S.

The following specimens were exhibited:—

Rock-specimens and Microscopic sections exhibited by the Rev. Edwin Hill, M.A., F.G.S., and Prof. T. G. Bonney, D.Sc., F.R.S., V.P.G.S., in illustration of their paper.

Rock-specimens and Microscopic sections exhibited by J. R. Dakyns, Esq., M.A., and J. J. H. Teall, Esq., M.A., F.R.S., F.G.S., in illustration of their paper, by permission of the Director-General of the Geological Survey.

February 10th, 1892.

Sir Archibald Geikie, D.Sc., LL.D., F.R.S., President, in the Chair.

Richard Fuge Grantham, Esq., M.Inst.C.E., Northumberland Chambers, Northumberland Avenue, W.C., was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "The Raised Beaches, and 'Head' or Rubble Drift of the South of England: their relation to the Valley Drifts and to the Glacial Period; and on a late post-Glacial Submergence.—Part I." By Joseph Prestwich, D.C.L., F.R.S., F.G.S.

2. "The *Olenellus*-Zone in the North-West Highlands." By B. N. Peach, Esq., F.R.S.E., F.G.S., and J. Horne, Esq., F.R.S.E., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

The following specimens were exhibited:—

Specimens of *Olenellus Lapworthi*, Peach, from the 'Serpulite Grit' and 'Fucoid Beds' below the Durness Limestone of Ross-shire, exhibited by B. N. Peach, Esq., F.R.S.E., F.G.S., in illustration of his and Mr. Horne's paper, by permission of the Director-General of the Geological Survey.

Models illustrating the present and past conditions of the Geology of the Highlands, including the Glaciers and their effects, by Major R. T. W. L. Brickenden, F.G.S.

Specimen of Mica from the McDonnell Range, Central Australia; Asbestos from near Broken Hill, New South Wales; and Quartz-crystals from Quartz-reef 'track,' Bendigo, Victoria, exhibited by Wm. Nicholas, Esq., F.G.S.

ANNUAL GENERAL MEETING,

February 19th, 1892.

Sir Archibald Geikie, D.Sc., LL.D., F.R.S., President, in the Chair.

Report of the Council for 1891.

This year, as last, the Council are happily enabled to congratulate the Fellows on the continued prosperity of the Society and the perfectly satisfactory condition of its finances.

The number of Fellows elected during 1891 was 63, of whom 43 paid their fees before the end of the year, making with 19 previously elected Fellows who paid their fees in 1891, a total accession in the course of the year of 62 Fellows.

During the same period, however, there was a total loss of 50 Fellows—28 by death, 14 by resignation, and 8 removed from the list for non-payment of their Annual Contributions.

The actual increase in the number of Fellows is, therefore, 12.

Of the 28 Fellows deceased, 6 were Compounders, 18 Contributing Fellows, and 4 non-Contributing Fellows.

On the other hand, in 1891 5 Fellows compounded for their Annual Contributions, and 1 non-resident Fellow became a contributor.

From the above figures it will be seen that in the number of Contributing Fellows the increase is 18. The total number of Contributing Fellows, which on Dec. 31st, 1890, was 886, had therefore become 904 on Dec. 31st, 1891.

The total number of Fellows, Foreign Members, and Foreign Correspondents was at the same dates respectively 1405 and 1418.

It may be remembered that at the end of 1890 there was one vacancy in the list of Foreign Members and there were two vacancies in the list of Foreign Correspondents.

In the course of the following year 2 Foreign Members died, and

2 were elected, leaving again one vacancy in the List of Foreign Members at the end of the year.

During the same period 1 Foreign Correspondent died, and 4 were elected, but there was still one vacancy in the List of Foreign Correspondents at the end of 1891.

Briefly stated, the Society's Income and Expenditure during the past year were as follows:—

The total Receipts on account of Income amounted to £2845 9*s.* 8*d.*, being £68 3*s.* 4*d.* more than the estimated Income for 1891. The Expenditure during that year, leaving out of account the sum of £516 2*s.* 3*d.* expended in the purchase of £400 London and South Western Railway 4 °/₀ Preference Stock, was £2476 5*s.* 7*d.*, being £272 4*s.* 5*d.* less than the estimate. The excess of Receipts over Expenditure in 1891 was therefore £369 4*s.* 1*d.*

The Council now record the completion of Volume XLVII., and the commencement of Volume XLVIII. of the Society's Quarterly Journal. It should be mentioned in this place that the task of editing the first number of Vol. XLVII. was undertaken by Professor T. Rupert Jones, F.R.S.

During the year under review the Society has suffered great losses by the death of several of its most distinguished Fellows, two of whom had filled the Presidential Chair with conspicuous ability.

It seems appropriate that this opportunity should be taken of recording the decease of an old and trusted servant of the Society, Mr. Isaac Charlton, the former House Steward. He had retired only last June on the completion of his fifty years of service.

The Council have made the following awards of medals and memorial funds:—

The Wollaston Medal has been awarded to Baron Ferdinand von Richthofen, in recognition of his important researches in and elaborate descriptions of the geology of China, North America, &c.

The Murchison Medal, with a sum of ten guineas from the proceeds of the Fund, has been awarded to Professor A. H. Green, F.R.S., in recognition of his valuable investigations concerning the geology of the Yorkshire Coalfield and adjoining districts, and in numerous other areas.

The Lyell Medal, with £25 from the proceeds of the Fund, has been awarded to Mr. Geo. H. Morton, F.G.S., in acknowledgment of his laborious and continuous researches, during a period of over forty years, amongst the rocks of the neighbourhood of Liverpool, North Wales, and the adjoining counties.

The balance of the proceeds of the Wollaston Donation Fund has been awarded to Mr. Orville A. Derby, F.G.S., in token of appreciation of his researches in the geology and mineralogy of Brazil.

The balance of the proceeds of the Murchison Geological Fund has been awarded to Mr. Beeby Thompson, F.G.S., in recognition of his labours and observations concerning the geology and palæontology of the Lias of Northamptonshire.

One moiety of the balance of the proceeds of the Lyell Geological Fund has been awarded to Mr. J. W. Gregory, F.G.S., in token of appreciation of his valuable palæontological observations on the Echinodermata and his geological researches; the other moiety to Mr. E. A. Walford, in acknowledgment of his excellent work amongst the Jurassic rocks of North Oxfordshire, and to aid both recipients in their future investigations.

A sum of £21 from the Barlow-Jameson Fund has been awarded to Prof. C. Mayer-Eymar, of Zürich, in appreciation of his observations and descriptions of the geology and palæontology of Egypt and other areas, and to assist him in his further researches.

Report of the Library and Museum Committee for 1891.

Library.

It is once more the agreeable duty of your Committee to announce that several extremely valuable additions have been made to the Society's Library, both by donation and by purchase.

As Donations the Library has received about 92 Volumes of separately published works and Survey Reports, and 162 Pamphlets, besides about 112 Volumes and 45 detached Parts of the publications of various Societies. Besides these, 15 Volumes of Newspapers have been received. The total addition, by donation, to the Society's Library is therefore about 219 Volumes and 162 Pamphlets.

The Library has, moreover, received by presentation 28 Maps.

The Books and Maps above referred to were received from 111 personal Donors, from the Editors or Publishers of 9 Periodicals, from 110 Societies, and from 22 Surveys and other Public Bodies, making in all 252 Donors.

By purchase, on the recommendation of the Standing Library Committee, the Library has received the addition of 21 Volumes and 12 Parts of Books, and of 37 Volumes and 11 Parts of various Periodicals and works published serially.

The cost of Books and Periodicals purchased during the year 1891 was £74 15*s.* 0*d.*, and of Binding £89 3*s.* 0*d.*, making a total expenditure on the Library of £163 18*s.* 0*d.*

Considerable progress has been made during the past year towards filling up the gaps which unfortunately existed in many sets of scientific serials in the Society's Library, no less than 39 sets previously imperfect having been now as far as possible completed.

Museum.

No additions have been made to the collections during the past year; but the important work of labelling in a distinctive manner the type specimens and registering them has been confided to a specialist, Mr. C. Davies Sherborn, F.G.S.

Moreover, the well-known specimen of the 'Oeningen Fox,' which Murchison brought to this country two generations ago, has been cleaned and remounted under the superintendence of Dr. Woodward.

The total sum expended on the Museum in 1891 amounts to £27 14*s*. 9*d*., comprising the following items:—

	£	*s*.	*d*.
Special work at the Museum	20	5	6
Remounting the Oeningen specimen	5	15	0
Sundries	1	14	3
	£27	14	9

Comparative Statement of the Number of the Society at the close of the years 1890 and 1891.

	Dec. 31, 1890.		Dec. 31, 1891.
Compounders	313	......	312
Contributing Fellows	886	......	904
Non-contributing Fellows	129	......	124
	1328		1340
Foreign Members	39	......	39
Foreign Correspondents	38	......	39
	1405		1418

Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1890 *and* 1891.

Number of Compounders, Contributing and Non-contributing Fellows, 31st December, 1890 ..		1328
Add Fellows elected during former year and paid in 1891		19
Add Fellows elected and paid in 1891		43
		1390
Deduct Compounders deceased	6	
Contributing Fellows deceased	18	
Non-contributing Fellows deceased	4	
Contributing Fellows resigned	14	
Contributing Fellows removed	8	
	—	50
		1340

1 Non-resident Fellow was placed on the Contributing List.

Number of Foreign Members and Foreign Correspondents, 31st December, 1890 ..		77	
Deduct Foreign Members deceased	2		
Foreign Correspondent deceased	1		
Foreign Correspondents elected Foreign Members	2		
	—	5	
		72	
Add Foreign Members elected		2	
Foreign Correspondents elected		4	
		—	78
			1418

Deceased Fellows.

Compounders (6).

Clarke, S., Esq.
Davies, W., Esq.
Deane, Rev. G.
Ramsay, Sir A. C.
Rogers, W., Esq.
Wilson, H., Esq.

Resident and other Contributing Fellows (18).

Barkas, T. P., Esq.
Birkett, Lieut.-Col. R. C.
Brady, H. B., Esq.
Cartwright, E., Esq.
Devonshire, Duke of.
Duncan, Prof. P. M.
Grantham, R. B., Esq.
Hawkshaw, Sir J.
Hunter, W. H., Esq.
King, J. L., Esq.
Lundy, J., Esq.
Needham, S. H., Esq.
Nicols, A., Esq.
Northesk, Earl of.
Spooner, C. E., Esq.
Stephens, Prof. W. J.
Wilkinson, C. S., Esq.
Wyld, R. S., Esq.

Non-contributing Fellows (4).

Drew, F., Esq.
Grant, Colonel C. W.
Ormerod, G. W., Esq.
Smith, G. F., Esq.

Foreign Members (2).

Leidy, Prof. J.
Römer, Prof. F. von.

Foreign Correspondent (1).

Stoppani, Prof. A.

Fellows Resigned (14).

Barron, W. A., Esq.
Brain, Lieut.-Col. D. L.
Dufty, J. N., Esq.
Filliter, E., Esq.
Foord, A. S., Esq.
Grenfell, J. G., Esq.
Henriques, A. G., Esq.
Lewis, Major J. F.
Lindsay, Rev. T. E.
Martin, F. W., Esq.
Monckton, E. P., Esq.
Roberti, I. L., Esq.
Rose, T. K., Esq.
Scott, R. H., Esq.

Fellows Removed (8).

Clements, Rev. G.
Curran, Rev. J. M.
Garrison, F. L., Esq.
Henderson, F. B., Esq.
Macleod, R. W., Esq.
Margetson, J. C., Esq.
Pritchard, Rev. E. C.
Renshaw, C. B., Esq.

The following Personages were elected from the List of Foreign Correspondents to fill the vacancies in the List of Foreign Members during the year 1891.

Dr. Charles Barrois, of Lille.
Mons. Gustave H. Cotteau, of Auxerre.

The following Personages were elected Foreign Correspondents during the year 1891.

Señor Don Antonio del Castillo, of Mexico.
Professor W. Dames, of Berlin.
Professor Emanuel Kayser, of Marburg.
Professor Karl August Lossen, of Berlin.

After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to Sir Archibald Geikie, retiring from the office of President.

That the thanks of the Society be given to Dr. W. T. Blanford and Mr. W. H. Hudleston, retiring from the office of Vice-Presidents.

That the thanks of the Society be given to Dr. W. T. Blanford, J. Carter, Esq., Dr. J. Evans, J. C. Hawkshaw, Esq., and F. W. Rudler, Esq., retiring from the Council.

After the Balloting-glasses had been duly closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

OFFICERS.

PRESIDENT.

W. H. Hudleston, Esq., M.A., F.R.S.

VICE-PRESIDENTS.

Prof. T. G. Bonney, D.Sc., LL.D., F.R.S.
L. Fletcher, Esq., M.A., F.R.S.
G. J. Hinde, Ph.D.
Prof. J. W. Judd, F.R.S.

SECRETARIES.

H. Hicks, M.D., F.R.S.
J. E. Marr, Esq., M.A., F.R.S.

FOREIGN SECRETARY.

J. W. Hulke, Esq., F.R.S.

TREASURER.

Prof. T. Wiltshire, M.A., F.L.S.

COUNCIL.

Prof. J. F. Blake, M.A.
Prof. T. G. Bonney, D.Sc., LL.D., F.R.S.
James W. Davis, Esq., F.L.S.
R. Etheridge, Esq., F.R.S.
L. Fletcher, Esq., M.A., F.R.S.
Prof. C. Le Neve Foster, D.Sc., B.A.
Sir A. Geikie, D.Sc., LL.D., F.R.S.
Alfred Harker, Esq., M.A.
H. Hicks, M.D., F.R.S.
G. J. Hinde, Ph.D.
W. H. Hudleston, Esq., M.A., F.R.S.
Prof. T. McKenny Hughes, M.A., F.R.S.
J. W. Hulke, Esq., F.R.S.
Prof. J. W. Judd, F.R.S.
J. E. Marr, Esq., M.A., F.R.S.
H. W. Monckton, Esq.
Clement Reid, Esq., F.L.S.
J. J. H. Teall, Esq., M.A., F.R.S.
W. Topley, Esq., F.R.S.
Prof. T. Wiltshire, M.A., F.L.S.
Rev. H. H. Winwood, M.A.
H. Woodward, LL.D., F.R.S.
H. B. Woodward, Esq.

LIST OF
THE FOREIGN MEMBERS
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1891.

Date of Election.	
1848.	James Hall, Esq., *Albany, State of New York, U.S.A.*
1851.	Professor James D. Dana, *New Haven, Connecticut, U.S.A.*
1853.	Count Alexander von Keyserling, *Raykküll, Russia.*
1856.	Professor Robert Bunsen, For. Mem. R.S., *Heidelberg.*
1857.	Professor H. B. Geinitz, *Dresden.*
1859.	Dr. Ferdinand von Römer, *Breslau.* (*Deceased.*)
1866.	Dr. Joseph Leidy, *Philadelphia, U.S.A.* (*Deceased.*)
1867.	Professor A. Daubrée, For. Mem. R.S., *Paris.*
1871.	Dr. Franz Ritter von Hauer, *Vienna.*
1874.	Professor Albert Gaudry, *Paris.*
1875.	Professor Fridolin Sandberger, *Würzburg.*
1876.	Professor E. Beyrich, *Berlin.*
1877.	Dr. Carl Wilhelm Gümbel, *Munich.*
1877.	Dr. Eduard Suess, *Vienna.*
1879.	Major-General N. von Kokscharow, *St. Petersburg.*
1879.	M. Jules Marcou, *Cambridge, U.S.A.*
1879.	Dr. J. J. S. Steenstrup, For. Mem. R.S., *Copenhagen.*
1880.	Professor Gustave Dewalque, *Liége.*
1880.	Baron Adolf Erik Nordenskiöld, *Stockholm.*
1880.	Professor Ferdinand Zirkel, *Leipzig.*
1882.	Professor Sven Lovén, *Stockholm.*
1882.	Professor Ludwig Rütimeyer, *Basel.*
1883.	Professor J. S. Newberry, *New York, U.S.A.*
1883.	Professor Otto Martin Torell, *Stockholm.*
1884.	Professor G. Capellini, *Bologna.*
1884.	Professor A. L. O. Des Cloizeaux, For. Mem. R.S., *Paris.*
1884.	Professor J. Szabó, *Pesth.*
1885.	Professor Jules Gosselet, *Lille.*
1886.	Professor Gustav Tschermak, *Vienna.*
1887.	Professor J. P. Lesley, *Philadelphia, U.S.A.*
1887.	Professor J. D. Whitney, *Cambridge, U.S.A.*
1888.	Professor Pierre J. van Beneden, *Louvain.*
1888.	Professor Eugène Renevier, *Lausanne.*
1888	Baron Ferdinand von Richthofen, *Berlin.*
1889.	Professor Ferdinand Fouqué, *Paris.*
1889.	Marquis Gaston de Saporta, *Aix-en-Provence.*
1889.	Professor Karl Alfred von Zittel, *Munich.*
1890.	Professor Heinrich Rosenbusch, *Heidelberg.*
1890.	Herr Dionys Stur, *Vienna.*
1891.	Dr. Charles Barrois, *Lille.*
1891.	M. Gustave H. Cotteau, *Auxerre.*

LIST OF
THE FOREIGN CORRESPONDENTS
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1891.

Date of Election.	
1863.	Dr. F. Senft, *Eisenach.*
1866.	Professor Victor Raulin, *Montfaucon d'Argonne.*
1866.	Baron Achille de Zigno, *Padua.* (*Deceased.*)
1874.	Professor Igino Cocchi, *Florence.*
1874.	Dr. T. C. Winkler, *Haarlem.*
1877.	Professor George J. Brush, *New Haven, U.S.A.*
1879.	M. Édouard Dupont, *Brussels.*
1879.	Dr. Émile Sauvage, *Boulogne-sur-Mer.*
1880.	Professor Alphonse Renard, *Ghent.*
1881.	Professor E. D. Cope, *Philadelphia, U.S.A.*
1882.	Professor Louis Lartet, *Toulouse.*
1882.	Professor Alphonse Milne-Edwards, *Paris.*
1884.	M. Alphonse Briart, *Morlanwelz.*
1884.	Professor Hermann Credner, *Leipzig.*
1884.	Baron C. von Ettingshausen, *Grätz.*
1884.	Dr. E. Mojsisovics von Mojsvár, *Vienna.*
1885.	Professor G. Lindström, *Stockholm.*
1885.	Dr. A. G. Nathorst, *Stockholm.*
1886.	Professor J. Vilanova y Piera, *Madrid.*
1887.	Senhor J. F. N. Delgado, *Lisbon.*
1887.	Professor A. Heim, *Zürich.*
1887.	Professor A. de Lapparent, *Paris.*
1888.	Professor W. C. Brögger, *Christiania.*
1888.	M. Charles Brongniart, *Paris.*
1888.	Professor Edward Salisbury Dana, *New Haven, U.S.A.*
1888.	Professor Anton Fritsch, *Prague.*
1888.	M. Ernest Van den Broeck, *Brussels.*
1889.	Professor G. K. Gilbert, *Washington, U.S A.*
1889.	M. A. Michel-Lévy, *Paris.*
1889.	Dr. Hans Reusch, *Christiania.*
1889.	Professor Antonio Stoppani, *Milan.* (*Deceased.*)
1889.	M. R. D. M. Verbeek, *Padang, Sumatra.*
1890.	M. Gustave F. Dollfus, *Paris.*
1890.	Herr Felix Karrer, *Vienna.*
1890.	Professor Adolph von Könen, *Göttingen.*
1890.	M. Friedrich Schmidt, *St. Petersburg.*
1891.	Señor Don Antonio del Castillo, *Mexico.*
1891.	Professor W. Dames, *Berlin.*
1891.	Professor Emanuel Kayser, *Marburg.*
1891.	Professor Karl August Lossen, *Berlin.*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE "DONATION FUND"

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., &c.

"To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,"—"such individual not being a Member of the Council."

1831. Mr. William Smith.
1835. Dr. G. A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. H. Falconer. }
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Professor A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy. }
1844. Rev. W. D. Conybeare.
1845. Professor John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Rev. Dr. W. Buckland.
1849. Professor Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil. }
1854. Sir Richard Griffith.
1855. Sir H. T. De la Beche.
1856. Sir W. E. Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Mr. James Hall. }
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Professor Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Professor Gustav Bischof.
1864. Sir R. I. Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Professor Carl F. Naumann.
1869. Dr. H. C. Sorby.
1870. Professor G. P. Deshayes.
1871. Sir A. C. Ramsay.
1872. Professor J. D. Dana.
1873. Sir P. de M. Grey-Egerton.
1874. Professor Oswald Heer.
1875. Professor L. G. de Koninck.
1876. Professor T. H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Professor Bernhard Studer.
1880. Professor Auguste Daubrée.
1881. Professor P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. W. T. Blanford.
1884. Professor Albert Gaudry.
1885. Mr. George Busk.
1886. Professor A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.
1889. Professor T. G. Bonney.
1890. Professor W. C. Williamson.
1891. Professor J. W. Judd.
1892. Baron Ferdinand von Richthofen.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON "DONATION FUND."

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. Professor G. P. Deshayes.
1838. Sir Richard Owen.
1839. Professor C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Professor Edward Forbes.
1842. Professor John Morris.
1843. Professor John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape-of-Good-Hope Fossils. / M. Alcide d'Orbigny.
1849. Mr. William Lonsdale.
1850. Professor John Morris.
1851. M. Joachim Barrande.
1852. Professor John Morris.
1853. Professor L. G. de Koninck.
1854. Dr. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Professor G. P. Deshayes.
1857. Dr. S. P. Woodward.
1858. Mr. James Hall.
1859. Mr. Charles Peach.
1860. { Professor T. Rupert Jones. / Mr. W. K. Parker.
1861. Professor A. Daubrée.
1862. Professor Oswald Heer.
1863. Professor Ferdinand Senft.
1864. Professor G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. W. Carruthers.
1870. M. Marie Rouault.
1871. Mr. R. Etheridge.
1872. Dr. James Croll.
1873. Professor J. W. Judd.
1874. Dr. Henri Nyst.
1875. Mr. L. C. Miall.
1876. Professor Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Professor W. J. Sollas.
1879. Mr. S. Allport.
1880. Mr. Thomas Davies.
1881. Dr. R. H. Traquair.
1882. Dr. G. J. Hinde.
1883. Mr. John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. S. Gardner.
1887. Mr. B. N. Peach.
1888. Mr. J. Horne.
1889. Mr. A. Smith Woodward.
1890. Mr. W. A. E. Ussher.
1891. Mr. R. Lydekker.
1892. Mr. O. A. Derby.

AWARDS OF THE MURCHISON MEDAL

AND OF THE

PROCEEDS OF "THE MURCHISON GEOLOGICAL FUND,"

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

"To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing geological science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any inquiries bearing upon the science of geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of geological science."

1873. Mr. William Davies. *Medal.*
1873. Professor Oswald Heer.
1874. Dr. J. J. Bigsby. *Medal.*
1874. Mr. Alfred Bell.
1874. Professor Ralph Tate.
1875. Mr. W. J. Henwood. *Medal.*
1875. Professor H. G. Seeley.
1876. Mr. A. R. C. Selwyn. *Medal.*
1876. Dr. James Croll.
1877. Rev. W. B. Clarke. *Medal.*
1877. Professor J. F. Blake.
1878. Dr. H. B. Geinitz. *Medal.*
1878. Professor C. Lapworth.
1879. Professor F. M'Coy. *Medal.*
1879. Mr. J. W. Kirkby.
1880. Mr. R. Etheridge. *Medal.*
1881. Professor A. Geikie. *Medal.*
1881. Mr. F. Rutley.
1882. Professor J. Gosselet. *Medal.*
1882. Professor T. Rupert Jones.
1883. Professor H. R. Göppert. *Medal.*
1883. Mr. John Young.
1884. Dr. H. Woodward. *Medal.*
1884. Mr. Martin Simpson.
1885. Dr. Ferdinand von Römer. *Medal.*
1885. Mr. Horace B. Woodward.
1886. Mr. W. Whitaker. *Medal.*
1886. Mr. Clement Reid.
1887. Rev. P. B. Brodie. *Medal.*
1887. Mr. Robert Kidston.
1888. Professor J. S. Newberry. *Medal.*
1888. Mr. E. Wilson.
1889. Professor James Geikie. *Medal.*
1889. Mr. Grenville A. J. Cole.
1890. Professor Edward Hull. *Medal.*
1890. Mr. E. Wethered.
1891. Professor W. C. Brögger, *Medal.*
1891. Rev. R. Baron.
1892. Professor A. H. Green. *Medal.*
1892. Mr. Beeby Thompson.

AWARDS OF THE LYELL MEDAL

AND OF THE

PROCEEDS OF THE "LYELL GEOLOGICAL FUND,"

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal "to be given annually" (or from time to time) "as a mark of honorary distinction as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,"—"not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper shall be written."

1876. Professor John Morris. *Medal.*
1877. Dr. James Hector. *Medal.*
1877. Mr. W. Pengelly.
1878. Mr. G. Busk. *Medal.*
1878. Dr. W. Waagen.
1879. Professor Edmond Hébert. *Medal.*
1879. Professor H. A. Nicholson.
1879. Dr. Henry Woodward.
1880. Mr. John Evans. *Medal.*
1880. Professor F. A. von Quenstedt.
1881. Sir J. W. Dawson. *Medal.*
1881. Dr. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. Dr. J. Lycett. *Medal.*
1882. Rev. Norman Glass.
1882. Professor Charles Lapworth.
1883. Dr. W. B. Carpenter. *Medal.*
1883. Mr. P. H. Carpenter.
1883. M. E. Rigaux.
1884. Dr. Joseph Leidy. *Medal.*
1884. Professor Charles Lapworth.
1885. Professor H. G. Seeley. *Medal.*
1885. Mr. A. J. Jukes-Browne.
1886. Mr. W. Pengelly. *Medal.*
1886. Mr. D. Mackintosh.
1887. Mr. Samuel Allport. *Medal.*
1887. Rev. Osmond Fisher.
1888. Professor H. A. Nicholson. *Medal.*
1888. Mr. A. H. Foord.
1888. Mr. T. Roberts.
1889. Professor W. Boyd Dawkins. *Medal.*
1889. M. Louis Dollo.
1890. Professor T. Rupert Jones. *Medal.*
1890. Mr. C. Davies Sherborn.
1891. Professor T. McKenny Hughes. *Medal.*
1891. Dr. C. J. Forsyth-Major.
1891. Mr. G. W. Lamplugh.
1892. Mr. G. H. Morton. *Medal.*
1892. Mr. J. W. Gregory.
1892. Mr. E. A. Walford.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially "as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much."

1877. Professor O. C. Marsh.
1879. Professor E. D. Cope.
1881. Dr. C. Barrois.
1883. Dr. Henry Hicks.
1885. Professor Alphonse Renard.
1887. Professor Charles Lapworth.
1889. Mr. J. J. Harris Teall.
1891. Dr. G. M. Dawson.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

"The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science."

1880. Purchase of microscope.
1881. Purchase of microscope lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Professor Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Professor Charles Mayer-Eymar.

ESTIMATES *for*

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				105	0	0
Due for Arrears of Admission-fees	94	10	0			
Admission-fees, 1892	214	4	0			
				308	14	0
Due for Arrears of Annual Contributions				84	0	0
Annual Contributions, 1892, from Resident Fellows, and Non-residents, 1859 to 1861				1700	0	0
Annual Contributions in advance				35	0	0
Dividends on Consolidated $2\frac{3}{4}$ per Cents.				101	1	4
Dividends on London and North-Western Railway 4 per cent. Consolidated Preference Stock				87	15	0
Dividends on London and South-Western Railway 4 per cent. Consolidated Preference Stock				93	12	0
Sale of Quarterly Journal, including Longman's account	165	0	0			
Sale of Geological Map, including Stanford's account	8	0	0			
Sale of Transactions, Library-catalogue, Ormerod's Index, Hochstetter's "New Zealand," and List of Fellows	5	0	0			
				178	0	0
				£2693	2	4

THOMAS WILTSHIRE, TREAS.

27th January, 1892.

the Year 1892.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes	20	0	0			
Fire-insurance	15	0	0			
Gas	40	0	0			
Fuel	30	0	0			
Furniture and Repairs	50	0	0			
House-repairs and Maintenance	20	0	0			
Annual Cleaning	15	0	0			
Washing and Sundries	30	0	0			
Tea at Meetings	12	0	0			
				232	0	0
Salaries and Wages, &c.:						
Assistant Secretary	250	0	0			
„ Half premium of Life Insurance	10	15	0			
Assistant Librarian and Assistant Clerk	260	0	0			
House Porter and Upper-Housemaid	80	0	0			
„ Allowance for Washing	5	4	0			
Under-Housemaid	45	0	0			
„ Allowance for Washing	2	12	0			
Errand Boy	20	16	0			
Charwoman and Occasional Assistance	20	0	0			
Accountant's Fee	10	10	0			
The late I. Charlton (pension)	17	10	0			
				722	7	0
Official Expenditure:						
Stationery	28	0	0			
Miscellaneous Printing	35	0	0			
Postages and other Expenses	90	0	0			
				153	0	0
Library (Books and Binding)				200	0	0
Museum				50	0	0
Publications:						
Geological Map	5	0	0			
Quarterly Journal	1000	0	0			
„ „ Commission, Postage, and Addressing	115	0	0			
List of Fellows	35	0	0			
Abstracts, including Postage	110	0	0			
				1265	0	0
Balance in favour of the Society				70	15	4
				£2693	2	4

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
Balance in Bankers' hands, 1 January, 1891.	415	15	3			
Balance in Clerk's hands, 1 January, 1891 .	18	2	3			
				433	17	6
Compositions				147	0	0
Arrears of Admission-fees	119	14	0			
Admission-fees, 1891	270	18	0			
				390	12	0
Arrears of Annual Contributions				79	7	4
Annual Contributions for 1891, viz.:						
Resident Fellows	1689	9	0			
Non-Resident Fellows ...	15	15	0			
				1705	4	0
Annual Contributions in advance				45	13	6
Dividends on $2\frac{3}{4}$ p. c. Consolidated Stock..	101	1	4			
,, L. & N. W. Railway Stock ..	87	15	0			
,, L. & S. W. Railway Stock ..	81	18	0			
				270	14	4
Taylor & Francis: Advertisements in Journal, Vol. 46..				2	17	6
Publications:						
Sale of Journal, Vols. 1–46	121	3	8			
,, Vol. 47 *	69	12	9			
Sale of Library Catalogue	0	10	0			
Sale of Geological Map	6	11	3			
Sale of Ormerod's Index.........................	2	13	1			
Sale of Hochstetter's "New Zealand"	0	8	0			
Sale of Transactions	2	12	0			
Sale of List of Fellows	0	10	3			
				204	1	0

	£	s.	d.
*Due from Messrs. Longmans, in addition to the above, on Journal, Vol. 47, &c.	70	0	7
Due from Stanford on account of Geological Map...	6	4	7

We have compared this statement with the Books and Accounts presented to us, and find them to agree.

(Signed) JOHN HOPKINSON, F. W. RUDLER, } *Auditors.*

30*th January*, 1892.

	£	s.	d.
	£3279	7	2

Year ending 31*st December,* 1891.

EXPENDITURE.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes	15	1	3			
Fire-insurance	15	0	0			
Gas	40	17	3			
Fuel	28	1	0			
Furniture and Repairs	42	8	7			
House-repairs	37	2	6			
Annual Cleaning	12	2	11			
Washing and Sundries	22	13	3			
Tea at Meetings	15	12	1			
				228	18	10
Salaries and Wages:						
Assistant Secretary	250	0	0			
Acting Editor	30	0	0			
Assistant Librarian and Assistant Clerk	260	0	0			
House Steward (six months' salary)	52	10	0			
House Porter and Upper-Housemaid	39	0	8			
,, Allowance for Washing	0	10	0			
Housemaid	30	8	0			
,, Allowance for Washing	0	5	0			
Errand Boy	27	12	0			
Charwoman	35	9	6			
Attendants at Meetings	6	0	0			
Accountant's Fee	10	10	0			
Late House-Steward (six months' pension)	35	0	0			
				777	5	2
Official Expenditure:						
Stationery	23	6	0			
Miscellaneous Printing	34	8	11			
Postages and other Expenses	79	2	6			
Gratuities voted to Assistant Librarian and Assistant Clerk	50	0	0			
Gratuity voted to late Housemaid	20	0	0			
				206	17	5
Library				163	18	0
Museum				27	14	9
Publications:						
Geological Map	17	8	3			
Journal, Vols. 1–46	7	7	11			
,, Vol. 47 ... £789 16s. 5d.; ,, ,, Commission, Postage, and Addressing ... £115 7s. 3d.	905	3	8			
List of Fellows	35	1	0			
Abstracts, including Postage	106	10	7			
				1071	11	5
Investment in £200 L. & S. W. Railway 4 per cent. Consolidated Pref. Stock, @ 126¼	255	5	9			
Investment in £200 L. & S. W. Railway 4 per cent. Consolidated Pref. Stock, @ 129	260	16	6			
				516	2	3
Balance in Bankers' hands, 31 Dec. 1891	264	17	11			
Balance in Clerk's hands, 31 Dec. 1891	22	1	5			
				286	19	4
				£3279	**7**	**2**

THOMAS WILTSHIRE, *Treasurer.*

"Wollaston Donation Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1891	21	16	0	Cost of striking Gold Medal awarded to Prof. J. W. Judd	10	10	0
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	29	1	4	Award to Mr. R. Lydekker	18	11	4
				Balance at Bankers', 31 December, 1891	21	16	0
	£50	17	4		£50	17	4

"Murchison Geological Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1891	19	10	0	Award to Prof. W. C. Brögger, with Medal	10	10	0
Dividends on the Fund invested in London and North-Western Railway 4 per cent. Debenture Stock	39	0	0	" Rev. R. Baron	27	13	0
				Cost of Medal	0	17	0
				Balance at Bankers', 31 December, 1891	19	10	0
	£58	10	0		£58	10	0

"Lyell Geological Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1891	51	9	0	Award to Prof. T. McK. Hughes, with Medal	25	0	0
Dividends on the Fund invested in Metropolitan $3\frac{1}{2}$ per cent. Stock	68	12	0	" Mr. G. W. Lamplugh	21	5	6
				" Dr. C. J. Forsyth-Major	21	5	6
				Cost of Medal	1	1	0
				Balance at Bankers', 31 December, 1891	51	9	0
	£120	1	0		£120	1	0

"Barlow-Jameson Fund." Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
Balance at Bankers', 1 January, 1891	51	5	6	Award to Mr. W. J. Harrison in 1890	20	0	0
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	13	8	4	Balance at Bankers', 31 December, 1891	44	13	10
	£64	13	10		£64	13	10

"Bigsby Fund." Trust Account.

Receipts.	£	s.	d.
Balance at Bankers'. 1 January, 1891	9	18	7
Dividends on the Fund invested in $2\frac{3}{4}$ per cent. Consolidated Stock	5	12	0
	£15	10	7

Payments.	£	s.	d.
Cost of striking Gold Medal awarded to Dr. G. M. Dawson	11	6	7
Balance at Bankers', 31 December, 1891	4	4	0
	£15	10	7

Valuation of the Society's Property; 31st December, 1891.

Property.	£	s.	d.	£	s.	d.
Due from Longman & Co., on account of Journal, vol. xlvii. &c.				70	0	7
Due from Stanford, on account of Map				6	4	7
Balance in Bankers' hands, 31 Dec. 1891				264	17	11
Balance in Clerk's hands, 31 Dec. 1891				22	1	5
Funded Property:—						
Consolidated $2\frac{3}{4}$ per Cents. at 95	3769	2	6	3580	13	4
London & North-Western Railway 4 per cent. Consolidated Pref. Stock at 129.	2250	0	0	2902	10	0
London & South-Western Railway 4 per cent. Consolidated Pref. Stock at 127.	2400	0	0	3048	0	0
Arrears of Admission-fees (considered good)				94	10	0
Arrears of Annual Contributions (considered good)				84	0	0
				£10,072	17	10

[*N.B.—The above does not include the value of the Collections, Library, Furniture, and stock of unsold Publications.*]

	£	s.	d.
Balance in favour of the Society	10,072	17	10
	£10,072	17	10

THOMAS WILTSHIRE, *Treas.*

27th January, 1892.

Award of the Wollaston Medal.

In handing the Wollaston Medal, awarded to Baron Ferdinand von Richthofen, to Mr. W. Topley, F.R.S., for transmission to the recipient, the President addressed him as follows:—

Mr. Topley,—

To Baron Ferdinand von Richthofen the Council of the Geological Society has awarded this year the Wollaston Medal in recognition of the great merit of the researches carried on by him over a large part of the Old World and of the New. From the outset of his career he has been distinguished by a rare combination of the power of minute patient observation, with the faculty of broad, and often brilliant, generalization. It is this union of mental gifts which has placed him high among the leaders of science of his time, and which gives such a charm and value to his writings.

Beginning his early investigations among the eruptive rocks of his native country, he was gradually led to undertake a detailed investigation of the geology of that interesting region in the South Tyrol around Predazzo and St. Cassian. The elaborate monograph of this tract which he published in 1860 was a remarkable achievement for so young a man, and gave ample promise of his future distinction. Soon after its publication he had the good fortune to be attached to a naval expedition sent out to the East by the Prussian Government to arrange commercial treaties with China, Japan, and Siam. He was thus afforded opportunities of turning to account his power of rapid observation, of enlarging his geological experience, and of meditating upon those problems to the solution of which he might devote his life. We are all familiar with the brilliant series of papers and works which has followed from the labours of the twelve years spent by him abroad.

Crossing the Pacific he came in contact with Professor J. D. Whitney, who was then conducting the Geological Survey of California. The young and eager German was induced to settle for a time on the Pacific border of the American Continent, where he devoted himself to the study of the marvellous volcanic phenomena of that region. Among the contributions made by him to the geology of the United States his remarkable generalizations as to the order of succession of the volcanic rocks and the nature of 'massive eruptions' have attracted special attention.

What he had seen of China had convinced him that an investigation of its geology would prove of the utmost interest and value. Accordingly in the summer of 1868, instead of turning homewards, he returned to that country, and spent somewhere about three years in a series of journeys through the vast Celestial Empire. The massive volumes and splendid atlas which contain his account of China form one of the most important contributions ever made to geological literature. In every chapter there is some luminous remark or suggestive inference that lights up the formidable array of facts with which the pages are crowded. The description of the Chinese Loess and the manner in which the author works out his explanation of that puzzling formation are a model of geological description.

As a geologist, a scientific traveller, an exponent of facts, and a generalizer from facts to their connecting causes, Baron von Richthofen stands in the forefront of the science of our day, and in awarding him the Wollaston Medal this Society does itself as much honour as it seeks to confer on him. When you, Mr. Topley, transmit this Medal to him and express to him our appreciation of his labours, will you also convey to him our personal regard and our hope that he may long be able to continue the work which has rendered his name so illustrious?

Mr. Topley, in reply, said:—

Mr. President,—

I am desired by Baron von Richthofen to express his extreme regret that important duties detain him in Berlin, and render it impossible for him to be present here to-day.

He requests me to offer to this Society his warmest thanks for the honour now conferred upon him, and for placing his name in the list of distinguished geologists to whom this Medal has been awarded.

In a letter which I have just received Baron von Richthofen says:—

"If I were personally present I would not fail to remark that I "am deeply impressed by the consciousness how unfavourably the "humble work I have been able to accomplish compares with the "honour now conferred upon it; and that it will be my endeavour "to render myself more worthy of it by never ceasing to work "in the interests of geological and, what is so nearly related to it, "geographical science, my line of research being indeed chiefly in "that field where both these branches of science meet.

"British geologists have had the largest share in the geological "exploration of other continents than Europe. It has been my lot, "too, to do a chief part of my work abroad. This common interest "has, among others, contributed to connect me with many of my "fellow-workers in science in your country. It is a sincere grati-"fication to me to have this tie strengthened by being put under "the obligation of gratitude towards this illustrious Society in "which the names of British geologists are embodied."

The feeling of gratification with which Baron von Richthofen will receive this Medal, will, I am sure, be shared by the geologists in Germany and Austria. No one is held in higher honour by them, both for personal worth and scientific attainments, than Baron von Richthofen, and to no one would they more gladly see this medal awarded.

Award of the Wollaston Donation Fund.

The President then handed the Balance of the proceeds of the Wollaston Fund, awarded to Mr. Orville A. Derby, F.G.S., to Mr. H. Bauerman, F.G.S., for transmission to the recipient, addressing him as follows:—

Mr. Bauerman,—

I have the pleasure of handing to you the balance of the proceeds of the Wollaston Fund for transmission to Mr. O. A. Derby, to whom the Council has adjudged this Award in recognition of the value of his various communications on the Geology and Palæontology of Brazil. Some of these writings have far more than a local interest. I would especially refer to those in which Mr. Derby gives the results of his petrographical researches on the nepheline-bearing rocks, on the distribution of the sources of the rarer minerals, and on the ore-deposits of the Jacupiranga district. In transmitting this Award to him, will you convey the best wishes of the Council and the Society for his continued success in scientific investigation?

Mr. Bauerman, in reply, said:—

Mr. President,—

I have been asked, by telegram from Mr. Derby, to represent him, as the interval since the Award was announced has not been sufficient to allow of an acknowledgment by letter. I thank you heartily for the recognition of the excellent work done by Mr. Derby in a country whose geological structure is almost unknown, and I consider that in addition to the honour conferred on the recipient, the Award is of value as likely to encourage the local government in carrying on the systematic investigation of the province in the manner that they have so worthily begun.

Award of the Murchison Medal.

The President in presenting the Murchison Medal to Prof. A. H. Green, M.A., F.R.S., addressed him as follows:—

Professor Green,—

In awarding to you the Murchison Medal, the Council desires to mark its sense of the importance of the contributions which you have made to our knowledge of English geology, more particularly in the Coalfield of Yorkshire, with which your name will ever be honourably associated. It might not be appropriate were I to allow myself to dwell on the special value of your geological labours. I will only say that they long ago placed you among the ablest field-geologists of this country. But besides the work done by you in the field, and expressed on maps and sections, we owe a further debt to you for the clear, terse, and interesting descriptions which you have given of your researches. It is always pleasant as well as instructive to read one of your writings, and this eminent faculty of exposition you have turned to valuable account in your admirable 'Manual of Geology.' There is to myself a peculiar pleasure in being the channel through which this Award of the Council comes to you, for I can look on an unbroken friendship with you extending over some thirty years. In handing to you the Medal founded by Murchison, I am reminded of our early intercourse in the Geological Survey under that great leader, when we discussed together the questions to which we have each since devoted ourselves. And I am sure I fulfil the desire of every Fellow of this Society when I express the hope that, in your high position at Oxford and in the original research which you will doubtless still carry on, you may continue for many years that career of distinction which we gladly recognize to-day.

Prof. Green, in reply, said:—

Mr. President,—

Under any circumstances it would be most gratifying to receive from the Geological Society a recognition of my attempts to enlarge the boundaries of our favourite science. But I hold myself specially fortunate on this occasion on two grounds. A Medal that bears the name of the great chief under whom we both served is specially welcome; and a further charm is added when I feel that I am receiving this Award from one to whom I have been bound in close friendship for a period of more than thirty years. If anything could strengthen the link that binds us together, it would be the receipt of the Murchison Medal at your hands. I thank most cordially the Society and yourself for the honour you have done me.

Award of the Murchison Geological Fund.

The President then presented the Balance of the proceeds of the Murchison Geological Fund to Mr. Beeby Thompson, F.G.S., addressing him as follows:—

Mr. Beeby Thompson,—

The balance of the proceeds of the Murchison Fund has been adjudged by the Council to you as a mark of its high appreciation of the insight, endurance, and enthusiasm with which you have prosecuted your laborious investigation of the Upper and Middle Lias of Northamptonshire. Your minute tracing of the successive zones of these formations admirably shows how the Maps of the Geological Survey may be made to serve as the basis for more detailed and exhaustive work, such as can only be undertaken by a permanent resident in a district. We hope that this Award may encourage you to persevere by showing how cordially you possess the sympathies of this Society.

Mr. Beeby Thompson, in reply, said:—

Mr. President,—

I feel greatly the honour that has been conferred upon me by the present Award. I am a comparatively young geologist, having commenced the study of the science some twelve years ago in connexion with the issue of a Journal by the Northamptonshire Natural

History Society. My highest ambition at first was to give a connected *résumé* of all that had been published on the local geology; but I soon found deficiencies in the record, and these I have since done my best to supply. It is now one of the greatest pleasures of my life to go out into the field and interrogate the rocks; and although we frequently come to violent blows, I hope we shall ever remain the best of friends.

I thank you, Sir, for the kind and encouraging words with which you have accompanied this presentation.

Award of the Lyell Medal.

In presenting the Lyell Medal to Mr. G. H. Morton, F.G.S., the President addressed him as follows:—

Mr. Morton,—

The Lyell Medal has been adjudged by the Council to you in recognition of your long and meritorious services to geology in the work which you have done around Liverpool. To you we are largely indebted for the extent of our knowledge of the Triassic and other strata of that district. Your full and accurate account of the glacial phenomena of your neighbourhood forms an especially important part of your labours. In handing you this Medal, with the sincere good wishes of the Council and of the Society, I may add that, had he been alive, no one would have taken a keener interest in your work or rejoiced more heartily at its due recognition than the illustrious founder of this Medal, Charles Lyell.

Mr. Morton, in reply, said:—

Mr. President,—

I fear that I shall fail, by any words at my command, to adequately express how much I appreciate the great honour conferred on me by the Award of the Lyell Medal. This kind recognition by the Council of any original work that I may have done is most gratifying, for it is one of the greatest honours that can be bestowed on a geologist.

The Medal has been awarded to me before I am too advanced in years to hope to do more work, and it will stimulate me to renewed exertion. The pleasure I now feel is increased at receiving the Medal from your hand, Sir, not only as President of the Geological Society, but as the Director-General of the Geological Survey. I thank you for the complimentary manner in which you have referred to my work in the Triassic and other strata around Liverpool.

Award of the Lyell Geological Fund.

The President then presented one half of the Balance of the proceeds of the Lyell Geological Fund to Mr. J. W. Gregory, B.Sc., F.G.S., addressing him as follows:—

Mr. Gregory,—

One moiety of the Balance of the proceeds of the Lyell Fund has been assigned by the Council to you as a token of its warm appreciation of your researches and as an encouragement to you to continue them. You have shown yourself to be at once an accomplished palæontologist and an able petrographer; and we trust that in both capacities you may live amply to fulfil the promise which you have given of a brilliant career in the future.

Mr. Gregory, in reply, said:—

Mr. President,—

The Fund which the Council has so kindly awarded me helps me to realize more than usually the responsibility of holding an appointment at the Natural History Museum, for I feel that it is to the opportunities afforded by its collections and libraries, and by the generous assistance and encouragement of the more experienced members of the staff, that the little that I have been able to do is entirely owing. You, Sir, have kindly referred to the fact that I have occasionally wandered from the work of descriptive palæontology; I can only offer as an excuse for thus presuming to intrude into the other branch of geological work, the desire occasionally to exchange the air of the museum for that of the field, as well as the wish for the training acquired in pursuing the more precise method of research.

This Award will encourage me to try to continue in the path of its founder in regarding fossils not merely as the cells of a phylogenetic tree, but as the witnesses from whose evidence we must learn the physical conditions and faunistic migrations of the successive periods of the past.

In presenting the other half of the Balance of the proceeds of the Lyell Geological Fund to Mr. Edwin A. Walford, F.G.S., the President addressed him as follows:—

Mr. Walford,—

The Council has awarded you the other moiety of the Lyell Fund in recognition of the great merit of your studies among the Lias and Lower Oolites and your contributions to our knowledge of the *Trigoniæ* and *Polyzoa* of the Jurassic rocks. We hope that you will accept this Award as an aid and stimulant to further research, and that we may have the pleasure and profit of continuing to receive the results of your labours.

Mr. Walford, in reply, said:—

Mr. President,—

I thank you for this recognition of such work as I have done. My stratigraphical labours have consisted principally in filling in the details of the broad outlines so well laid down by the officers of the Geological Survey. In palæontology my work amongst the Mollusca and Bryozoa has been done in the few intervals of leisure snatched from a busy business life. I wish that I had been able to accomplish more, for what I have done is but evidence of what I would wish to do.

Award of the Barlow-Jameson Fund.

The President then handed the Proceeds of the Barlow-Jameson Fund, awarded to Prof. C. Mayer-Eymar of Zürich, to Dr. W. T. Blanford, F.R.S., addressing him as follows:—

Dr. Blanford,—

In asking you to be so good as to transmit to Prof. Mayer-Eymar a donation from the Barlow-Jameson Fund, awarded to him by the Council, I hope that you will convey to him an expression of the interest we take in the work which he is now carrying on so vigorously in Egypt, and of our desire to aid him in it. His previous training in the palæontology of the Cretaceous and Tertiary rocks of Switzerland, France, and Italy eminently qualified him for the task to which he is now devoting himself, and in which we sincerely wish him success.

Dr. Blanford, in reply, said:—

Mr. President,—

I am very pleased to undertake the duty of transmitting the Award from the Barlow-Jameson Fund to Prof. Charles Mayer-Eymar. The money will be devoted to one of the most important objects for which these funds were originally founded—the payment of the travelling expenses of a geologist who is engaged in investigating the structure of a distant country.

Professor Mayer-Eymar, in a letter from Cairo written on the 4th of the present month, asks me to convey his thanks to the Society, expresses his warm acknowledgment of the assistance to his work that the present Award will give, and promises, as evidence of his gratitude, to send in the course of next month, for the information of the Society, an account of his three principal stratigraphical discoveries in Egypt.

The Murchison Centenary.

The President then said:—

Before passing from the subject of the Awards, I should like to refer very briefly to the remarkable and interesting coincidence that this Anniversary day of our Society is also the centenary of one of the great geologists who founded our Medals and Funds. Exactly one hundred years ago (viz. on February 19th, 1792) Roderick Impey Murchison was born. Twenty years have passed away since he was removed from our midst; and at this distance of time we can better estimate the value of his work and its influence on the progress of our science. I do not purpose, on the present occasion, to attempt such a critical estimate. I am sure, however, that I express not my own feeling only, but that of every Fellow of the Society, when I say that though we have been able to correct some of his observations, and discard some of his deductions, the solid work which he accomplished, more especially in the establishment of his Silurian system, stands on a basis which seems even stronger and broader now than when he laid it more than half a century ago. His name has become a household word in Geology, and will go down to future ages as that of one of the great pioneers of the science.

To those who knew him personally and learnt to appreciate the frank, generous, and sympathetic nature that underlay the somewhat formal bearing of the old soldier, this day brings many pleasing memories. That the recollection of his personal worth remains yet fresh without as well as within the pale of our Society has been vividly brought to my knowledge by an incident as unwonted as it is gratifying. Within these few days an old friend of Murchison, who desires to remain unknown, has come to me with the wish to be allowed to offer here a tribute to his memory at this Anniversary of the Geological Society and centenary of his birth. As a mark of sincere admiration for the man as well as the geologist, and with the view of helping to encourage the cultivation of the spirit in which he laboured, I have been asked to select two geologists, by preference Scotsmen, who are disciples of Murchison or who are carrying on the kind of research to which he devoted himself. To each of these workers the generous donor asks to be allowed to give a framed portrait of Murchison together with a sum of £50. The conditions of the gift circumscribed my choice, but I feel confident that I shall carry the Society with me when I say that there are pre-eminently two Scottish geologists who have worthily followed in Murchison's footsteps, but with no slavish regard for the opinions of their master, who are continuing and extending his work, and who by their constant association alike in the field and in descriptive writing deserve to share in this tribute to the memory of their former chief. I need hardly say that I allude to Mr. B. N. Peach and Mr. John Horne.

The President then presented an envelope containing a cheque for £50 to Mr. B. N. Peach, F.G.S., and requested him to convey a similar packet to Mr. J. Horne, F.G.S.

Mr. Peach, in reply, said:—

Mr. President,—

On behalf of my colleague, Mr. Horne, and myself I beg to thank you for your kindness in considering that we have carried on the work of our old chief, Sir Roderick Murchison, in the true spirit, and I beg to request that you will convey our thanks to the unknown donor of this munificent gift.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

Sir ARCHIBALD GEIKIE, D.Sc., LL.D., F.R.S.

GENTLEMEN,—

Among the losses which this Society has suffered in the year that has passed since our last Anniversary, there is none that awakens a keener feeling of regret than the death of our friend and associate Sir ANDREW CROMBIE RAMSAY. For more than five and thirty years he was one of the most prominent of our Fellows, taking an unceasing and active interest in the prosperity of the Society, serving it as Member of Council, as Vice-President, and as President, receiving its highest award, and contributing fresh lustre to its reputation by his own researches.

He was born in Glasgow on 30th January, 1814. From his father, a chemist of note in his day, who had invented several processes wherein the applications of chemistry were turned to practical use in industrial manufactures, he inherited a love of science, and though for a time this love seemed quenched in the commercial pursuits to which, as a young man, he had to devote himself, it eventually asserted itself with such force as to turn him wholly into the cultivation of Geology as the master-passion and occupation of his life. While still engaged in business he profited much by intercourse with Professor Nichol, of Glasgow University, the eloquent writer on Astronomy, who directed his reading and encouraged him to persevere in the cultivation of Geology. Delicacy of health in the end required him to leave Glasgow for a time, and he betook himself to the Island of Arran—a delightful training-ground, where he not only recovered his health, but laid the foundations of his fame as one of the ablest stratigraphical geologists of his day. With every peak and corrie, every glen and rivulet, every bay and reef in this fascinating island he made himself familiar, mapping the whole on the scale of two inches to a mile, and making a model of it of the same size.

In the year 1840 the meeting of the British Association was held at Glasgow, and proved to be the turning-point in Sir Andrew's career. His map and model of Arran were exhibited to the members of the Association, and attracted special notice from the geologists, particularly from Murchison. The author of the 'Silurian System' was at that time planning an expedition to America, and being on the look-out for an active and clever assistant, he made choice of the young Scot who had shown his skill so signally in working out the structure of a district which Murchison himself had studied with Sedgwick many years before. Ramsay accordingly came to London about the middle of March 1841, and was introduced into the company of the leading geologists of the time, dining at the Geological Club, which then met at the 'Crown and Anchor,' by Temple Bar, and meeting, among others, Sedgwick, Lyell, Buckland, Phillips, Greenough, Fitton, Sopwith, Edward Forbes, and Owen. At the last moment Murchison's plans were changed. Instead of going to America he decided upon continuing his researches in Russia, and could not take Ramsay with him. But, with characteristic thoughtfulness, he did not start on his journey until he had secured for his young friend a place on the Geological Survey under De la Beche. Within a few days thereafter, viz. in April 1841, Ramsay joined the staff of the Survey at Tenby, and began that distinguished official career which lasted for more than forty years.

Long after that early time, when he had risen to have charge of the whole operations of the Survey, Ramsay used to recall the feeling of wonderment with which in these first months he went out day after day to geologize, not as the chance occupation of a holiday snatched from the cares of business, nor as the relaxation of a brief sojourn in the country in search of renovated health, but as the ordinary and regular employment of his life. It all seemed like a dream; every day came with the zest of a holiday. Under De la Beche he soon acquired the methods of mapping and section-drawing which that incomparable field-geologist had introduced, and he was able to break ground for himself among the ancient rocks of South Wales, at that time almost unknown.

He found leisure this year to see through the press the little volume on Arran which embodied the results of his survey of that island. This, his earliest work and one of the most admirable that he ever wrote, struck the key-note which we find steadily vibrating through all his subsequent publications. It showed him to be above everything a skilful decipherer of geological structure, a lucid expositor of his observations, a cautious and yet bold generalizer from the facts gathered by him, a lover of nature, and above all of that mountain-world where nature may be communed with in her sterner and more impressive moods, and lastly, a writer on geology whose reading was not confined to the records of his own science, but who ranged freely over English literature, and allowed his thoughts and his language to be influenced thereby.

In four short years after he had joined the staff of the Survey, Ramsay had given such signal proofs of his prowess as a surveyor and his general capacity for affairs that, when in 1844 the Survey was remodelled and enlarged, he was chosen by De la Beche to be the first Local Director. Happy in his work, he was happy also in his companionships. The Director-General had the faculty of choosing men singularly well qualified for carrying out the work which he so sagaciously conceived. Edward Forbes, Warington Smyth, Robert Hunt, W. Talbot Aveline, Henry W. Bristow, Alfred Selwyn, and others formed the band of enthusiastic workers with whom Ramsay was associated, who discussed with him the problems of the younger days of geology, who ranged far and wide in his society over the hills of Wales during the day, and kept up talk and argument with him until late at night. This mingling of hard physical exercise with earnest conference over scientific questions, as well as with endless social merriment, gave to the Survey-parties a reputation which led to their being frequently sought by outsiders of similar tastes and temperament. I remember being told by Robert Chambers how he, on one occasion, joined the jovial Surveyors, and being the senior member of the party was voted into the chair at the head of the table; how he had to carve, and could thus appreciate the gigantic appetites which ten hours of toil among the Welsh hills engendered, and how amid arguments, anecdotes, and tobacco the evening passed quickly away.

So rapidly had Ramsay's reputation grown that not only did he receive, after only four years of service, the important appointment to the second place on the staff of the Geological Survey, but in 1848 he was chosen Professor of Geology at University College, London—a post which he continued to hold, besides his Survey appointment, until 1851, when, on the institution of the Royal School of Mines at Jermyn Street, he received the Professorship of Geology there. His official position was now definitely settled. He remained Director in the Survey and Professor in the School for the next twenty years, and only relinquished these appointments to accept the higher post of Director-General in succession to Murchison.

The even tenour of official life offers little in the way of incident for a biographer to chronicle. But Ramsay's energy could not be confined within the limits of his official duties, engrossing and exacting as these duties were. Year after year he betook himself to the Continent and spent his holiday there, usually in enlarging his geological experience by studying in foreign lands, and in totally different surroundings, the questions that occupied so much of his attention at home. In this way, for example, he came to know more of what is called "glacial geology" than any of his contemporaries, for he had the advantage of being familiar with the problems of ancient and extensive glaciation, as these are manifested in Britain, while at the same time he learnt to know by heart the characters and scenery of the living glaciers of Switzerland. His researches among the Permian rocks of England were supplemented and broadened by his studies of the Rothliegende of Germany. And while following the trail of rocks in other countries, he was never unmindful of the courtesies due to foreign geologists. Few of his contemporaries had a wider circle of acquaintances abroad. He visited these brethren of the hammer, discussed with them, corresponded with them, and in many instances formed with them close and enduring friendships, as delightful and useful to them as they were to himself.

His longest journey was that undertaken by him in the year 1857, when, as delegate from this Society, he attended the Meeting of the American Association for the Advancement of Science. During that visit, in company especially with his old and beloved friend, W. E. Logan, Director of the Geological Survey of Canada, and with Professor James Hall, of Albany, he saw much of the general geology, and still more of the glaciation, of the Northern States and of Canada. It was the enlarged views of geological questions which such extensive travel enabled him to attain, combined with the patient mastery of detail necessitated by the requirements of the Survey, which gave his expositions their special charm.

To enumerate all the Memoirs contributed by our late associate to the literature of his favourite science would lead me far beyond the necessary limits of this notice. But a brief statement of the branches of enquiry under which they may be grouped will serve to show his industry, the breadth of his grasp, and the large debt which British Geology will for ever owe to him.

First I would place his stratigraphical work, in which his genius as a field-geologist specially shines. Last year, in my Anniversary Address, I took occasion to record my admiration of the way in which, with his colleagues, he unravelled the complicated structure of the volcanic tracts of North Wales. His elucidation of the Snowdonian region, the beauty and, considering the small scale of his maps, the wonderful accuracy of his mapping, the vivid realization afforded by his sections of the essential structures of difficult mountain-ground, and the minuteness of detail in his descriptive Memoir, combine to form at once a masterpiece of geological work and his own fittest and most enduring monument. The late Henry D. Rogers, who knew from long personal experience what geological surveying involves, once remarked to me that nothing had so impressed him with the geological prowess of Ramsay and his colleagues in the Survey of Wales as a visit he paid to the Snowdon country with the Survey Maps in his hands. And I feel sure this must be the judgment of every competent observer who takes these maps with him through that interesting district.

To the general body of geologists perhaps our friend was best known from his contributions to the literature of Ice and its geological effects. So much has been written on this subject since he began his labours that most readers have very little idea of the state of the question at that time. Buckland had recognized traces of ice-scratchings in different parts of Britain. Lyell had found relics of vanished glaciers among the hills of Forfarshire, and Darwin among those of Wales. Agassiz not only confirmed their inferences as to the former presence of valley-glaciers, but boldly asserted the existence of evidence that the whole of Scotland and the north of England had been covered with a moving sheet of ice. These early pioneers, however, had few followers. What seemed then to be the extravagance of Agassiz's notions no doubt helped to retard the pursuit of an enquiry which was laughed at by the old steady-going philosophers who stood firm on the ancient ways. Vast as the modern literature of glacial geology is, it can hardly be said to have begun to exist when Ramsay broke ground as an enquirer into the superficial drifts, scratched rocks, and perched boulders of North Wales. With all the enthusiasm of his nature he threw himself into the study of these phenomena, visited Switzerland again and again, climbed into snow-fields, scaled peak, pass, and precipice, wandered over and crept under many a glacier, traced the erratic blocks from the ice-surface far up the mountain-slopes and far down the valleys, and thus made himself master not only of the ways of the existing glaciers, but of the work done by them when they were hundreds of feet thicker and thousands of yards longer than they are now. With this wide experience he prosecuted the investigation of the old glaciers of Wales, and by publishing his results largely contributed to give that impetus to the progress of this branch of geology which was perhaps the most marked feature of the advance of British geology during his life.

Connected with his glacial work, and indeed arising naturally out of it, there was another department of enquiry which always had for Ramsay a peculiar fascination—the history of the topographical features of a country. Others before him had been exercised by the peculiar difficulties of the problems presented by these features, and had offered various more or less plausible solutions of them. But to him, more than to any other writer, do we owe the resuscitation of this subject and the convergence upon it of a large experience in the examination alike of existing geological processes and of the relation between the form of the ground and the structure and disposition of the rocks underneath it. As far back as his early years in Wales, his attention had been drawn to such questions, and we have the results given by him in that first and most remarkable essay in the Survey Memoirs, 'On the Denudation of South Wales.' Few such suggestive papers have appeared in the literature of our science. It opened up a new world of possible geological enquiry.

Later in time, as his thoughts became more concentrated upon the phenomena of glaciation, his attention was arrested by the existence of lakes in old and existing glacier-districts, and by the evident proofs that many of these lakes lie in strongly ice-worn rock-basins. He noted the abundance of such lakes in regions which either nourish glaciers now, or can be shown to have done so formerly; while, on the other hand, he was struck with the comparative scarcity and even frequent absence of lakes from districts where probably no glaciers ever existed. Pondering on this subject, he evolved his famous doctrine that the glaciated rock-basins in certain districts had been eroded by the grinding action of glacier-ice. His views, which had been shaping themselves for some years, during his constant study of glacial phenomena, at last took shape in the well-known paper read to this Society in the year 1862. So strong was the opposition to his conclusions, especially among the older and more influential members of the Society's Council, that, as I have been told, had he not himself been at the time President of the Society, the paper would certainly have been rejected. Into the controversy which he raised, and which is not yet closed, I do not propose to enter here. I would remark that whether or not we agree with the doctrine maintained in this paper, we must admit that its publication has stimulated investigation in a most remarkable degree. The very opposition which the author's conclusions evoked excited an interest in glacial geology, and led into that branch of the science many observers who might otherwise never have entered it. Attention was called in this way to other collateral subjects of enquiry, and thus the tide of research in glacial matters was kept full and flowing.

But besides the question of the origin of lakes, Ramsay had long meditated upon the whole subject of the shaping of terrestrial features. To him, as to all who were then thinking of these questions, Jukes's ever-memorable essay on the River Valleys of the South of Ireland came as the revelation of a new method of geological enquiry, opening out boundless possibilities of successful research into the origin of scenery. He was not slow in availing himself of the aid thus afforded. From time to time, up to the close of his official life, he seemed to find recreation in trying to trace back the history of the present landscapes of the country. At one time we find him following the stages by which Anglesey became an island. At another we listen as he tells us the story of the 'sacred Dee.' Again, he leads us backward to the time when the Thames began to flow and the valleys of the South-east of England took their present trend.

If there was one aspect which, beyond the charm of their freshness and accuracy, marked the writings of our distinguished associate, it was, I think, their remarkable suggestiveness. As we read them we seem to be led onward beyond the written words to ideas and applications of ideas which may never have been present to his mind, but which, as they rise before us, impress us with a sense of his genius in penetrating so far and with such happy instinct along the path of fruitful enquiry. As an illustration of this faculty I would especially refer to his Presidential Addresses to this Society on 'Breaks in the Succession of the British Strata.' This subject had been long in his mind; for he had, so far back as 1856, chosen it as the subject of an address to the Geological Section of the British Association. When he resumed it before this Society he could treat it with a fullness of knowledge derived from an intimate personal acquaintance with the whole range of the geological record in this country, and with the breadth of outlook which the publication of Darwin's 'Origin of Species' had then made possible. As a teacher of geology he had few equals in the power of luminous exposition and happy illustration. His range of experience in the field was so wide that there were few departments on which he did not speak from actual personal knowledge of the facts. His students soon recognized this feature of his lectures. He told them much that they could not find in books, and many a time the outlines of his own published ideas were first sketched to his pupils, much as the results of his personal unpublished observations were also given in the discussions at the Geological Society. The young men who passed out from his teaching into all parts of the world retained an affectionate regard for him; and he had the joy of seeing his lessons bear fruit in the stores of new knowledge of the geology of distant lands which from time to time they sent home. His well-known work on the 'Physical Geography and Geology of Great Britain' was originally given as a short course of lectures to working men, and gradually expanded in successive editions into its present form.

Before closing this brief and inadequate outline of the life-work of Sir Andrew Ramsay, I may refer to a class of his writings much less generally known to the world at large, but, when they appeared, fully appreciated by his wide circle of friends—the articles, chiefly anonymous, which he contributed to the periodicals of the day, and especially to the *Saturday Review*. These show him at his best, as he touches lightly on geological topics, or discusses some historical question where geology can be of assistance, or deals with literary or social subjects widely apart from science. I remember one of his essays on the relations of geology to poetry, in which he showed how the very language of geological disquisition arranged itself in rhythmical measure, and where he quoted the first sentence of Lyell's 'Elements of Geology' (with, I think, some slight verbal change) as two lines of English heroic verse. He had a tolerably wide acquaintance with our literature, and took especial pleasure in its poetry. Keats was one of his favourite authors; he was never weary of the quaint turns in the 'Ode to the Grecian Urn' or of the antique massiveness of 'Hyperion.' Ballad poetry too had many charms for him; and as in these respects I shared his tastes, I can recall many a ramble with him when field-work and rock-sections, which we had met to discuss, obtruded themselves as an unwelcome interruption in the full career of our repetition of Border ballads.

Sir Andrew's claims to recognition for the value of his scientific work were amply acknowledged early in his career and up to the time of his retirement. To begin with our own Society, he was elected a Fellow in 1844. Four years afterwards he was chosen a Member of Council, and with slight intermissions he continued to hold that office for more than thirty years. In 1862 he was elected President, and repeatedly thereafter he was appointed a Vice-President. He received our Wollaston Medal in 1871. The Royal Society enrolled him among its Fellows in 1849, and awarded him one of its Royal Medals in 1879. The Royal Society of Edinburgh bestowed its Neill Medal upon him in 1866. He was elected a member (usually honorary) of many scientific societies in this country; while, of the numerous bodies abroad which placed his name among those that they wished specially to honour, I will only mention the Nuovi Lincei of Rome, the Royal Academy of Sciences of Turin, the Académie Royale de Belgique, the American Philosophical Society, and the American Academy of Arts and Sciences, Boston. As a mark of the appreciation of the Italian Government for his services to science, and to the Italian geologists who started the Geological Survey of that kingdom, or who came to this country for the purposes of study, he was created a Knight of the Order of SS. Maurice and Lazarus.

His long residence in Wales during the progress of the Survey there kindled in him an enthusiastic interest in the Principality, its language and antiquities. Some of his most cherished friendships were made there, and it was there that he found his wife, who was the daughter of the Rev. Chancellor Williams of Llanfairynghornwy, Anglesey. He married in 1852, and is survived by his widow and one son and four daughters.

On the death of Sir Roderick Murchison in 1872, Sir Andrew was appointed to succeed him as Director-General of the Geological Survey; and he continued to administer the affairs of this branch of the public service until the end of 1881, when he retired, and received the honour of knighthood for his long and distinguished services. His health gradually became impaired, and, quitting London, he took up his abode permanently at Beaumaris, where he spent the last eight years of his life. So long as he was able he kept up his interest in his old pursuits, and was pleased to renew old times with the friends who found their way to Wales to visit him. But he took no personal part in geological discussion after his retirement, devoting his time mainly to his favourite authors, to whom he could now return free from all official distractions. In spite of increasing feebleness, his vigorous constitution nevertheless enabled him to linger until the present winter. He died on the 9th December last, within a few weeks of reaching his 78th year. In the old churchyard of Llansadwrn, almost within hearing of the Menai Strait, on the history of which he had so long pondered, and within sight of the Snowdon mountains which he knew and loved so well, and which he taught so many others to know and love, his honoured remains were laid at rest.

Of the man himself, as we knew him in daily intercourse, we shall ever retain the kindliest memory. His frank manly bearing, his well-cut features beaming with good nature, his keen sense of humour, his gaiety of spirits, his ready powers of conversation, and above all his unfailing generous sympathy and helpfulness, gathered around him a large circle of devoted friends, who admired his genius and loved his character. To them his retirement ten years ago from public life was a keen personal loss, and now they mourn that he has passed for ever away. We in the Geological Society are happy in the remembrance that we enjoyed for so long the company of one so deserving to be held in honour, and that, among those who have been our Presidents and have received our highest award, we can point with pride to the name of Andrew Crombie Ramsay.

Another of the former Presidents of this Society has been removed from our midst by the death of Professor P. Martin Duncan, which took place on the 28th of May last. Born at Twickenham on 20th April, 1824, he was educated at King's College, London, as a physician, took the degree of Bachelor of Medicine in 1846, and was chosen an Associate of the College in 1849. At first he practised his profession at Colchester, and took so much interest in the affairs of that town that eventually he was elected its Mayor. Already, even in the midst of the many calls on his time and energies, he had begun to interest himself in natural-history pursuits, and the way in which he arranged the contents of the local museum showed how keen a sympathy and wide a knowledge he possessed in that department of enquiry. Eventually finding the definite adoption of scientific work as the labour of his life far more to his taste than the medical profession, he settled in London, and giving up his practice, took to the study of palæontology. He began with corals, and soon showed such mastery of the subject that he was speedily acknowledged to be one of the ablest investigators of invertebrate palæontology in this country.

In the year 1870 he was appointed to the Chair of Geology in

King's College, and next year received a Fellowship. Soon afterwards he also became Professor of Geology at Cooper's Hill. These appointments he continued to hold up to the end of his life.

His earliest palæontological papers were read in 1863. From that time almost to the last he continued to follow out the lines of research on which he originally started. He specially devoted himself to the study of the fossil Corals, and came to be recognized as our chief authority on that subject. These studies led him to investigate also the fossil Echinoids, especially those from Australia, India, and Northern Africa. In all his palæontological work he sought to connect the former range of the organisms with questions in physical geography and geology. He not only mastered the forms and affinities of the fossils, but used their evidence in the endeavour to trace the distribution of land and sea during former geological periods. He also wrote many papers on zoology, especially devoting his attention to the anatomy of the recent forms of some of the great groups with whose fossil representatives he was so familiar.

He became a Fellow of this Society in 1849, served as one of the Secretaries from 1864 to 1870, was frequently Vice-President, became President in 1876, and received the award of the Wollaston Medal in 1881. In the year 1868 he was elected into the Royal Society. During his busy life he took an active part in the business of the various societies of which he was a member. Yet he also found time for much writing and editing of scientific works of a more popular kind. His health at last began to fail, and he died after a long and painful illness. Those who knew Professor Duncan intimately regarded him with sincere affection. His sense of humour, combined with much kindliness and helpfulness, gained him the esteem of a wide circle of acquaintances; while his many solid contributions to geological and palæontological literature made his name honoured and familiar in every country where geology and palæontology are studied.

Among the recently deceased Fellows of the Society, two peers deserve to be remembered on this occasion. The Duke of Devonshire, though not himself a man of science, evinced keen sympathy with scientific enquiry, and did much to promote it. He founded, at his own cost, the laboratory for physical research in the University of Oxford. He was the first President of the Iron and Steel Institute, and was largely instrumental in starting that useful association. He was also President of the important Royal Commission appointed in 1870 to report upon Scientific Instruction and the Advancement of Science, and he took infinite pains in the enquiry, evincing from beginning to end the warmest interest in the evidence collected. He was elected a Fellow of this Society in 1829, and is thus the oldest member who has been removed from among us during the past year. He was born in 1808, and died on December 21st, 1891.

The Earl of Northesk specially interested himself in stone-implements, of which he formed a large collection. With great liberality, he lent this collection for exhibition in various local museums, where its contents have been much appreciated. At present it is located in the Winchester Museum, where it fills two rooms. The Earl was elected a Fellow of our Society in 1883. He was born in 1843, and died on September 9th last.

Frederic Drew was born on 11th August, 1836, at Southampton. In 1853 he entered the Royal School of Mines, where his career was unusually distinguished. In 1855 he joined the Geological Survey, and during the short time of his service did much valuable work in the South-east of England. Although the general succession of the Lower Cretaceous rocks round the borders of the Weald was then well established, little was known of the area of the Hastings Sands. The subdivisions of these strata were traced out by Mr. Drew over a large tract of country, and the names given by him have passed into the accepted nomenclature of English geology. Fitton had noted the subdivisions of the Lower Greensand on the coast of Kent, and had suggested correlations with other districts inland, but Mr. Drew was the first who mapped those subdivisions along the northern side of the Weald. He also gave them the names by which they are now known. The general results of his survey of the Hastings Sands were published in the Journal of this Society for 1861, and those of his examination of the Lower Greensand divisions in the Geological Survey Memoir on Romney Marsh in 1864.

In 1862 Mr. Drew retired from the Geological Survey to enter the service of the Maharaja of Kashmir. The opportunities for geological research which he had expected to find in this new field proved less favourable than he had been induced to anticipate; but he was soon advanced to more responsible work, for, having gained the confidence and esteem of the ruler of the country, he was appointed Governor of Jummoo, and afterwards of Ladak.

In 1872 he returned to England, and in 1875 was appointed one of the Science Masters at Eton—a post which he filled until his death. Besides the writings descriptive of his early labours in the South-east of England, Mr. Drew published an account of the districts with which his long residence in the East had made him familiar. His important work, 'The Jummoo and Kashmir Territories,' appeared in 1875, and an abridged edition in 1877 under the title of 'The Northern Barrier of India.' Some interesting observations on the Alluvial Deposits and glacial records of the Upper Indus Basin were communicated by him to this Society, and were published in the Journal for 1873. He was elected among the number of our Fellows in 1858, and soon after his return to this country was chosen into the Council, on which he served during three years, from 1874 to 1876. Those who were privileged with his friendship will cherish as long as they live the recollection of his gentleness, helpfulness, and entire unselfishness, his generous devotion to every cause which seemed to him to be deserving of his sympathy, and his quiet enthusiasm for that domain of natural science to which he had given the labours of his life. Under pressure of ill-health, which would have daunted a less resolute nature, he clung to his duty at Eton until at last driven to seek the milder air of Bournemouth for some relief from the sciatica and attendant complications from which he had long been a sufferer. But it was then too late. He died on the 28th of October last.

Mr. William Kinsey Dover, who died on March 27th, 1891, in his 75th year, was elected a Fellow of this Society in 1880. It was only in the latter part of his life that he devoted himself to palæontology, but he was soon successful in making a large collection of fossils from the Skiddaw Slates of the Lake District. This collection he presented in 1890 to the Woodwardian Museum at Cambridge.

Richard Boxall Grantham, who died in December last, in his 86th year, was one of the oldest Fellows of this Society, having been elected in 1833. From the year 1823 up to within a few days of his death he was actively engaged in professional work as a civil engineer. In his early years, in association with his father, he was employed in operations for the improvement of the River Shannon. After filling an appointment as County Surveyor in Ireland, he came in 1836 to England, and was at first engaged here in railway surveys. Amongst other work, he was placed in charge of the Great Western branch line from Gloucester to Cheltenham, which involved some heavy cutting through the Lias. To the geological characters of the rocks with which his professional work brought him in contact he paid much attention. In 1844 he came to London, and was elected a Member of the Institution of Civil Engineers in that year. For the next fourteen years he was still much employed in railway-construction in the West of England. Amongst his undertakings may be mentioned the Forest of Dean Central Railway, which required deep cuttings through the Old Red Sandstone and Carboniferous Limestone.

From 1856 onwards his professional work was chiefly connected with arterial and agricultural drainage, land-improvements, the reclamation of alluvial land, and the protection of various parts of the coast from erosion by the sea. Amongst the more important of these undertakings may be mentioned the Thames Valley drainage above Oxford; the Somersetshire Valleys drainage; the reclaiming and marling of Delamere Forest; the restoration of Brading Harbour, with the reclamation of a large area of valuable alluvial land; and various protective works along the Sussex coast and the Isle of Thanet. He was also engaged in various ways in questions relating to water-supply. He acted as Inspector under the Land Drainage Act of 1861, and reported for the Inclosure Commission in 1871 on the Somersetshire floods. He was Chairman of the British Association Committee on Coast Erosion, and contributed several important papers to the published Reports of that Committee. He wrote also on the Norfolk Broads, and published an account of the process by which he turned the barren tract of Delamere Forest into a comparatively fertile district.

John Thornhill Harrison, who died at Ealing on 4th November last, in his 76th year, was born at Thornhill in Durham, and was educated at Sunderland, and at Edinburgh University. Beginning the career of an engineer under his brother, Mr. T. E. Harrison, who was Engineer to the North Eastern Railway, he afterwards served, under Mr. I. K. Brunel, upon the Great Western and other railways in the West of England. For a time he gave up active work in his profession, and devoted his attention to agricultural pursuits. He served on the Royal Commission on Pollution of Rivers (1865), and afterwards, having been appointed one of the Engineering Inspectors of the Local Government Board, conducted a large number of important official enquiries in various parts of the kingdom. His experience in all questions relating to water-supply, &c., was thus extensive, and he had abundant opportunities of applying to practical uses his knowledge of geology.

Though he contributed nothing to the publications of this Society, he furnished papers, on coast-changes, estuaries and harbours, and on the Thames Valley drainage, to the earlier volumes of the 'Proc. Inst. Civ. Engineers.' Last year he read before the same Institution a paper 'On the Subterranean Water in the Chalk Formation of the Upper Thames, and its relation to the Supply of London.' This paper was to some extent a re-statement of schemes for water-supply contained in a Report to the Local Government Board in 1884. In 1889 he published a work 'On the Creation and Physical Structure of the Globe.' He became a Member of the Institution of Civil Engineers in 1847, and a Fellow of this Society in 1871.

In the death of Sir John Hawkshaw on 2nd June, 1891, we have to regret the loss of one of the most distinguished engineers on our list of Fellows. He was born in 1811 in the West Riding of Yorkshire. After some experience in engineering works in this country he became, in 1832, Manager of the Copper Mines of the Bolivar Mining Association in Venezuela, remaining there nearly three years. In 1838 he published a small work which contains information on the rocks of that region. From 1834 onwards his main professional work lay in England; but he either carried out or was consulting engineer to numerous foreign engineering undertakings. Up to 1850 he resided in Manchester, but in that year he removed to London.

The mere enumeration of the more important operations planned or assisted by Sir John Hawkshaw would occupy considerable space. Information regarding his more specially engineering works will be found in the full obituary notice published in 'Proc. Inst. Civ. Eng.' vol. cvi. On the present occasion room can be found only for the mention of a few of them which possess some particular geological interest. His experience as an engineer to several railways intersecting the Pennine Chain, where cuttings and tunnels were required, led to the publication by him in 1841 of a paper in the Transactions of this Society on the Fossil Trees found in the excavations for the Manchester and Bolton Railway. In 1843 he published, in Sturgeon's 'Annals of Philosophy,' some observations on the state at that time of geological inquiry as to the origin of coal, and in 1846 he issued a "Plan of part of the Yorkshire Coalfield.' He reported (1863) on M. de Lesseps's proposed Suez Canal, and his report, which contains numerous observations of geological interest, decided Said Pasha in favour of the scheme. From 1862 until its completion in 1871, he was engineer to the Amsterdam Ship Canal, the most important work of its kind now completed, with the exception of the Suez Canal.

His professional avocations led him to plan or report upon many engineering projects involving some acquaintance with geological structure, such as water-supply, arterial drainage, canalization, docks, harbours, and the improvement of river-channels.

Sir J. Hawkshaw was Consulting Engineer for the Severn Tunnel. When great trouble arose from the enormous quantities of water met with, he was appointed Chief Engineer, and under his direction the work was successfully completed. The Brighton Intercepting Sewer, 7 miles long, was also a work of his in which considerable quantities of water had to be encountered.

To the general public he became well known from his advocacy of the Channel Tunnel. In 1865 he employed Mr. H. Day to make a detailed geological survey of the shores of the adjacent country, and Mr. H. M. Brunel to ascertain the nature of the bottom and the outcrops of strata under the sea. Fuller investigations were afterwards undertaken by the French engineers, and still later by the South Eastern Railway. Whilst fully convinced of the feasibility of the scheme from an engineering point of view, Sir J. Hawkshaw in later years was much impressed by the military and political objections urged against it, and he ultimately declined to take further part in the work.

In 1836 Sir John became an Associate of the Institute of Civil Engineers, and in 1838 was elected Member. He was President of the Institution in 1861, was knighted in 1873, and was President of the British Association in 1875. He was elected a Fellow of this Society in 1837, and of the Royal Society in 1855.

The name of S. Collett Homersham will be chiefly remembered by geologists for his services in connexion with the deep boring for water at Richmond. Under his father, who was engineer to the Richmond Waterworks, he devoted himself with great enthusiasm and care to the preservation of specimens of all the rocks passed through in the operations, and by so doing provided a body of information such as exists in the case of no other deep boring in the

London basin. The valuable temperature observations made in the same boring were taken under his personal supervision. The geological results obtained were published by him conjointly with Prof. Judd in our Journal for the years 1884 and 1885. Mr. Homersham became an Associate Member of the Institution of Civil Engineers in 1881, and was elected a Fellow of this Society in 1882. He died on 31st January last at the early age of 36.

Mr. Edward Byron Lindon, who was killed in July last whilst descending a shaft in the Copeland District, New South Wales, was born in Lancaster in 1860. He became an Associate of the Royal School of Mines in 1880, and a Fellow of this Society in 1890.

In 1885 he went to Victoria and thence to Queensland, where he was appointed Mineralogist to the Brisbane Museum. In 1887 he commenced practice as a mining engineer in Brisbane. He published some papers on Australian minerals in the Proceedings of the Royal Society of Queensland.

Thomas Roberts, M.A., who died on 24th January last, began his scientific career at the University College of Wales, Aberystwith. In 1879 he entered at St. John's College, Cambridge, and took a high place in the Natural Science Tripos, geology being his chief subject. In 1883 he succeeded the late E. B. Tawney as Assistant to the Woodwardian Professor. In addition to discharging the duties of this office he gave lectures and demonstrations chiefly relating to palæontology.

His most important contributions to science were published in the Journal of this Society, on the Correlation of the Upper Jurassic Rocks of the Swiss Jura with those of England, on the Upper Jurassic Clays of Lincolnshire, and (conjointly with Mr. Marr) on the Lower Palæozoic Rocks of Haverfordwest. In 1886 his essay on 'the Jurassic Rocks of the neighbourhood of Cambridge' gained the Sedgwick Prize. He likewise published several palæontological papers. Full of promise, and amid the regret of a large circle of friends, he has been cut off by the prevalent scourge of influenza at the early age of 35. He was elected a Fellow of this Society in 1883, and in 1888 received part of the proceeds of the Lyell Fund.

Charles Smith Wilkinson, whose name is familiar in connexion with the Geology of New South Wales, was born in Northamptonshire in 1843. In 1852 his family settled in Melbourne, and from that time onwards Australia was his home. In 1859 he was appointed to the Geological Survey of Victoria, under Mr. Selwyn, but the service was disbanded before he had been long on the staff. In 1874 he was appointed Geological Surveyor to the Department of Lands, New South Wales, and next year, when the Geological Survey of that Colony was transferred to the Department of Mines, he was appointed Government Geologist for New South Wales, an office which he filled until his death.

He was elected a Fellow of this Society in 1876, and of the Linnean Society in 1881; he was President of the Linnean Society of New South Wales in 1884, and of the Royal Society of New South Wales in 1888. His numerous geological and other scientific writings are chiefly to be found in the official Reports. A list of his papers is given in the Australian Catalogue of Messrs. Etheridge and Jack. He added greatly to our knowledge of the geology of parts of Victoria and New South Wales. His last paper was an excellent Summary of the Mineral Resources of the latter Colony, published in the Journal of the Society of Arts in September 1891.

Mr. Thomas Pallister Barkas was born on March 5th, 1819, at Newcastle-upon-Tyne, in which city he resided till his death on July 10th last. Succeeding his father as a builder, he continued the business from 1833 to 1843. The next two years he devoted to lecturing on various scientific subjects,—a practice which he continued indeed more or less throughout later life, insomuch that he is estimated to have given at least 3000 gratuitous lectures. From 1845 to 1870 he carried on business as a bookseller; in the latter year he opened the Art Gallery and News Room, which he managed till his death.

Being from early life much interested in science, he, about the year 1868, became especially attracted by geology, and began collecting remains of fishes and reptiles from the Northumberland Coal Measures, as had been so well done before him by Mr. Thos. Atthey, of Cramlington. Aided as he was by the men and boys at the pits, his collection soon became large. He published from time to time notices and descriptions of his various discoveries, but the results were summed up in his 'Atlas of Carboniferous Fossils' and 'Illustrated Guide,' both published in 1873. He was elected a Fellow of this Society in 1869.

By the death of Joseph Leidy our list of Foreign Members has lost one of its most distinguished names. He was a naturalist in the widest and truest sense, having sympathies with every branch of enquiry which tended to enlarge our knowledge of Nature. His own labours, indeed, embraced a remarkably wide range of acquirement. From some of his published works he might have been supposed to be entirely given up to the study of human anatomy, from others he would have been set down as a man wholly devoted to microscopic research among rhizopods, entozoa, or other minutest forms of life; from yet another set he appeared as an accomplished mineralogist, and from still another he stood forth as one of the most accomplished palæontologists of his time.

He was born in Philadelphia on September 9th, 1823. Even in his school-days he showed his love for natural objects, especially delighting in minerals and plants. He exhibited also such skill in drawing that it was at one time intended that he should become an artist. Chance, however, decided his fate otherwise. There was a druggist in his neighbourhood whose shop had great attractions for him. Passing most of his time there, he learnt a good deal about drugs and prescriptions, insomuch that he was even once put in temporary charge of the establishment. His contact with medicine and medical pursuits, likewise the dissection of some cats, dogs, and chickens, awakened within him such a desire to study anatomy that, mainly through the influence of his stepmother, he was allowed to choose the profession of a physician. Studying in the University of Pennsylvania he took the degree of Doctor of Medicine in 1844, and for two years engaged in practice. His love of investigation, however, found no free scope for its exercise amid the exhausting demands of a laborious profession. He accordingly determined to give up medical practice, in which he had every reason to look forward to success, and to apply himself to original research and to teaching. The appointment of Prosector to the Chair of Anatomy in his own University gave him an official position. But it was the fostering and liberal assistance extended to him by the Academy of Natural Sciences of Philadelphia which started him on his career and continued through life to be his chief aid in the prosecution of scientific work.

After twice visiting this country and the Continent in the years 1848 and 1849, he was appointed in 1853, at the early age of thirty, Professor of Anatomy in his *alma mater*—a position which he filled with the greatest distinction until his death nearly forty years afterwards. He early rose to be the universally acknowledged head of the anatomists of America, and for skill, industry, and success alike in investigation and in exposition there were probably few that equalled him in Europe.

His studies, however, had not been confined to human anatomy. He had directed his enquiries far and wide through the various grades of the animal kingdom, not only in the living world but among the extinct organisms of bygone ages. He was thus led by a natural transition to researches in palæontology, and more particularly among the fossil vertebrates. On his achievements in other departments of biology, so marvellous in amount and so valuable in quality, I am not competent nor would it be appropriate here to dwell. But in his palæontological work he came in touch with geology, and to this side of his labours I should like briefly to refer.

A few years before he attained his professorship some important discoveries of mammalian bones had been made in the West. These and other fossil remains found their way to Leidy, who worked out their structure and affinities and brought to light a mass of facts of the highest interest in their bearings upon the history of life upon the American Continent. The results of his investigations were published in 1853 in a memoir with the title of 'Ancient Fauna of Nebraska.' This research, which established his reputation as the ablest of American palæontologists, proved to be only the first of a series of brilliant investigations by which he portrayed the structure and zoological relations of the vertebrate fauna of the North American Continent during a succession of geological periods. To give an adequate account of this continuous mass of laborious research and happy generalization would require far more space than can be allowed here. Dr. Leidy was universally acknowledged to be the Cuvier of American palæontology. And the praise lavished upon him by his own fellow-citizens was re-echoed in no stinted measure in Europe.

I cherish as one of the most memorable incidents of a visit which I paid to Philadelphia in the year 1879 my meeting with this distinguished naturalist and most lovable man. With what modesty he spoke of his own work, with what generous appreciation he referred to that of others, with what infinite patience and gentleness he would unfold and explain his views to any questioner who seemed to be interested in them! I well remember the pathos of his remarks as he told me how he had been led to abandon his researches in vertebrate palæontology and return to his first love—

the rhizopods, on which he published that same year a magnificent monograph. "Formerly," he said, "every fossil bone found in the States came to me, for nobody else cared to study such things. But now Professors Marsh and Cope, with long purses, offer money for what used to come to me for nothing, and in that respect I cannot compete with them. So now, as I get nothing, I have gone back to my microscope and my rhizopods and make myself busy and happy with them." I do not suppose Dr. Leidy ever made an enemy or lost a friend. A more tender, gentle, helpful nature could not be lodged in human form.

Dr. Leidy's achievements in science were fully acknowledged by his contemporaries. He was elected into innumerable Academies and learned societies in his own country and all over the world. We made him one of our Foreign Correspondents in 1863, and a Foreign Member three years later. In 1884 he was awarded our Lyell Medal. Among his later honours one of the most distinguished and appropriate was the Cuvier Medal bestowed upon him by the Academy of Sciences of Paris in 1888. The last time he came to Europe was in 1889, but his stay here was shortened and saddened by the serious illness of his wife. His own health began to give way not long thereafter. He struggled on, however, kept his post and did his duty with the same quiet devotion and courage which had marked him all through life. He died on 30th April, 1891, amid the universal sorrow of all who knew him, and leaving a name beloved and honoured wherever science has made its way.

Another serious blank in the list of our Foreign Members has been caused by the death of Professor C. Ferdinand von Römer. This illustrious geologist and most estimable man was born at Hildersheim, in Hanover, on the 5th of January, 1818. Educated at Göttingen, he was intended for the legal profession, which was that of his father, who became Councillor of the High Court of Justice. But before the close of his academic career he began to attend lectures on natural science and was gradually drawn away by them, so that he abandoned the pursuit of the law and went to the University of Berlin to study science. He took the degree of Ph.D. there in 1842 and chose as the subject of his Latin thesis a disquisition on the fossil Astartæ. He was now fairly launched upon his career as a geologist and palæontologist. He first betook himself to the study of the so-called 'Transition formation' of Rhineland and published a book about it in 1844. The following year he enlarged his experience by a visit to America, where he spent a year and a half in investigating the geology and palæontology of Texas and other Southern States. The results of this research were embodied in several publications after his return to Europe. In one of these he described the Cretaceous system of Texas; in another (dedicated to Murchison) he gave an account of the Silurian fauna of W. Tennessee. From 1847 to 1855 he remained at Bonn as 'Privat-docent' and busy in the elaboration of his Texas materials. In the last-named year he was appointed to the Chair of Geology, Palæontology, and Mineralogy in the University of Breslau, and continued to hold that position until his death.

But while Breslau remained his headquarters he made many and extensive journeys through all parts of Europe. Remote as was his home, there were few Continental geologists more widely known in person than he. His tours were made indeed not only to see the geology of other countries, but to meet foreign geologists and to discuss with them the problems of his favourite field of science.

His scientific writings show the great extent of his acquirements and the wide range of subjects that interested him. He was a palæontologist who contributed to our knowledge especially of the fossil invertebrata, including sponges, graptolites, corals, crustaceans, arachnids, molluscs, echinoderms, ophidians, and even mammals. On some of these divisions of the animal kingdom he wrote monographs which were important contributions to morphology, such, for instance, as those on *Cupressocrinus*, *Melonites*, and the asteroids and blastoids of Bundenbach. The enormous amount of research spent by him on his great work 'Lethæa Palæozoica' shows his indomitable industry and power of concentration. He was likewise a good geologist, and besides the treatises on Texas and smaller papers, he produced in 1870 a huge work in three quarto volumes on the geology of Upper Silesia. He added also some papers to the literature of mineralogy.

Ferdinand von Römer, as we met him in his journeys or at some meeting or Congress, seemed one of the most genial of men. There was a light-hearted gaiety about the way he discussed even the driest problems of science. He had a happy knack in finding a humorous side to everything, and he continued to impart his own good spirits to all who shared his society. Yet one knew that under all this playfulness there lay that earnest and diligent zeal in the severest toil and drudgery which had enabled him to produce so large and so valuable an amount of scientific work.

He was elected a Foreign Member of this Society in 1859, and received the Murchison Medal in 1885. It was intended to celebrate on the 10th of next May the fiftieth anniversary of his doctorate, and many of the Fellows of this Society have doubtless received the invitation, signed by illustrious geologists and palæontologists all over the Continent, to take part in the testimonial which it was proposed to found in his honour. But he has been removed from his labours and triumphs by the hand of Death before this festival could be held. He died on the 14th of December, 1891.

Baron Achille de Zigno, who died on January 15th last, at the age of 79, was elected a Foreign Correspondent of this Society in 1886. His earliest publications were mainly stratigraphical, the first, on the sedimentary rocks of Trevigiano, being published in 1841. He soon, however, turned his attention expressly to palæontology, and wrote on various divisions of the animal kingdom. Botany was always a favourite study with him, and he published numerous papers on fossil plants. His most important work—'Flora Fossilis Formationis Oolithicæ'—is a general monograph of the Oolitic Flora, the first part of which was issued in 1856, the latest in 1885. With this exception and also his 'Introduzione allo Studio della Geologia' (1843), his writings deal chiefly with the rocks and fossils of Venetia and the adjacent districts. His contributions to our Journal treat of the stratified Formations of the Venetian Alps (vol. vi. 1850), and the Oolitic Flora (vol. xvi. 1860). A brief paper communicated to the Geological Society of France in 1853 compared the flora of Scarborough with that of the Oolitic rocks in the Venetian Alps.

In the Address which it was my privilege to lay before you at our last Anniversary, I gave a sketch of the history of volcanic action within the area of the British Isles during the vast interval of geological time represented by the succession of rocks from early pre-Cambrian formations to the top of the Silurian system.

I propose now to take up the narrative at the point where I then left it, and to trace, though necessarily again only in broadest outline, what seem to me to have been the salient features of volcanic action in this region from the end of the Silurian period down to older Tertiary time, when the last British volcanoes became extinct.

We have seen that the later Silurian ages were marked by a diminution and final cessation of volcanic activity within our borders. The great Arenig, Llandeilo, and Bala eruptions of Wales, of the Lake district, of the south of Scotland, and of the east of Ireland had long passed away; their cones had been washed down, and their sheets of lava and tuff had sunk under a thick pile of overlying sediments in which no trace has been found of any contemporaneous volcanic eruptions. In the far west of Ireland, however, remains of volcanic outbreaks appear among Upper Silurian rocks, but their limited extent and thickness sufficiently mark the feeble condition into which volcanic action had now passed. Nevertheless, other evidence is not wanting that terrestrial disturbances affected our area during the later ages of the Silurian period. The bands of coarse conglomerate, which form so notable a feature among the Upper Silurian rocks, may indicate such disturbances, even when no actual unconformability can be traced between them and the strata on which they rest. In this connexion it is not unimportant to observe that in the west of Mayo, Galway, and Kerry, where the Upper Silurian rocks include vast mountainous masses of conglomerate, and where therefore terrestrial instability may be supposed to have been greatest, the few recognizable traces of Upper Silurian volcanoes are to be found.

There can be no doubt, however, that the movements of the earth's crust over the area of the British Isles during the deposition of the Upper Silurian rocks were on the whole, like the volcanic action of the same geological interval, of a comparatively feeble kind, and that it was not until after the close of the Silurian period that those great terrestrial commotions arose to which our older Palæozoic rocks mainly owe their plicated, cleaved, and fractured character. That the time during which these disturbances continued was long protracted may be inferred from the relations of the Silurian rocks to those which immediately and conformably succeed them. The shales and sandstones at the top of the Silurian series pass upwards without break into the red sandstones and conglomerates of the Lower Old Red Sandstone. Yet the rapid change in the nature of the sediment and its included organic remains sufficiently shows that, though the movements may not have been at first of such violence as to produce actual unconformability in any of the tracts which have yet been studied, the conditions of deposition and of the environment of animal life within the area were nevertheless profoundly modified. The prolific Upper Silurian fauna may be said to disappear as the red-coloured strata set in. This sudden change in the palæontological and lithological aspect of the rocks is now recognized as probably the result of an uprise of the sea-floor and the eventual conversion of its site into a series of large lakes or inland seas separated by intervening ridges of land.

VI. OLD RED SANDSTONE.

The vast mass of red sediments which in this country lie between the top of the Upper Silurian series and the base of the Carboniferous system can generally be clearly grouped in two great divisions. Of these the lower and by far the more important, alike in thickness, extent, and palæontological riches, lies conformably on the highest Silurian strata. The upper division passes upward conformably into the Carboniferous rocks. In Scotland and in the south-west of Ireland a marked unconformability exists between the two subdivisions. In those regions this unconformability certainly points to the lapse of a considerable interval of time and to important geographical changes whereby the conditions and areas of deposit were extensively modified.

It is almost entirely in the lower section of the Old Red Sandstone that volcanic records have been preserved, though the upper section is not entirely destitute of such chronicles. Geologists are in the habit of grouping the Old Red Sandstone and the Devonian rocks as equivalent or homotaxial formations, deposited in distinct areas under considerably different conditions of sedimentation. No one, however, can have attempted to follow out the sequence of strata in Devonshire, and to trace some analogy between the Devonian succession and that of the Old Red Sandstone, without encountering many difficulties for which he can find no solution. Into these problems it is not needful for me here to enter. I shall briefly refer to the evidence for the existence of volcanic rocks in the Devonian series of the south-west of England, without attempting to decide whether or to what extent the eruptions therein chronicled are to be regarded as having been geologically synchronous with those of the Old Red Sandstone in the north.

(A). Lower Old Red Sandstone.

In the area of the British Isles we are fortunate in the possession of portions of the sites of a number of the ancient basins in which the Lower Old Red Sandstone was deposited. Even now we can trace some of their shore-lines, walk over the shingle of their beaches, examine the silt of their deeper gulfs, and exhume the remains of the plants that shaded their borders, as well as of the fishes that swarmed in their waters. The sediments which accumulated in some of these basins amount to many thousand feet in thickness; yet from bottom to top they abound in evidence of shallow-water conditions of deposit. We are thus led to infer that the disturbance of the crust which brought about the formation of the hollows continued for a vast interval, the floors of the basins sinking and the intervening tracts being ridged up as the results of one great movement of the terrestrial crust, while at the same time the surface of the land was undergoing extensive denudation and the basins were receiving a constant influx of sediment.

We need not suppose that these movements of subsidence and upheaval were uninterrupted and uniform. Indeed, the abundant coarse conglomerates which play so prominent a part in the materials thrown into the basins serve to suggest that at various intervals during the prolonged sedimentation the subterranean disturbances were specially vigorous. But the occurrence of strong unconformabilities among the deposits of the basins sets this question at rest by proving that the terrestrial movements were so great as to break up the floor of one of the largest of the lakes and to place its older sediments on end, in which position they were covered up and deeply buried by the succeeding deposits.

Among the many points of interest in the Old Red Sandstone of this country, not the least impressive is the evidence that the terrestrial disturbances to which I have alluded were accompanied and followed by prolonged and vigorous volcanic action. Groups of volcanoes rose in long lines from the waters of most of the lakes, and threw out enormous quantities of lava and ashes over tracts hundreds of square miles in extent. So vast indeed were these discharges across what is now the Midland Valley of Scotland that the portions of sheets of lava and tuff visible at the surface form some of the most conspicuous ranges of hills in that district, stretching continuously for forty or fifty miles and reaching heights of more than 2000 feet above the sea. Exposed in hundreds of ravines and escarpments, and dissected by the waves along both the eastern and western coasts of the country, these volcanic records may be studied with a fulness of detail which cannot be found among earlier Palæozoic formations.

It might have been supposed that a series of rocks so well displayed and so full of interest would long ere this have been examined and described in minute detail. But they can hardly be said to have yet received, as a whole, the attention they deserve. I am unwilling to add to the length of this Address by references to the various authors who, each in his own measure, have added to the sum of our knowledge of the subject; but I cannot refrain from an allusion to one or two of the more important of these pioneers. First and most important of all were the classic descriptions of Ami Boué. As a young medical student at the University of Edinburgh, Boué had imbibed from Jameson a love of mineralogy and geognosy, and for some years he spent his leisure time in personally visiting most parts of Scotland to study the geological structure of the country. As the result mainly of his own observations, he drew up an account of the Old Red Sandstone which, when it appeared in his 'Essai,' marked the first great forward step in the investigation of this section of the geological record.[1] He was the earliest observer to divide what he calls the "roches feldspathiques et trappéennes" into groups according to their geological position and mineralogical character, and to regard them as of igneous origin and of the age, or nearly of the age, of the red sandstone of Central Scotland.[2] Of later writers who have treated of the volcanic rocks of the Old Red Sandstone my old friend Charles Maclaren deserves special recognition. His survey and description of the Pentland Hills embodied the first detailed and accurate investigation of any portion of these rocks, and his 'Geology of Fife and the Lothians' may still be read with pleasure and instruction.[3] Boué indicated roughly on the little sketch-map accompanying his 'Essai' the chief bands of his felspathic and trappean rocks of the Old Red Sandstone, but their position and limits were more precisely defined in Macculloch's 'Geological Map of Scotland,' which was published in 1840, five years after the sudden and tragic death of its author. The observers who have more recently studied these rocks have been chiefly members of the Geological Survey, and to some of the more important results obtained by them I shall refer in the sequel.

Up to the present time, however, no connected account has been given of the volcanic rocks of the Old Red Sandstone. The brief outline which I now offer to the Society is the first attempt of this

[1] 'Essai Géologique sur l'Ecosse' (Paris, no date, but probably 1820).

[2] *Op. cit.* p. 329.

[3] 'Geology of Fife and the Lothians,' 1839.

kind, but the subject deserves, and, if life and opportunity be allowed me, will before long receive, fuller treatment.

I. Distribution of Volcanic Districts.—The area within which volcanic rocks belonging to the Old Red Sandstone appear is one of the most extensive regions over which the volcanic eruptions of any geological period can be traced in the British Isles. Its northern limit reaches as far as the islet of Uya in Shetland, and its southern appears in England in the Cheviot Hills—a distance of about 250 miles. But volcanic rocks of corresponding age occur even as far to the south as the hills near Killarney. The most easterly margin of this area is defined by the North Sea on the coast of Berwickshire, and its extreme western boundary extends to near Lough Erne in the north of Ireland—a distance of some 230 miles. If we include the Devonian volcanic rocks as contemporaneous with those of the Old Red Sandstone, the area of eruption will be greatly enlarged, so as to include the diabases and tuffs of Devon and Cornwall. But leaving the latter out of account for the present, and confining our attention to the Old Red Sandstone series, we find that within the wide limits over which the volcanic rocks are distributed a number of distinct and often widely separated centres of eruption may be traced. Taking these as they lie from north to south we may specially enumerate the following:—

1st. The Shetland and Orkney Islands, including probably several distinct volcanic groups of which the most northerly extends through the centre to the north-western headlands of the mainland of Shetland, while another lies in the island of Shapinshay, one of the Orkneys.

2nd. The Moray Firth, embracing probably several scattered volcanic vents. One of these occurs near Buckie, on the coast of Banffshire; another at Gartly and Strathbogie, in the west of Aberdeenshire.

3rd. The basin of Lorne to the west of the mainland of Argyllshire, extending from Loch Creran to Loch Melfort and the hills on the west side of Loch Awe.

4th. The great central basin of Scotland, which, for the sake of distinctness, I have called 'Lake Caledonia,'[1] stretching between the edge of the Highlands and that of the Southern Uplands from the east coast south-westwards across Arran and the south end of Cantire into Ireland as far as Lough Erne. Numerous separated

[1] Trans. Roy. Soc. Edin. vol. xxviii. (1878) p. 354.

volcanic groups occur in this great basin, of which I shall give a more detailed account.

5th. The Cheviot basin, including the rocks of the Cheviot Hills and others, probably independent, which are cut off by the sea along the eastern coast of Berwickshire between St. Abb's Head and Eyemouth.

6th. The Killarney tract, including the hills lying around Lough Guitane in the east of County Kerry.

At the outset I wish to call the attention of geologists to a feature in the volcanic history of Britain which first comes out prominently in the records of the Old Red Sandstone, and appears with increasing distinctness during the rest of the long sequence of Palæozoic eruptions. I allude to the persistence with which the vents have been opened in the valleys and have avoided the high grounds. I formerly dwelt on this relation with reference to the Carboniferous volcanic phenomena,[1] but the observation may be greatly extended. With regard to the Old Red Sandstone of Central Scotland, though the lavas and tuffs that were discharged over the floor of the sheet of water which occupied that region gradually rose along the flanks of the northern and southern hills, yet it was on the lake-bottom and not among the hills that the orifices of eruption broke forth.

So far as I am aware, no undoubted vents of the age of the Lower Old Red Sandstone have been detected among the high grounds of the Highlands, although a fringe of the lavas may be traced here and there along the base of the hills. In some cases, doubtless, the position of the valleys may have been determined by lines of fault that might well serve as lines of relief along which volcanic vents would be opened. But in many instances it can be proved that, though the vents have risen in valleys and low grounds, they have not selected lines of fault even though these existed in their neighbourhood. I shall have occasion to give illustrations of these statements in subsequent parts of this Address.

By far the most varied development of the Old Red Sandstone is to be found in the great Midland Valley of Scotland. It is there that the remarkable volcanic phenomena of the system have been most abundantly displayed and are most clearly recorded. I shall therefore base my description of the volcanic eruptions of the Lower Old Red Sandstone chiefly on the results of a study of that region, contenting

[1] *Op. cit.* vol. xxix. (1879) p. 454.

myself for the present with a more cursory reference to other districts.[1]

Throughout most of the area of 'Lake Caledonia' the present limits of the Lower Old Red Sandstone are sharply defined by large parallel faults. On the north-west side one, or rather a parallel series, of these runs from Stonehaven along the flank of the Highland mountains to the Clyde, thus traversing the whole breadth of the island. On the south-east side another similar series of faults, which there skirts the edge of the Silurian table-land, has nearly the same effect in precisely marking off the margin of the Old Red Sandstone. As thus limited, the tract has a breadth of about fifty miles in Scotland, while the portion of it now visible in the British Isles has an extreme length of about 280 miles.

But though the boundary-faults determine, on the whole, the present limits of the tract of Old Red Sandstone, they do not necessarily indicate the shore-lines of the sheet of water in which that great series of deposits was laid down. They point to an enormous subsidence of the tract between them—a prolonged and extensive sagging of the strip of country that stretches across the Midland Valley of Scotland into the north of Ireland.[2] This downward movement began as far back as the close of the Silurian period, but the marginal fractures and the disruption and plication of the thick masses of sandstone and conglomerate which were accumulated in the lake chiefly took place after the close of the period of the Lower Old Red Sandstone. I think we may reasonably connect these movements with the general sinking of the area conse-

[1] My own investigations of this region have been continued over an interval of forty years. Besides personally traversing every portion of it, I have mapped in detail, for the Geological Survey, many hundreds of square miles of its area from the outskirts of Edinburgh south-westwards into Lanarkshire, in Ayrshire, and in the counties of Fife, Perth, and Kinross. The Geological Survey maps of the volcanic tracts of the Sidlaw Hills have been prepared by my brother, Prof. James Geikie, and Messrs. H. M. Skae and D. R. Irvine. The Western Ochils were mapped chiefly by Mr. B. N. Peach, partly by Prof. J. Young, Mr. R. L. Jack, and myself; the Eastern Ochils were surveyed mainly by Mr. H. H. Howell; while the volcanic belt between the tracts mapped by me in Lanarkshire and in Ayrshire was chiefly traced out by Mr. Peach. As a rule, each of these geologists has described in the Survey Memoirs the portions of country surveyed by him.

[2] In some of the dislocations along the Highland border, the Old Red Sandstone is bent back upon itself, and the older schists are thus made to recline upon it, as if there had been a push over from the Highland area.

quent upon the enormous outpouring of volcanic materials during that period.

Along both the northern and southern margins of the basin there occur, on the farther side of the boundary-faults, outlying patches of Lower Old Red Sandstone that rest unconformably on the rocks forming the flanks of the hills. These areas possess a peculiar interest, inasmuch as they reveal some parts of the shore-line of the lake, and show the relation between the older rocks and the sediments of the Old Red Sandstone. We learn from them that the shore-line was indented with wide bays, but nevertheless ran in a general north-easterly direction. It thus corresponded in trend with the present Midland Valley, with the axes of plication among the schists of the Highlands as well as among the Silurian rocks of the Southern Uplands, and with the subsequent faulting and folding of the Old Red Sandstone. I may remark in passing that the conglomerates and other associated materials which have been preserved in these bays and hollows beyond the lines of the great faults, though they lie unconformably on the rocks beneath, are not the basement portions of the Old Red Sandstone. On the contrary, where their probable stratigraphical horizon can be recognized or inferred, they are found to belong to parts of the series considerably above the base of the whole. They point to the gradual sinking of the basin and the creeping of the waters with their littoral shingles farther and farther up the slopes of the hills on either side. But this is not all the evidence that can be adduced to show that the limits of the lake extended considerably beyond the lines of dislocation between which the present area of Old Red Sandstone mainly lies. No one can look at the noble escarpments of the Braes of Doune on the one side, or walk over the upturned conglomerates and porphyrites which flank the Lanarkshire uplands on the other, without being convinced that if the effects of the boundary-faults could be undone, so as to restore these rocks to their original positions, their prolongations, now removed by denudation, would be found sweeping far into the Highlands on the north and into the Silurian uplands on the south.

If the area of Lake Caledonia' were taken to be defined by the boundary-faults, it covered a space of about 10,000 square miles. But, as we know that it certainly stretched beyond the limits marked by these faults, it must have been of still greater extent. We shall probably not exaggerate if we regard it as somewhat larger than the present Lake Erie, the superficies of which is about 9900 square miles. In this long narrow basin the remarkable volcanic history was enacted of which I now proceed to give some account.

The Lower Old Red Sandstone of Central Scotland may be conveniently divided into three great groups, each of which marks a distinct epoch in the history of the basin wherein they were successively accumulated. The lowest of these groups indicates a time of quiet sedimentation during which the basin was defined by plication of the terrestrial crust, and when by the same subterranean movements some parts of the floor of the lake were pushed upward above water and were then denuded and buried. The middle group consists mainly of volcanic rocks. It points to the existence of lines of active volcanic cones situated along the centre of the lake. The uppermost group records the extinction of volcanic action and the gradual obliteration of the lake, partly by the pouring of sediment into it, and, partly no doubt, by the continued terrestrial movements which had originally produced the basin.

Confining our attention for the present to the records of the middle group, we find evidence of at least eight distinct clusters of volcanic vents ranged along the length of the basin for a distance of some 150 miles. The independence of these volcanic districts may be inferred from the following facts:—1st. The actual vents of discharge may in some cases be recognized. 2nd. Even when these vents have been buried, we may often observe, as we approach their probable sites, a marked increase in the thickness of the volcanic accumulations as well as a great development of agglomerates and tuffs. 3rd. Traced in opposite directions the volcanic materials are found to thin away or even to disappear. Those from one centre of discharge may be observed now and then to overlap those from another, but the two series remain distinct. The following summary may suffice to indicate the position of the eight volcanic centres and the distribution of the ejected material around them:—

1st. Beginning at the north-eastern end of the area, we first encounter a series of volcanic rocks which attain their maximum thickness in Forfarshire around the town of Montrose, whence they thin away towards the north-east and south-west. The main vents probably lay somewhere to the east of the present coast, under the floor of the North Sea. Admirable sections of the lavas of this district may be examined along the shore to the north and south of Lunan Bay, likewise along the cliffs a few miles south of Stonehaven.

2nd. The volcanoes which poured out the masses of material that now form the chain of the Ochil and Sidlaw Hills appear to have been the most vigorous in the whole region. Their chief vents lay towards the south-west in the neighbourhood of Stirling, where the lavas, agglomerates, and tuffs discharged from them reach a thickness of not less than 6500 feet, without revealing their bottom. From that centre the lavas range continuously for sixty miles to the north-east until they overlap those of the Forfarshire group. How far they stretched south-west cannot now be ascertained, for they have been dislocated and buried in that direction under the Carboniferous formations of the Midland Valley. While the most active vents were situated in the Stirling district, others rose at irregular intervals along the length of the lake towards the north-east. The numerous bosses around Dundee, of which Dundee Law may be taken as a type, possibly mark a cluster of vents in that neighbourhood.

3rd. A third group of active orifices lay nearer the southern margin of the lake, and had its centre on the southern outskirts of the city of Edinburgh. There was a large vent on the site of the Braid Hills, from which lavas and tuffs were thrown out to a total depth of at least 7000 feet. These materials form now the chain of the Pentland Hills. They can be followed south-westwards for ten miles, until they dwindle down and die out among conglomerates and sandstones. Their north-easterly prolongation is concealed under the Carboniferous strata which overlap them unconformably.

4th. Another distinct group of small volcanoes had its centre about 25 miles to the south-westward on the same line as those of Edinburgh. In no part of the basin can the isolation of the different volcanic clusters be so impressively observed as in the area to the south-west of the Pentland Hills. On the one hand, the lavas and tuffs from the Edinburgh vents die out, and, on the other, as we follow the conglomerates south-westwards a new volcanic series makes its appearance, rapidly increasing in the number and thickness of its members until, where traversed by the River Clyde, it occupies the whole breadth of the tract of Old Red Sandstone, and must be several thousand feet in thickness. These lavas and tuffs may have come mainly from one or more vents near to the site of the well-known eminence of Tinto. From that centre they extend north-eastwards for about sixteen miles before they finally die out, while in a south-westerly direction they can be traced only for about ten miles, when they are lost under the Carboniferous formations which are faulted down against them.

5th. Among the high bleak muirlands on the confines of the three counties of Lanark, Ayr, and Dumfries, traversed by the Duneaton Water, a fifth volcanic area may be traced. Its boundaries, however, are indeterminable, as it is overspread with Carboniferous rocks both to the north-east and south-west. It possesses considerable interest, inasmuch as it exhibits, better perhaps than any other of the volcanic areas, the alternation of volcanic discharges with the continuous accumulation of the ordinary sand and gravel of the lake. In its near neighbourhood also lies one of the granite bosses to which I shall afterwards refer in connexion with the vents of 'Lake Caledonia.'

6th. The remaining portion of the Old Red Sandstone area on the mainland of Scotland from the valley of the Nith to the Firth of Clyde has been so broken up by faults, and so much of it is overspread with Carboniferous rocks, that some uncertainty must remain as to the distribution of its volcanoes. There were probably several centres of activity. One of these was possibly situated near New Cumnock, and from it may have come the lavas and tuffs of Corsincone on the one side, and those of the hills ranging towards Dalmellington on the other. Another vent, or rather group of vents, lay among the hills to the right and left of the Girvan Valley, south of the village of Straiton. A third rose some miles to the north-east, near Maybole, and poured out the lavas of the Carrick Hills, of which such instructive coast-sections are exposed from Turnberry Point to the Heads of Ayr. But for my present purpose it will suffice to class these different vents together as the Ayrshire group.

7th. At the extreme south of Cantire another display of volcanic rocks of Lower Old Red Sandstone age may be studied. Beds of andesitic lavas with tuffs and massive conglomerates overlie the schists of that region, and are themselves unconformably covered by the volcanic series of Lower Carboniferous age, to be afterwards described.

8th. We have now to cross to Ireland, where a continuation of the same volcanic types may be traced. On the Antrim coast at Cushendall the coarse conglomerates are in main part made up of the fragments of a remarkable quartz-porphyry, which is exposed on the shore at that locality.[1] Though there is no proof that this igneous rock has been directly connected with any volcanic discharge, it may be paralleled with such bosses as Tinto, which supplied materials for some of the overlying conglomerates. Farther to the south-west, however, in the county of Tyrone, abundant porphyrite

[1] See Explanation to Sheet 14, Geol. Surv. Ireland, p. 25.

and diabase lavas, like those of Central Scotland, afford evidence of contemporaneous volcanic action in the wide tract of Lower Old Red Sandstone which stretches from Pomeroy to Enniskillen.

In spite, therefore, of the effects of powerful faults and of the unconformable overspread of younger formations, the position of at least eight separate groups of volcanoes can be more or less definitely fixed along the site of the great basin in which the Lower Old Red Sandstone of Central Scotland and the North of Ireland was deposited.

In the following sketch of the chief characteristics of this volcanic region, I shall refer (1) to the petrography of the various groups of rock; (2) to the manner in which they are arranged in the general geological structure of the ground; taking in consecutive order (*a*) the lavas and tuffs of the superficial outpourings, (*b*) the vents with the materials now filling them, and (*c*) the dykes and sills, some of which may be regarded as records of the closing phases of the volcanic activity of the period.

II. Petrography.—In presenting a general summary of the petrographical characters of the igneous rocks of the Lower Old Red Sandstone, it may be convenient to include not only those of 'Lake Caledonia,' but also some which have been obtained from other basins, though, on the whole, the prevailing types in one region are found to be repeated in the others.

1. *Bedded Lavas.*—Beginning with the lavas which were poured out at the surface, we have to notice a considerable range of chemical composition among them, although as a rule they are characterized by general similarity of external appearance. At the one end come diabases and other ancient forms of basalt or dolerite, wherein the silica percentage is below or little above 50. By far the largest proportion of the lavas, however, are porphyrites (altered andesites), having about 60 per cent. of silica. With these are associated lavas containing more or less unstriped felspar and a somewhat higher proportion of silica, which may be grouped as trachytes, though no very sharp line can be drawn between them and the andesites. It is possible that some felsitic or rhyolitic bands noticeable in the Pentland Hills and elsewhere may have flowed out as acid lavas.

It is noteworthy that the lava-sheets of the Lower Old Red Sandstone, if we consider the character of the prevalent type, hold an intermediate grade between the average chemical composition of those of Silurian and of those of later Carboniferous time. On the one hand, they hardly ever assume the character of thoroughly acid rocks, like the nodular rhyolites of Bala and Upper Silurian age;[1] on the other hand, they seldom include such basic lavas as the basalts, so common in the Carboniferous system, and never, so far as I know, contain varieties comparable to the 'ultra-basic' compounds which I shall have occasion to allude to as characteristic of a particular volcanic zone in that system.

(*a*) The Diabase-lavas are typically developed in the chain of the Pentland Hills, where they form long bands intercalated between felsitic tuffs,—a remarkable association, to which I shall make more detailed reference in a later part of this Address. They range in texture from a compact dark greenish base to a dull earthy amygdaloid. One of their most remarkable varieties is a fine-grained green porphyry, with large flat tabular crystals of plagioclase arranged parallel to the direction of flow (Carnethy Hill). Most of them, however, are more or less amygdaloidal, and some of them (Warklaw Hill) strongly so. The following analyses, made many years ago in the laboratory of the Royal School of Mines under the direction of Prof. E. Frankland, but never published, show their chemical composition:—

Analyses of Diabase-Lavas from the Pentland Hills.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	P_2O_5.	CO_2.
Carnethy Hill*	51·16	22·27	2·94	4·02	5·61	3·46	2·42	2·58	3·42	0·48	1·28
Buiselaw. Sp. grav. 2·80 — Soluble in HCl	...	1·30	1·53	1·14	2·43	0·98	...	...	...	0·32	...
Buiselaw. Sp. grav. 2·80 — Insoluble in ditto.	52·00	17·46	7·85	...	6·80	1·06	1·66	4·17	2·68	...	...
Warklaw Hill. Sp. grav. 2·77. — Soluble in HCl	...	5·23	7·32	...	7·88	3·65	...	...	...	0·12	5·01
Warklaw Hill. Sp. grav. 2·77. — Insoluble in ditto.	47·77	13·08	0·84	...	4·07	0·30	1·17	2·30	2·48	...	...

* There was a trace of manganous oxide in this specimen.

(*b*) The Porphyrites, which constitute by far the largest proportion of the lavas, have a characteristic but limited range of lithological varieties. The prevailing type presents a close-grained, rather dull texture, and a colour varying from pinkish grey, through many shades of green and brown, to purplish red, which last is, on the whole, the predominant hue. Minute lath-shaped felspars may frequently be detected with the naked eye on fresh surfaces, while scattered crystals,

[1] The only examples known to me are those of Benaun More and other hills in County Kerry.

which are generally hæmatitic pseudomorphs after some pyroxene, occasionally after hornblende or mica, may often be observed. The usual porphyritic constituents are plagioclase felspars, occasionally in abundant tabular crystals measuring half an inch or more across, also one or more pyroxenes (augite, enstatite), and sometimes brown mica. Where large felspar-crystals occur in a compact green matrix, the rock assumes a resemblance to the *verde antique* of the ancients.

The texture of the porphyrites occasionally becomes faintly resinous, where a considerable proportion of glass still remains undevitrified, as in the well-known varieties from the Cheviot Hills, and in another variety in the Ochil Hills near Bridge of Allan. It sometimes presents a nodular or coarsely perlitic character, weathering out in nut-like balls, like the rock of Buckham's Wall Burn in the Cheviot Hills. Much more frequent is a well-developed amygdaloidal structure, which indeed may be said to be the chief characteristic of these rocks as a whole. The steam-vesicles, now filled with agate, quartz, calcite, or zeolite, vary in size from mere granules up to large irregular cavities a foot or more in diameter. Where the kernels are coated with pale green-earth and lie in a dark brown matrix they give rise to some of the most beautiful varieties of rock in any volcanic series in this country, as may be seen on the Ayrshire coast at Culzean and Turnberry. Some rocks contain the vesicles only as rare individuals, others have them so crowded together as to form the greater part of the cubic contents of the mass. When the infiltration-products have weathered out, some of the amygdaloids present a striking resemblance to recent slaggy brown lavas; lumps of them must have been originally light enough to float in water.

My colleague in the Geological Survey, Mr. J. S. Grant Wilson, some years ago made for me a large series of determinations of the specific gravity of the volcanic rocks of the Lower Old Red Sandstone of Scotland. He found that the porphyrites collected from various districts to illustrate the more typical varieties of rock averaged about 2·66. He also made a series of chemical analyses of a number of the same rocks from the Cheviot Hills, where they are well preserved. The results are shown in the following Table:—

Analyses of Porphyrites from the Lower Old Red Sandstone of Scotland. By JAMES S. GRANT WILSON, Esq.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	H_2SO_4.	Loss.
Scawd Law ...	59·29	16·30	1·77	3·70	·41	4·81	3·15	4·19	3·44	3·84	...	...
Rennieston ...	62·81	16·40	·55	3·27	·81	4·46	1·64	3·60	3·02	4·04	...	...
Cunrieston ...	63·38	15·77	·73	2·65	·08	4·44	1·88	1·88	4·54	4·69	...	...
Duncan'sDubs	59·44	16·15	1·05	2·83	·37	6·70	2·46	3·18	3·70	3·35	...	...
Whitton Hill	60·70	17·98	·65	2·58	·20	7·07	2·20	3·57	2·95	3·45	...	...
Cuddies' Tops	60·58	12·25	1·01	4·13	·15	4·40	2·86	2·19	3·61	....	·55	2·15
Cocklawfoot. .	62·29	17·03	·93	2·44	·21	3·92	2·71	1·14	3·20	·29*	·37	4·81
Morebattle ...	59·82	16·96	·20	6·57	·15	4·73	2·84	2·63	3·04	...	trace	1·98

* This is CO_2.

The microscopic structure of the porphyrites of the Lower Old Red Sandstone has been partially investigated, especially those of the Cheviot Hills, by Mr. Teall[1] and by Dr. Petersen.[2] Much, however, still remains to be done before our knowledge of this branch of British petrography can be regarded as adequate. The groundmass in some of the rocks consists mainly of a brown glass with a streaky structure (as in the well-known variety of Kirk Yetholm); more usually it has been devitrified more or less completely by the appearance of felspathic microlites until it presents a confused felspar aggregate. The porphyritic felspars are often large, generally striped, but sometimes including crystals that show no striping. They are frequently found to be full of inclusions of the base, and these sometimes consist of glass. The ferro-magnesian constituents are usually rather decomposed, being now represented by chloritic pseudomorphs, but augite, and perhaps still more frequently enstatite, may be recognized or its presence may be inferred among them. Magnetite is commonly traceable, and apatite may be occasionally detected. As the result of decomposition, calcite, chlorite, and limonite are very generally diffused through the rocks.[3]

(*c*) The lavas which may be separated as TRACHYTES offer no

[1] Geol. Mag. for 1883, pp. 100, 145, 252.

[2] 'Mikroskopische und chemische Untersuchungen am Enstatit-porphyrit aus den Cheviot Hills,' Inaug. Dissert. Kiel, 1884.

Descriptions have also been published of detached rocks from other districts, such as those by Prof. Judd and Mr. Durham of specimens from the Eastern Ochils, Quart. Journ. Geol. Soc. vol. xlii. (1886) p. 418.

[3] I have again to thank my colleague, Dr. F. H. Hatch, for the notes on the microscopic structure of the rocks with which he has furnished me for the second part of this Address.

distinctive features externally by which they may be distinguished from the porphyrites. Indeed, both groups of rocks appear to be connected by intermediate varieties. In the Cheviot Hills some of the lavas are found, on microscopic examination, to contain a large admixture of unstriped porphyritic felspars, which can sometimes be recognized as sanidine in Carlsbad twins. The groundmass is sometimes a brown glass, but is usually more or less completely devitrified, portions of it being enclosed in the large felspars. Chlorite pseudomorphic after augite or enstatite may be detected, and sometimes a brown mica. A specimen of one of these rocks, from a locality to the north-west of Whitton, near Jedburgh, was found by Mr. J. S. Grant Wilson to have the following composition:—

Chemical Analysis of a Trachyte from the Lower Old Red Sandstone.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	Total.
N.W. of Whitton Hill, Jedburgh, (No. 1938) ...... Sp. gr. 2·55.	62·44	18·99	3·35	1·8	·25	1·84	1·37	5·02	2·65	2·48	100·19

(*d*) Acid rocks such as Felsites and Rhyolites are extremely rare among the lavas poured out at the surface during the time of the Lower Old Red Sandstone. The only nodular felsite of this age which I have met with is that of Lough Guitane among the 'Dingle Beds,' near Killarney, to which reference will be made in a later part of this Address. As already stated, some acid lavas may possibly be included in the great felsitic tuff-bands of the Pentlands and among the sills of the same chain.

2. *Intrusive Sills, &c.*—While the interbedded lava-sheets are mainly porphyrites, the intrusive rocks are generally much more acid, and may be grouped under the convenient head of felsites. Some intrusive porphyrites and even more basic rocks do indeed occur in dykes and sills as well as also filling vents. But the rule remains of general application over the whole country that the materials which have consolidated in the volcanic orifices, or have been thrust among the rocks in dykes, bosses, or sills, are decidedly acid. In this series of rocks a greater range of types may be traced. At the one end we find true granites or granitites, as in the intrusive bosses of Spango Water and of Galloway, which, for reasons which I will afterwards adduce, may with some probability be assigned to the volcanic history of the Lower Old Red Sandstone period. The augite-granitite of the Cheviot

Hills, so well described by Mr. Teall, has invaded the bedded porphyrites of that region.[1] A similar rock has been noticed by my brother, Prof. James Geikie, associated with the Lower Old Red Sandstone volcanic rocks of the east of Ayrshire. A remarkable petrographical variety has been mapped by Mr. B. N. Peach, rising as a small boss through the lower part of the great lava-sheets of the Ochil Hills above Tillicoultry. It is a granophyric quartz-diorite, which, under the microscope, is seen to be composed of short, thick-set prisms of plagioclase, with abundant granophyric quartz, a pleochroic hypersthene, and needles of apatite. Sometimes the pyroxene is replaced by green chloritic pseudomorphs.[2]

At the other end of the series come the felsites, quartz-porphyries, minettes, vogesites, 'hornstones,' and 'claystones,' which have a close-grained texture, often with porphyritic felspars, quartz, or black mica, generally a whitish, pale buff, orange, pink, or purplish-grey colour, and a specific gravity of about 2·55.

Though I class these rocks as intrusive, I am not prepared to assert that in none of the instances where they occur as sheets may they possibly have been erupted at the surface as lavas. In one or two cases the evidence either way is doubtful, but as the great majority of the acid rocks can be shown to be intrusive in their behaviour, I have preferred to keep them all in the same category. I am prepared to find however that, as so vast an amount of felsitic débris was ejected to form the tuffs, some of this material may have flowed out in streams of lava.

The following Table shows the chemical composition of some of the acid sills and dykes:—

Chemical Analyses of Acid Eruptive Rocks from the Lower Old Red Sandstone. By Prof. E. Frankland.

	SiO_2.	Al_2O_3.	Fe_2O_3.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	P_2O_5.	H_2O.
'Hornstone,' Torgeith Knowe, Pentlands	73·91	14·41	·76	·07	1·21	4·90	3·36	1·57	...	·90
'Hornstone,' Braid Hills*	64·73	17·01	2·35	24	4·19	·66	3·27	3·75	·26	2·78
Tinto, Lanarkshire:										
Soluble in hydrochloric acid ...	·04	1·01	1·24	...	·92	·52	...	...	·16	...
Insoluble in ditto	70·28	12·54	·43	...	·91	...	3·92	5·84	...	1·99

* This specimen also yielded 0·13 of ferrous oxide, and 2·42 of carbon dioxide.

[1] Geol. Mag. for 1883, pp. 100, 145, 252, and 'British Petrography,' pp. 272, 278.

[2] From notes by Dr. Hatch.

The rock of Tinto, which may be considered typical of the prevailing felsitic, acid intrusive rocks of the series, presents several slightly different varieties. Dr. Hatch informs me that as the result of his examination of a number of microscopic slides prepared from specimens taken by me from various parts of the hill, some are minettes showing small isolated crystals of orthoclase and rare flakes of biotite, sometimes granules of quartz, imbedded in a brown, finely microlitic groundmass of felspar powdered over with calcite; while other specimens have a granular instead of a microlitic groundmass, and contain a considerable amount of quartz in addition to the constituents just mentioned. A conspicuous knob on the south side of Tinto, called the Pap Craig, is a mass of augite-diorite, which has risen through the other rocks.[1] The sills in the same region show still further differences. Some are true 'felspar-porphyries,' and 'quartz-porphyries' varying in the relative abundance and size of their porphyritic orthoclase and quartz, while others, by the introduction of hornblende or pseudomorphs after that mineral, pass into vogesites.

3. *Tuffs & Agglomerates.*—The fragmental materials ejected from or filling up the vents range from the finest compacted dust up to some of the coarsest agglomerates in this country. In general they consist mainly of detritus of porphyrite, and have been derived from the blowing up of already consolidated masses of that rock. The fragments are generally angular, and range from minute grains up to blocks as large as a cottage. The tuffs are often more or less mixed with ordinary non-volcanic sediment, and as they are traced away from the centres of eruption they pass insensibly into sandstones and conglomerates.

But while, as might be expected, the tuffs are most commonly made up of débris of the same kind of lavas as those that usually form the sheets which were poured out at the surface, they include also bands of material derived from the destruction of much more acid rocks. Throughout the chain of the Ochil Hills, for example, in the midst of the bedded porphyrite-lavas, many of the thin courses of fine tuff consist largely of felsitic (rhyolitic) fragments, with scattered felspar crystals. The most remarkable examples of this nature, however, are to be met with at the great vent of the Braid Hills and in the chain of the Pentland Hills, which runs south-westward from it.

[1] This rock differs considerably from the other intrusive masses in its neighbourhood. Dr. Hatch has found it to be composed chiefly of lath-shaped striped felspar, with some granular augite, magnetite, and interstitial quartz.

These rocks are generally pale flesh-coloured or buff in tint, and compact in texture. The finer varieties are so compact as to present to the naked eye no recognizable grains; they might be mistaken for felsites, and indeed, except where they contain recognizable fragments of rock or broken crystals of felspar, they can hardly be discriminated. They consist of exceedingly fine compacted felsitic dust. Here and there, however, the scattered crystals of felspar and small angular fragments of felsite which may be detected in them increase in number until they form the whole of the rock, which is then an angular tuff or fine volcanic breccia, made up of different felsites or rhyolites, among which, even with the naked eye, delicate flow-structure may be detected. In these pale acid tuffs fragments of different porphyrites may often be observed, which increase in number as the rocks are traced away from the main vent of the Braid Hills.

At my request my colleague, Mr. George Barrow, has determined the silica percentages in a few specimens which I have selected as showing some of the more characteristic varieties of these tuffs. His results are exhibited in the following Table:—

Percentage of Silica in some Tuffs from the Braid and Pentland Hills.

	Silica percentage.
1. Quarry above Woodhouselee	63·3
2. South-west side of Castlelaw Hill	73·15
3. Quarry on road, ½ mile N.E. of Swanston (Braid Hill vent)	74·1
4. South-west side of Castlelaw Hill	75·0
5. Castlelaw Hill	76·00
6. South side of White Hill Plantation	90·00

From these analyses it may be inferred that the average amount of silica in the more typical varieties is between 70 and 75 per cent. The last specimen in the Table, with its abnormally high percentage of acid, must be regarded as an exceptional variety, where there has either been an excessive removal of some of the bases, or where silica has been added by infiltration.

The microscopic examination of these rocks has not added much to the information derivable from a study of them in the field. In their most close-grained varieties they are hardly to be distinguished from felsites. But they generally show traces of the minute particles of detrital felsite of which they are essentially composed. The brecciated varieties exhibit finely-streaked flow-structure in some of the felsite fragments. Pieces of andesite, grains of quartz, and other extraneous ingredients appear in the rocks towards the southern limits of their area, where they are associated with and pass laterally and vertically into ordinary non-volcanic sedimentary strata.

III. Structure of the Ground.—We have now to consider the manner in which these various volcanic products have been grouped around and within the orifices of discharge. The first feature to arrest the eye of a trained geologist who approaches them as they are displayed in one of the ranges of hills in Central Scotland is the banded aspect of the rocks. If, for example, he looks eastward from the head of the Firth of Tay, he marks on the right hand, running for many miles through the county of Fife, a succession of parallel escarpments, of which the steep fronts face northwards, while their long dip-slopes descend towards the south. On the left hand a similar but higher series of escarpments, stretching far eastwards into Forfarshire, through the chain of the Sidlaw Hills, repeats the same features, but in opposite directions. If he stands on the alluvial plain of the Forth, near Stirling, and looks towards the north, he can trace bar after bar of brown rock and grassy slope rising from base to summit of the western end of the Ochil Hills. Or, if from any height on the southern outskirts of the city of Edinburgh, he lets his eye range along the north-western front of the chain of the Pentland Hills, especially towards evening, he can follow the same parallel banding as a conspicuous feature on each successive hill that mounts above the plain.

1. *Bedded Lavas and Tuffs.*—On a nearer inspection this dominant topographical feature is found to correspond with a well-marked stratification of the whole volcanic series. Where two sheets of porphyrite are separated by layers of tuff, sandstone, or conglomerate, a well-marked hollow will generally be found to indicate the junction-line; but even where the lavas follow each other without such interstratifications, their differences of texture and consequent variations in mode and amount of weathering usually suffice to mark them off from each other and to indicate their trend along the surface.

It is in the picturesque and instructive coast-sections, however, that the details of this bedded structure are most clearly displayed.

On both sides of the country, along the shores of Ayrshire on the west and those of Kincardineshire and Forfarshire on the east, the volcanic group has been admirably dissected by the waves. The lava-beds have been cut in vertical section, so that their structure and their mode of superposition, one over another, can be conveniently studied, while, at the same time, the upper surfaces of many of the flows have been once more laid bare as they existed before they were buried under the accumulations of the lake in which they were erupted.

Though distinctly bedded, the porphyrites show none of the regularity and persistence so characteristic of the more basic lavas of Carboniferous and of Tertiary time. Some of them are not more than from 4 to 10 feet thick, and generally on the coast-cliffs they appear to be less than 50 feet. A continuous group of sheets can sometimes be traced for 10 miles or more from the probable vent of discharge.

That these lavas were erupted in a markedly pasty condition may be inferred from certain of their more prominent characteristics. Sometimes, indeed, they appear as tolerably dense homogeneous masses, breaking with a kind of prismatic jointing; but more frequently they are strongly amygdaloidal, and sometimes so much so that, as already stated, the amygdales form the larger proportion of their bulk. Where the secondary infiltration-products have weathered out, the rough scoriform rock looks as if it might only recently have been erupted. In a few instances I have observed an undulating rope-like surface, which reminded me of well-known Vesuvian lavas. Usually the top and bottom of each sheet assume a strikingly slaggy aspect, which here and there is exaggerated to such an extent that between the more solid and homogeneous parts of two consecutive flows an intermediate band occurs, 10 or 12 feet thick, made up of clinker-like lumps of slag, the interspaces being filled in with hardened sand. In some cases these agglomeratic layers may actually consist in part of ejected blocks; but the way in which many of the lavas have cooled in rugged scoriaceous surfaces is as conspicuous as on any modern *coulée*. The loosened slags, or the broken-up cakes and blocks of lava, have sometimes been caught up in the still moving, pasty current, which has congealed with its vesicles drawn out round the enclosed fragments, giving rise to a mass that might be taken for a breccia or agglomerate. Now and then we may observe that the upper slaggy portion of a sheet has assumed a bright red colour from the oxidation of its ferruginous minerals; and from the contrast it thus presents to the rest of the rock we may perhaps legitimately infer that the disintegration took place before the outflow of the next succeeding lava. If this inference be well founded, and it is confirmed by other evidence which will be subsequently adduced, it points to the probable lapse of considerable intervals of time between some of the outflows of lava.

But perhaps the most singular structure displayed by these lavas is to be seen in the manner in which they are traversed by and enclose portions of sandstone. Since I originally observed this feature on the Ayrshire coast, near Turnberry Point, many years ago, I have repeatedly met with it in the various volcanic districts of the Lower Old Red Sandstone across the whole of the Midland Valley of Scotland. The first and natural inference which a cursory examination of it suggests is that the molten rock has caught up and carried along pieces of already consolidated sandstone. But a little further observation will show that the lines of stratification in the sandstone, even in what appear to be detached fragments, are marked by a general parallelism, and lie in the same general plane with the surface of the bed of lava in which the sandy material is enclosed. In a vertical section the sandstone is seen to occur sometimes in narrow dykes with even, parallel walls, but more usually in irregular twisting and branching veins, or even in lumps which, though probably once connected with some of these veins, now appear as if entirely detached from them. Frequently, indeed, the nodular slaggy porphyrite and the sandstone are so mixed up that the observer may hesitate whether to describe the mass as a sandstone enclosing balls and blocks of lava, or as a scoriaceous lava permeated with hardened sand. A close connexion may be traced between these sandstone-enclosures and the beds of sandstone interstratified between the successive lavas. We can follow the sandy material downwards from these intercalated beds into the porphyrites below them. On exposed upper surfaces of the porphyrite sheets an intricate reticulation of sandstone-veins may be noticed, in each of which the stratification of the material runs across the veins, showing sometimes distinct current-bedding, but maintaining a general parallelism with the bedding of the volcanic sheets and their fragmentary accompaniments. If we could remove the sandstone-veinings and aggregates we should find the upper surfaces of these igneous masses to present a singularly fissured and slaggy appearance, reminding one of the rugged, rent, and clinkerloaded slopes of a modern viscous lava, like some of those in the Atrio del Cavallo on Vesuvius. There cannot, therefore, be any doubt that the sandstone so irregularly dispersed through these lavas was introduced originally as loose sand washed in from above so as to fill the numerous rents and cavernous interspaces of the porphyrites. A more striking proof of the subaqueous character of the eruptions could hardly be conceived.

The general character of the tuffs in the structure of the ground agrees with what might have been expected would mark the accompaniments of extremely slaggy and viscid lavas. They are in most of the volcanic districts comparatively insignificant in amount, by far the largest proportion of solid material ejected from the various vents having everywhere, save at the Pentland Hills, consisted of streams of lava. Round or within some of the vents the fragmentary materials attain a remarkable coarseness, as may be seen in the great agglomerates of Dumyat, near Stirling, the largest of which is more than 700 feet thick. These massive accumulations doubtless represent a long series of explosive discharges from the summit of the lava column in one or more adjacent vents. Traced away from the orifices of emission, the tuffs rapidly grow finer in grain, less in thickness, and more mixed with ordinary detritus, until they pass into the non-volcanic sediment or die out between the lava-sheets.

Good sections, showing the nature and arrangement of the thin intercalations of porphyrite-tuff between the successive outpourings of lava, may be examined on the coast. Thus, near Turnberry Point, in Ayrshire, upwards of a dozen successive flows of lava, with their sandy and ashy intervening layers, are exposed in places upon the beach, and partly also in section along the cliffs on which the ruins of the historic castle of Turnberry stand. Again, along the coast of Forfarshire, from the Red Head to Montrose, the numerous sheets of porphyrite are separated by layers of dull purplish tuff passing into conglomerate, with blocks of porphyrite a yard or more in diameter.

But by far the most remarkable tuffs in the whole basin are those felsitic varieties to which I have already referred as occurring in the Pentland Hills. Proceeding from the great vent of the Braid Hills, these tuffs extend south-westwards for 8 or 9 miles, and their peculiar materials, mixed with ordinary sediment, may be traced several miles farther. They occur in successive sheets, which, from a maximum thickness and number at the north end, gradually thin away southwards. Each sheet consists of different layers of material—some of it in angular chips, some in fine compacted dust—pointing to many distinct explosions in the accumulation of a single sheet. These pale rocks are strongly marked off from the dark and much heavier diabases and porphyrites between which they are intercalated. As we trace them southwards fragments of porphyrite become increasingly abundant in them; but near the vent they are remarkably homogeneous and felsitic in character. Indeed, I have sometimes thought it possible that certain more flinty homogeneous parts in these thick bands might be actually remnants of lava-streams. The rocks weather so deeply into their mass that it is often difficult to procure tolerably fresh specimens; moreover, even when a fresh fracture can be obtained it is sometimes hardly possible to discriminate between the compacted volcanic dust and the same material still existing as a mass of felsite. If not true superficial lavas, some of the felsite-like portions may perhaps be intrusive sills or veins.

That these acid tuffs were erupted from the vent of the Braid Hills, which is still largely filled with similar materials, may be regarded as tolerably certain. The much more basic lavas intercalated between them in like manner thicken towards the north and thin away southwards. They are thickest at the north end, on the brink of the vent; and but for their very different composition, there would be no hesitation in looking upon both lavas and tuffs as having been ejected from the same orifice. I shall return to this question in describing the structure and materials of the Braid Hills.

The amount of volcanic material ejected from the more important vents of 'Lake Caledonia' was much greater than the height of the present hills would lead us to suppose. The rocks have been tilted into positions much more inclined than those which they originally occupied, so that to measure their actual thickness we must take a line approximately perpendicular to the dip. In this way we ascertain that the accumulated mass of lavas and tuffs immediately outside the vent at the north end of the Pentland Hills must be at least 7000 feet thick, for the base of the series is concealed under the unconformable overlap of the Lower Carboniferous Sandstones, while the top is cut off by a fault which brings down the Carboniferous formations against the eastern flank of the hills. Probably not less voluminous is the pile of ejected material in the Ochil Hills, where, though the base of the whole is concealed by the fault which throws down the coalfield, some 6500 feet of lavas, tuffs, and conglomerates can be seen. There were thus, during the time of the Lower Old Red Sandstone, more than one volcano in Central Scotland which might be compared in bulk of ejected material to Vesuvius.

That the eruptions were mainly subaqueous is indicated, as I have shown, by the intercalated bands of sandstone and conglomerate between the successive porphyrites, as these are traced away from the centres of discharge, and likewise, even more impressively, by the hardened sand which has been washed into former fissures and cavities in the lavas. But that, in some cases, the volcanic cones were built up above the surface of the lake may be legitimately inferred from the remarkable volcanic conglomerates which occur, more particularly in the great chain of the Ochil and Sidlaw Hills. These thick accumulations of well-rounded and water-worn blocks are interspersed between sheets of porphyrite, and are mainly made up of porphyrite fragments. Impressive sections of them may be seen along the Kincardineshire coast. The conglomerates are sometimes so remarkably coarse, many of their blocks exceeding 2 feet in diameter, and so rudely bedded, that it is only by noting the position of oblong boulders that one can make out the general direction of the stratification. In their smooth rounded forms these blocks resemble the materials of storm-beaches on an exposed coast. The trituration of the porphyrite fragments has given rise to a certain amount of green paste, which firmly wraps round the stones and retains casts of them after they have dropped out. It is further deserving of remark that while in some districts, as in the central Ochils, the materials were entirely derived from the destruction of volcanic rocks, in others a large proportion of non-volcanic materials is mingled with the débris of the porphyrites. South of Stonehaven, for example, large boulders of quartzite form a conspicuous feature in the conglomerates, of which in places they make up quite half of the total constituents. There can be little doubt, I think, that the materials of these coarse detrital accumulations were gathered together as shingle-beaches, and were derived in part from volcanic cones which had risen above the level of the lake. They seem to suggest considerable degradation of these cones by breaker-action, whereby blocks of rock a yard or more in diameter could be rounded and smoothed.

Another inference deducible from such conglomerates, and to which I have already alluded, is that considerable intervals of time took place between some of the eruptions. Round the vents, indeed, where the successive sheets of volcanic material follow each other continuously, it is perhaps impossible to form any definite opinion as to the relative chronological value of the lines of separation between different ejections. But where some hundreds of feet of coarse conglomerate, chiefly composed of well-rounded porphyrite blocks, intervene between two streams of porphyrite, we may conclude that the interval between the outpouring of these lavas must have been of considerable duration. Other evidence of a similar tendency may be recognized in the intercalation of groups of varied sedimentary accumulations, such as those which were deposited over the site of Eastern Forfarshire and Kincardineshire during the time that elapsed between two successive floods of lava. In the Den of Canterland, for example, in the midst of the volcanic sheets we find interesting evidence of one of these intervals of quiescence, during which layers of fine olive shales were laid quietly down, while macerated vegetation, drifting over the lake-bottom, was buried with egg-packets of *Pterygotus*, remains of fishes, and abundant gally-worms (*Campecaris*) washed from the neighbouring land. So undisturbed were the conditions of deposition that calcareous sediment gathered round some of the organisms and encased them in limestone nodules.

2. *Vents.*—I will now refer to some of the vents from which this vast mass of volcanic material was ejected, and to the structure of the rocks that have filled them up. It must be borne in mind that across the centre and south of Scotland a number of bosses of igneous rock occur which may plausibly be referred to the volcanic phenomena of the Lower Old Red Sandstone, but cannot be proved to be actually part of them. I allude more particularly to the bosses of granite and other acid rocks which rise through the Silurian strata of the Southern Uplands.[1] The largest are the well-known masses of Galloway, with which must be grouped the bosses near New Cumnock, that of the Spango Water, and those of Cockburn Law and Priestlaw in Lammermuir, together with a number of masses of felsitic material scattered over the same region, such as the Dirrington Laws of Berwickshire. These bosses present some points of structure in common with true vents. They come like great vertical columns through highly-folded and puckered strata, and, as they truncate Llandovery and Wenlock formations,

[1] I suggested this possible connexion many years ago in Trans. Geol. Soc. Edin. vol. ii. (1874) p. 21.

they are certainly younger than the older part of the Upper Silurian series. They must be later, too, than the chief plication of these strata; but they are older than the basement Carboniferous rocks which contain pebbles of them. Their date of eruption is thus narrowed to the interval between the later part of the Upper Silurian period and the close of the Old Red Sandstone. I have myself little doubt that they are to be associated with the volcanic epoch we are now considering, as it was the only known great episode of igneous activity in this region during the interval within which the protrusion of these granites must have taken place. In the Cheviot Hills, indeed, we have evidence of the eruption of a large mass of augite-granitite through the porphyrite-lavas of the Lower Old Red Sandstone, with abundant veins projecting from it into them. Mr. Teall and Mr. Clough, who have so well described this mass, were inclined to regard it as marking the source whence the lavas and tuffs of the region proceeded.[1] It may not improbably have been protruded up one or more funnels which had previously served as orifices for volcanic discharges, and in that case would mark one of the later phases of the volcanic energy of the region. Its position may be suggestively compared with that occupied by the granophyric bosses in the Tertiary volcanic series of the Inner Hebrides.

Leaving these granitic masses aside for the present, I would direct attention to the more important bosses and groups of bosses which, lying well within the volcanic area, appear to mark some of the vents of the basin. These are most numerous along the chain of the Ochil and Sidlaw Hills; but they probably do not mark the sites of the chief vents of that chain, which appear to be concealed under the Carboniferous rocks of the Midland Valley. The bosses now visible rise through different portions of the volcanic series, and are therefore not the oldest or original vents of the group. In the south-western part of the chain they are chiefly small in size, seldom exceeding half a mile in diameter, and have been filled sometimes with crystalline, sometimes with fragmental materials. Two bosses, containing the remarkable granophyric quartz-diorite already referred to, emerge from among the tuffs in a low part of the series, immediately above the village of Tillicoultry in Clackmannan. Two or three more, which are occupied by quartz-porphyries, pierce the volcanic group a few miles to the west of Loch Leven. The

[1] Teall, Geol. Mag. for 1883, p. 106; Clough, Mem. Geol. Survey, 'Geology of the Cheviot Hills,' Sheet 108 N.E., 1888, p. 24.

whole of the visible necks of the Ochil Hills may be regarded as one connected group, subsidiary to the main orifices which lay rather farther to the south and west.

For some miles eastwards from the central Ochils an interval occurs, marked by the presence of only a few small intrusive masses. But as the broad anticline of the Firth of Tay opens out and allows the lower or pre-volcanic members of the Old Red Sandstone to appear at the surface, another group of bosses emerges from the lower sandstones and flagstones. Some of these cover a considerable space at the surface, though a portion of their visible area may be due to lateral extravasation from adjacent pipes, the true dimensions of which are thereby obscured. Some of the masses are undoubtedly sills. In the case of Dundee Law we probably see both the pipe and the sill which proceeded from it; the prominent well-defined hill marking the former, while the band of rock which stretches from it south-westwards to the shore belongs to the latter. The material that forms the rocks and sills in this district is generally a dark compact andesite. The rock of Dundee Law, Dr. Hatch remarks, shows under the microscope "striped lath-shaped felspars abundantly imbedded in a minute granular groundmass, speckled with granules of magnetite, but showing no unaltered ferro-magnesian constituents."

Beyond this group of rocks no similar group is to be found throughout the rest of the volcanic district. The rapid increase of the porphyrites towards Montrose, however, points to the existence of some vents in that direction, probably now concealed under the waters of the North Sea.

The sites of some of the orifices of discharge along the southern line of volcanoes can be satisfactorily distinguished in the broken hilly ground that flanks the Southern Uplands, from Carrick, in Ayrshire, into the heart of Midlothian. Beginning at the south-western end, we find a number of large bosses of pink felsite rising through the Silurian rocks and the lower parts of the Old Red Sandstone; while around them, broken by faults and much cut down by denudation, lie the bedded porphyrites and volcanic conglomerates. Some of the detached eminences of erupted rock that rise through the Old Red Sandstone between these hills and the adjacent coast not improbably mark the sites of other vents. The conspicuous Hill of Mochrum, near Maybole, may be one of these, but it differs from the rest in composition, for it consists mainly of tuff and ashy conglomerates, with a mass of porphyrite, part of which is amygdaloidal.

Some forty miles to the north-east, the conspicuous and graceful cone of Tinto may mark another volcanic centre, though in that case, judging from the unconformable position of the overlying porphyrites, it must belong to an earlier series of eruptions. This hill, consisting of felsitic rocks which have been already referred to, rises to a height of 2335 feet above the sea. It forms part of a continuous mass, which runs in an east and west direction for about five and a half miles, with a breadth of about a mile. Some part, at least, and possibly the whole of this oblong mass is in the form of a sill, which dips towards the north. The conglomerates and sandstones that lie almost at the base of the Lower Old Red Sandstone plunge under it on the southern side, and similar sandstones overlie it on the north. If there be a neck, as one might infer from the shape of the hill, its precise limits are concealed. But there were other, though probably smaller, vents in the immediate neighbourhood. One of these may be marked by the felsite boss which overlooks the village of Douglas, four miles to the south-west of the Tinto mass, while another forms the beautiful little cone of Quothquan Hill, which rises from among the porphyrites on the right bank of the Clyde, immediately opposite to Tinto.

But unquestionably the most interesting vent in the whole region is that which lies at the northern end of the chain of the Pentland Hills. The lavas that flowed from the Tinto centre of eruption die out one after another as they are traced north-eastwards, until, in a distance of about 16 miles, the last of them disappears. Immediately beyond that limit, as already mentioned, another volcanic band begins towards the north and rapidly increases in bulk, until, after a course of less than 8 miles, it has attained a thickness of some 7000 feet. At these maximum dimensions it forms the great scarped front of the Pentland Hills, which rises into so prominent a feature in the southern landscape of Edinburgh. Its component lavas and tuffs, which I have shown to present so singular a contrast in composition, and which may be distinguished from each other by topographical form and local colour (even when seen from a distance), range in parallel bands from south-west to north-east, until, along the base of the northern wall of the Pentlands, their continuity abruptly ceases. The lower ground, which extends from the foot of that steep declivity to the southern suburbs of Edinburgh, and includes the group of the Braid Hills, is occupied by another and more complex group of rocks in which the parallelism and continuity, so persistent in the Pentland chain, entirely disappear. When I mapped this district, many years ago, for the Geological

Survey, I found it extremely difficult to understand. Being then myself but a beginner in geology, and the study of old volcanic rocks not having yet advanced much beyond its elementary stage, I failed to disentangle the puzzle. Not until after more than twenty years, largely spent in the investigation of volcanic rocks elsewhere, had I an opportunity of re-surveying the ground and bringing to its renewed study a wider knowledge of the subject. I will here offer an outline of the chief results, hitherto unpublished, at which I have arrived.

The abrupt truncation of the bedded lavas and tuffs along the base of the northern face of the Pentland Hills marks approximately the southern margin of a large vent from which at least some, if not most, of these rocks were probably ejected. The size of this vent cannot be ascertained on account of the unconformable overspread of Lower Carboniferous strata. But that it must have been a large and important volcanic orifice may be inferred from the fact that the visible area of the materials that fill it up measures two miles from north-east to south-west, and a mile and a half from south-east to north-west, thus including a space of rather more than two square miles. Its original limits towards the north and south can be traced by help of the bedded lavas that partially surround it, but on the two other sides they are concealed by the younger formation. We shall probably not over-estimate the actual area of the vent if we state it at about four square miles.

The materials that now fill this important orifice consist mainly of 'claystones:' that is, dull rocks, meagre to the touch, varying in texture from the rough porous aspect of a sinter through stages of increasing firmness till they become almost felsitic, and ranging in colour from a dark purple-red, through shades of lilac and yellow, to nearly white, but often strikingly mottled. A more or less laminar structure is often to be observed among them, indicating a dip in various directions (but especially towards the north) and at considerable angles. Throughout this exceedingly fine-grained material lines of small lapilli may occasionally be detected, also bands of breccia, consisting of broken-up tuff of the same character, and of fine 'hornstone' and felsite, with delicate flow-structure. Though exhibiting on the whole so little structure, this tract must be regarded as consisting mainly of fine volcanic dust derived from the explosion of lavas of a much more acid type than those which flowed out to form the bedded porphyrites and diabases of the Pentland Hills. Various veins, dykes, and small bosses of felsite ('hornstone'), porphyrite, and even more basic material such as fine dolerite, have been intruded into the tuffs and breccias.

On the outskirts of the main vent some subordinate necks may be observed, perhaps marking lateral eruptions from the flanks of the great cone. Three of these occur in a line more than half a mile long, running in a south-westerly direction from the southern edge of the vent. The smallest of these measures about 500 feet in diameter; the largest is oblong in shape, its shorter diameter being about 500 feet and its longer about 1000 feet. The materials that fill these lateral vents are coarse agglomerates with veins and irregular intrusions of a fine horny or flinty felsite.

It will thus be seen that, viewed as a whole, the materials which now occupy the vents of the volcanic chains in the Lower Old Red Sandstone of Central and Southern Scotland are much more acid than the lavas erupted at the surface. In the Pentland district this more acid material was ejected at intervals in abundant discharges of dust and lapilli, while between these successive discharges copious streams of diabasic and andesitic lavas, either from the same or from some closely-adjoining vent, were poured out. Elsewhere the acid volcanic magma, as I have already stated, has likewise been blown out in fragmentary discharges; but it appears to have seldom or never communicated with the surface in the form of actual outpourings of lava. Throughout the whole region, however, as a closing phase of the volcanic history, the acid magma rose after the outpouring of the more basic lavas and filled such chimneys of the volcanoes as were not already blocked with agglomerate. Probably after these pipes were plugged the final efforts of volcanic energy were expended in the protrusion of the acid material as sills between the bedding-planes of the surrounding rocks, and as dykes and veins in and around the vents.

3. *Sills and Dykes.*—Nowhere throughout the volcanic tracts of the Lower Old Red Sandstone is there any such development of sills as may be seen beneath the Silurian volcanic sheets of North Wales. Those which occur are most abundant in the Lanarkshire district, to the north-west and south-west of Tinto, and in the south of Ayrshire. From the village of Muirkirk to the gorge of the Clyde, below the Falls, the Upper Silurian and Lower Old Red Sandstone strata are traversed by numerous intrusive sheets of pink and yellow felsite, quartz-porphyry, minette, lamprophyre and allied rocks, which are no doubt to be regarded as part of the volcanic phenomena with which we are here concerned. In the south of

Ayrshire, between the villages of Dalmellington and Barr, there is a copious development of similar sills, especially along one or more horizons near the base of the Old Red Sandstone. Garleffin Fell, Glenalla Fell, Turgeny, and other heights are conspicuous prominences formed of these rocks; above the sills lie thick conglomerates and sandstones on which the great porphyrite-sheets rest. In the Dundee district, as already mentioned, the sills are of a more basic character (andesites and diabases); they send veins into and bake the sandstones among which they have been intruded, and are sometimes full of fragments of such indurated sandstone, as may be well seen on the northern shore of the Firth of Tay, west of Dundee.

A conspicuous characteristic of most of the volcanic tracts of the Lower Old Red Sandstone in 'Lake Caledonia' is the comparative scarcity of contemporaneous dykes. In the band of acid sills between Muirkirk and the Clyde a considerable number of dykes have been mapped, which must be regarded as due to the same series of movements and protrusions of the magma that produced the adjacent sills. Throughout the length of the Southern Uplands dykes of felsite, minette, lamprophyre, vogesite and other varieties, which may also be connected with the volcanic phenomena of the Lower Old Red Sandstone, not infrequently occur among the Silurian rocks. On the Kincardineshire coast, south of Bervie, a number of dykes of pink quartz-porphyry traverse the conglomerates and sandstones. The coast south of Montrose displays some singularly picturesque sections, where a porphyry dyke running through porphyrite lavas and agglomerates stands up in wall-like and tower-like projections. On the shore at Gourdon, as well as at Cortachy and Alyth, intrusive dykes of serpentine occur. One would expect to meet with a network of dykes in and around the volcanic vents; but even there they are usually not conspicuous either for number or size. Those in the great vent of the Braid Hills have been already referred to, and allusion has been made to the possibility that, besides the acid tuffs intercalated among the lavas of the Pentland Hills, there may be sills and veins of felsite which it is difficult to distinguish from parts of the tuffs. On North Black Hill, at the base of the volcanic group of the Pentland chain, there is distinct evidence of the intrusion of felsite.

In the Ochil Hills also, groups of dykes of felsite and porphyrite may be observed, especially near the necks. They are fairly numerous in the neighbourhood of Dollar. By far the most abundant series yet observed, however, occurs beyond the limits of the region which I am now describing, in the tract that surrounds the granite boss of the Cheviot Hills. The dykes consist there of granite, felsite, quartz-porphyry, and porphyrite. Of the latter rock Mr. Clough mapped no fewer than forty dykes. He noted, moreover, that not only these, but the dykes of felsite and quartz-porphyry tend to point, in a general way, towards the granite, as if that were the great centre from which they radiate.[1]

Volcanic activity had entirely ceased in 'Lake Caledonia' long before the last sediments of the Lower Old Red Sandstone had been laid down. The great cones of the Ochil Hills, for example, sank below the waters of the lake in which they had so long been a conspicuous feature, and so protracted was the subsidence of the lake-bottom that the site of these volcanoes was buried under 8000 or 9000 feet of sandstones and conglomerates, among which no trace of any volcanic eruptions has yet been found. The sagging of the terrestrial crust over an area from which such an enormous amount of volcanic products had been discharged, would doubtless be a protracted process. Long after the subsidence of the lake-bottom and the accumulation of its thick mass of sediments, after even the entire effacement of the topography and the deposition of the thick Carboniferous formations over its site, the downward movement showed itself in the production of the gigantic north-east faults, and the sinking of the Carboniferous rocks for several thousand feet. Those dislocations, as was natural, have run through the heart of some of the volcanic groups, carrying much of the evidence of these ancient volcanoes out of sight, and leaving us only fragments from which to piece together the records of a volcanic period which is by no means the least interesting in the long volcanic history of this country.

The limits of this Address forbid me to enter upon an adequate description of the other volcanic regions which I have above enumerated, with the view of showing that the time of the Lower Old Red Sandstone was eminently marked by volcanic activity in the region of the British Isles. A rapid glance at some of their more salient features, however, may help to deepen the impression which we receive from a study of the phenomena of Central Scotland.

In the year 1878, I called attention to the evidence for the existence of contemporaneous volcanic rocks in the Old Red Sand-

[1] Geol. Surv. Mem. on the Cheviot Hills, p. 28.

stone north of the Grampian chain.[1] There appear to have been at least three distinct and widely-separated groups of volcanoes in the great lake or inland sea in which the thick pile of the Caithness Flags was deposited, and which for the sake of brevity of reference I have named 'Lake Orcadie.' Not far from the southern shore, two or more small vents made their appearance. Their exact position has not been ascertained, but the basic lavas which proceeded from them have been traced on the maps of the Geological Survey. These diabases are well exposed in the long narrow valley of Strathbogie, where they have been mapped for the Geological Survey by Mr. L. Hinxman;[2] while 25 miles to the north, and doubtless belonging to another vent, a smaller patch has been traced by Mr. J. Grant Wilson near Buckie.[3]

At a distance of some 90 miles northward from these Moray Firth vents a second volcanic district has been detected among the Orkney Islands by Messrs. Peach and Horne.[4] The lavas which were there ejected occur at the south-eastern corner of the island of Shapinshay, where they are regularly bedded with the flagstones. They consist of dark green amygdaloidal olivine-diabases. Their thickness cannot be ascertained, as their base is not seen, but they have been cut by the sea into trenches which show them to exceed thirty feet in depth. The position of the vent from which they came has not been ascertained. Neither here nor in the Moray Firth area do any sills accompany the interbedded sheets, and in both cases the volcanic action would seem to have been of a feeble and short-lived character.

Much more important were the volcanoes that broke out nearly 100 miles still farther north, where the Mainland of Shetland now lies. I shall never forget the pleasure with which I first recognized the traces of these eruptions, and found near the most northerly limits of the British Isles proofs of volcanic activity in the Lower Old Red Sandstone. Since my observations were published,[5] Mr. Peach, who accompanied me in Shetland, has returned to the district and, in concert with his colleague Mr. Horne, has extended our knowledge of the subject.[6] The chief vent or vents lay towards the west

[1] Trans. Roy. Soc. Edin. vol. xxviii. (1878) p. 345.
[2] Sheet 76 of the Geological Survey Map of Scotland.
[3] Sheet 95 of the same map.
[4] Proc. Roy. Phys. Soc. Edin. vol. v. (1879) p. 80.
[5] Trans. Roy. Soc. Edin. vol. xxviii. (1878) p. 418.
[6] *Ibid.* vol. xxxii. (1884) p. 359.

and north-west of the Mainland and North Mavine; others of a less active and persistent type were blown out some 25 miles to the east, where the islands of Bressay and Noss now stand. In the western district streams of slaggy porphyrite and diabase with showers of fine tuff and coarse agglomerate were thrown out, until the total accumulation reached a thickness of not less than 500 feet. These volcanic ejections took place contemporaneously with the deposition of the red sandstones, for they are intercalated in these strata.

No trace of any of the vents of eruption has been found in the western and chief volcanic district, but in Noss Sound a group of small necks occurs, filled with a coarse agglomerate of pieces of sandstone, flagstone, and shale. Messrs. Peach and Horne infer that these little orifices never discharged any streams of lava. More probably they were opened by explosions which only gave forth vapours and fragmentary discharges, such as the band of tuff intercalated among the flagstones in their neighbourhood.

But one of the most striking features of the volcanic phenomena of this remote region is the relative size and number of the sills and dykes which here as elsewhere mark the latest phases of subterranean activity. Messrs. Peach and Horne have shown that three great sheets of acid rocks (granites and spherulitic felsites) have been injected among the sandstones and basic lavas, that abundant veins of granite, quartz-felsite, and rhyolite radiate from these acid sills, and that the latest phase of igneous action in this region was the intrusion of a series of bosses and dykes of basic rocks (diabases) which traverse the sills.

The basin of Lorne has not yet been described, though various writers have referred to different parts of it. My own observations have been too few to enable me to give an adequate account of it. The volcanic sheets of this area form a notable feature in the scenery of the West Highlands, for they are the materials out of which the remarkable terraced hills have been carved, which stretch from Loch Melfort to Loch Creran, and which reappear in picturesque outliers among the mountains traversed by Glen Coe. Between the ancient schists that form the foundation-rocks of this district and the base of the volcanic series, lies a group of sedimentary strata which in some places must be 500 feet thick. This group consists of exceedingly coarse breccias at the bottom, above which come massive conglomerates, volcanic grits or tuffs, fine sandstones, and courses of shale. While the basement-breccias are composed mainly of detritus of the underlying schists, they pass up into coarse conglomerates made up almost entirely of fragments of different lavas (porphyrites, diabases, &c.), and more than 100 feet thick, which often show little or no trace of stratification, but break up into large quadrangular blocks by means of joints which cut across the imbedded boulders. These volcanic conglomerates form some of the more conspicuous features of the coast to the south and north of Oban. They offer many points of resemblance to those of 'Lake Caledonia.' They have obviously been derived from lava-sheets that were exposed to strong breaker-action, which at the same time transported and rounded blocks of granite, schist, and other crystalline rocks derived from the adjacent hills. During the intervals of quieter sedimentation indicated by the fine sandstones and shales, volcanic explosions still continued, as may be seen by the occurrence of occasional large bombs which have fallen upon and pressed down the fine ashy silt that was gathering on the bottom.

But these earlier explosions were merely preliminary to those which led to the outflow of the great sheets of lava that now constitute so large a part of the hills of Lorne. In the few traverses which I have made across different parts of this district I have noted the general resemblance of the rocks to those of the Lower Old Red Sandstone of the Midland Valley of Scotland, their bedded character, and the occurrence of occasional layers of stratified material between them. The work of the Geological Survey, however, having now nearly reached this ground, we shall before long be in possession of detailed information regarding the general character and sequence of its volcanic history.

The Cheviot Hills represent a portion of the outpourings of another important and active volcanic centre of Lower Old Red Sandstone time. This tract has now been mapped by the Geological Survey both on the English and Scottish sides of the Border, and thus its detailed structure is well known. To the Survey maps and Memoirs, and to the papers by Mr. Teall, I must content myself to refer for full information.

To the north of the Cheviot area, and possibly independent of it, lie the remarkably coarse agglomerates and felsitic bosses, dykes, and veins, so well exposed along the coast between Eyemouth and St. Abb's Head. The occurrence of *Pterygotus* and other organic remains in the continuation of some of these rocks inland defines their geological age. To the west of them lie the granite bosses of Priestlaw and Cockburn Law and the quartz-porphyries of the two Dirrington Laws. In these various protuberances we not improbably see the remains of another group of vents which were active over the east of Berwickshire.

The Lower Old Red Sandstone tract of the North of Ireland was probably deposited in the same continuous area with that of the Midland Valley of Scotland. We find the sandstones, conglomerates, and volcanic rocks well developed south of Campbeltown in Cantire, and similar rocks appear on the Antrim coast at Cushendall, and still more extensively in the interior between Pomeroy and Omagh. Sheets of diabase and porphyrite, and occasional showers of tuff, have been poured out in Tyrone among the sandstones and conglomerates, which in some places are largely made up of detritus of the volcanic rocks. The sections visible in that district present the closest resemblance to what may be seen in almost any part of the Old Red Sandstone tracts of Central Scotland. In one respect, perhaps, the Pomeroy porphyrites possess a local peculiarity; nowhere among rocks of this age have I noticed a more perfect flow-structure. So marked is this structure in some cases (Sentry Box Hill) that the rock splits into parallel flags, the amygdaloidal cavities being flattened and drawn out in the direction of movement.[1]

In the South of Ireland the top of the Upper Silurian group of strata is followed upwards conformably by the great series of red sandstones and conglomerates known as the 'Dingle Beds.' Lithologically these rocks present the closest resemblance to the Lower Old Red Sandstone of Central Scotland. They occupy a similar stratigraphical position, and though they have not yielded any palæontological data for comparison, there can, I think, be no hesitation in classing them with the Scottish Lower Old Red Sandstone, and regarding them as having been deposited under similar geographical conditions. They offer one feature of special interest for my present purpose, since they include a well-marked group of contemporaneous volcanic rocks, which are quite unique among the later Palæozoic formations of this country, inasmuch as they include acid rocks of the type of nodular felsites, like those so characteristic of the Silurian period.

The area where this remote and isolated volcanic group is best

[1] Farther south-west, near Boyle, in the county of Roscommon, certain curious felspathic breccias in the Old Red Sandstone contain pieces of andesitic and felsitic rocks, with fragments of devitrified glass, suggestive of the occurrence of volcanic eruptions during their deposition, though no undoubted tuffs and lavas appear to crop out in the narrow strip of the formation there exposed. See, however, Jukes and Foot, Journ. Roy. Geol. Soc. Ireland, vol. i. (1866) p. 249.

developed forms a range of high rugged ground along the northern front of the hills that stretch eastward from the Lakes of Killarney. Their general distribution is shown on Sheets 184 and 185 of the Geological Survey of Ireland;[1] though I may again remark that petrography has made great strides during the thirty years and more that have passed since these maps and their accompanying Memoirs were published, and that, were the district to be surveyed now, probably a considerable tract of ground coloured as ash would be marked as felsite. At the same time the existence of both these rocks here cannot be gainsaid.

The felsite was long ago brought into notice by Dr. Haughton, who published an analysis of it.[2] It is also referred to by Mr. Teall for its spherulitic structure.[3] Seen on the ground it appears as a pale greenish-grey close-grained rock, sometimes exhibiting flow-structure in a remarkably clear manner, the laminæ of devitrification following each other in wavy lines, sometimes twisted and delicately puckered or frilled, as in some schists. Portions of the rock are strongly nodular, the nodules varying in size from less than a pea to that of a hen's egg.

The close resemblance of this rock to many of the Lower Silurian nodular felsites of Wales cannot but strike the geologist. It presents analogies also to the Upper Silurian felsites of Dingle. But its chief interest arises from the geological horizon on which it occurs. Lying in the so-called 'Dingle Beds,' which, as I have said, may be regarded as the equivalents of the Lower Old Red Sandstone of England and Scotland, it is, so far as my observations go, the only example of such a nodular felsite or rhyolite of later date than the Silurian period. We recognize in it a survival as it were of the peculiar Silurian type of acid lava, the last preceding eruption of which took place not many miles to the west, in the Dingle promontory. But elsewhere this type did not survive the end of the Silurian period.

The detrital rocks accompanying the felsite in the district east of Killarney vary from such close-grained felsitic material as cannot readily be distinguished from the felsite itself to unmistakable felsitic breccias. Even in the finest parts of them occasional

[1] See the Memoir (by J. B. Jukes and G. V. Du Noyer) on Sheet 184, p. 15. Other volcanic rocks have been mapped at Valentia Harbour in the Dingle Beds, but these I have not had an opportunity of personally examining.

[2] Trans. Roy. Irish Acad. vol. xxiii. (1859) p. 615.

[3] 'British Petrography,' p. 349.

rounded quartz-pebbles may be detected, while here and there a reddish shaly band, or a layer of fine pebbly conglomerate with quartz-pebbles an inch in length, shows at once the bedding and the dip. Mr. W. W. Watts, who with Mr. A. McHenry of the Irish Staff of the Geological Survey, accompanied me over this ground, informs me that the slides which have been prepared from the specimens we collected completely confirm the conclusions reached from inspection of the rocks in the field.[1] He finds among the angular grains slightly damaged crystals of felspar, chiefly orthoclase. Many portions of these felspathic grits reminded me much of the detrital Cambrian rocks which in the Vale of Llanberis have been made out of the pale felsite of that locality.

(B). Upper Old Red Sandstone.

In the northern half of Britain, where the Old Red Sandstone is so well displayed, the two great divisions into which this series of sedimentary deposits is divisible are separated from each other by a strongly marked unconformability. The interval of time represented by this break must have been of long duration, for it witnessed the effacement of the old water-basins, the folding, fracture, and elevation of their thick sedimentary and volcanic accumulations, and the removal by denudation of, in some places, several thousand feet of these rocks. The Upper Old Red Sandstone, consisting so largely as it does of red sandstones and conglomerates, indicates the return or persistence of geographical conditions not unlike those that marked the deposition of the lower subdivision. But in one important respect its history differs greatly from that which I have sketched for the older part of the system. Though the Upper Old Red Sandstone is well developed from the Cheviot to the Ochil Hills, and over so much of Ireland, no trace has ever been there detected in it of any contemporaneously erupted volcanic rocks.

[1] Mr. Watts has also examined the microscopic structure of the felsite of Benaun More. He says that the spherulites appear to have a micropegmatitic structure, owing to the intergrowth of quartz and felspar. In some parts of the rock the spherulites, from ·02 to ·01 inch in diameter, are surrounded by exceedingly minute green needles, possibly of hornblende, while inside some of them are small quartz-grains. Larger porphyritic felspars occur outside the spherulites, some being of plagioclase, but most of orthoclase. The spherulitic structure is not so well developed near the felspars. A few of the large nodules are hollow and lined with crystals; while some of them show a finely concentric lamination like the successive layers of an agate.

The topographical changes which preceded its deposition must have involved no inconsiderable amount of subterranean disturbance, yet the volcanic energy which had died out so completely long before the close of the time of the Lower Old Red Sandstone does not appear to have been rekindled until the beginning of the Carboniferous period.

Only one district in the British Isles, so far as I am aware, furnishes any record of volcanic activity in the later part of the Old Red Sandstone period.[1] It lies far to the north among the Orkney Islands, near the centre of the scattered outliers which I have united as parts of the deposits of 'Lake Orcadie.' The thick group of yellow and red sandstones which form most of the high island of Hoy, and which, there can be little doubt, are correctly referred to the Upper Old Red Sandstone, rest with a marked unconformability on the edges of the Caithness flagstones. At the base of these pale sandstones, and regularly interstratified with them, lies a band of lavas and tuffs which can be traced from the base of the rounded hills to the edge of the cliffs, along the face of which it runs as a conspicuous feature, gradually sloping to a lower level, till it reaches the sea under the well-known sea-stack of the Old Man of Hoy. It is about 200 feet thick, and consists of three or more sheets of porphyrite, usually well marked off from each other as separate flows. Beneath it and lying across the edges of the flagstones below, there is a zone of dull red, fine-grained tuff, banded with seams of hard red and yellow sandstone.

On the low ground immediately to the north the flagstones are pierced by several volcanic necks which we may with little hesitation recognize as marking the sites of the vents from which this series of lavas and tuffs was discharged. The largest of them forms a conspicuous hill about 450 feet high, the smallest is only a few yards in diameter and rises from the surface of a flagstone ridge. They are filled with a coarse, dull green, volcanic agglomerate, made up of fragments of the lavas with pieces of hardened yellow sandstone and flagstone. Around the chief vent the flagstones through which it has been opened have been greatly hardened and blistered. On the northern coast of Caithness I have described a remarkable

[1] There may be some examples of Upper Old Red Sandstone volcanic rocks in Ireland which I have not yet been able personally to examine. On the maps of the Geological Survey (Sheet 198, and Explanation, pp. 8, 17) contemporaneous rocks of this age are marked as occurring at Cod's Head and Dursey Island, on the south side of the mouth of the Kenmare estuary.

volcanic vent about 300 feet in diameter, which rises through the uppermost group of the Caithness flagstones. It is filled with a coarse agglomerate consisting of a dull greenish diabase paste crowded with blocks of diabase, sometimes three feet in diameter, and others of red sandstone, flagstone, limestone, gneiss, and lumps of black cleavable augite.[1] That this volcanic orifice was active about the same time with those in the opposite island of Hoy may be legitimately inferred.

These northern volcanoes made their appearance in a district where during the preceding Lower Old Red Sandstone period there had been several widely separated groups of active volcanic vents. So far as the fragmentary nature of the geological evidence permits of an opinion, they seem to have broken out at the beginning or at least at an early stage of the deposition of the Upper Old Red Sandstone, and to have become entirely extinct after the lavas of Hoy were poured forth. No higher platform of volcanic materials has been met with in that region. With these brief and limited Orcadian explosions the long record of Old Red Sandstone volcanic activity comes to an end.

VII. DEVONIAN.

Throughout the wide region of Wales, where the Old Red Sandstone is so massively developed, no trace of contemporaneous volcanic activity has been detected in the many thousand feet of red strata which intervene between the top of the Silurian and the base of the Carboniferous system. The rapid and complete change in the pre-Carboniferous type of sedimentary accumulations from that of South Wales to that of Devonshire constitutes one of the long-standing problems of British Geology. Among the many contrasts which the Devonian rocks present to the Old Red Sandstone of South Wales, not the least important is the abundant evidence which the former include of vigorous, long-continued and frequently renewed volcanic activity. Since the early and classic researches of De la Beche,[2] many geologists have studied these igneous rocks; but I would especially refer to the labours of our lamented associate Mr. Champernowne, which, more than those of

[1] Trans. Roy. Soc. Edin. vol. xxviii. (1878) p. 405. Since that paper appeared my colleagues in the Survey have detected another smaller, but otherwise similar neck on the same coast.

[2] Geol. Surv. 'Report on the Geology of Cornwall, Devon, and West Somerset' (1839). p. 37 *et seq.*

any other observer, have shown the abundance of volcanic material among the rocks of Devonshire, and the resemblance which in this respect they offer to the Devonian system of North Germany.[1] Unfortunately the geological structure of the Palæozoic rocks of the South-west of England has been complicated to an amazing extent by plication and fracture, with concomitant cleavage and metamorphism. Hence it is a task of extreme difficulty to trace out with any certainty definite stratigraphical horizons, and to determine the range of contemporaneous volcanic action. Mr. Ussher has recently shown us with what success this task may be accomplished when it is pursued on a basis of minute mapping combined with a sedulous collection and determination of fossils.[2] But years must necessarily elapse before such detailed work is carried over the whole Devonian region, and probably not till then will the story of the volcanic history of the rocks be adequately made out.

In the meantime it has been established that while there is a singular absence of igneous rocks in North Devon, a strip of country extending from Torquay to Plymouth contains abundant records of contemporaneous volcanic action. It has not yet been possible to map out the respective limits of the bedded lavas and the tuffs, to distinguish the true sills, and to fix on the position of the chief vents of eruption. So intense has been the compression and shearing of the rocks that solid sheets of diabase have been crushed into fissile schists, which can hardly be distinguished from tuffs. Moreover, owing perhaps in large measure to the mantle of red Permian (or Triassic) strata, which has been stripped off by denudation from large tracts of this region which it once overspread, the Devonian rocks have been deeply 'raddled.' But probably one of the main sources of difficulty in studying the petrography of the area is to be found in the results of atmospheric weathering. Devonshire lies in that southern non-glaciated strip of England where the rocks have been undergoing continuous decay for a protracted period, and where no ploughshare of ice has swept off the deep weathered crust so as to leave hard surfaces of rock, fresh and bare, under a protecting sheet of boulder-clay. It is seldom that a really fresh

[1] See in particular his last paper 'On the Ashprington Volcanic Series of South Devon,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 369.

[2] This geologist has spent many laborious years in the investigation of the geology of Devonshire, and has published numerous papers on the subject. The valuable memoir by him specially referred to above will be found in Quart. Journ. Geol. Soc. vol. xlvi. (1890) p. 487.

piece of any igneous rock can be procured among the lanes and shallow pits where alone, for the most part, the materials are exposed.

Much therefore remains to be done, both in the stratigraphy and petrography of the Devonian volcanic rocks of this country. So far as at present known, the lavas are mainly or entirely 'greenstones,' varying from a compact to an amygdaloidal or slaggy texture. They occur in sheets, either singly or in groups, and are regularly bedded among the sedimentary strata. Originally they seem to have been dolerites, and among the fresher slides Dr. Hatch has found most of them to possess an ophitic structure, though some show granular and others porphyritic structure. With these rocks are associated abundant diabase-tuffs, frequently mingled with ordinary non-volcanic detrital matter, and shading off into the surrounding grits and slates. There is thus clear evidence of the outpouring of basic lavas and showers of ashes during the Devonian period in the South-west of England, under conditions analogous to those which characterized the formation of the Devonian system in Nassau and the Harz.

The exact range of the eruptions in geological time has still to be ascertained. So far as at present determined, volcanic activity was not awakened during the accumulation of the Lower Devonian formations. It was not until the sporadic coral-reefs and shell-banks had grown up, which form the basement limestones of the Middle Devonian group, that the first eruptions took place. As Mr. Champernowne and Mr. Ussher have shown, some of these reefs were overwhelmed with streams of lava or buried under showers of ashes. The volcanic discharges, however, were only local, probably from many scattered vents, and never on any great scale. Some districts remained little or not at all affected by them, so that the growth of limestone went on without interruption, or at least with no serious break. In other areas again the place of the limestone is taken by volcanic materials.

The chief epoch of this volcanic action marked by the 'Ashprington Volcanic Series' appears to have occurred about midway in the Middle Devonian period. But in certain districts it may have extended into Upper Devonian time. Some intrusive sills of diabase may mark the later phases of the volcanic history. But the occurrence of such sills even in the Upper Devonian rocks, and the alteration of the strata in contact with these (spilosite), point to the continuance or renewal of subterranean disturbance even in the later Devonian ages, if not in subsequent geological time. That volcanic activity accompanied the deposition of the Carboniferous rocks of Devonshire has long been well-known.

VIII. CARBONIFEROUS.

Within the area of the British Isles, the geological record is comparatively full and continuous from the base of the Upper Old Red Sandstone to the top of the Coal Measures. We learn from it that the local basins of deposit in which the later portion of the Old Red Sandstone was accumulated sank steadily in a wide general subsidence, in consequence of which the clear sea of the Carboniferous Limestone ultimately spread across Western Europe from the west coast of Ireland into Westphalia. The Carboniferous period, as chronicled by its sedimentary deposits, was thus a time of slow submergence and quiet sedimentation, terrestrial and marine conditions alternating along the margins of the sinking land according as the rate of depression surpassed or fell short of that of the deposition of sediment. Such a state of balance among the geological agencies does not seem likely to be accompanied with any serious display of volcanic energy. And indeed throughout the Carboniferous rocks of Western Europe there is for the most part little trace of contemporaneous volcanic eruptions. Yet striking evidence exists that, along the western borders of the continental area, in France as well as in some parts of Britain, which had for so many geological ages been the theatre of subterranean activity, the older half of Carboniferous time witnessed an abundant and variable display of volcanic phenomena.

From the very beginning of the Carboniferous period to the epoch when the Coal Measures began to be accumulated, the southern half of Scotland continued to be a theatre of active vulcanism. The vents shifted their positions there in the course of that prolonged interval of geological time and gradually grew less energetic, but there does not appear to have been any protracted section of the interval when the subterranean activity became entirely quiescent. It is not, however, in Southern Scotland only that the records of Carboniferous volcanic action are preserved, though they are there most complete. Traces of other vents of eruption during the early half of the Carboniferous period have been found in the Isle of Man, in Derbyshire, in Devonshire, and in the South-west of Ireland. To some of these districts further reference will be made in the sequel.

The geologist who traces from older to younger formations the progress of some persistent operation of nature observes the evidence gradually to increase in amount and clearness as it is furnished by successively later parts of the record. He finds that the older rocks have generally been so dislocated and folded, and are often so widely covered by younger formations, that the evidence which they no doubt actually contain may be difficult to decipher or may be altogether concealed from view. In following, for instance, the progress of volcanic action, as he passes from the older to the younger Palæozoic chronicles, he is impressed by the striking contrast between the fulness and legibility of the Carboniferous records and the comparative meagreness and obscurity of those of the earlier periods. The Carboniferous rocks have undergone far less disturbance than the Silurian and Cambrian formations; while over wide tracts, where their volcanic chapters are fullest and most interesting, they form the rocks at the surface, and can thus be subjected to the closest scrutiny. Hence the remains of the later volcanic phenomena of the Palæozoic periods present a curiously modern aspect when contrasted with the fragmentary and antique look of those of older date.

Two great phases or types of volcanic action in Carboniferous time may be clearly distinguished:—1st. Plateaux, where the volcanic materials were discharged so copiously that they now form broad tablelands or ranges of hills, sometimes many hundreds of square miles in extent; 2nd. Puys, where the ejections were often confined to the discharge of a small amount of fragmentary materials from a single independent vent, and where, when lavas and more copious showers of ash were thrown out, they generally covered only a small area round the volcano which discharged them. I shall trace the distribution and characters of each of these types.

(A) The Plateaux.

Under this term I group all the more copious eruptions during the Carboniferous period, when the fragmentary materials generally formed but a small part of the discharges, but when the lavas were poured out over so wide an area as to form lava-fields sometimes more than 2000 square miles in area, and so persistently as to build up a pile of volcanic material sometimes upwards of 1500 feet in thickness. This phase of volcanic action was especially characteristic of the earlier part of the Carboniferous period across the South of Scotland, but does not appear elsewhere in the same system in

Britain. On the whole, it preceded the type of the Puys, although in the centre of the Midland Valley of Scotland the two types appear to have overlapped or to have been for a short interval contemporaneous. The eruptions of the Plateaux extended from the close of the Old Red Sandstone period through that section of Carboniferous time which was marked by the deposition of the Calciferous Sandstones,[1] but entirely ceased before the accumulation of the Main or Hurlet Limestone, which forms the base of the 'Carboniferous Limestone Series' of Scotland. But the limits of their duration were not everywhere the same. Thus they seem to have begun and to have ceased rather earlier in the eastern part of the region. There their lavas lie directly upon the Upper Old Red Sandstone containing scales of *Bothriolepis* and other characteristic fishes, and are covered by the Cement-stone Group of the Calciferous Sandstones. In the west, on the other hand, a considerable thickness of Carboniferous strata underlies the volcanic sheets, which thence extend upwards to the base of the Main (Hurlet) Limestone. On the other hand, the type of the Puys, although it appeared in Fife and Midlothian during the time of the Calciferous Sandstones, attained its chief development during that of the Carboniferous Limestone, and did not finally die out until the beginning of the deposition of the Coal Measures.

I. Distribution.—The geographical positions of the Plateaux are easily described, for notwithstanding the effects of many powerful faults and extensive denudation, the general position of these tracts and their independence of each other can still be traced. They are entirely confined, as I have said, to the southern half of Scotland. In noting their situations we are again brought face to face with the remarkable fact, so strikingly manifested in the geological history of Britain, that volcanic action has been apt to recur again and again in or near to the same areas. The Carboniferous volcanic plateaux were poured out from vents, some of which not impossibly rose among those of the Lower Old Red Sandstone.

[1] For the sake of clearness I use here the subdivisions of the Carboniferous system which are characteristic in Scotland. The Calciferous Sandstones are the stratigraphical equivalents of the lower portion of the Carboniferous Limestone and Limestone Shale of England. They consist of two groups:—the lower (Red Sandstone Group), formed mainly of red sandstones; the upper (Cement-stone Group), made up of white and grey sandstones, black, blue, or green shales, bands of cement-stone, ironstone, limestone, and sometimes oil-shales and thin coals.

Another fact, to which also I have already alluded as partially recognizable in the records of Old Red Sandstone vulcanism, now becomes increasingly evident—the tendency of volcanic vents to be opened along lines of valley rather than over tracts of hill. The vents that supplied the materials of the largest of the Carboniferous volcanic plateaux broke forth along the broad Midland Valley of Scotland, between the ridge of the Highlands on the north and that of the Southern Uplands on the south. Others appeared on the southern side of these uplands, in the hollow bounded to the south-west by the hills of the Lake District. It is not a question of the rise of volcanic vents merely along lines of fault, but on broad tracts of low ground rather than on the surrounding or neighbouring heights. It can easily be shown that this distribution is not the result of better preservation in the valleys and greater denudation from the higher grounds, but that it points to the influence of marked topographical features upon the original position of volcanic vents. The following summary of the position and extent of the Plateaux will afford some idea of their general characters :—

(1) The chief plateau rises into one of the most conspicuous features in the scenery of Central Scotland. Beginning at Stirling, it forms the marked table-land of the Fintry, Kilsyth, and Campsie Hills, stretching westwards to the Clyde near Dumbarton, whence, sweeping southwards beyond that river into the hilly moorlands which range from Greenock to Ardrossan, it spreads eastwards along the high watershed between Renfrewshire, Ayrshire, and Lanarkshire to Galston and Strathavon. But it is not confined to the mainland, for its prolongation can be traced by the islands of Cumbrae to the southern end of Bute, and thence by the south of Arran to Campbeltown in Cantire. Its visible remnants thus extend for more than 100 miles from north-east to south-west, with a width of some 35 miles in the broadest part. We shall probably not exaggerate if we estimate the original extent of this great volcanic area as not less than between 2000 and 3000 square miles. It is in this tract that the phenomena of the Plateaux are most admirably displayed. Ranges of lofty escarpments reveal the succession of the several eruptions, and the lower ground in front of these escarpments presents to us, as the result of stupendous denudation, many of the vents from which the materials of the plateau were ejected, while in the western portion of the area admirable coast-sections lay bare to view the minutest details of structure.

(2) Some fifty miles to the east of this main volcanic district, and entirely independent of it, lies the plateau of the Garlton Hills in East Lothian, which, as its limits towards the east and north have been reduced by denudation, and towards the west are hidden under the Carboniferous Limestone series of Haddington, covers now an area of not more than about sixty square miles. That the eruptions from this area did not extend far to the west or north is shown by the absence of all trace of them among the Lower Carboniferous rocks of Midlothian and Fife. Small though the plateau is, it possesses much interest from the remarkable variety of petrographical character in its lavas, from the size and composition of its necks, and from the picturesque coast-line where its details have been admirably dissected by the waves. In many respects it stands by itself as an exception to the general type of the other plateaux.

(3) South-westwards from Edinburgh, on the stratigraphical horizon of the volcanic plateaux, a band of lavas and tuffs, which can be followed into Lanarkshire, but is not continuously visible, possibly indicates the outcrop of the mere edge of a distinct but buried plateau, the main part of which may lie under the Carboniferous rocks that stretch away towards the west.

(4) Another and entirely disconnected plateau occurs in the broad plain or Merse of Berwickshire. The northern limit of its volcanic tuff may be found in the River Whiteadder above Duns, whence the erupted materials rapidly widen and thicken towards the south-west by Stitchell and Kelso until they die out against the flanks of the Cheviot Hills. The eastern extension of this volcanic area is lost beneath the Cement-stone group which covers the broad Merse down to the sea. Its western boundary must once have reached far beyond its present limits, for the low Silurian country in that direction is dotted over with scattered vents to a distance of several miles from the bedded lavas. This extensive denudation has thus cleared away the erupted materials and exposed the volcanic pipes over many square miles of country.

(5) The last plateau, which I may call that of the Solway basin, though its present visible eastern limits approach those reached by the lavas from the Berwickshire area, was quite distinct, and had its chief vents at some distance towards the south-west. On the north-western flanks of the Cheviot Hills the Upper Old Red Sandstone is overlain by the lowest Carboniferous strata without the intercalation of any volcanic zone, so that there must have

been some intermediate ground that escaped being flooded with lava from the vents of the Merse, on the one hand, and of the Solway on the other. The Solway lavas form a much thinner group than those of any of the other plateaux. From the wild moorland between the sources of the Liddell and the Rule Water, they run in a narrow and much-faulted band south-westward across Eskdale and the foot of Annandale, and are traceable in occasional patches on the farther side of the Nith along the southern flanks of Criffel, even as far as Torrorie on the coast of Kirkcudbright—a total distance of about 45 miles. It is probable that this long outcrop presents merely the northern edge of a volcanic platform which is mainly buried under the Carboniferous rocks of the Solway basin. Yet it exhibits all the chief characters of the other plateaux, and even occasionally rivals them in the dignity of the escarpments which mark its progress through the lonely uplands between the head of Liddesdale and the Ewes Water. Together also with the Merse plateau it illustrates in a striking manner the distribution of the volcanic eruptions along the valleys and low plains. The vents from which the lavas and tuffs proceeded are chiefly to be found on the lower grounds, though these bedded volcanic rocks rise to a height of 1712 feet (the Pikes) to the west of the Cheviot Hills. Between the Silurian uplands of Selkirkshire and Berwickshire on the north and the ridge of the Cheviot Hills on the south, the broad plain was dotted with volcanic vents and flooded with lava, while to the south-west the corresponding hollow between the uplands of Dumfries and Galloway, on the one side, and those of Cumberland on the other, was similarly overspread. The significance of these facts will be more apparent when the grouping of the vents has been described. We shall then also be better able to realize the validity of the inference that the present plateaux are mere fragments of what they originally were, wide areas having been removed from the one side of them by denudation, and having been concealed on the other under later portions of the Carboniferous system.

II. Petrography.—The volcanic materials characteristic of the plateau-type of eruptions consist mainly of lavas in successive sheets, but include also various tuffs in frequent thin courses and less commonly in thick local accumulations. The lavas are chiefly porphyrites, but these vary a good deal in the relative proportions of silica. Some of them become markedly basic and pass into dolerites and olivine-basalts. With these rocks are occasionally associated 'ultra-basic' varieties where the felspar almost disappears, and the material consists mainly of ferro-magnesian minerals. The more basic rocks are generally found towards the base of the volcanic series, where they appear as the oldest flows. On the other hand, in the Garlton Hills lavas of a much more acid nature are met with—true sanidine-trachytes, which overlie the porphyrites and basalts of the earlier eruptions. No adequate investigation has yet been made of the chemical and microscopic characters of these various rocks, regarded as a great volcanic group belonging to a definite geological age, though many of the individual rocks and the petrography of different districts have been more or less fully described. I cannot here enter into much detail on the subject, but must content myself with such a summary as will convey some idea of the general composition and structure of this very interesting group of rocks.

(a) *Augite-olivine Rocks (Picrites and Limburgites).*—At the base of the Plateaux there are found here and there sheets of 'ultra-basic' material, some of which appear to be bedded with the other rocks and to have flowed out as surface-lavas, though it may be impossible to prove that they are not sills. Thus on the south side of the Garlton Hills, at Whitelaw Hill, a dark heavy rock is found to contain hardly any felspar, but to be made up mainly of olivine and augite.

(b) *Basalts.*—Among the sheets of the Plateaux, but especially in the lower parts of the series, other basic lavas take, in some of the districts, a conspicuous place. They are dark, often black, usually more or less porphyritic, with large felspars, frequently also large crystals of augite or olivine, and may be described as porphyritic olivine-basalts, or more rarely olivine-free basalts or dolerites. But they differ greatly in structure from the Tertiary basalts of the Inner Hebrides and Antrim, for they rarely present any trace of the ophitic structure so characteristic of the latter. Their groundmass consists of short laths or microlites of felspar (probably labradorite) and granules or small crystals of augite and magnetite, with sometimes a little fibrous brown mica. The large porphyritic felspars are striped (probably labradorite), the augites are frequently chloritized, and the olivines are generally more or less serpentinized. But in some cases all these minerals are as fresh as in a recent basalt.

Examples of these rocks may be seen among the lowest lavas of most of the Plateaux, but they are especially abundant and remarkable in the Campbeltown plateau of Argyllshire, where they have recently been mapped for the Geological Survey by Mr. R. G. Symes, and in that of the south end of Bute, where, together with an interesting series of dykes and sills, they have been surveyed by Mr. W. Gunn. But even where, as in the Garlton Hills, the lavas are for the most part somewhat acid in composition, those first poured out, which form the lowest band, include some typical olivine-basalts.

The following analysis shows the composition of a specimen from the Garlton Hills :—

Analysis of Olivine-basalt from the Garlton Hills.
By Mr. J. S. Grant Wilson.

	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	K_2O.	Na_2O.	H_2O.	Total.
Kippie Law, Spec. grav. 2·8	46·01	19·19	5·91	6·75	0·19	8·68	6·81	1·20	3·27	3·07	101·08

(c) *Porphyrites* (*Andesites*).—These are the most abundant lavas of the Plateaux. They occur in every district, and usually form the main constituents of the pile of volcanic material. They vary in colour from a pale pinkish grey, through many shades of red, purple, brown, and yellow, to sometimes a dark green or nearly black rock. Their texture ranges from almost semi-vitreous through different degrees of compactness to open cellular slaggy masses. Generally through their base porphyritic felspars are abundantly disseminated, sometimes in large, flat, tabular forms like those of the Lower Old Red Sandstone already referred to. The amygdaloidal kernels consist of calcite, zeolites, chalcedony, or quartz. It is from the amygdaloids on either side of the Clyde that the fine examples of zeolites have been chiefly obtained for which the South of Scotland has long been famed.

Under the microscope these rocks present the usual fine aggregate of felspar microlites, with granules or crystals of magnetite and sometimes pyroxene. The porphyritic felspars, often so large and well defined, generally contain inclusions of the groundmass. Occasionally some of the large porphyritic constituents are augite, or pseudomorphs after that mineral. The alteration of the rocks has oxidized some of the iron ore and given rise to the prevalent purplish and reddish tints.

(d) *Trachytes.*—Some of the most remarkable lavas to be found in any of the Plateaux are those which constitute a large part of the Garlton Hills. They overlie the lower porphyrite and basalt platform which surrounds them as a narrow belt, while they occupy the central and much the largest part of the area. They have been included among the porphyrites, but are pale rocks, generally with a yellowish crust, presenting when quite fresh a grey, compact, felsitic base with large porphyritic crystals of felspar.

A number of specimens selected by me as illustrative of the different varieties were analysed by Dr. E. Frankland and Mr. Grant Wilson, and their results are stated in the subjoined table. The specific gravity of the rocks is about 2·6.

Analysis of Bedded Trachytes from the Garlton Hills.[1]

<table>
<tr><th></th><th>SiO_2.</th><th>Al_2O_3.</th><th>Fe_2O_3.</th><th>FeO.</th><th>MnO.</th><th>CaO.</th><th>MgO.</th><th>K_2O.</th><th>Na_2O.</th><th>H_2O.</th><th>Total.</th></tr>
<tr><td>Pepper Craig ...</td><td>62·61</td><td>18·17</td><td>0·32</td><td>4·25</td><td>0·205</td><td>2·58</td><td>0·74</td><td>4·02</td><td>6·49</td><td>0·801</td><td>100·186</td></tr>
<tr><td>Kae Heughs ...</td><td>61·35</td><td>16·88</td><td>0·41</td><td>5·01</td><td>0·26</td><td>2·39</td><td>0·44</td><td>6·12</td><td>5·26</td><td>1·70</td><td>99·82</td></tr>
<tr><td>Phantassie ......</td><td>62·66</td><td>13·37</td><td colspan="2">7·88</td><td>0·98</td><td>2·11</td><td>0·85</td><td colspan="2">11·12</td><td>Loss. 1·66</td><td>100·63</td></tr>
<tr><td>Bangley ....</td><td>59·85</td><td>25·41</td><td colspan="3">7·25</td><td>3·46</td><td>0·45</td><td>1·43</td><td>2·24</td><td>...</td><td>100·09</td></tr>
<tr><td>Hopetoun Mon^mt.</td><td>61·84</td><td>20·72</td><td colspan="3">8·95</td><td>2·15</td><td>0·32</td><td colspan="2">6·47</td><td>...</td><td>100·45</td></tr>
</table>

The microscopic characters of these rocks have not yet been worked out, but I have asked Dr. Hatch to undertake the task, and we may expect soon to have a full description of them from him. His preliminary examination shows them to be well-marked and wonderfully fresh sanidine-trachytes, containing large crystals of perfectly unaltered sanidine, sometimes also oligoclase. In some of the sheets small but well-formed crystals of yellowish-green augite, in addition to the porphyritic felspars, are imbedded in a fine groundmass composed chiefly of microlites of sanidine, but with granules of augite and magnetite plentifully interspersed, and occasionally prisms of apatite. In others there is little or no ferro-magnesian constituent. Other trachytes rather less basic than the augite-bearing varieties here referred to, but resembling the second group, occur as bosses in the Garlton Hills district, and are referred to in the following section (*e*).

[1] The first two analyses are by Mr. Wilson, the last three by Dr. Frankland.

(e) *Rocks of the Necks.*—In many of the necks connected with the Plateaux other types of massive rock are to be found. Among these, perhaps the most frequent are felsites, yellow, grey, and pink in colour, exceedingly compact, sparingly porphyritic, and showing small blebs or large porphyritic, more or less rounded, crystals of quartz. Acid rocks of this character also appear as sills and dykes. Other varieties that occur in similar positions are more basic in composition, including dark, coarse, granular diabases. In the Jedburgh district the most frequent rocks are beautiful varieties of olivine-basalt, which form most of the prominent hills of the neighbourhood. Not a few of these masses occur as necks, sometimes with agglomerates.

In the Garlton Hills district some of the necks present another petrographical type which directly connects them with the remarkable lavas of the higher part of that plateau. Thus the rock of Traprain Law is of a trachytic character, and in the opinion of Dr. Hatch proves to be really a phonolite. He is now engaged in its investigation. In its general platy structure and sonorous ring under the hammer it reminds one of some true phonolites. The neck of North Berwick Law the same observer finds to be also a trachyte, showing a plexus of lath-shaped sanidines that diminish in size to minute microlites, but with no porphyritic or ferro-magnesian constituent. The Bass Rock, though its geological relations are concealed by the sea, is in all probability another neck of this district. It proves to be likewise a mass of trachyte composed almost entirely of lath-shaped crystals of sanidine with no ferro-magnesian constituent, but a good deal of iron ore. It shows none of the large porphyritic felspars so characteristic of the Garlton Hills lavas, but it closely resembles some of those rocks, particularly the lavas of Score Hill, Pencraig, Lock Pit Hill, and Craigie Hill. The occurrence of trachytic rocks in the bosses around the Garlton Hills marks them off from the usual diabases and basalts of the basin of the Firth of Forth, and directly connects them with the trachyte-lavas of the district, while the presence of phonolite among them is of special interest.

The rock of Traprain Law was analysed for me in Dr. Frankland's laboratory, with the results given in the table on the following page. This analysis shows a close agreement with the composition of the Bangley rock as stated in the previous table. Unfortunately the alkalies were not separately determined.

Analysis of the Rock of Traprain Law.

SiO_2.	Al_2O_3.	Fe_2O_3, FeO, MnO.	CaO.	MgO.	K_2O, Na_2O.	Total.
56·36	25·00	10·62	3·83	1·35	4·01	101·17

(f) *Tuffs.*—The fragmentary ejections of the Plateaux vary in texture from the finest-grained tuffs to coarse agglomerates.[1] As they have been derived from the explosions of porphyrite-lavas, they consist mainly of porphyrite débris. They are often deep red in colour, as for example those of Dunbar, but are most frequently greenish. They have a granular texture, due to the small lapilli of various porphyrites embedded in a fine dust of the same material. Grains of quartz may frequently be detected even in the finer tuffs. Some of these may have been ejected from the volcanic vents or may have been grains of sand in the ordinary sediment of the sea-bottom. Both at the base and at the top of the plateau-series, the tuffs are interstratified with and blend into sandstones and shales, so that specimens may be collected showing a gradual passage from volcanic into non-volcanic detritus. In many of the tuffs of the necks fragments of sandstone and other stratified rocks occur, representing the strata through which the vents were drilled. In the tuffs of the Eaglesham district pieces of grey and pink granite have been met with which, if they are portions of an old granite mass below, must have come from a great depth.[2] In the coarser tuffs and agglomerates a larger variety of lava-form rocks is to be found than can be seen among the bedded lavas of the Plateaux. They include felsites and quartz-porphyries, and more rarely basic lavas (diabases, &c.).

III. Geological Structure.—The structure of the various plateaux presents a general similarity, with many local variations. Each plateau is built up entirely or almost entirely of sheets of volcanic material, the intercalations of ordinary sedimentary layers being few and unimportant and usually occurring either towards the base or the top of the volcanic series. The vents of eruption are in some instances still to be recognized on the plateaux themselves. More usually they occur on the lower ground flanking the volcanic escarpments, where they have been laid bare by denudation.

[1] For accounts of these rocks, see Explanation of Sheet 33, Geol. Surv. Scotland, p. 32; Sheet 22, pp. 11–14; Sheet 31, pp. 14–17.

[2] Explanation of Sheet 22, Geol. Surv. Scotland, p. 12.

Dykes are associated with many of the vents, while the sills which may mark the latest manifestations of volcanic energy, though not developed on so large a scale as among the Cambrian and Silurian volcanoes, can nevertheless be distinctly recognized.

1. *Bedded Lavas and Tuffs.*—The successive sheets of lava in a plateau usually form thin and widespread beds which are only occasionally separated by intercalations of tuff or of red marl. They are generally marked off from each other by the slaggy upper and under portions of the successive flows, and this structure gives a marked bedded aspect to the escarpments, as in the Campsie and Largs Hills, or still more conspicuously in Little Cumbrae and the southern end of Bute. Considerable diversity of structure may be noticed among these sheets. Some present a compact jointed centre passing up and down into the slaggy material just referred to; others have assumed a vesicular character throughout, and now appear as marked amygdaloids.

In each plateau the lavas may be observed to increase in total thickness in certain directions. Thus in the great tableland above Largs they attain a depth of more than 1500 feet, rapidly thinning away towards the south. In the Campsie Fells they are thickest towards the west. In the Solway plateau they attain a maximum development about Birrenswark, whence they diminish in bulk towards the north-east and south-west. In some cases, within or close to the area of greatest thickness the chief visible vents of discharge are to be found.

The remarkable trachyte-lavas of the Garlton plateau constitute a group by themselves, and display some marked differences in their mode of occurrence from the more prevalent type of lavas. They fail to show that terrace arrangement in successive, approximately parallel sheets which, though not always exhibited by the porphyrites, is eminently characteristic of them. Yet from some points of view, particularly from the westward, a succession of steep escarpments and longer dip-slopes can here and there be detected among the Garlton Hills, while there can be no doubt that the trachytes lie as a great cake above a lower platform of more basic lavas.

The volcanic history of this area, which is remarkably clear, differs sufficiently from that of the other Plateaux to deserve separate mention. At first, about the close of the deposition of the red sandstone group of the Calciferous Sandstones, from a number of vents a large discharge of ashes and blocks of rock took place. These fragmentary materials, mingled here and there with the ordinary sediment of the sea-floor, spread out over a considerable area, for they extend from Dunbar to beyond North Berwick—a distance of some twelve miles. They now form the picturesque cliffs at these two towns, where the composition and arrangement of the volcanic tuffs are so admirably exhibited. Next in order came the outflow of basic lavas (olivine-basalts with probably picrites) and porphyrites (andesites), which form a thin but continuous sheet all over the area of the plateau. Lastly rose the successive flows of trachyte, less regularly bedded than the more basic rocks, and apt to assume lumpy irregular forms on the surface. During the period of the emission of these rocks there seem to have been occasional outflows of andesite. Three of the chief vents are recognizable in the picturesque trachytic cones or domes of Traprain Law, North Berwick Law, and the Bass Rock. The latest eruptions had ceased and the cones and lava-sheets had probably been buried under sediment before the commencement of the deposition of the thick Main (or Hurlet) Limestone of the Carboniferous Limestone series which lies immediately to the west of the plateau.[1]

Although the tuffs form on the whole a comparatively unimportant part of the constituents of the Plateaux, they attain in a few localities an exceptionally great development, and even where they occur only as thin partings between the successive lava-flows they are always interesting memorials of the volcanic activity of a district. In many portions of the plateaux the lowest members of the volcanic series are tuffs and agglomerates, showing that the eruptions generally began with the discharge of fragmentary materials. Thus the great lava-escarpment of the Kilpatrick Hills rests on a continuous band of tuff which is thickest towards the west, near the group of vents above Dumbarton, while it thins away eastward and disappears in Strathblane. At the west end of the Campsie Fells the porphyrites form the base of the volcanic series. But perhaps the most remarkable group of basal tuffs is that which underlies the lavas of the Garlton plateau to which reference has just been made.

Extensive accumulations of tuff form in one or two localities a large proportion of the thickness of the whole volcanic series of a plateau. Thus in the north-eastern part of Ayrshire, between Eaglesham and the valley of the Irvine, the lavas die out for a space

[1] This important stratum, which can be recognized all over the lowlands of Central Scotland, serves as a good base for the Scottish Carboniferous Limestone series. In the plateau-districts it lies immediately, or nearly so, above the volcanic rocks.

and give place to tuffs. During the discharge of the fragmentary materials over that ground no lava seems to have flowed out for a long period. Ordinary sediment, however, mingled with the volcanic detritus, and there were even pauses in the eruptions when layers of ironstone were deposited, together with thin impure limestone that enclosed shells of *Productus giganteus*.[1]

Where the highest members of the volcanic series can be seen passing conformably under the overlying Carboniferous strata they are generally found to be mainly composed of fine tuffs, showing that the last feeble efforts of the plateau-volcanoes consisted in the discharge of showers of ashes. These materials became mingled with a gradually increasing proportion of ordinary mechanical sediment which finally overspread and buried the volcanic tracts of ground, as these slowly sank in the general subsidence of the region. There is thus an insensible passage from the volcanic detritus into the fossiliferous shales and limestones which are succeeded by the Main or Hurlet Limestone. Examples of this gradation may be seen in many natural sections along the flanks of the Ayrshire plateau from above Kilbirnie to Strathavon.

It is still possible to fix in some quarters the limits beyond which neither the lavas nor the tuffs extended, and thus partially to map out the original areas of the Plateaux. We can see, for example, that in certain directions the Carboniferous formations can be followed continuously downward below the Main Limestone without the intervention of any volcanic material, or with only a slight intermixture of fine volcanic lapilli, such as might have been carried by a strong wind from some neighbouring active vents. By this kind of evidence and by the proved thinning-out of the materials of the plateau we can demonstrate that in the north of Ayrshire the southern limits of the great volcanic bank did not pass beyond a line drawn from near Ardrossan to Galston. We can show, too, that the lavas of the Campsie Fells ended off about a mile beyond Stirling before they reached the line of the Ochil heights, and that the *coulées* which flowed from the Solway vents did not quite join with those from the Berwickshire volcanoes.

Moreover, evidence enough remains to enable us to form a tolerably clear conception of the original average slopes of the surface of some of the plateaux. Thus in the great escarpment above Largs and the high ground eastward to Kilbirnie the volcanic series must

[1] Explanation of Sheet 22, Geol. Surv. Scotland, p. 12.

be at least 1500 feet thick, from where it rests upon the Lower Calciferous Sandstones on the west to where it passes under the Main Limestone on the east. This thick mass of lavas and tuffs thins away southwards and probably disappears a short distance south from Ardrossan in a space of about ten miles. The original southward slope of the plateau would thus appear to have been about 1 in 35. Again, the northward slope of the same plateau may be estimated from observations in the Campsie Fells. Above Kilsyth the total depth of the volcanic sheets is about 1000 feet, while to the westward it is still thicker. From the top of the Meikle Bin (1870 feet) above Kilsyth north-eastwards to Causewayhead, where the whole volcanic series has died out, is a distance of twelve miles, so that the slope of the surface of erupted materials on this side was about 1 in 63.

Judging from the sections exposed along the faces of the escarpments, we may infer that the volcanic sheets had a tolerably uniform surface which sloped gently away from the chief vents, but with local inequalities according to the irregularities of the lava-streams that were heaped up round the vents and flowed outward in different directions and to various distances from them. At the beginning, these flat volcanic domes were certainly submarine. While they were being formed continuous subsidence appears to have been in progress. But the great thickness of the volcanic accumulations and the rarity of any ordinary sedimentary strata among them make it not improbable that at least their higher parts rose above the water.

2. *Vents.*—We have now to consider the character and distribution of the vents from which this large amount of volcanic material was discharged. The position of these vents is recognized in the necks so abundantly scattered over the different districts. The great majority of the necks consist of coarse agglomerate. Some are formed of a massive rock, generally acid, but sometimes more basic in composition, while others include both agglomerates and lava-form material in different proportions.

The distribution of the necks can best be understood from the maps of the Geological Survey, where they have been carefully indicated. As might have been expected, they are not found outside the original limits within which it can be shown that the lavas and tuffs were erupted. They occur most abundantly and attain their largest size in and around the districts where the Plateaux are most extensively developed. No doubt a large number of them are concealed under these plateaux. A few appear at the surface among the lavas and tuffs, but by far the largest number now visible have been revealed by denudation, the escarpments having been cut back so as to lay bare the underlying rocks through which the necks rise. Thus along the flanks of the great escarpment that extends from near Stirling by Fintry and Strathblane to Dumbarton somewhere about 50 vents may be counted in a distance of about 16 miles. Nowhere in Scotland do such necks form a more conspicuous feature in the scenery as well as the geology than they do between Fintry and Strathblane, where, standing out as bold isolated hills in front of the escarpments, their conical and rounded outlines present a striking contrast to the terraced escarpments behind them. Along the west front of the hills between Gourock and Ardrossan 17 agglomerate-vents occur in a distance of 16 miles. In Roxburghshire a group of large agglomerate-necks is dotted over the Silurian country around Melrose and Selkirk.[1]

From the evidence of these necks it is plain that the volcanic materials must in each case have been supplied, not from one great central orifice, but from abundant vents standing sometimes singly, with intervening spaces of several miles, often in groups of four or five within a single square mile. The size of the funnels, as measured by the diameter of the necks, varies from less than 100 feet to upwards of a mile.[2] In shape they are usually circular or elliptical, but examples occur where the material of the neck extends into an oblong mass a mile or more in length and not many yards in width. Occasionally it can be shown that such long narrow dyke-like masses of agglomerate have risen along lines of fault.[3] But in this and in other series of volcanic vents it is remarkable how seldom any relation can be traced between their sites and actually visible lines of dislocation.

[1] In this region and farther southward, besides the plateau-eruptions, a later group of puys is to be seen, and it is difficult to discriminate between the necks belonging to the two groups. Those which lie to the east are probably connected with the plateaux, those to the west with the puys. The latter are referred to on p. 135.

[2] In some instances of large irregularly-shaped masses of agglomerate and tuff we not improbably see the coalescence of successive vents nearly on the same site. A large tract of this kind on the high grounds of Renfrewshire, referred to on a later page, is probably an example.

[3] A good illustration of this structure has been mapped by Mr. B. N. Peach near Mosspaul at the head of Ewesdale, in a vent, or perhaps group of vents, which should probably be placed among those of the puys.

The agglomerates that fill up the vents vary greatly in the nature and relative proportions of their constituents. Usually the included blocks and lapilli are pieces of porphyrite, like the rocks of the Plateaux. But with these occur also fragments probably detached from the sides of the funnels through which the explosions took place, such as pieces of greywacke, sandstone, and shale. Considerable induration may be observed among these non-volcanic ingredients. In some cases, as in that of the occurrence of pieces of granite referred to on p. 114, it can be shown that the stones have been brought up from some considerable depth. In others it is easy to see that the blocks have slipped down from some higher group of strata now removed from the surrounding surface by denudation. Some striking illustrations of this feature will be cited from the necks in the south of Roxburghshire (p. 145).

When the vents have been filled by the uprise of some molten rock, it is generally, as we have seen, of a more acid character than the ordinary lavas of the Plateaux. Usually it consists of felsite, which is commonly of a dull yellow or grey tint, and often contains scattered blebs of quartz. Good examples of this ordinary material may be seen among the remarkable group of necks on either side of the valley north of the village of Strathblane and in those above Bowling. The great necks of the Garlton Hills—Traprain Law, North Berwick Law, and the Bass Rock—have already been alluded to as trachytic bosses obviously related to the trachytes of the adjacent plateau. Examples occur, however, where the funnels of eruption have been finally sealed up by the rise of much more basic material, and this has happened even in a district where most of the lava-form necks consist of felsite. Thus, in the Campsie Fells, several such bosses occur, of which the most conspicuous forms the hill of Dungoil (1396 feet). Farther west, among the Kilpatrick Hills, bosses of this kind are still more numerous. The felsitic knobs, bosses, dykes, and sills are particularly abundant along the escarpments and among the rocks underlying them all the way from Fintry to the Clyde. The group of necks near Ancrum and Jedburgh is mainly made up of olivine-basalts. This more basic composition of itself suggests that these bosses may be connected rather with the puy- than with the plateau-eruptions.

In not a few examples, the agglomerate of the vents is pierced by a plug or veins of lava-form material. Many illustrations of this composite structure may be observed along the west front of the great escarpments from Fintry to Ardrossan. In that region the intruded rock is generally a dull yellowish or grey felsite. Among the Roxburghshire vents, on the other hand, where the injected material is commonly olivine-basalt, it occasionally happens, as in Rubers Law, that the uprise of the lava has almost entirely cleared out or concealed the agglomerate, and in some of the bosses where no agglomerate is now to be seen the basalt may have taken its place.

The largest and most interesting vents, however, are those which occur within the limits of the Plateaux, where they are still surrounded with lavas and tuffs that probably came out of them. Of these by far the most extensive and remarkable lies among the high moorlands of Renfrewshire between Largs and Lochwinnoch, where the ground rises to more than 1700 feet above the sea. This area is unfortunately much obscured with drift and peat, so that the limits of its rocks cannot be so satisfactorily traced as might be desired. I think it probable that several successive vents have here been opened close to each other, but their erupted ashes probably cannot be distinguished. The tract measures about four miles in length by rather more than two in breadth. Over this space the rocks exposed at the surface are fine tuffs, breccias, and coarse agglomerates, largely made up of felsitic material and pierced by innumerable protrusions of various felsitic rocks in bosses and veins as well as also by dykes of a more basic kind, such as dolerites and andesites. Some of the tuffs present a curiously indurated condition ; and they are frequently much decayed at the surface.[1]

Another interesting vent lies in the heart of the Campsie Fells, where, instead of forming a prominence, it is marked by a great hollow measuring about a mile in length and half a mile in breadth. It is occupied mainly by a coarse tumultuous agglomerate, like that of other necks in the same district, but with a matrix rather more indurated, and assuming in certain parts a crystalline texture, so as to be at first sight hardly distinguishable from some of the surrounding porphyrites. Even in this altered condition, however, its included fragments may be recognized, particularly blocks of sandstone which have been hardened into quartzite. Numerous small veins of pink and yellow felsite traverse the agglomerate, and are found also cutting the bedded porphyrites that encircle it. The induration of the materials filling this vent

[1] This tract of ground was mapped for the Geological Survey by Mr. R. L. Jack, now in charge of the Geological Survey of Queensland. See Sheet 31, Geol. Surv. Scotland.

and that of Renfrewshire just referred to is such as might have been produced by the long-continued ascent of steam and heated vapours through fragmentary materials left in the funnel after the explosions had ceased.[1]

3. *Dykes and Sills.*—Dykes occur in considerable numbers around the vents, but are less noticeable in the heart of the plateaux at a distance from these vents. Thus they have been found abundantly traversing the red sandstones that underlie the volcanic series through which so many vents rise between Fintry, Strathblane, and Dumbarton, and between Gourock and Ardrossan. Some of the larger vents are traversed by a network of dykes and veins. The large vent above referred to among the Campsie Fells is a good example of this structure, and a still more remarkable illustration is furnished by the great Renfrewshire vent.[2]

The great majority of the dykes consist of felsite, resembling in lithological characters the material of the necks and doubtless connected with its uprise. There occur also dykes of andesite and dolerite. Some of these, especially those which run for many miles cutting every rock in the districts in which they occur and crossing large faults without deviation, are certainly long posterior to the Carboniferous period. Whether the small inconstant dykes of more basic composition found in the same districts with the felsites are to be looked upon as part of the volcanic phenomena of the Plateaux is a question to which at present no definite answer can be given. I shall have occasion to show that in the next volcanic period the lavas that flowed from the Puys were more basic than those of the Plateaux and that they are associated with more basic dykes and sills. In Roxburghshire, where it is so difficult to distinguish between the denuded vents of the two periods, the dark heavy olivine-basalts and dolerites of the bosses may, as I have already remarked, be connected rather with the later than with the earlier volcanic episode. And if that be their true age, the dykes of similar material may be connected with them.

The sills associated with the plateau-type of Carboniferous volcanic action form a less prominent feature than they do among the earlier Palæozoic formations or in the puy-type which succeeded them. They consist in general of short lenticular sheets of felsite like that of the necks and dykes in proximity to which they

[1] Explanation of Sheet 31, Geol. Surv. Scotland, p. 16.

[2] The group of veins shown in fig. 277 of my 'Text-book of Geology' occurs in this Renfrewshire vent.

commonly appear. The best area for the study of them is the ground which stretches out from the base of the great escarpments of the Campsie, Kilpatrick, and Ayrshire Hills. Among the agglomerate-vents and abundant dykes, intrusive sheets may likewise be observed, where the igneous material has been injected between the bedding-planes of the red sandstones. But these sheets are of comparatively trifling dimensions. Very few of them reach a mile in length, the great majority falling far short of that size. The general absence of sills of porphyrite and olivine-basalt, when we consider how thick a mass of these rocks has been poured out in the plateaux, is not a little remarkable. That the felsitic sills, as well as the dykes and bosses of the same material, are not of older date than the lavas of the Plateaux, is proved by the manner in which they pierce these lavas, especially towards the bottom of the series.

When the volcanic episode of the plateau-eruptions came to an end, such banks or cones as rose above the level of the shallow sea which then overspread Central Scotland were carried beneath the water by the continued subsidence of the region. The downward movement may possibly for a time have been accelerated, especially in some districts. Thus we find that from the Campsie Fells into Lanarkshire and Ayrshire the first traceable deposit which overlies the volcanic series is the Hurlet Limestone with its associated strata. This limestone, though usually not more than five or six feet thick, increases locally to a much greater thickness. At Petersfield, near Bathgate, for example, it is between 70 and 80 feet in depth, while at Beith, in North Ayrshire, it increases to 100 feet, which is the thickest mass of Carboniferous Limestone known to exist in Scotland. At both of these localities the limestone lies upon a series of volcanic rocks, and we may infer that perhaps the subsidence advanced there somewhat more rapidly or to a greater extent, so as to form hollows in which the limestone could gather to an abnormal depth. The water would appear to have become for a time tolerably free from mechanical sediment, for the limestone is extensively quarried all over the country for industrial purposes. It is a crinoidal rock, abounding in many species of corals, brachiopods, lamellibranchs, and gasteropods, with trilobites, cephalopods, and fishes.

A variable thickness of strata intervenes between the top of the volcanic series and the Main Limestone. Sometimes these deposits consist in large measure of a mixture of ordinary sandy and muddy material with the washed-down tuff of the cones, and probably with volcanic dust and lapilli thrown out by the latest eruptions. Thus along the flank of the hills from Barrhead to Strathavon yellow and green ashy sandstones, grits, and conglomerates are succeeded by ordinary sandstones, black shales, and ironstones, while here and there true volcanic tuff and conglomerate make their appearance.[1] Farther west, in the Kilbirnie district, the limestone lies directly on the tuffs that rest upon the porphyrites.

But perhaps the most striking contrast between adjacent localities in regard to the distance between the limestone and the top of the volcanic series is to be observed along the southern front of the Campsie Fells. In spite of the abundant faults which have there so broken up the regular sequence of the rocks, we can see that at Banton the limestone lies almost immediately on the tuffs. But a little to the westward, sandstones, conglomerates, shales, and thin limestones begin to intervene between them and swell out so rapidly that on Craigmaddie Muir and South Hill of Campsie, only some five miles off, they must form a total thickness of not less than from 600 to 800 feet of ordinary non-volcanic deposits, chiefly thick pebbly sandstones. Such local variations not improbably serve to indicate hollows on the flanks of the plateaux that were filled up with detritus before the depression and clearing of the water that led to the deposition of the Main Limestone.

I have already remarked that the eruptions of the plateau period lasted longer in the western than in the eastern parts of the region. In the Garlton district, where the peculiar viscous trachytic lavas probably gave rise to a more uneven surface or more prominent cones than was usual among the porphyrite plateaux, the eruptions ceased some time before the deposition of the Main Limestone. As the area sank, the successive zones of the Calciferous Sandstones crept over the flanks of the trachytes until at last they had completely buried these before the limestone spread over the area. In the Berwickshire and Solway districts this extinction of the plateau-vents appears to have taken place at a still earlier part of the Carboniferous period, for there the porphyrites, while they rest on the Upper Old Red Sandstone, are covered with at least the higher group of the Calciferous Sandstone. The equivalent of the Main Limestone of Central Scotland must lie many hundred feet above them.

The submergence of the plateaux, and their entombment under the thick Carboniferous Limestone series, did not mark the close of

[1] Explanation of Sheet 22, Geol. Surv. Scotland, p. 12.

volcanic activity in Central Scotland during Carboniferous time. The plateau-type of eruption ceased and was not repeated, but a new type arose, to which I would now call your attention.

(B) The Puys.

After the beginning of the Carboniferous Limestone period in the British area, when eruptions of the plateau-type had ceased, volcanic activity showed itself in a different guise both as regards the nature of its products and the manner and scale of their discharge. Instead of the widely extended lava-sheets and tuffs piled above each other to a thickness of many hundred feet and over areas of hundreds of square miles, we have now to study the records of a feebler phase of vulcanism, where scattered groups and rows of *Puys*, that is, of small volcanic cones, threw out in most instances merely tuffs and these often only in trifling quantity, though here and there their vents poured forth also lavas and gradually piled up more important volcanic ridges. The evidence for these less vigorous manifestations of volcanic activity is furnished (1) by layers of tuff and sheets of basalt intercalated among the strata that were being deposited at the time of the eruptions, (2) by necks of tuff, agglomerate, or different lava-form rocks that mark the positions of the orifices of discharge, and (3) by sills and dykes that indicate the subterranean efforts of the volcanoes. The comparatively small thickness of the accumulations usually formed by these vents, their extremely local character, the numerous distinct horizons on which they appear, and the intimate way in which they mingle and alternate with the ordinary Carboniferous strata are features which at once arrest the attention of the geologist, presenting, as they do, so striking a contrast to those of the Plateaux.

From the clear intercalation of these volcanic materials in successive platforms of the Carboniferous system, the limits of geological time within which they were erupted can be fixed with considerable precision. It may be said that, in a broad sense, they coincided with the deposition of the Carboniferous Limestone, and certainly it was during the time of that formation that the eruptions which produced them reached their greatest vigour and widest extent. Here and there, however, indications may be found that the phase of the Puys began during the time of the Calciferous Sandstones, and that it may perhaps have been contemporaneous with the later eruptions of the Plateaux. At Edinburgh, for example, the older lavas and tuffs of Arthur Seat, Calton Hill, and Craiglockhart

Hill overlie the red sandstone group and pass underneath the upper group of white sandstones and black shales—a platform whereon the plateau rocks should have occurred had they extended over that district. There appears indeed to be in this locality a commingling of the petrographical types both of the Plateaux and of the Puys, for both in Arthur Seat and Calton Hill the higher lavas are porphyrites not unlike some of those in the plateaux. Over the western part of Midlothian, the eastern portion of West Lothian, and the southern margin of Fife abundant traces occur of puy-eruptions during the deposition of the upper group of the Calciferous Sandstones. Elsewhere in Central Scotland there is no evidence of the vents having been opened until after the deposition of the Main Limestone. They remained active in West Lothian until near the close of the time represented by the Carboniferous Limestone; but in Ayrshire they continued in eruption until the beginning of the accumulation of the Coal Measures. These western examples of the puy-type are the latest known, as the eastern instances round Edinburgh are the earliest.

I. Distribution.—In tracing the geographical distribution of the puy-eruptions we are first impressed with the force of the evidence for their extremely local and restricted character. Thus in the area of the basin of the Firth of Forth traces of them are abundant to the west of the line of the Pentland Hills, while to the east of that line not a vestige can be detected, though the same series of stratigraphical horizons is well developed on both sides of the Lothian coal-field. Again, to the westward of this central district of puys, over the area of Stirlingshire, Lanarkshire, and Renfrewshire lying to the north of the great Ayrshire plateau, no record of puy-eruptions has been noticed. Immediately to the south of that plateau, however, these eruptions were numerous in the north of Ayrshire.

Another fact which at once attracts notice in Scotland is the way in which the puy-vents have generally avoided the areas of the plateaux, though they sometimes approach them closely. As a rule, it is possible to distinguish the tuffs and agglomerates which have filled up these vents from those which mark the sites of the eruptive orifices of the plateaux. There are, no doubt, some instances, as in Liddesdale, where puys have appeared on the sites of the older lavas, but these are exceptional collocations.[1] On the other hand,

[1] A means of definitely placing some of these vents in the series of puy-eruptions is stated farther on, at p. 145.

many examples may be found where puys have risen in the inter-space between the limits of the eruptions of two plateau-areas. Thus the tract between the Campsie plateau-eruptions on the west and those of the Garlton Hills on the east was dotted over with puys.

While the central valley of Scotland continued to be the chief theatre of volcanic activity during the later section of the Carboniferous period with which we are now dealing, scattered groups of puys appeared far beyond that region. Though the phase of energy now exhibited, if we judge of it from the amount of material discharged and the extent of the areas over which that material was distributed from any single centre, was of an increasingly feeble character, it manifested itself throughout a much more extensive region than that within which the plateau-eruptions had been confined. Passing beyond the broad plain of the middle of Scotland we find a chain of puys extending down Liddesdale on the southern flank of the Silurian uplands. Traces of a more distant group occur in the south of the Isle of Man.[1] As we follow the successive subdivisions of the Carboniferous system along the Pennine chain from the Border into the heart of England, though the natural sections are abundant, we meet with no trace of included volcanic rocks until we reach Derbyshire. The whole of that wide interval of 150 miles, so far as the present evidence goes, remained during Carboniferous time entirely free from any volcanic eruption. Over the sea-floor of the Carboniferous Limestone, in what is now the heart of England, vents were opened from which the sheets of 'toadstone' were ejected, which have so long been a familiar feature in English geology. Beyond this limited district the Carboniferous formations of the south-west of England remain, on the whole, devoid of contemporaneous volcanic intercalations. In the south-western counties traces of Carboniferous volcanic action have not yet been recognized except in Devonshire, where they were long ago noticed by Sir Henry de la Beche in the early days of the Geological Survey.[2] To the west of Dartmoor, Brent Tor and some of the surrounding igneous masses may mark the positions of eruptive vents during an early part of the Carboniferous period.[3]

[1] J. Horne, Trans. Geol. Soc. Edin. vol. ii. (1874) p. 332 *et seqq.*

[2] 'Report on the Geology of Cornwall, Devon, and West Somerset' (1839), p. 119 *et seq.*

[3] 'The Eruptive Rocks of Brent Tor' (Mem. Geol. Survey), by F. Rutley. 1878.

Far to the west, in the Golden Vale of Limerick, yet another group of puys may be found, which rose from the floor of the Carboniferous Limestone sea, and threw out showers of ashes and streams of lava. These, the most westerly remains of Carboniferous volcanoes within our borders, are the only examples which, so far as I know, occur in Ireland. Though the Carboniferous formations are so widely spread over the island, and exposed in so many natural and artificial sections, they have nowhere else yielded evidence of interstratified volcanic rocks.[1] The Limerick puys seem to have risen as a solitary group several hundred miles from their nearest contemporaries.

The total area within which the puy-eruptions of Carboniferous time took place was thus considerably less than that over which the volcanoes of the Lower Old Red Sandstone were distributed, yet its vents were scattered across the larger part of the site of the British Isles. From the vents of Fife to those of Limerick is a distance of above 300 miles; from the latter eastward to those of Devonshire is an interval of 250 miles; while the space between the Devonshire volcanoes and those of Fife is about 400 miles. In this triangular space volcanic action of the peculiar type we are now considering manifested itself at each of the apices, to a slight extent along the centre of the eastern side, but with much the greatest vigour throughout the northern part of the area.

II. Petrography.—We have now to consider the nature of the materials erupted by the volcanic activity of the Puys. As before, it may be convenient to take first the lavas poured out at the surface and the tuffs associated with them, next the products which now fill the orifices of discharge, and lastly the sills, dykes, and veins.

i. *Lavas ejected at the surface.*—The geologist who passes from the study of the Plateau lavas to those of the Puys at once remarks the prevalent more basic character of the latter. The great majority of them are basalts, generally olivine-bearing, and presenting a number of types. Such more acid rocks as porphyrites occur only rarely. If, however, we select specimens from different centres of eruption we may obtain a range of rock-species from 'ultra-basic' materials, such as picrites, to pale porphyrites.

1. The most basic rock among the bedded basalts is Picrite. Some of the basalts, indeed, approach this rock in poverty of felspar, but I know of only one locality where picrite occurs in such a

[1] The supposed Carboniferous volcanic rocks of Bearhaven on the coast of Cork are noticed on p. 147, *note*.

position that it may be, though doubtfully, included among the bedded basalts. This is the quarry near Blackburn, to the east of Bathgate, where I originally observed it.[1] The rock occurs there on the line of the basalt-flows from the Bathgate Hills, and I mapped it as one of them before the microscope revealed the remarkable composition of the mass. I am still inclined so to regard it, though I cannot prove that it may not be a sill.

The microscopic structure of this rock is now well known. As exposed in the quarry, an interesting difference is observable between the lower and upper parts of the sheet. The lower portion is a picrite with abundant serpentinized olivine, large crystals of augite, and a considerable amount of ores. The upper portion, on the other hand, has plagioclase as its most abundant definite mineral, with a minor quantity of minute prisms of augite and of iron ores, and scattered crystals of olivine. Here, within the compass of a few yards and in one continuous mass of rock, we have a transition from a variety of olivine-basalt into a picrite.

2. By far the largest number of the lava-beds of the puy-type are Basalts. They exhibit some variety of structure as seen in the field. Some are solid, compact, black rocks, not infrequently columnar and weathering into spheroidal exfoliating forms. Others are somewhat granular in texture, acquiring green and brown tints by weathering, not infrequently showing amygdaloidal kernels and even passing into well-marked amygdaloids. Many of them exhibit a slaggy structure at their upper and under surfaces.

These external differences are an index to corresponding variations in composition and microscopic structure. The rocks may be arranged in two groups, in one of which there is no olivine, while in the other that mineral is present. Dr. Hatch, in whose hands I placed a series of illustrative slides prepared from the rocks of the basin of the Firth of Forth, and who I hope will ere long be able to undertake an exhaustive study of the petrography of these rocks, informs me that he can recognize the following distinct types of structure and composition.

A. *Basalts with Olivine.*—(*a*) Containing large porphyritic olivines, usually more or less serpentinized, granular augite, scattered grains of magnetite, and only a small amount of felspar microlites, thus approaching picrite. Lavas of this character occur at the bottom of the volcanic series of the Bathgate Hills at Hillhouse

[1] Trans. Roy. Soc. Edin. vol. xxix. (1879) p. 506.

and at Kirkton West quarry. Others are found intercalated among the basalts of Burntisland and Kinghorn.

(*b*) Showing abundant rather small olivines, mostly altered into serpentine or calcite, and grains of augite, imbedded in a mesh of slender felspar-crystals, with microlitic augite and minute granules of magnetite. The rocks are often much calcified. This is the common type of the puy-lavas in Central Scotland. It is typically exhibited at Dalmeny and among the Bathgate Hills, Linlithgowshire, and it forms numerous beds in the fine volcanic group seen on the coast of Fife between Burntisland and Kirkcaldy.

(*c*) Holocrystalline olivine-dolerite, granular to subophitic in structure, with porphyritic olivines, and lath-shaped felspars partly penetrating the augite: Gallaston, N.W. of Kirkcaldy.

(*d*) A characteristic variety containing large porphyritic augites, olivines, and felspars in a partially glassy groundmass which shows felspar-laths, granular augite, and magnetite. The well-known rock of the Lion's Haunch, Arthur Seat, exhibits this structure, but it is probably later than any of the Carboniferous puys. The same structure, however, is found in the crag at the west end of Duddingstone Loch and in the lowest part of the volcanic group of Calton Hill.

(*e*) In this variety the porphyritic constituents are augite and olivine, but not felspar, and the base is partially glassy: Craiglockhart Hill, Edinburgh.

Additional types will no doubt be detected when the whole series of rocks is fully investigated.

B. *Basalts without Olivine.*—Examples of such rocks may be found associated with the more ordinary olivine-bearing varieties. They pass into dolerites. A gradation may also be observed into the olivine-basalts. Many years ago I traced this passage on the east side of Arthur Seat. The lower portion of the rock forming the Crow Hill ridges is an olivine-dolerite, but as we follow the mass eastward the olivine disappears and the rock exhibits under the microscope a mesh of striped felspars with granular and microlitic augite. We have here another example of the chemical and mineralogical contrasts which may arise within one mass of igneous material.

3. In a few districts the puys have emitted streams of Porphyrite. Rocks of this kind occur in the Limerick basin, having a silica-percentage of more than 60. On the Calton Hill, Edinburgh, and on Arthur Seat certain dull, often strongly porphyritic varieties

overlie the bedded basalts of the lower part of the volcanic group, but these are the only localities in Scotland, so far as I know, where such rocks are associated with the puy-type of vent.

ii. *Intrusive Sheets, Necks, and Dykes.*—As a rule, rocks which occur intrusively, especially where they form a considerable mass, have assumed a much more coarsely crystalline texture than those of similar chemical composition which have been poured out at the surface. But with this obvious distinction, the two groups have so much in common, that the geologist who passes from the study of the subterranean phenomena of the Plateaux to that of the corresponding phenomena of the Puys is at once impressed with the close relationship between the material which, in the case of the puys, has consolidated above ground, and that which has been injected below. There is no such contrast between them, for example, as that between the basic and intermediate lavas of the plateaux and the acid intrusions associated with them. The following chief types of rocks may be recognized among the intrusive masses of the puy-series.

(*a*) Olivine-Augite Rocks, *Picrite, &c.*—The now well-known example of picrite in Inchcolm, in the Firth of Forth, occurs as an intrusive sheet among the Lower Carboniferous Sandstones.[1]

Rocks approaching limburgite occur among the sills and bosses which pierce the Carboniferous Limestone series of Fife between Cowdenbeath and Inverkeithing. One of these is found at Pitandrew, near Fordel Castle. Dr. Hatch finds it to consist of "numerous porphyritic crystals of olivine with a few grains of augite and an occasional small lath-shaped crystal of felspar imbedded in a groundmass which is composed principally of idiomorphic augite microlites, small crystals of a brown mica, granules of magnetite and prisms of apatite. In addition, there is a considerable amount of interstitial matter, which is partly colourless glass, and partly shows a slight reaction between crossed nicols." Another example of the same type of rock occurs as a plug or boss in the tuff-vent of the Hill of Beath.

(*b*) Rocks of the character of Olivine-basalt and Olivine-dolerite play a leading part among the sills connected with the puy-eruptions. The presence or absence of olivine, however, appears to be a mere accident of cooling or otherwise, and hardly to deserve to be made the basis of a definite classification. I have shown that in the same mass of rock at Blackburn a gradation can be traced

[1] Trans. Roy. Soc. Edin. vol. xxix. (1879) p. 506. Teall, 'British Petrography,' p. 94.

from a rock largely composed of altered olivine into one consisting mainly of felspar with but little olivine. And even among the Carboniferous sills, Dr. Stecher has ascertained that the marginal portions which cooled first and rapidly, and may be taken, therefore, to indicate the mineral composition of the rock at the time of extrusion, are often rich in olivine, while that mineral may be hardly or not at all discernible in the main body of the rock.[1]

Some of the rocks of this group are holocrystalline, like the Corstorphine Hill sheet, but more frequently they show more or less of a devitrified groundmass. They exhibit the much more largely crystalline structure of intrusive sheets as compared with superficial lavas.

(*c*) In the field, Dolerite and Basalt without Olivine (Olivine-free Diabase) are not to be distinguished from the rocks just enumerated. They occur under precisely similar conditions, and show a corresponding range of variation from holocrystalline rocks to others with a marked proportion of devitrified groundmass. In the Ratho rock, as Mr. Teall has pointed out, micropegmatite plays the part of interstitial matter.[2] Other varieties have been discriminated by Dr. Hatch, having their mesh of lath-shaped felspar filled in with granular augite, magnetite and base, as in tholeiite. He further distinguishes another type presenting rather large lath-shaped felspars, here and there penetrating ophitic orthoclase, and with granular augite (Burntisland sills). In one type the ophitic structure is developed ; in another the coarse-grained dolerite shows large felspars in a base which was once glassy (Muckraw, Linlithgowshire). Many large sills of coarse dolerite exhibit a tendency towards an ophitic structure, the felspars penetrating the augite, but contain besides more or less quartz, sometimes also orthoclase, and even large patches of a glassy base (Bowden Hill and Queensferry, Linlithgowshire). As I pointed out many years ago, some of the sills in West Lothian contain bitumen and give off a bituminous odour when freshly broken. They have been injected into bituminous shales or coal-seams.[3]

(*d*) Porphyrite appears to be of as rare occurrence among the intrusive as among the interstratified parts of the puy-series. Some of the necks, and possibly sills, in the Limerick basin consist of it.

[1] Stecher, Tschermak's Mineralog. Mittheil. vol. ix. (1887) p. 193. Proc. Roy. Soc. Edin. vol. xv. (1888) p. 162.

[2] 'British Petrography,' p. 190.

[3] Geol. Survey Memoir on Geology of Edinburgh (Sheet 32, Scotland), p. 46.

(*e*) Acid rocks, such as Felsite and Quartz-porphyry, as I have already said, are extremely rare among the puy-eruptions. The only important examples known to me are those around the Limerick basin, where they rise apparently in old vents and form conspicuous rounded or conical hills. These rocks have recently been examined microscopically by Mr. W. W. Watts. One of the most interesting varieties, which occurs at the Standing Stone near Oola, was found by him to show quartz enclosing ophitically the felspars which, with well-terminated prisms, project into it. Farther west, near Knockaunavoher, a boss of quartz-porphyry occurs with conspicuous quartz.

iii. *Tuffs.*—The fragmental rocks connected with the puy-eruptions form a well-marked group, easily distinguishable, for the most part, from the tuffs of the Plateaux. They vary from exceedingly fine compacted dust or volcanic mud, through various stages of increasing coarseness of texture, to basalt-conglomerates and tumultuous agglomerates.

Of the finer kinds, the best example is furnished by a remarkable group of 'green and red marls' which lie above a seam of coal (Houston Coal) in the Calciferous Sandstones of West Lothian.[1] These strata, which differ much from any of the rocks with which they are associated, are exceedingly fine in grain, not well laminated like the shales, but breaking into irregular fragments under the influence of weathering. They look like indurated mud. Mr. H. M. Cadell, who has recently re-examined them in connexion with a revision of the Geological Survey Map (Sheet 32), has found that they pass into ordinary granular tuff. They appear to mark a phase in the volcanic history of the Lower Carboniferous rocks of the Firth of Forth, when exceedingly fine ash or perhaps even volcanic mud was erupted in considerable quantity. The 'marls' attain in some places a thickness of nearly 200 feet, and can be traced over most of the eastern part of Linlithgowshire. This volcanic platform, which has been followed in mining for oil-shale, is one of the most extensive among the puy-eruptions. The material probably came from one or more vents among the Bathgate Hills.

Palagonite-tuff occasionally occurs. It is met with in the Burntisland district,[2] and Mr. Watts has detected fragments of palagonite among the tuffs of the Limerick basin.

Basalt-tuff and basalt-conglomerate are the usual forms of frag-

[1] Memoir on Sheet 32, Geol. Surv. Scotland (1861), p. 42.

[2] Trans. Roy. Soc. Edin. vol. xxix. (1879) p. 515.

mentary material connected with the puys. They are usually dull green in colour and granular in texture, the lapilli consisting of various decayed basalts in a soft paste of the same materials. Many of the lapilli are highly vesicular—a kind of basic pumice. Among the bedded tuffs, stratification is generally well-marked by alternations of finer and coarser material. Occasional large blocks or bombs indicating some paroxysm of explosion may be observed even among the finer tuffs, shales, and other strata, which round the sides of these masses have had their layers bent down by the fall of heavy blocks.[1] Interstratifications of non-volcanic materials are of constant occurrence among the tuffs, which consequently pass both laterally and vertically into sandstone, shale, limestone, &c. Many of the bedded tuffs likewise contain fossils, such as crinoids, corals, brachiopods, fish-teeth, or macerated fragments of land-plants. Coal-seams also are occasionally interstratified among them.

The materials which fill the necks are generally much coarser than those that form intercalated beds. Huge blocks of basalt and large masses of sandstone, shale, limestone, ironstone, or other strata may be seen wrapped up in a matrix of coarse basalt-tuff. But many necks may be observed to consist of a tuff quite as fine as that of the beds. Such necks appear to mark the sites of tuff-cones where only fine ashes and lapilli were ejected, and where, after sometimes a brief and feeble period of activity, the orifice has become extinct.

III. Geological Structure.—The puy-type of volcanic hill differs widely in one respect from those which we have hitherto been considering. In the earlier epochs of vulcanism within the British area, it is the masses of material discharged from the vent rather than the vents themselves which arrest attention. Indeed, so copiously have these masses been erupted that the vents are often buried, or their positions have been rendered doubtful, by the uprise in and around them of sills and bosses of molten rock. But among the Carboniferous puys the vent is often the only record that remains of the volcanic activity. In some cases we know that it never ejected any igneous material to the surface. In others, though it may be filled with volcanic agglomerate or tuff, there is no record of any shower of such detritus having been discharged from it. In yet a third class of examples, we see that lava rose in the vent, but no evidence remains as to whether or not it ever flowed

[1] Geol. Mag. for July 1864, p. 22.

out above ground. Other cases occur where beds of lava or of tuff, or of both together, have been intercalated in a group of strata, but with no trace whatever of the vent from which they came. The most complete chronicle, preserving at once a record of the outflow of lava, of the showering forth of ashes and bombs, and of the necks that mark the vents of eruption, is only to be found in some of the districts.

I shall therefore, in this section of my Address, reverse the order of treatment I have hitherto followed, and treat first of the necks, then of the materials emitted from them, and lastly of the sills and dykes.

1. *Vents.*—A large number of vents rise through the Carboniferous rocks of Scotland. Some of these are not associated with any interbedded volcanic material, so that their geological age cannot be more precisely defined than that they must be later than the particular formations which they pierce. Some of them, as I shall endeavour to show, are in all probability Permian. But there are many which, from their position with reference to the nearest intercalated lavas and tuffs, are almost certainly to be regarded as of Carboniferous age. Those which are immediately surrounded by sheets of lava and tuff, similar in character to the materials in the vents themselves, are without hesitation connected with these sheets as marking the orifices of discharge.

The vents of the puys never attain the size often reached by those of the plateaux. Their smallest examples measure only a few yards in diameter, their largest do not much exceed half a mile.[1] They have seldom any apparent relation to faults. Probably the dis-

[1] The following measurements of necks in the great chain of them which runs in a north-east and south-west direction from Melrose across into Liddesdale are taken from the 6-inch field-maps of the Geological Survey, and were chiefly mapped by Mr. B. N. Peach. A few of those first enumerated probably belong to the plateau series, in which the necks are, on the average, larger than those of the puys. The great neck at Melrose measures 8800 by 4200 feet; Carewood Rig, on the borders of Roxburghshire and Dumfriesshire, 7000 × 2400; the largest of the chain of necks from Linhope to Skelfhill, 4500 × 500; Black Law, between Bedrule and Jedburgh, 3400 × 1600; Greatmoor, near Maiden Paps, Roxburghshire, 2600 × 2400; Tinnis, Liddesdale, 1500 × 1000; Rubers Law, 1500 × 1000; Minto Hill (north), 1500 × 1100; Minto Hill (south), 2300 × 1650. These are the largest necks of the region. The smallest mapped by Mr. Peach are the following:—Pike Law, Arkleton, Tarras Water, 500 × 500 feet; Harwood, Stonedge, 5 miles S.E. from Hawick, 500 × 300; Arkleton Burn, Dumfriesshire, 400 × 100; Roan Fell, Liddesdale, 300 × 200; Hartsgarth Burn, Liddesdale, 250 × 200; Dalbate Burn, 250 × 120.

locations of the Carboniferous system are on the whole later than the volcanic phenomena. It may sometimes be observed, however, that the vents are arranged in lines or in scattered groups. A remarkable instance of the linear distribution is furnished by the chain of necks which extends from the Vale of the Tweed at Melrose south-westwards across the watershed and down Liddesdale. I shall refer again more particularly to this district. As examples of the arrangement of vents in groups I may cite those of the west of Fife, of West Lothian, and of the north of Ayrshire.

A convenient classification of the vents may be made by dividing them into four groups according to the nature of the material that now fills them:—1st, necks of non-volcanic débris; 2nd, necks of tuff and agglomerate; 3rd, necks of similar materials, but with a central plug or branching veins of basalt; 4th, bosses of basalt or other lava.

(1) In a few instances the orifices of eruption have been filled up entirely with non-volcanic material. They have served as funnels for the discharge of explosive vapours only, without the expulsion of any solid volcanic materials. At least no trace of fragmentary lavas is met with in them, nor are any beds of tuff or lava intercalated among the surrounding strata. Some interesting examples of this kind were laid bare in the open ironstone-workings near Carluke, in Lanarkshire. They were circular in ground-plan, descended vertically into the strata, and were somewhat wider at the top of the quarry than at the bottom. They were filled with angular pieces of Carboniferous sandstone, shale, limestone, ironstone, and other rocks, these materials being rudely arranged with a dip towards the centre of the neck, where the blocks were largest in size. Though no fragments of the igneous rocks were observed among the débris, a few string-like veins of 'white trap,' or altered basalt, were seen to traverse the agglomerate here and there. The necks and the strata surrounding them were highly impregnated with pyrites and sulphate of lime.[1]

A vent of the same nature, but on a much larger scale, has been mapped by Mr. Peach in the west of Fife, near Grange, where it rises through the higher coal-bearing part of the Carboniferous Limestone series. It measures 1500 feet or more in diameter, and does not appear ever to have emitted any ashes or lava. Mr. Peach found it filled with non-volcanic sediment, arranged in layers dipping at high angles towards the middle of the vent, and among these

[1] Jas. Geikie, Mem. Geol. Surv. Scotland. Explanation of Sheet 23, p. 39.

layers he noticed a number of the common shells and crinoids of the Carboniferous Limestone sea. The formation of this neck took place after the deposition of the Index Limestone, which is pierced by it, and immediately to the west lies the Gair Limestone. It would thus appear that the eruption which produced this funnel gave forth only gaseous explosions, and took place on the sea-floor; further, that the low crater-walls were washed down to such an extent that the sea entered and carried some of its characteristic organisms into the lagoon within.[1]

(2) The majority of the rocks connected with the puys consist of tuff or agglomerate. Externally they generally appear as smooth rounded grassy hills that rise disconnected from other eminences. In some districts their materials consist of a greenish granular tuff, with rounded balls of various basic lavas and pieces of sandstone, shale, limestone, or other strata through which they have been drilled. This is their usual character in West Lothian. But in other cases the tuff becomes a coarse agglomerate, made up partly of large blocks of basalt and other volcanic rocks and partly of the sedimentary strata around them, of which large masses, many cubic yards in bulk, may be seen.

Many examples might be cited where no lava of any kind has risen in the vents, or where at least all the visible materials are of a fragmentary character. But it is not infrequent to find small veins and dykes of basalt which have been injected into the tuff or agglomerate. The finest illustration of this structure with which I am acquainted is the Binn of Burntisland, in Fife, where the vent has been so dissected by weathering that its walls strikingly remind one of those of a crater. Narrow veins of black basalt may there be seen threading their way as prominent ribs, standing out from the crumbling slopes and crags of green tuff.

(3) It has often happened that, after the explosions in a vent have ceased, lava has risen in the chimney and finally sealed it up. In such cases the main mass of the rock may consist of tuff or agglomerate, with a plug of basalt, dolerite, or even more basic material, of much smaller dimensions, in the centre or towards one side. Binns Hill, West Lothian, and the Beith and Saline Hills of Fife are good examples of this structure.

(4) In other cases no fragmental material is present in the vent, or possibly one or two traces of it may be seen adhering to the walls of the funnel, the prevailing rock being some form of lava. Necks of

[1] See Sheet 39, Geol. Surv. Scotland.

this kind are much less frequent in the puy- than in the plateau-type. But examples may be found in several districts. The most striking with which I am acquainted are those which form so picturesque a group of isolated cones around the volcanic basin of Limerick, especially on the south side. The vents there have been filled by the uprise of much more acid rocks than the lavas of the basin, for, as I have already stated, they include even quartz-porphyry. In the basin of the Firth of Forth some of the prominent bosses of basalt probably mark the sites of former vents, such as Dunearn Hill in Fife, the Castle Rock of Edinburgh, and Galabraes Hill near Bathgate. Some striking vents occur in the Jedburgh district, showing the nearly complete usurpation of the funnel by basalt, but with portions of the tuff still remaining visible.

In certain examples of puys denudation has not yet proceeded so far as to isolate the column of agglomerate or tuff from the sheets of tuff that were strewn around the old volcano. Hence the actual limits of the vent are still more or less concealed, or at least no sharp line can be drawn between the vent and its ejections. Several admirable illustrations of this relation are to be found in Fife. Thus, in the Saline Hills, seams of coal are actually worked under the surrounding bedded tuffs, the central chimney not having yet been reached.

2. *Bedded Lavas and Tuffs.*—In some districts or from certain vents (Midlothian, West Lothian, North Ayrshire, Heads of Ayr) only fine tuff seems to have been thrown out, which we now find intercalated among the surrounding strata. The eruptions of the Puys appear to have been generally neither as vigorous nor as long-continued as those of the Plateaux. They never gave forth such widespread sheets of fragmentary materials as those of Dunbar and the Garlton Hills, or those of the north-east of Ayrshire. A single discharge of ashes seems in many cases to have been the solitary achievement of one of those little volcanoes; at least only one thin band of tuff may be discoverable to mark its activity.

When volcanic energy reached its highest intensity during the time of the Puys, not only tuffs, but sheets of lava were emitted, which, gathering round the vent or vents, formed cones or long-connected banks and ridges. Nowhere in the volcanic history of this country have even the minutest details of that history been so admirably preserved as among the materials erupted from the Carboniferous puys. The volcanoes rose in the shallow lagoons and here and there from deeper parts of the sea-bottom. Their successive discharges of lavas and tuffs in the centres of greatest activity gradually built up piles of material, which, in the case of the Bathgate Hills in West Lothian, probably in the end exceeded 2000 feet in thickness. It must be remembered, however, that the eruptions took place in a subsiding area, and that even the thickest pile of volcanic ejections, if the downward movement kept pace with the volcanic activity, need not have grown into a lofty volcanic hill. The volcanic materials are found to replace locally the ordinary Carboniferous sedimentary strata. It is interesting in this regard to note that during pauses in the volcanic activity, while the subsidence doubtless was still going on, some of these strata extended themselves across the volcanic tracts so as to interpose, on more than one platform, a mass of ordinary sediment between the lavas and tuffs already erupted and those of succeeding discharges, and thus to furnish valuable geological chronometers by which to define the stratigraphical horizons of the successive phases of volcanic energy.

That, in the shallower lagoons, some of the tuff-cones built themselves above the level of the water, and remained for some time there before being submerged and washed down or buried under sand and mud, seems to be legitimately inferred from the abundant fragments of coniferous wood which are to be met with in the tuff of the necks. Such wood is comparatively rare among the ordinary surrounding strata, where *Stigmaria* and *Lepidodendron* are of constant occurrence. We seem to recognize in these bits of stems and trunks portions of the pines which clothed the outer slopes of the volcanic cones that rose here and there above the surface of the lagoons.

Where the puys ejected streams of lava besides showers of ashes, the banks or ridges which they formed not improbably rose as islets out of the water. Some of these banks were at least twelve miles in length, and had their materials supplied from many separate vents along their surface. But that they never attained to anything approaching the elevation which their sheets of lava and tuff would have reached had they been poured out upon a stable platform is admirably shown by the fact just referred to, that recognizable stratigraphical horizons can sometimes be traced right through the heart of these thick volcanic accumulations. One of the largest areas of basalts and tuffs connected with the puys is that of the Bathgate Hills, above referred to, where a depth of more than 2000 feet of igneous rocks has been piled up. Yet several well-known seams of stone can be traced through it, such as the Hurlet Limestone, already referred to, and the Index Limestone. Only at the north end, where the volcanic mass is thickest and the surface-exposures of rock are not continuous, has it been impossible to subdivide the mass by mapping intercalations of sedimentary strata across it. It would thus seem that, even where the thickest and widest accumulations gathered round the puys, they formed low flat domes, rather than hills, which, as subsidence went on and the tuff-cones were washed down, gradually sank under water, and were buried under the accumulating silt of the sea-floor. I shall offer some further details regarding the structure of the puys and their erupted lavas and tuffs when I give a rapid résumé of the characters of some illustrative districts wherein these phenomena can best be studied.

3. *Sills and Dykes.*—One of the characteristic features of Central Scotland is the great number and often the large size and extraordinary persistence of the sills which have been injected among the Carboniferous strata. The precise geological age of these intrusive sheets cannot, of course, be more exactly defined than by stating that they are younger than the rocks which they traverse. I have, however, been led, for the following reasons, to connect the great majority of them with the puys, though some of them are certainly of far later date.

In the first place, they certainly do not form part of the phenomena of the plateaux, where the sills are in great measure acid rocks, while those now under consideration are much more basic. But not only so, they appear for the most part on platforms later than the plateau-eruptions. A most remarkable illustration of this statement is furnished by the chain of the Campsie Fells, where, on the north side, among the Calciferous Sandstones which emerge from under the lavas of this plateau, many intrusive sheets and bosses of felsite may be seen, while on its southern side come the great basic sills which, from Milngavie by Kilsyth to Stirling, run in the Carboniferous Limestone series. A similar contrast may be observed in Renfrewshire between the felsitic sills below the plateau-lavas south of Greenock and the basic sills above these lavas in the Carboniferous Limestone series around Johnstone and Paisley.

In the second place, the basic sills often occur in obvious connexion with the vents or bedded lavas and tuffs of the puy series. A conspicuous and well-known example of this dependence is supplied by the intrusive sheets of Salisbury Crags, Heriot Mount, and the

Dasses, which project from beneath the bedded volcanic rocks of Arthur Seat. Another not less remarkable instance is to be found in the sills of Burntisland, underlying the basalts and tuffs of that district in the immediate neighbourhood of some of the vents from which these bedded rocks were erupted.

In the third place, even where no visible vents appear now at the surface near the sills, the latter generally occupy horizons within the stratigraphical range indicated by the interbedded volcanic rocks. It must be remembered that all the Carboniferous vents were deeply buried under sedimentary deposits, and that large as is the number of them which has been exposed by denudation, it is probably much smaller than the number still concealed from our view. The sills are to be regarded as deep-seated parts of the volcanic protrusions, and they more especially appear at the surface where the strata between which they were injected crop out from under some of the higher members of the Carboniferous system. Thus the remarkable group of sills between Kilsyth and Stirling may quite possibly be connected with a group of vents lying not far to the eastward, but now buried under the higher parts of the Carboniferous Limestone, Millstone Grit, and Coal Measures. Again, the great series of sills that gives rise to such a conspicuous range of hills in the north and centre of Fife may have depended for its origin upon the efforts of a line of vents running east and west through the county. Some vents indeed have been laid bare in that district, especially in the conspicuous group of the Saline Hills, but many more may be concealed under higher Carboniferous strata farther east.

In the fourth place, the materials of which the sills consist link them in petrographical character with those that proceeded from the puys. The rocks of the intrusive sheets around Edinburgh and Burntisland, for instance, are very much what an examination of the bedded lavas in their neighbourhood would lead us to expect. There is, of course, the marked textural difference between masses of molten rock which have cooled very slowly within the crust of the earth and those which have solidified with rapidity at the surface. There is likewise the further contrast between the composition of the volcanic magma at widely separated periods of its extravasation. At the time when the streams of basalt flowed out from the puys, its constitution was comparatively basic, in some localities even extremely basic. Any sills dating from that time may be expected to show an equal proportion of bases. But those which were injected at a long subsequent stage in this volcanic period may well have been considerably more acid.

In actual fact, as I have already remarked, the petrographical range of the sills varies from picrite to dolerite without olivine, and in some districts even to such rocks as felsite and quartz-porphyry. But the great majority of these sheets in the basin of the Firth of Forth, where they are chiefly displayed, are dolerites (diabases), either with or without olivine.

The structure of these intrusive sheets and their contact-metamorphism have been fully described, and some of them have become, as it were, 'household words' in geology.[1] Exposed in so many fine natural sections in the vicinity of Edinburgh, they early attracted the notice of geologists, and furnished a battle-ground on which many a conflict took place between the Plutonist and Neptunist champions at the beginning of the present century.

While one is struck with the great size and extent of the sills now under consideration, as compared with the small and local sheets underneath the plateaux, there is a further fact regarding them that deserves remark—their capricious distribution. Their occurrence seems to have little or no relation to the measure of volcanic energy as manifested in superficial eruptions.

Thus in the north of Ayrshire, where a long band of lavas and tuffs, pointing to vigorous activity, lies at the top of the Carboniferous Limestone series, and where the strata underneath it are abundantly exposed at the surface, the sills occur as thin and inconstant bands in the central and eastern parts of the district only. The bedded lavas and tuffs at the head of the Slitrig Water have no visible accompaniment of sills. In the Limerick basin, also, no clearly separable sills have been recognized, though possibly a more rigid scrutiny may yet discriminate them among the lower parts of the bedded lavas; but they have not been found among the tuffs below these lavas, nor in the limestones which underlie them. Again, in the Edinburgh and Burntisland districts, the sills bear a much larger proportion to the amount of bedded lavas and tuffs than they do in the Bathgate and Linlithgow district, where

[1] See, for instance, Maclaren's 'Geology of Fife and the Lothians,' 1839; 'Geological Survey Memoir on the Geology of Edinburgh' (Sheet 32), 1861; Trans. Roy. Soc. Edin. vol. xxix. (1879) p. 437; Allport, Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 553; Teall, 'British Petrography,' p. 187; E. Stecher, 'Contacterscheinungen an schottischen Olivindiabasen,' Tschermak's Mineralog. Mittheil. vol. ix. (1887) p. 145; Proc. Roy. Soc. Edin. vol. xv. (1888), p. 160.

the superficial eruptions were especially vigorous and prolonged. It would seem from these facts that the extent to which the crust of the earth round a volcanic orifice is injected with molten rock in the form of intrusive sheets between the strata does not depend upon the energy of the volcano as gauged by its superficial outpourings, but on other considerations not quite apparent. Possibly, the more effectively this volcanic energy succeeded in expelling the materials from the vent, the less opportunity was afforded for subterranean injections. And if the protrusion of the sills took place after the vents were solidly sealed up with agglomerate or lava, it would doubtless often be easier for the impelled magma to open a way for itself laterally between the bedding-planes of the strata than vertically through the thick solid crust. The size and extent of the sills may thus be a record of the intensity of this latest phase of the volcanic eruptions.

Dykes take a comparatively unimportant place in the eruptive phenomena of the puys. They occur in some numbers, but on a small scale, among the tuff vents, and there they can without much hesitation be set down as part of the material that was discharged through these pipes. It is more difficult to ascertain the age of the dykes which traverse the Carboniferous rocks at a distance from the vents. I have given reasons for classing the east and west dykes as probably Tertiary.[1] Others may be Permian; while a certain proportion may, with some probability, be regarded as parts of the puy-eruptions of Carboniferous time. The materials of these dykes resemble those of the finer-grained sills. They are chiefly dolerites and olivine-basalts (diabases).

IV. Illustrative Examples of Puy-eruptions.—A better idea of this interesting type of Carboniferous volcanic action will probably be obtained from a brief account of a few districts where it is typically developed. I have elsewhere dealt so fully with the basin of the Firth of Forth that it will be enough to refer to published papers on that region.[2] A less known district is that of the north of Ayrshire. I have had occasion to allude to the marked band of volcanic materials which there intervenes between the Carboniferous Limestone and the Coal Measures, and from its position appears to mark the latest Carboniferous outflows of

[1] Trans. Roy. Soc. Edin. vol. xxxv. (1888) pp. 29 *et seq.*

[2] See especially Maclaren's 'Geology of Fife and the Lothians,' the Memoirs of the Geological Survey of Scotland, on Sheets 31 and 32, and my Memoir, already cited, Trans. Roy. Soc. Edin. vol. xxix. (1879) p. 437.

volcanic rocks. Where best developed it has a zone of tuff at the bottom, a central and much thicker zone of bedded basalts, and an upper group of tuffs, on which the Coal Measures rest conformably. A few vents, probably connected with this volcanic tract, are to be seen at the surface between Fenwick and Ardrossan. But others have been buried under the Carboniferous sedimentary rocks, and have been discovered in the underground workings for coal and ironstone. These mining operations have, indeed, revealed the presence of far more volcanic material below ground than would be surmised from what can be seen at the surface. Here and there thin layers of tuff appear in brook-sections, indicating what might be conjectured to have been trifling discharges of volcanic material. But the prosecution of the ironstone-mining has proved that, at the time when the seam of Black-band Ironstone of that district was accumulated, the floor of the shallow sea or lagoon where this deposition took place was dotted over with cones of tuff, in the hollows between which the ferruginous and other sediments gathered into layers. The seam is in one place thick and of good quality; yet only a short distance off it is found to be so mixed with fine tuff as to be worthless, and even to die out altogether. In one pit-shaft about a mile and a half to the south-west of Dalry, a thickness of 115 fathoms of tuff was passed through, and in another pit 90 fathoms of similar tuff were sunk into before the position of the ironstone was reached by driving levels through the tuff into the sedimentary strata outside of it. Only a short distance from these thick piles of tuff, their place is entirely taken up by the ordinary sedimentary strata of the district. The working-plans of the mines show the tuff to occur in irregular patches and strips, between which the ironstone is workable. From these data we perceive that the shafts have in some cases been sunk directly upon the tops of puys of tuff which were, in one case, nearly 700 feet, and in another instance, 540 feet high.[1]

One of the most interesting developments of puys lies in that little-known tract of country which stretches from the valleys of the Teviot and Rule Water south-westwards across the high moorland watershed and down Liddesdale. Through this district a zone of bedded olivine-basalts and associated tuffs runs in a broken band which, owing to numerous faults and extensive denudation, covers now only a few scattered patches of the site over which it once spread. The geological horizon of this zone lies in

[1] Explanation of Sheet 22, Geol. Surv. Scotland (1872), p. 16.

the Calciferous Sandstones, many hundred feet above the position of the top of the plateau-lavas.

So great an amount of material has been here removed by denudation that not only has the volcanic zone been bared away, but the vents which supplied its materials have been revealed in the most remarkable manner over an area some twenty miles long and eight miles broad. Upwards of forty necks of agglomerate may be seen in this district, rising through the Silurian, Old Red Sandstone, and lowest Carboniferous rocks. It fills the geologist with wonder to meet with those stumps of old volcanoes far to the west among the Silurian lowlands, sometimes fully ten miles away from the nearest relic of the bedded lavas connected with them.[1] That these vents, though they rose through ground which at the time of their activity was covered with the volcanic series of the plateaux, do not belong to that series, but are of younger date, has been proved in several cases by Mr. Peach. He has found that among the blocks composing their agglomerates, pieces of the sandstones, fossiliferous limestones, and shales of the Cement-stone Group, overlying the plateau-lavas, are to be recognized. These vents were therefore drilled through some part at least of the Calciferous Sandstones, which are thus shown to have extended across the tract dotted with vents. After the volcanic activity ceased, fragments of these strata tumbled down from the sides into the funnels. Denudation has since stripped off the Calciferous Sandstones, but the pieces detached from them and sealed up at a lower level in the agglomerates still remain. Mr. Peach's observations indicate to how considerable an extent sagging of the walls of these orifices took place, with the precipitation not merely of blocks, but of enormous masses of rock, into the volcanic chimneys. In one instance, between Tudhope Hill and Anton Heights, a long neck, or perhaps group of necks, which crosses the watershed, shows a mass of the red sandstone, many acres in extent, and large enough to be inserted on the one-inch map, which has fallen into the vent.

From the descriptions published more than thirty years ago by Jukes and his colleagues in the Geological Survey of Ireland, geologists learnt how full and interesting are the proofs of great volcanic activity contemporaneously with the deposition of the Carboniferous Limestone series in the Limerick district of the South-

[1] They have been recognized and mapped by Mr. B. N. Peach for the Geological Survey. See Sheets 11 and 17, Geol. Surv. Scotland.

west of Ireland.[1] Nowhere, indeed, is the evidence more complete for the occurrence of a long succession of volcanic eruptions during a definite period of geological time. The officers of the Survey showed that there were here two chief periods of activity during the older part of the Carboniferous period, each of them being marked by a group of tuffs and lavas, while the interval of quiescence between them is represented by a thousand feet of limestone. During a visit to this most instructive region, in company with my colleagues Messrs. McHenry and Watts, I was interested to find that it affords so admirable an illustration of the puy-type of eruption. At the base of this volcanic series to the east of Limerick, there is striking evidence that the first eruptions were spasmodic, with intervals of longer and shorter duration, during which the compact black limestone with its fragmentary organisms was deposited, little or no volcanic detritus falling at that time. Yet even in some of the limestones the microscope reveals fine broken needles of felspar, representing doubtless the first ejected materials.[2] As we trace the strata upwards they pass into the ordinary tuff of the lower volcanic group. This tuff abounds in porphyrite (andesite) fragments, with a few felsitic rocks, enclosed in an opaque groundmass, through which are scattered broken felspars and occasional vesicular lapilli. The tuffs of the upper group are readily distinguishable from those of the lower, even in the field. They are found, when examined microscopically, to contain abundant vesicular lapilli of palagonite-tuff with fragments of various amygdaloids, and bombs of a basic pumice.

The lavas occur in numerous sheets, sometimes separated by beds and even thin partings of tuff and volcanic conglomerate. This alternation of lava-streams and showers of ashes is well displayed in the upper group above Nicker.[3] Some of the flows are porphyrites, showing the characteristic andesitic base of minute felspar-

[1] See especially Explanations of Sheets 144 & 154, Geol. Surv. Ireland (1860, 1861). The geology of the district had been previously noticed by earlier observers, to whose writings reference is made on p. 26 of the Explanation of Sheet 144. See also Jas. Apjohn, Journ. Geol. Soc. Dublin, vol. i. (1832) p. 24; Edw. Hull, Geol. Mag. for 1874, p. 205. The microscopic structure of some of the Limerick volcanic rocks has been described by Mr. Allport, Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 552, and by Prof. Hull, Geol. Mag. for 1873, p. 153.

[2] The details of the microscopic structure of the Limerick volcanic rocks here given are taken from notes of a preliminary examination undertaken for me by Mr. W. W. Watts. But see the papers cited in the previous note.

[3] Explanation of Sheet 144, Geol. Surv. Ireland, pp. 26–34.

laths with magnetite and enstatite, and with porphyritic crystals, often large, of zoned plagioclase, as well as of ilmenite and hæmatite. The large majority of the sheets, so far as I observed, are basalts. Mr. Watts finds them, both in the lower and upper volcanic group, to contain granular augite and magnetite set in a more or less devitrified glass with microlites of felspar and porphyritic plagioclase, serpentinized olivine, and some well-marked augite. Among the upper basalts on Nicker Hill certain rocks occur wherein the felspar diminishes in quantity, while augite and olivine become conspicuous, together with a little enstatite. The augite occurs in large porphyritic forms as well as of medium size and in small prisms. The olivine, as usual, is now in the condition of serpentine. These rocks are more basic than the ordinary basalts, containing only 38·66 per cent. of silica, and thus approaching the limburgites.

All round the edges of the Limerick basin, where the escarpments of the volcanic groups, rising abruptly above the plain, show that these rocks once extended far beyond their present limits, the progress of denudation has revealed a number of bosses which probably mark some of the vents from which the lavas and tuffs were erupted. Especially striking is the line of these vents along the southern margin. The rocks now filling them have been already referred to as on the whole more acid than the lavas of the basin, including, indeed, felsites and even quartz-porphyries.[1]

IX. PERMIAN.

In our survey of the past geological history of this country we have now arrived at a notable interval of quiescence in volcanic action. The portion of geological time represented by the Coal Measures, during which, so far as we know, there were no volcanic eruptions within our borders, must have been of long duration;

[1] Contemporaneous volcanic rocks have been believed to occur among the Lower Carboniferous rocks of Bear Island, and on the opposite mainland westward to White Ball Head at the entrance to Bantry Bay. There are some interesting agglomerates in that district, but I did not detect any evidence that they are truly bedded among the strata. They seemed to me rather to be intrusive masses of the nature of necks, for they certainly present in some places clear evidence of having disrupted the strata, though elsewhere lying apparently between them. For the present, therefore, I do not include them among the proofs of Carboniferous volcanic activity. The agglomerate at White Ball Head contains numerous large hornblende-crystals and large flakes of muscovite. Dykes and veins of diabase and felsite are associated with these breccias.

but it was only a part, and possibly only a small part, of the total interval between the cessation of eruptive activity in Carboniferous and its re-commencement in Permian time. A considerable fragment of the geological record is obviously missing in Britain after the end of the Carboniferous formations. We have none of those Permo-Carboniferous strata which elsewhere connect the Coal Measures with the Permian rocks. Whether, had this gap been filled up here, it would have supplied any trace of contemporaneous volcanic action cannot be determined. All that we know is that, in the Permian period, after the long interval just referred to, volcanic activity in a greatly enfeebled manifestation once more broke out.

I. Distribution.—The rocks now to be described exhibit a still more restricted range than those of the Carboniferous period. They are developed, indeed, only in two widely separated regions. Of these, the largest and most important lies in the centre and south-west of Scotland, forming either two distinct tracts or extending in a straggling band from the east of Fife across the basin of the Firth of Forth to the north of Ayrshire, and thence, with a more persistent and well-developed series of volcanic records, through the centre of that county into Nithsdale and several of the adjacent valleys, even as far as Annandale. There the volcanic rocks end, although the red sandstones continue into Cumberland, and are largely exhibited in the Midland and South-western counties of England. Not until we reach the neighbourhood of Exeter do we again encounter volcanic rocks associated with any portion of the 'poikilitic' rocks of England. There is thus a northern or Scottish and a southern or Devonshire region in which volcanic records are preserved which we have now to consider.

Twenty-five years ago I was able to announce the existence of traces of a group of Permian volcanoes in the south-west of Scotland.[1] Various additions to our knowledge of them have been made during the interval, but the main facts remain much as they were then stated by me. No fossils have yet been obtained to fix with more precision the age of the rocks among which these volcanic records are preserved. But the extension of the detailed mapping of the Geological Survey has confirmed the original inference as to the stratigraphy.[2] The red sandstones, among which

[1] Geol. Mag. for 1866, p. 243, and Murchison's 'Siluria,' 4th ed. (1867) p. 332.

[2] On the age of these sandstones, see Murchison's 'Siluria,' 4th ed. p. 331; Quart. Journ. Geol. Soc. vol. vii. (1851) p. 163, note; vol. xii. (1856) p. 267;

lie the intercalated volcanic rocks, cover several detached areas in Ayrshire and Dumfriesshire. Lithologically these strata present a close resemblance to the Penrith sandstone and breccias of Cumberland, the Permian age of which is generally admitted. They lie unconformably sometimes on Lower and Upper Silurian rocks, sometimes on the lower parts of the Carboniferous system, and sometimes on the red sandstones which form its highest subdivision. They are thus not only younger than the latest Carboniferous strata, but are separated from them by the interval represented by the unconformability. There can thus be little hesitation in regarding them as not older than the Permian period.

The only palæontological evidence yet obtained from these rocks in Scotland is that furnished by the well-known footprints on the red sandstone of Annandale. These impressions indicate the existence of early forms of amphibians or reptiles during the time of the deposition of the red sand. The precise zoological grade of these animals has never yet been determined, so that they furnish little help towards fixing the stratigraphical position of the red rocks in which the footprints occur.

II. Structure.—That the volcanic rocks now to be described belong to the time of the red sandstones with which they are associated is abundantly clear. They consist of lavas and tuffs, which are in some places underlain and everywhere overlain with these sandstones, which contain likewise interstratifications of them. Unfortunately, however, so enormous has been the denudation of the country that these rocks have been worn away from wide tracts which they almost certainly once overspread. The result has been that while the lavas and tuffs ejected at the surface during Permian time have been reduced to merely a few detached fragments, the progress of denudation, by removing this superficial volcanic casing, has revealed the vents of discharge to an extent unequalled in any older geological system, even among the puys of the Carboniferous period. The Permian rocks, escaping the effects of those great earth-movements which dislocated, plicated, and buried the older Palæozoic systems of deposits, still remain for the most part approximately horizontal or only gently inclined. They have thus been more

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Binney, *ibid.* vol. xii. (1856) p. 138, vol. xviii. (1862) p. 437; Harkness, *ibid.* vol. xii. (1856) p. 262. The rocks are mapped more especially in Sheets 9, 14, and 15 of the Geological Survey of Scotland, to which, and their accompanying explanations, reference is made.

liable to complete removal from wide tracts of country than older formations which have been protected by having large portions of their mass carried down by extensive faults and synclinal folds, and by being buried under later sedimentary accumulations. We ought not therefore to judge of the extent of the volcanic discharges during Permian time merely from the small patches of lava and tuff which have survived in one or two districts, but rather from the number, size, and distribution of the vents which the work of denudation has laid bare.

And here let me remark that the evidence for the geological age of some parts of the volcanic series now to be described is less direct and obvious than most of that with which I have been hitherto dealing. It consists of two kinds. (*a*) In the first of these we find a series of lavas and tuffs regularly interstratified with the red sandstones, which it is agreed to regard as Permian. The geological horizon of these rocks is sufficiently clear. (*b*) Connected with them are necks which obviously served as vents for the discharge of the volcanic materials, and pierce not only the Coal Measures, but even parts of the bedded lavas. So far there is not much room for difference of opinion; but as we recede from districts where the record is tolerably complete, we enter extensive tracts where only the necks remain. All that can be positively asserted regarding the age of these protrusions is that they must be later than the rocks which they pierce. But we may inferentially connect them with the series now under consideration by showing that they can be followed continuously outward from the latter as one prolonged group, having the same distribution, structure, and composition, and that here and there they rise through the very highest part of the Coal Measures. It is by inferences of this kind that I include as relics of Permian volcanoes a large number of vents scattered over the centre of Scotland, especially in the east of Fife.

1. *Bedded Lavas and Tuffs.*—I shall first describe the volcanic chronicle as it has been preserved in the south-west of Scotland, where the existence of Permian volcanoes in Britain was first recognized.[1] The volcanic rocks in that district rise from under the central basin of red sandstone, which they completely enclose. Their outcrop at the surface varies up to about a mile or rather more in breadth, and forms a pear-shaped ring, measuring about nine miles across at its greatest width.

[1] See explanation of Sheet 14, Geol. Surv. Scotland (1869), p. 22; and the paper in the Geol. Mag. for 1866 already cited.

This volcanic ring runs as a tract of higher ground encircling the hollow in which the Permian red sandstones lie, and forming a marked chain of heights above the Carboniferous country around. It is built up of a succession of beds of different lavas, with occasional ashy partings, which present their escarpments towards the coal-field outside, and dip gently into the basin under the inner trough of brick-red sandstones. The lavas are dull reddish or purplish-grey to brown or almost black rocks; sometimes compact and porphyritic, but more usually strongly amygdaloidal, the vesicles having been filled up with calcite, zeolites, or other infiltration. The porphyritic minerals are in large measure dull red earthy pseudomorphs of hæmatite, in many cases after olivine. These rocks have not yet been studied in regard to their composition and microscopic structure. A few slides, prepared from specimens collected in Ayrshire and Nithsdale, have been examined by Dr. Hatch, who finds them to present remarkably basic characters. One from Mauchline Hill is a picrite, composed chiefly of olivine and augite, with a little striped felspar. Others from the Thornhill basin in Dumfriesshire show an absence of olivine, and sometimes even of augite. The rock of Morton Castle consists of large crystals of augite and numerous grains of magnetite in a felspathic groundmass full of magnetite. Around Thornhill are magnetite-felspar rocks, composed sometimes of granular magnetite with interstitial felspar. Throughout all the rocks there has been a prevalent oxidation of the magnetite, with a consequent reddening of the masses.

That these are true lava-flows, and not intrusive sills, is sufficiently obvious from their general outward lithological aspect, some of them being essentially sheets of slag and scoriæ. Their upper surfaces may be found with a fine indurated red sand wrapping round the scoriform lumps and protuberances, and filling in the rents and interspaces, as in the case of the Old Red Sandstone lavas already referred to. Further evidence to the same effect is supplied by the fragmentary materials accompanying them. Here and there, under the platform of bedded lavas, lie bands of brick-red sandstone, full of fragments of slag and fine volcanic dust. Similar materials may be observed to form partings between some of the successive flows. But the most abundant accumulation of such detritus is to be seen immediately above the zone of lavas, where it contains the records of the closing phases of volcanic activity in the south-west of Scotland during the Permian period. Thick beds of tuff and volcanic breccia occur there, interleaved with seams of ordinary red sandstone, into which they gradually pass upward. Yet, even among the sandstones above the main body of tuff, occasional nests of volcanic lapilli, and even large bomb-like lumps of slag, point to intermittent explosions before the volcanoes became finally extinct and were buried under the thick mass of red Permian Sandstone.

There is good reason to believe that both the volcanic sheets and the red sandstones overlying them, instead of being restricted to an area of only about 30 square miles, once stretched over all the lowlands of Ayrshire; and not only so, but ran down Nithsdale, and extended into several of its tributary valleys, if, indeed, they were not continuous across into the valley of the Annan.[1] Traces of the lavas and tuffs are to be found at intervals over much of the area here indicated. The most important display of them, next to their development in Ayrshire, occurs in the vale of the Nith at Thornhill, whence they extend continuously up the floor of the Carron Valley for six miles. They form here, as in Ayrshire, a band at the base of the brick-red sandstones, and consist mainly of bedded lavas with the basic characters above referred to. These lavas, however, are followed here by a much thicker development of fragmental volcanic materials. Abundant volcanic detritus is diffused through the overlying sandstones, sometimes as a gravelly intermixture, sometimes in large slaggy blocks or bombs, and sometimes in intercalated layers of tuff, while an occasional sheet of one of the dull red lavas may also be detected. The final dying-out of the volcanic energy by a series of intermittent explosions, while the ordinary red sandy sediment was accumulating, is here also admirably chronicled.

But we can detect the edges of yet more distant streams of lava emerging from under the red sandstones and breccias to the east of the Nith. On the farther side of the Silurian ridge, which forms the eastern boundary of the Nith Valley, above which it rises some 700 or 800 feet, there is preserved at the bottom of the valley of the Capel Water, which flows into Annandale, another small outlier of a similar volcanic band. Three miles to the south-east of it two little fragments of the volcanic group lie on the sides of a small tributary of the Water of Ae, while another outlier may be observed two miles lower down the latter stream. But we have evidence that the volcanic materials extend still farther eastward under

[1] See Memoirs of Geol. Surv. Scotland, Sheet 15 (1871), p. 35; Sheet 9 (1877), p. 31.

the Permian sandstones of the Lochmaben basin of Annandale, for breccias largely made up of pieces of the bedded lavas are found close to the northern edge of the basin on the west side of the River Annan. To this remarkable adherence of the lavas and tuffs to the bottom of the Permian valleys I shall afterwards more specially refer.

The thickness of the whole volcanic group cannot be very accurately determined. It reaches a maximum in the Ayrshire basin, where, at its greatest, it probably does not exceed 500 feet, but is generally much less; while in the Nithsdale and Annandale ground the detached and much denuded areas show a still thinner development.

2. *Vents.*—We have now to consider the necks connected with the lavas and tuffs here described, and extending far beyond these into distant districts of Central Scotland. In Ayrshire the lower part of the Permian volcanic band is pierced by several small necks of agglomerate. There cannot, I think, be any doubt that these necks mark the positions of some of the vents from which the later eruptions took place. Immediately beyond them necks of precisely similar character rise through the upper division of the Coal Measures. There can be as little hesitation in placing these also among the Permian vents. And thus step by step we are led away from the central lavas through groups of necks preserving still the same features, external and internal, and rising indifferently through rocks of any geological age from the Coal Measures backward. Thus, although if we began the investigation at the outer limits of this chain of necks we might well hesitate as to their age, yet, when we can fix their geological position in one central area, we are, I think, justified in classing all the connected groups that retain the same general characteristics as parts of one geologically synchronous series. It is to denudation that we owe their having been laid bare to view; but at the same time, denudation has removed the sheet of ejected materials which may have originally connected most of these vents together. In this regard it is most instructive to follow the vents south-eastwards from the Ayrshire basin into Nithsdale for a distance of some eighteen miles. If we traced them down that valley to Sanquhar, without meeting with any vestige of superficial outflows to mark their stratigraphical position, we might possibly hesitate whether the age of those which are so far removed from the evidence that would fix it should not be left in doubt. But if we continued our traverse only a few hundred yards

farther we should find some few fragmentary outliers of the Permian lavas capping the Upper Coal Measures; and if we merely crossed from the Nith into the tributary valley of the Carron Water, we should see preserved in that deep hollow a great series of Permian lavas, tuffs, and agglomerates. It is only by a happy accident that here and there these superficial volcanic accumulations have not been swept away. There was probably never any great thickness of them, but they no doubt covered most, if not all, of the district within which the vents are found.

The Permian necks are, on the whole, smaller than those of the Carboniferous Period. The largest of them probably do not exceed 4000 feet in longest diameter, and very few approach that size. The smallest are twenty yards, or even less, in diameter. They generally rise as prominent rounded, dome-shaped, or conical hills, which, as the rock comes close to the surface, remain permanently covered with grass. They thus form a distinctive feature in the scenery of the districts where they occur, as may be well seen in the Dalmellington Coal-field.

As in those of older geological periods, the necks of this series are, as a whole, irregularly circular or oval in ground-plan, but sometimes, like those of the Carboniferous system already referred to, they take curious oblong shapes, and occasionally look as if two vents had coalesced. Here and there also the material of the vents has found its way between the walls of a fissure or the planes of the strata, so as to appear rather as a dyke than as a neck. The necks descend vertically through the rocks which they pierce, having thus the form of vertical columns of volcanic material ending at the surface in grassy rounded hillocks or hills.

In almost all cases the necks consist of a coarse agglomerate, generally rather red in colour, made up of blocks of such lavas as form the bedded sheets, together with fragments of the stratified rocks through which the chimneys have been blown out. This material is unstratified, but, when it is replaced by less coarse tuff, a rude stratification may often be noticed, the dip being irregularly inward at high angles towards the middle of the vent.[1]

Occasionally some form of molten rock has risen in the funnel and has partially or wholly removed or concealed the agglomerate. This feature is especially noticeable among the necks that pierce the Dalmellington Coal-field. Portions of basic lavas traverse the agglomerate or intervene between it and the surrounding strata, as if

[1] Trans. Roy. Soc. Edin. vol. xxix. (1879) p. 463.

forced up the wall of the funnel, while here and there sills run outward from the necks into the surrounding Coal Measures. Again, in one of the necks in the Muirkirk Coal-field which was pierced by a mine driven through it from side to side, fingers and sheets of 'white trap,' that is, some highly altered basalt, were found to run out from the neck into the surrounding strata.[1] Dark heavy basalt or some still more basic rock has here and there filled up a vent. As so many of the necks rise through coal-fields, opportunities are afforded of studying the effects of volcanic action upon the coal-seams, which for some distance from them have been destroyed.

Another feature which can be recognized from the information obtained in mining operations is that, in the great majority of instances, no connexion can be traced between the positions of the vents and such lines of dislocation as can be traced at the surface or in the underground workings. Some vents, indeed, have evidently had their positions determined by lines of fault, as, for instance, that of the Green Hill below Dalmellington. Yet in the same neighbourhood a number of other examples may be found where the volcanic funnels seem to have avoided faults, though these exist close to them.

In regard to the distribution of the vents in Scotland, two distinct aggregations of them may be recognized. The first and most important of these embraces the Ayrshire, Nithsdale, and Annandale districts in the west; the second lies in the basin of the Firth of Forth, far to the east.

In the western district upwards of 60 distinct vents have been mapped in the course of the Geological Survey. They run from the north of Ayrshire to the foot of the Southern Uplands, and descend for some distance the vale of the Nith. The area over which they are distributed measures roughly about 40 miles from north-west to south-east, and at its greatest breadth 20 miles from south-west to north-east. But within this tract the vents are scattered somewhat sporadically in groups, sometimes numbering as many as twenty necks in a space of sixteen square miles, as in the remarkable district of Dalmellington.

In considering their distribution we cannot but be impressed by the striking manner in which these necks keep to the valleys and low grounds. I have already alluded to this characteristic, as shown by the volcanoes of the Old Red Sandstone and Carboniferous periods. But it is displayed by the Permian volcanoes in a still

[1] Explanation of Sheet 23, Geol. Surv. Scotland, p. 39.

more astonishing way. Beginning at the northern end of the long chain of necks in the West of Scotland, we find a row of them on the plains fronting the volcanic plateau of the Ardrossan, Dunlop, and Stewarton Hills. Thence we may follow them as single individuals or in small groups across the broad lowland of Ayrshire southward to the very base of the great chain of the Southern Uplands. There a cluster of some two dozen of them may be seen rising out of the Carboniferous rocks on the low grounds, but they abruptly cease close to the base of the hills; not one has been detected on the adjacent Silurian heights. Moreover, if we turn into the valleys that lead away from the great Ayrshire plain to the interior, we find necks of the same character in these depressions. They ascend the valley of Muirkirk, and may be met with even at its very head, near the base of the Hagshaw Hills. Again, on the floor of the remarkable transverse valley trenched by the Nith across the Southern Uplands, Permian necks pierce the Coal Measures, while the outlying fragments of bedded lava show that these vents flooded the bottom of that valley with molten rock. Turning out of Nithsdale into the long narrow glen of the Carron Water, we find its floor and sides still covered with sheets of lava and tuff. And so we may travel onward from the vale of the Nith into that of the Capel Water, and thence into the Water of Ae and across into the great strath of Annandale, and detect, if not actual vents, at least beds of lava and tuff and layers of volcanic detritus that were ejected from them.

All along these valleys, which were already valleys in Carboniferous time, traces of the volcanic activity of this epoch may be detected. But, so far as I am aware, in not a single case has any vent been observed to have been opened on the high surrounding ridges. There has obviously been a determining cause why the volcanic orifices should have kept to the plains and the main valleys with their tributaries, and should have avoided the hills which rise now to heights of 500 to 1000 feet or more above the bottoms of the valleys that traverse them. It might be said that the valleys follow lines of fracture, and that the vents have been opened along these lines. But my colleagues in the Geological Survey, as well as myself, have failed to find in most cases any evidence of such dislocations among the rocks that form the surface of the country, while it is sometimes possible to prove that they really do not exist there.

Though only a few scattered patches of the Scottish Permian bedded lavas and tuffs have been preserved, enough is left to indicate that the vents were active only in the early part of the period represented by the red sandstones, for it is entirely in the lower part of these strata that the volcanic rocks occur. The eruptions gradually ceased, and the sheets of ejected material, probably also the volcanic cones, were buried under a considerable thickness of red sandstone. Whether or not any portion of the erupted material was built up above the level of the water, there seems to be no question that the vents were, on the whole, subaqueous.

From the Ayrshire plain a few widely scattered vents, which may belong to the Permian series, may be traced across Lanarkshire and Midlothian to the Firth of Forth.[1] But it is in the east of Fife that we next meet with a large assemblage of them. No trace of any sandstones which can be even surmised to be Permian has there been detected; hence the geological age of the vents now to be described can only be inferred from the kind of indirect evidence already alluded to. But the inference appears to be well grounded, for it is based on the fact that some of these necks, like those of Ayrshire, pierce the highest group of the Coal Measures. In these instances, therefore, it can be shown that the eruptions took place after the Coal Measures, and the only known post-Carboniferous volcanic period to which they can be referred is that with which we are now dealing. But the necks which happen to rise through the Coal Measures are only part of a large group that rises indifferently through the Carboniferous Limestone series and Calciferous Sandstones of the east of Fife. They are assuredly all one connected aggregate, resembling each other alike in their external characters, internal structure, and component materials, and the limit of their age must be determined by the geological horizon of the youngest formation which they traverse. By this process of reasoning I reach the conclusion that this remarkable series of old volcanoes in the east of Scotland dates from the same period as that of Ayrshire and Nithsdale.

Some idea of the importance and interest of the volcanic area of eastern Fife may be gathered from the fact that in a space of about 70 square miles no fewer than 60 necks may be counted, and others are probably concealed under Carboniferous strata and below the drift-deposits which cover so much of that part of the country. The area extends from St. Andrew's Bay and the Vale of the Eden southwards to the coast of the Firth of Forth from Lundin Links to St.

[1] I have little doubt that the later rocks of Arthur Seat, which can be shown to pierce the older bedded masses, belong to this series.

Monans. All over the inland tract the necks form more or less marked eminences, rising frequently into conical hills, such as Kelly Law and Largo Law, which are conspicuous landmarks from the southern side of the Firth. But the distinguishing characteristic of the area is the display of the necks along the coast and the manner in which their form, composition, internal structure, and relations to the surrounding rocks have there been laid open. No such series of dissected vents is to be met with in the volcanic records of any other geological period within the compass of these islands.

Having already given some account of the chief characters of these necks in the east of Fife, I need not on the present occasion, do more than refer to my published paper for details.[1] The materials that have filled the vents are agglomerates and tuffs, not infrequently with intrusions or plugs of basic lavas. There does not appear to be any relation between the diameter of a funnel and the size of the blocks that now fill it. At the Buddo Ness, for example, on the coast east of St. Andrew's, we find a little neck not more than 60 feet in diameter, yet packed with blocks of shale 6 feet long, while the sandstone through which the orifice has been drilled is altered into a kind of quartzite for several yards away from the edge. On the other hand, some of the larger necks consist of comparatively fine tuff.

On the shore, where denudation has been most effective, there exist only the necks and their associated dykes and veins. In the interior, however, at the large necks of Largo, there still remains a good deal of the fragmental matter that gathered around the vents from which it was discharged. There must be an area there of not much less than four square miles covered with tuff. Unfortunately the sections are not numerous, and it is hardly possible to map out separately the tuff which forms the vents from that which is lying on the Carboniferous rocks around them. There are probably at least three necks in this area of tuff, that is, there were here three volcanic vents, probably opened successively, and almost touching each other, like groups of puys in Auvergne. On the outskirts of the area of tuff it is possible to see the junction of the volcanic detritus with the Carboniferous Limestone series underneath, and to ascertain that there is a strong unconformability between them. This relation goes to confirm the inference as to the great interval of time between the eruptions of these volcanoes and the deposition of the rocks of the Carboniferous period.

[1] Trans. Roy. Soc. Edin. vol. xxix. (1879) pp. 455–474.

3. *Sills.*—The phenomena of sills and dykes are less clearly exhibited among the Permian volcanic rocks than in the older series. Probably the best district for the study of this subject is that around Dalmellington. The Coal Measures are there traversed by many basic sills, which have produced great destruction among the coal-seams. Some of the rocks are extremely basic, including a beautiful picrite like that of Inchcolm (Letham Hill, near Waterside). The age of these sills must be later than the Coal Measures into which they have been injected. Some of them are obviously connected with the agglomerate-necks, and the whole or the greater number should thus probably be assigned to the Permian period.[1]

I have now to ask you to transfer your attention to the South-west of England, where the existence of an interesting volcanic group towards the base of the red sandstones and breccias of central Devonshire has long been known. That county and Cornwall furnish one of the most striking examples to be met with in this country of the persistence of volcanic action over a limited area through a long succession of geological periods. There seems good reason to regard the agglomerates and tuffs of the Meneage district to the south of Falmouth as evidence of volcanic action in some part of the Lower Silurian period.[2] The vigorous and prolonged eruptions of Devonian time I have already referred to. In the Carboniferous rocks also, as De la Beche long ago pointed out, there is evidence of renewed volcanic energy in the same region. And again, after the close of the Carboniferous period, still within the same restricted space, we have the remains of yet one more series of eruptions. Thus during a great part of Palæozoic time the extreme south-west of England continued to be a theatre of volcanic action.

The geological age of the igneous rocks now to be referred to depends upon the particular place in the geological record to which we assign the remarkable breccias and sandstones with which they are associated. By many geologists who have been unable to recognize any true break in the red rocks from their base up to the bottom of the Lias, these strata have been grouped as one

[1] See Explanation of Sheet 14, Geol. Surv. Scotland, p. 22.

[2] These rocks, which have often been described, are more particularly identified as volcanic intercalations, probably of Caradoc age, by Messrs. Somervail and Fox, Trans. Roy. Geol. Soc. Cornwall, 1885. See also Mr. Collins's paper in the same Transactions, vol. x. part 2, p. 52.

great series and have been assigned to the 'New Red Sandstone' or Trias. This is the classification adopted on the published maps of the Geological Survey. On the other hand, various able observers have pointed out the obvious resemblance of the coarse breccias at the bottom of the series to recognized Permian breccias in the centre of England and to the typical Rothliegende of Germany. I need only refer to the strongly expressed views of Murchison, who, in his 'Siluria,' stated that he "entirely agreed with Conybeare and Buckland, who after a journey in Germany in 1816, distinctly identified the Heavitree Conglomerate near Exeter with the Rothliegende of the Germans."[1] I do not pretend to bring forward any additional evidence or argument that would help to settle this disputed question. My own inclination is to regard the rocks as probably Permian, and to follow Murchison in looking upon their associated igneous masses as furnishing additional reason for assigning them to that stratigraphical position.[2]

No proper account has yet been written of the volcanic group to which I now refer. De la Beche was, I think, the first to recognize the true volcanic nature of the rocks and their contemporaneous interstratification in the red sandstones.[3] As traced on the Geological Survey maps these rocks lie at or near the base of the red sedimentary deposits, resting sometimes directly on the Culm Measures, sometimes on an intervening layer of red strata. They include various lavas, often strongly amygdaloidal and vesicular, and also red gravelly tuffs and volcanic conglomerates which are regularly banded with the red sandstones. No petrographical description of these rocks, so far as I am aware, has yet appeared.[4] I have

[1] 'Siluria,' 4th edit. (1867) p. 333. See also Berger, Trans. Geol. Soc. vol. i. (1811) pp. 98-102; Conybeare and Phillips, 'Geology of England and Wales,' p. 313, footnote; De la Beche, 'Report on the Geology of Cornwall, Devon, and W. Somerset,' chap. vii. p. 193. The subject has been discussed more recently by Messrs. Hull and Irving, who follow the view of Murchison.

[2] Murchison cogently argued that as no signs of volcanic activity were known in the Trias, but were abundant in the Permian system, the Devonshire rocks might be regarded as appertaining to the older series. *Op. cit.* Triassic volcanic rocks, however, are now well known on the Continent.

[3] De la Beche quotes J. J. Conybeare as pointing out the intimate connexion of these igneous and stratified rocks ('Annals of Philosophy,' 2nd ser. vol. ii. (1821) p. 165); but this author wrote at the time of the plutonist and neptunist controversy, and does not commit himself to any distinct expression of opinion on the subject.

[4] An outline of some of their characters will be found in a paper by Mr. W. Vicary in Trans. Devonshire Assoc. 1865, vol. i. part iv. p. 43.

seen the lavas in one or two localities on the ground, but have not yet had an opportunity of properly examining the district. A small collection of specimens from these lavas is exhibited in the rock-collection of the Jermyn Street Museum. Externally, as seen in the quarries and natural exposures, some of these rocks present the closest resemblance to those of the Permian basins of Ayrshire and Nithsdale. They show considerable differences of texture even within the same mass, some portions being dull fine-grained purplish-red rocks, with scattered pseudomorphs of hæmatite and a few porphyritic felspars, other parts passing into an exceedingly coarse amygdaloid. Here and there I observed near Exeter veins of fine hard sandstone in some of the dark lavas, like those which I have referred to as occurring characteristically in porphyrites of the Old Red Sandstone, likewise in the Permian lavas of Scotland.

From the specimens in the Jermyn Street Museum it would appear that these volcanic rocks include more acid varieties then have been met with in the Permian series of Scotland. Dr. Hatch, after a microscopical examination of them, informs me that while some are olivine-basalts, containing ferruginous pseudomorphs after olivine (Raddon Court, Pocombe, and near Budlake), others are true andesites (Ide, Kellerton Park) and even mica-trachytes (Copplestone, near Knowle Hill). By some of the older writers the existence of quartz-porphyries is also mentioned.[1]

That these lavas were contemporaneously erupted early in the period of deposition of the red sandstones was clearly perceived and stated by De la Beche. He recognized the amygdaloids as slaggy lavas, and saw that the volcanic breccias and tuffs are interleaved with the sandstones. But he appears also to have detected some of the probable vents from which these materials were ejected. He thought the chief centre of activity lay at Kellerton Park, while in other localities he found the bosses of igneous rock "to descend in mass downwards, as if filling up some crater or fissure through which these rocks had been vomited."[2] He speaks also of "quartziferous

[1] See De la Beche 'Report,' pp. 203, 204. My colleague, Mr. Ussher, has recently found close to the Thurlestone outlier of conglomerate near Kingsbridge, Devonshire, a small boss of quartz-porphyry which rises through and alters the Devonian rocks. The actual junction of this mass with the conglomerate is not seen, nor have any fragments of the porphyry been noticed among the pebbles. Mr. Ussher informs me that in the quarry the visible exposure of the acid rock is surrounded and covered by mica-porphyrite, probably andesite.

[2] *Op. cit.* p. 201.

porphyries" occurring among them,[1] a statement which, if petrographically accurate, would suggest the uprise of a later more acid lava in some of the vents.

Though much remains to be done in this region before an adequate account can be given of the interesting series of eruptions which concludes the long volcanic history of the South-west of England, enough is known to indicate the general character of the phenomena. The eruptions were on even a feebler scale than those of the Permian period in Scotland, but they seem to have resembled them in their general character. Small puy-like vents were opened, from which dark scoriaceous lavas and showers of gravelly tuff and stones were discharged over the floor of the inland sea or lake-basin in which the red sandstones and breccias were accumulated. These outflows and explosions took place too, as in Scotland, towards the beginning of the deposition of the red strata, and entirely ceased long before that deposition came to an end. In each area the eruptions mark the close of Palæozoic volcanic activity in Britain. The varied and recurrent volcanic episodes which marked the passing of each successive geological period from the Archæan onwards now definitely terminate, not to be resumed until after the passing of the whole of the vast cycle of Mesozoic ages.

X. TERTIARY.

The entire absence of any evidence of volcanic eruptions over the area of the British Isles during so considerable a part of geological history as the whole of Mesozoic time is a most striking fact.[2] When we reflect that the stratigraphical records of this prodigious lapse of geological time are singularly complete in this country, that they are not only spread out over the half of England, but are found also across a considerable tract of the north of Scotland, as well as on a more limited scale in the north of Ireland, we feel that this want of any trace of contemporaneous volcanic activity almost certainly arises from the absence of eruptions over the regions where these records were accumulated. The gradually dwindling subterranean energy of Palæozoic time was followed by a vast period of quiescence, which, so far as we yet know, remained entirely unbroken until after the beginning of the Tertiary period.

Having only a few years ago published a detailed account of what seem to me to have been the more important characteristics of the

[1] *Ibid.* p. 204. [2] The same fact is observable throughout most of Europe.

volcanic phenomena in Tertiary time,[1] I need not do more on the present occasion than submit a mere summary of the subject.

The Tertiary volcanic rocks of this country display in their modes of occurrence some marked contrasts to those of older geological periods. The first of these to attract the attention of the student is the important part played by dykes, and the enormous area over which these are distributed. The second point of difference lies in the exceedingly restricted area of the superficial lavas now visible compared with the wide extension of the dykes. Further contrasts are to be found in the well-bedded structure of these lavas; their disposition in horizontal or nearly horizontal sheets, forming plateaux far broader and better defined than those of the Carboniferous system; the scarcity or absence of visible vents from large tracts over which the lavas spread; the non-appearance of marine sediments in any part of the volcanic series, and on the contrary the presence of remains of terrestrial vegetation in such positions as to indicate that the eruptions took place on land; and lastly the want of any immediately succeeding conformable formation which might have served to chronicle the close of the volcanic eruptions, and thus to define their upward geological limit.

On the other hand, the essential features of volcanic action are repeated with the same regularity in the Tertiary as in the older periods. We see that basic lavas flowed out first, that acid protrusions came later, that the vents of eruption were made use of for the uprise of huge bosses and plugs of different molten rocks, and that an abundant series of sills has been injected into the platform on which the bedded basalts lie.

Taking first the dykes as the most singular and widespread feature of the Tertiary volcanic period, we find them to be distributed over a region of somewhere about 40,000 square miles, that is more than a third of the total land-surface of the British Isles. They are more particularly developed in the west, centre, and south of Scotland, the north of England, and the north of Ireland. Within this wide region there are doubtless many dykes much older than those which alone can be classed as Tertiary. Excluding these, we nevertheless find many thousands which are united by certain

[1] 'The History of Volcanic Action during the Tertiary Period in the British Isles,' Trans. Roy. Soc. Edin. vol. xxxv. (1888) p. 21. I may refer to this paper for the previous literature of the subject. Since its publication, Prof. Judd, with whose ideas as to the order of succession of the volcanic phenomena of the Inner Hebrides I do not agree, has published a criticism of it in Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 187, and a further paper in vol. xlvi. (1890) p. 341.

common characters as one great series. Among these links of connexion are the prevalent trend of the dykes in a north-westerly or westerly course, their increase in numbers as they are traced towards the volcanic plateaux of Antrim and the Inner Hebrides, the fact that they traverse the important faults of the country, together with every geological formation, from the Chalk inclusive, downwards, and even the older parts of the basalt-plateaux. They run in long straight courses, sometimes for 60, 70, or even in one case more than 100 miles, though in the region of the plateaux they are much shorter and less regular in breadth and straightness.

There is good evidence that the dykes are not all of one age. They cross each other. Some of them are truncated by the acid bosses of the Tertiary series, while others of later date run through these bosses. But there is proof that even those which traverse the older parts of the plateau-basalts, and are therefore of later date than these, must be far older than the latest protrusions of the acid rocks.[1] In this manner it can be shown that the abundant north-west and south-east dykes of Antrim and the Inner Hebrides form part of the Tertiary volcanic phenomena.

This system of parallel dykes raises some interesting problems in the physics of the earth's crust. There must have been first formed a series of parallel fissures which, as they run in long straight lines through the most diverse kind of rocks and even without deviation across some of the most important faults in the country, must have been produced by enormous tension of the crust, connected doubtless with the upward pressure of a vast internal reservoir or series of reservoirs of molten rock. Into these fissures, which arose at successive epochs during the Tertiary volcanic period, the lava from beneath ascended, filling them from side to side, and cooling there as dykes. When we remember the vast area over which this process took place we must admit that, interesting as are the other volcanic phenomena of this geological period, the most striking feature is the existence of these great subterranean lakes of lava and the uprise of the material in so many thousands of fissures.

Whether any of these dykes succeeded in effecting a communication with the surface over the centre and south of Scotland or the north of England can probably never be ascertained, for any superficial outflow of material which may once have existed has apparently been entirely removed by denudation. But in the north of Ireland and in the long depression between the Outer Hebrides and

[1] *Op. cit.* p. 69.

the mainland of Scotland there was a copious outpouring of lava in numerous successive flows, until wide tracts of country were buried to a depth of sometimes more than 3000 feet. These lavas are generally dolerites and basalts, both with and without olivine, while some less basic varieties may be classed as andesites. They lie as outspread sheets from not more than 6 or 8 feet to 80 or 100 feet in thickness, showing sometimes a perfect columnar structure, sometimes weathering as dull greenish amygdaloids.

The fragmental rocks associated with these bedded lavas are comparatively insignificant in amount. They occasionally occur as well-marked bands of fine tuff separating the basalts, as in the well-known cliff-section at the Giants' Causeway. Elsewhere they appear as volcanic conglomerates or as coarse breccias, occasionally made up largely of non-volcanic materials. Of this last character are the remarkable breccias of Sgurr Dearg in Mull, which contain enormous masses of mica-schist, one such mass measuring 100 yards long by 30 yards wide.

Among the fine tuffs, and occasionally in cavities between two sheets of basalt, lenticular seams of lignite and even of true coal may be observed. From the detached leaves and fruits so well preserved in some of these tuffs and other associated deposits it is clear that the vegetation was terrestrial. The eruptions are thus recognized as subaerial. On successive lava-fields hollows arose in which water gathered, and into the pools and lakes thus formed leaves from the surrounding woodlands were blown or washed.

From the evidence of the fossil plants thus preserved, it may be inferred that the eruptions took place in older Tertiary time. Moreover, in some places the lowest basalts lie unconformably on Cretaceous rocks, or on conglomerate mainly made up of fragments of chalk and flints. Hence, both palæontological and stratigraphical evidence agree in indicating that the date of the volcanic outbursts of Antrim and the Inner Hebrides must be placed after the end of Mesozoic time.

Some of the vents of eruption whence these lavas were emitted can be detected on the plateaux and on the older rocks lying outside of them. They are less numerous than, for instance, those connected with the Carboniferous plateaux, though this comparative infrequency may be partly due to the fact that, save in Antrim, the geological structure of the ground has not yet been worked out in the same detail as the Carboniferous regions. Certain prominent bosses of basalt and dolerite rising out of the bedded basalts doubtless mark the sites of eruptive vents belonging to a late part of the volcanic period. Others filled with agglomerate may also be observed. Of these, the largest yet noticed occur outside of the basalt-plateaux. One of them, in Strath, Skye, has a diameter of more than two miles.

In none of the Palæozoic volcanic groups are the phenomena of the intrusive sheets or sills more conspicuously and instructively developed than in the Tertiary plateaux. These injected masses of rock may be observed throughout the whole region from the far north of Skye to the coast of Antrim, everywhere presenting the same essential characters, though varying much in number and thickness. Here and there they attain a prodigious development as regards the number of separate sills. This feature is more particularly to be noticed among the Jurassic strata underlying the base of the basalt-plateaux in the Inner Hebrides.[1] Elsewhere, though the sills are comparatively few in number, they attain a great thickness individually, as may be characteristically noticed in the great cliff of Fair Head in Antrim. These thicker masses present most interesting examples of segregation-veins and patches, wherein some of the component minerals have come together in coarse aggregates, the augite and magnetite being especially conspicuous. They likewise exhibit instances of the so-called 'contemporaneous veins,' where, into rents of the already consolidated rock, some of the still fluid portion has been injected. These structures are specially deserving of attention by students of the more ancient gneisses, wherein they may be paralleled with remarkably similar forms.

The material of these sills is usually dolerite, often olivine-bearing and with an ophitic structure. It is precisely the kind of rock we should expect to meet with if the basalt of the plateaux was injected among the rocks at some considerable depth from the surface, and was allowed to cool and consolidate there. The constant association of such sills with the base of the plateaux seems to link them with the volcanic operations that gave rise to these great outpourings of lava. Employing the same reasoning as that which has been made use of in regard to the records of the Palæozoic volcanic periods, we may infer that the Tertiary basic sills belong to a late part of the plateau-eruptions, when the overlying sheets of basalt had attained such a great aggregate thickness that it was easier for the volcanic magma to force its way between the planes of the Jurassic strata and the lower beds of basalt than to make a passage upward to the surface.

Besides the sills, the volcanic rocks of the Tertiary period of

[1] See, as illustrations of this structure in Trotternish, Skye, the figures in plate xvii. of the atlas accompanying Macculloch's 'Western Islands.'

volcanic activity include two other series of intrusive masses, one of a basic, the other of an acid nature. Through some of the basalt-plateaux rise huge bosses of olivine-gabbro and allied rocks. That these great piles of material are of later age than the bedded basalts around them is shown by the way in which the gabbro has been injected between and across the bedding of the basalts. They present remarkably coarse granitoid textures, and in many places segregations of the several component minerals, indicating the gradual cooling and crystallization of the rock at some considerable distance below the surface. No conclusive proof has yet been found that any of the gabbro bosses established a connexion with the surface and gave forth superficial ejections. They probably rose in some of the vents which had served as funnels for the outflow of the older plateau-basalts; but, instead of finding egress upward through the deep pile of volcanic sheets, they seem to have been thrust between the bedded lavas in the form of innumerable sills and veins. The structure thus produced was similar to that of the 'laccolites' of the Henry Mountains, so well described by Mr. Gilbert.[1] The central portions of the bosses remained mainly amorphous, and show now the coarsest texture. Owing to extensive denudation, the gabbro has had its cover of overlying rocks stripped off, and has been deeply trenched into corries and glens, between which the black rock mounts up into peaks and crests of singularly jagged and picturesque forms.

The other series of eruptive masses is strongly marked off from the gabbros alike in external form and internal composition. The rocks in it are thoroughly acid, ranging from a vitreous condition (pitchstone) through various trachytes, felsites, quartz-porphyries and granophyres into true granites. Most of them are intrusive. They occur in bosses, sills, and dykes or veins. As bosses they form in Skye extensive groups of conical mountains like the domite puys of Auvergne. Elsewhere they have been injected as sills between the bedding of the Jurassic rocks, as in Raasay and Strath, or in veins across the basalts of the plateaux and the gabbros. There can be no doubt that they are the last of all the Tertiary volcanic series, except the latest basalt-dykes which traverse them.[2]

[1] 'Geology of the Henry Mountains,' by G. K. Gilbert, U.S. Geographical and Geological Survey of the Rocky Mountain Region, 1877.

[2] An interesting corroboration of this sequence occurs in Iceland, where the granophyres likewise pierce the basaltic lavas: C. W. Schmidt, Zeitsch. Deutsch. Geol. Ges. vol. xxxvii. p. 738; Thoroldsen, Bihang t. Sv. Vet.-Akad. Handl. 14. ii. (1888), 17. ii. (1891); H. Bäckström Geol. Fören. Stockholm, Förhandl. vol. xiii. (1891) p. 637.

The uprise of these enormous domes of acid material is one of the most singular features in the geology of the Inner Hebrides. It has probably taken place partly through older vents, of which there are here and there some remains. Considerable alteration of the other volcanic rocks may be traced around the bosses, while the Cambrian (Lower Silurian) limestone through which they rise is changed into a white crystalline marble.

In Antrim the bedded basalts have been invaded by trachyte, but a band of tuffs intercalated between the upper and lower group of basalts consists mainly of trachyte débris, proving that trachytic rocks already existed at the surface, or were ejected in a fragmentary form before the later half of the basalts was poured out. In the Inner Hebrides, however, no evidence has yet been found that any of the granophyric puys established a connexion with the surface and generated superficial outflows of acid lavas.

One solitary instance is known of the discharge of an acid lava at the surface of the ground—that of the Scuir of Eigg. In this case we see that the basalt-plateau had been enormously denuded before the pitchstone of that famous hill was poured out into the eroded stream-channel in which it cooled and solidified. A long interval of time, therefore, elapsed between the cessation of the basalt streams of Eigg and the outflow of the pitchstone.

It is interesting to notice further that at least some, if not all, of the numerous basalt dykes of the Eigg plateau are older than the stream-channel, for they are cut off by the shingle of that channel. The uprise of these dykes consequently took place long before the outflow of the pitchstone. In this locality, therefore, the acid rock is the latest volcanic protrusion. Among the great granophyre bosses of Skye, on the other hand, though it can be proved that they are younger than a vast number of the basalt and andesite dykes, it is equally certain that a small number of dykes runs across them. In these cases the dykes are the most recent of the erupted masses. Yet, looking at the Tertiary sequence as a whole, we see that it illustrates the general law that the more basic eruptions preceded the more acid.

With the view of showing at a glance the stratigraphical position and leading petrographical characters of the volcanic zones in the geological history of the British Isles, as detailed in the present Address, the following generalized table is inserted.[1]

[1] Mr. B. N. Peach and Mr. J. Horne have recently found a band of tuff in the Torridon sandstone of Sutherland. The 'Torridonian' is therefore inserted in the table.

Table of the Periods of Volcanic Action in the British Isles.

	Granites, Granophyres, &c.	Felsites, Rhyolites, &c.	Pitchstone.	Trachytes.	Andesites (Porphyrites).	Gabbros.	Dolerites, Basalts (Diabases).	Picrites and highly basic lavas.	Tuffs, acid or basic.
Older Tertiary. (Plateaux, dykes, necks, bosses, sills)	*	*	*	*	*	*	*	*	*
Mesozoic. No volcanic rocks.									
Permian	...	*	...	...	...	...	*	*	*
Carboniferous	?								
Puy type........	...	*	...	...	*	...	*	*	*
Plateau type	...	*	...	*	*	...	*	*	*
Devonian	...	...	...	...	...	...	*	...	*
Old Red Sandstone.									
Upper	...	...	...	...	...	...	*	...	*
Lower	*	*	...	...	*	...	*	...	*
Silurian.									
Upper	...	*	...	...	...	...	...	...	*
Lower, Bala	*	*	...	...	*	*	*	*	*
„ Arenig	*	*	...	*	*	*	*	...	*
Cambrian	...	*	...	...	*	...	*	...	*
Uriconian	...	*	...	...	...	...	*	...	*
Dalradian	...	...	...	...	...	...	*	...	?
Torridonian	...	...	...	...	...	...	...	...	*
Lewisian	*	...	...	...	...	...	*	*	

Summary.

I am unwilling to add to the length of this already too long Address by offering a comparison of the phenomena which I have tried to portray to you with those which have been described in other countries. Nor do I propose to enter now upon a discussion of the theoretical questions arising out of the array of facts laid before you. My object has been to present a connected narrative of ascertained knowledge regarding the successive epochs of volcanic energy in this country, unencumbered with reference to regions beyond our immediate surroundings. But it will not, I hope, be deemed an inappropriate prolongation of my subject if, in conclusion, I attempt to place before you some of the facts of larger import and wider interest which such a narrative may be made to contribute towards the investigation of the nature of volcanic action.

1. In regard to the broad features of the distribution of volcanic action, it is important to remember the position of the British area along the western or oceanic border of the European continent. And when we look at the portions of that area which have been the scenes of volcanic activity, we observe how they follow a general linear north and south direction, parallel to the margin of the continental plateau. They are ranged along the greatest length of these islands, from the south of Devonshire to the far Shetlands. Yet east of a line drawn from Berwick to Exeter they cease to appear. All through the eastern portion of England, though the geological formations range from the Carboniferous Limestone to the latest Pleistocene deposits, and are abundantly exposed to view, no trace of volcanic rocks has been met with, unless we include in that category the various dykes of the northern counties. The recurrence of eruptions along the western, and their absence in the eastern tract, are two of the most obvious and striking facts in the history of volcanic action within our region.

2. Another not less remarkable feature is the persistence of volcanic activity within that western tract. I have brought before you the evidence which shows that from the primeval time vaguely termed Archæan, onward to that of the older Tertiary soft clays and sands of the south-east of England—that is to say, through by far the largest part of geological history, as chronicled in the stratified crust of the globe—this long strip of territory in the west of Europe continued to be intermittently a theatre of volcanic action. In the great divisions of Palæozoic and Tertiary time

which I have enumerated contemporaneous igneous rocks repeatedly occur, and in some of them on such a scale as to indicate prolonged and vigorous activity.

One conspicuous feature, however, in this long volcanic history is the entire absence of any evidence of eruptions during the whole of the Mesozoic periods. In this respect Britain only illustrates the general quiescence of volcanic energy over the European continent during that vast interval of geological time.[1]

3. Not only has there been a remarkable persistence of volcanic activity over the comparatively limited area of the British Isles, viewed as a whole, but if we examine the different parts of this area we perceive that many of them, of relatively restricted extent, have been the sites of a recrudescence of volcanic action again and again through a succession of geological periods. While the whole region has been in different quarters and at different times affected, there have been districts where the volcanic fires have been rekindled after long intervals of quiescence, the new vents being opened among or near to the sites of earlier volcanoes. In the south-west of England, for example, the tuffs and agglomerates of Cornwall (Meneage), probably of Caradoc age, were followed in Middle Devonian time by the outpouring of the Ashprington tuffs and diabases; these were succeeded in the Carboniferous period by the eruptions of the Culm Measures, and in the very same tracts came last of all the lavas and tuffs of the Permian conglomerates. Still more astonishing is the record of volcanic energy in the south of Scotland, where, within a space of not many hundred square miles, there are the chronicles of the Llandeilo eruptions of the Southern Uplands, the huge piles of porphyrites and tuffs of the Lower Old Red Sandstone, the long succession first of the plateaux and then of the puys of the Carboniferous period, the groups of tuff cones of the Permian period, and, lastly, the numerous dykes connected with the Tertiary volcanoes.

In this connexion it is well to notice that, besides areas specially liable to exhibitions of volcanic action, there have lain near to or among these areas others that seem to have remained continuously unaffected. Besides the non-volcanic eastern tract, already noticed, the Central Highlands of Scotland appear to have been exempt from volcanic eruption since the time of the metamorphism of their schists. In the wide spread of the Carboniferous rocks over the greater part

[1] The Triassic eruptions of the Continent were important, and traces of others are said to occur in the Cretaceous system in Portugal and Silesia.

of Ireland, volcanic rocks are absent except in the Limerick area, and over England in the same formations they are quite as rare.

4. The sites of volcanic vents in all the geological systems wherein they occur have not usually been determined by any obvious structure in the rocks now visible. They comparatively seldom depend on ascertainable lines of fault, even when faults, probably already existent, occur in their near neighbourhood. This independence, to which, however, there are occasional marked exceptions, comes out more particularly in the coal-fields pierced by vents, for there mining operations have revealed the positions of many more faults than can be traced at the surface. It may, of course, be asserted that the sites of the vents have been fixed by dislocations or lines of weakness in the terrestrial crust below the formations now visible at the surface. Such an assertion, however, though possibly well founded, does not seem capable of proof.

But there is one striking connexion between the sites of these vents and ancient topographical features to which I have several times adverted. All through the long volcanic history, as far back as such features can be traced, we see that orifices of discharge for the erupted materials have been opened along low grounds and valleys. The great central hollow of the Scottish midlands was a depression even as long ago as the time of the Lower Old Red Sandstone, and though it has probably been several times since then filled up, and more or less completely effaced, its ancient features have been partially revealed by extensive denudation. This vast depression, forty miles broad, between the Highland mountains on the one side and the Southern Uplands on the other, was the chief centre of volcanic activity in our region during the latter half of Palæozoic time. As I have shown, the vents of the Old Red Sandstone, Carboniferous, and Permian series are scattered all over it, but few or none of them are to be found on the high grounds that bound it. Again, in Tertiary time, the great outpouring of lava took place in the long hollow that lay between the ridge of the Outer Hebrides and the mainland of Scotland. But the most striking example of the way in which the vents keep to the valleys is that supplied by the Permian necks of Nithsdale and the neighbouring valleys. These depressions are as old as Permian, and even as Carboniferous time, but they appear to be entirely hollows of erosion, for they have yielded no evidence that their direction has been determined by lines of fault.

5. Looking at the broader features of volcanic action during the

Palæozoic ages in this country, we see clear evidence of a gradual diminution in its vigour. The widespread outpourings of lava and tuff in the Silurian period in England, Wales, Scotland, and Ireland were succeeded by the somewhat diminished, though still important, eruptions of the Lower Old Red Sandstone basins. The latter were followed by the still lessened outflows of the Carboniferous plateaux, which in turn preceded the yet feebler and more localized eruptions of the Carboniferous puys, the whole prolonged volcanic succession ending in the small scattered vents of the Permian period. There were of course oscillations of relative energy during this history, some of the maxima and minima being of considerable moment. But though progress towards extinction was not regular and uniform, it was a dominant feature of the phenomena.

6. The Permian volcanoes were the last of the long series, and, so far as we yet know, the whole of Mesozoic time within the area of Britain was absolutely unbroken by a single volcanic eruption. The chronological value of this enormous interval of quiescence may, perhaps, never be ascertainable, but the interval must assuredly cover a large part of geological time. The next eruptions were of older Tertiary date. They reproduced many of the characteristic features of Palæozoic vulcanism, and continued for a long time, measured according to our notions of chronology, but are not separable into clearly-defined periods like the Arenig and Bala volcanic rocks in the Silurian system or the plateaux and puys of the Carboniferous series. They form one great group which was probably begun and completed in older Tertiary time. Since they ceased, another interval of profound quiescence has succeeded, which still continues. But this interval is almost certainly of less duration than that which elapsed between the Palæozoic and Tertiary outbursts. In other words, remote as the date of those Tertiary volcanoes appears to be from our own day, it comes much nearer to us than did the era of the last Permian eruptions to the earliest of the Tertiary series.

7. Volcanic phenomena cannot be regarded as a mere isolated and incidental feature in the physics of the globe. During the short time within which man has been observing the operations of existing volcanoes he has hardly yet had sufficient opportunity of watching how far they can be correlated with other terrestrial movements. Nor, when he endeavours to trace some such connexion among the records of the geological past, has he yet collected materials enough to furnish a sufficiently broad and firm basis of

comparison. One formidable obstacle lies in the difficulty in determining chronological equivalents in separated groups of rock. Geologists have tried to determine whether the volcanoes of some particular period or region were in any way connected with such geological changes as extensive plication, dislocations of the crust, or elevation of mountain-chains. In regard to the volcanic history of Britain, various possible relations of this kind may be suggested; but nothing quite satisfactory has been determined.

The only fact that can be certainly affirmed is that our volcanoes have been active on sinking rather than on rising areas. We usually associate modern volcanic action with elevation, and there are certainly abundant proofs of such elevation around active or recently extinct volcanoes. It may be, however, that such uprise is merely a temporary incident, and that if we could survey the whole geological period of which human history chronicles so small a part, we might find that subsidence, and not upheaval, is ultimately the rule over volcanic areas. Be this as it may, there can be no question that with the one solitary exception of the Tertiary volcanoes, which were terrestrial and not submarine, all our vents were carried down and eventually buried under aqueous sediments. That they are now above sea-level is of course due to long subsequent movements not immediately connected with their original formation. The amount of subsidence which followed on a volcanic episode was sometimes enormous, even within the same geological period, as one may see by observing the prodigious piles of sedimentary material heaped over the Arenig lavas and tuffs. I do not wish to maintain that the downward movement was necessarily a consequence of the volcanic ejections, for we know that it took place over tracts remote from the centres of eruption. But I have sometimes asked myself whether it was not possibly increased as a sequel to vigorous volcanic action; whether, for instance, the great depth of the older Palæozoic sedimentary rocks in this country as compared with their development in other countries, and notably in Scandinavia, may not have been due to an acceleration of subsidence consequent upon volcanic action.

8. It appears to me that two types of volcanic manifestation may be recognized in the geological history of our region. In the first place there is the ordinary type of volcanic vents, with the local and limited outflowing lavas and often abundant ashes, as in the great series of Palæozoic eruptions. In the second place there is the type in which the formation of abundant fissures, and the uprise of lavas

in these, formed an important feature in the volcanic operations, culminating here and there in the opening of vents and the outflow of lava at the surface, with generally but little tuff. Of this second type we have only two illustrations in our geological history—that in the Archæan gneiss of the north-west Highlands, and that in the great system of Tertiary dykes in Scotland, the north of England, and the north of Ireland. In the Archæan area no trace remains of any superficial lavas, though the parallel dykes are so abundant; in the Tertiary series large sheets of the erupted lavas still remain in Antrim and the Inner Hebrides. It is curious that the first and the last igneous operations in this country should have been in some respects so much alike and so different from those which intervened between them.

9. The sequence of events from the beginning to the end of a volcanic period appears to have generally followed a well-defined order. In the case of the fissure-eruptions, vents seem to have been opened along the lines of some of the numerous dykes. In other cases, the communications with the surface were effected by successive explosions which finally blew out an orifice at the surface, with no visible relation to any fissures or dykes. Of course beneath the formations that now form the surface, and through which the necks rise, there may be lines of fault or weakness in older rocks which we cannot see. But, in what can be actually examined, the vents have commonly been drilled through rocks independently of faults.

The discharge of explosive vapours was sometimes the first and only effort of volcanic energy. Generally, however, fragmentary volcanic materials were ejected, or, if the eruption was more vigorous, lava was poured out. In a vast number of cases, especially in the later ages of Palæozoic time, only ashes were projected, and cones of tuff were formed. In the earlier ages, on the other hand, there was a much larger proportion of lava expelled. Towards the close of a volcanic period the vents were gradually choked up with the fragmentary materials that were ejected from and fell back into them. Occasionally, during the process of extinction, an explosion might still occur and clear the chimney, so as to allow of the uprise of a column of molten rock which solidified there; or the sides of the crater as well as of the cavernous funnel underneath fell in and filled up the passage. Heated vapours sometimes continued to ascend through the débris in the vent, and to produce on it a marked metamorphism.

There seems to have been commonly a contraction and subsidence of the materials in the vents, with a consequent dragging down or sagging of the rocks immediately outside, which are thus made to plunge steeply towards the necks.

When the vents were plugged up by the consolidation of fragmentary matter or the uprise of lava in them, the final efforts of the volcanoes led to the intrusion of sills and dykes not only into the rocks beneath the volcanic sheets, but also in many instances into at least the older parts of the sheets themselves. These subterranean manifestations of volcanic action may be recognized in almost every district. They vary greatly in the degree to which they are developed. Sometimes, as in the Cader Idris, Arenig, and Snowdon regions, they attain an extraordinary importance, alike as regards the number of the sheets and the thickness of some of these. In other cases they are exhibited on so small a scale that they might be overlooked, as in the tract of Carboniferous puy-eruptions in the north of Ayrshire. But they are so generally present as to form a remarkably characteristic feature of our volcanic districts.

It is obvious that the time of intrusion of the sills cannot be precisely determined. They were not likely to be injected at an epoch when the volcanic magma could find egress to the surface. That they did not arise before such egress was obtained may be inferred (1st) from their petrographical characters, which are usually those of the later and not of the earlier outflows of the magma; and (2nd) from the fact that they not only lie among the rocks below the volcanic series, but intersect the lower parts of that series, sometimes even the higher parts. We may therefore, with every probability, regard the sills as among the closing phases of a volcanic period.

10. The vertical thickness of volcanic material erupted during a volcanic period shows, on the whole, a progressive decrease during Palæozoic time. In the earlier ages vast piles of lavas and tuffs 5000 or 6000 feet in thickness were frequently heaped up, while in later ages the accumulations seldom reached a tenth part of that amount.

By the intercalation of the volcanic sheets among ordinary sedimentary strata, a definite beginning and end to the eruptions are marked. We see exactly where in the stratigraphical series the first showers of ashes fell, and where the last mingled with the ordinary sand and mud of the sea-floor. The same record shows that the volcanic accumulations were finally washed down, that they subsided with the rest of the ground around them, and that usually they were buried under overlying conformable sedimentary deposits. Thus cones of ashes and lava which may have been several thousand feet high completely disappeared.

11. If we consider the nature and composition of the volcanic materials so abundantly distributed in the British Isles, we may deduce some conclusions of much interest in relation to the changes which take place in the molten magma whence these materials proceed. I have shown that it is sometimes possible to observe a notable difference in mineralogical and chemical composition between two adjacent parts of the same mass of lava. In the Blackburn picrite, for example, there has been a separation of the heavy basic constituents, which have largely settled below, while the lighter felspar has mainly come to the top.

What can be shown to have taken place on a small scale in one erupted sheet must always have been tending to occur in the main mass of the magma itself, when the conditions for separation were favourable. If we reflect upon the sequence which I have described as so generally to be found in the petrographical characters of the successively erupted materials, we may, it seems to me, detect the proofs of a remarkable series of changes in the composition of the magma during a volcanic period.

With the important exception of the Snowdonian region and possibly others, we find that the earlier eruptions of each period were generally most basic, and that the later intrusions were most acid. Thus the diabase-lavas and tuffs at the base of the Cambrian series of St. David's are pierced by quartz-porphyry veins. The porphyrites of the Lower Old Red Sandstone were succeeded by bosses, sills, and dykes of granite, felsite, and lamprophyre. The eruptions of the Carboniferous plateaux began with extremely basic lavas, and ended with thoroughly acid felsites and quartz-porphyries. The basalts of the great lava-fields of the Tertiary period are pierced by masses of granophyre and even granite.

There has evidently been a progressive diminution in the quantity of bases and a corresponding increase in the amount of acid in the lavas erupted during the lapse of one volcanic period. This sequence is so well-marked and so common that it cannot be merely accidental. The acid and basic rocks, occurring as they do at each volcanic centre in the same relation to each other, are obviously parts of one connected series of eruptions. We seem to see in this sequence an indication of what was taking place within the magma. Apart altogether from gravitation, there was first an extensive separation of the more basic constituents, such as the ferro-magnesian minerals and ores, and the lavas which came off at that time were heavy and basic basalts, and even picrites. The removal of these elements left the magma more acid, and such rocks as andesites were poured out, until at last the deeper intrusive sills, dykes, and bosses became thoroughly acid rocks, such as felsite, quartz-porphyry, and granite, while if any superficial outflow took place it was such a rock as pitchstone. It is not my purpose at present to discuss the probable cause of this order of appearance, but to endeavour to lay a basis of ascertained facts on which the discussion may proceed.

12. A further interesting fact appears from the volcanic history which we have been tracing. On the whole, we may say that each eruptive period witnessed the same sequence of change from basic to acid lavas. And as the successive protrusions took place within the same circumscribed region, it is evident that in some way or other, during the long interval between two periods, the internal magma was renewed as regards its constitution, so that when eruptions again occurred they once more began with basic and ended with acid materials. This cycle of transformation is admirably exhibited in Central Scotland, where the porphyrites of the Old Red Sandstone with their felsite sills are followed by the basic lavas of the Carboniferous plateaux, succeeded in turn by the porphyrites, trachytes, and acid sills of that series. When the puy eruptions ensued, the magma had once more become highly basic.

That the true explanation of these alternations is of a complex order may be inferred from the exceptions which occur to the general rule. I have alluded to the Snowdon region, where the acid rhyolites are followed by more basic andesites, and there the sills are also more basic than the superficial lavas. In the Arenig and Cader Idris country the sills are likewise more basic than the bedded lavas. Among the Carboniferous puys of the basin of the Firth of Forth, the sills are not sensibly more acid than many of the superficial basalts, and they even include such rocks as picrite. Possibly in this last-named region we see an arrested sequence, the volcanic protrusions having for some cause ceased before the general uprise of the more acid magma.

13. There is one final group of facts which seems to me deserving of attention. In the great sills and bosses, particularly those of basic composition, the so-called 'contemporaneous veins' are of

frequent occurrence. These are usually more acid than the rock which they traverse, and they sometimes exhibit a well-defined granophyric structure. There can hardly be any doubt that they represent the still fluid and somewhat acid parts of the mass, which owing to internal movements were injected into portions that had already consolidated. But there is still another kind of vein to be found in some of the larger basic intrusive masses, where there has been a segregation of the constituent minerals along certain indefinite bands or lines, sometimes wavy or puckered. Pyroxene and magnetite, for example, may be found aggregated into layers or lumps which merge insensibly into the substance of the surrounding rock. In such instances there does not appear to have been any intrusion of one part of the mass into another, but rather a separation of some of the basic minerals along more or less well-defined planes, or round particular centres.

Both these structures in our eruptive rocks appear to me to be deserving of much more careful investigation than they have yet received.[1] An exhaustive study of them could hardly fail to throw light upon the changes which take place within the volcanic magma by the separation of its constituent minerals. On the other hand, it would bear closely on the origin of structures in the more ancient gneisses, which appear rather to belong to some segregation or rearrangement in an original igneous mass than to any subsequent mechanical or other metamorphism.

It only remains for me now in conclusion to express again my thanks to you for the honour which you conferred upon me two years ago by electing me to be President of this distinguished Society, and for the uniform kindliness and helpfulness which have been shown to me on every hand during my tenure of office. In vacating the Chair I am happy to think that in my successor you welcome a man who to the lustre of his scientific reputation adds this further and valuable qualification, that he has already served you for many years as Secretary, and is thus intimately acquainted with the conduct of your affairs.

[1] The recent elaborate investigations of J. H. L. Vogt on the iron-ore deposits of Scandinavia may be referred to in this connexion: Geol. Fören. Stockholm, Förhandl. vol. xiii. (1891) p. 476, and Mr. Teall's review, Geol. Mag. for 1892, p. 82.

February 24th, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

William James Eames Binnie, Esq., B.A. Cantab., C.E., 14 Campden Hill Gardens, W., was elected a Fellow; and Prof. Gustav Lindström, Stockholm, a Foreign Member of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1 "The Raised Beaches, and 'Head,' or Rubble-Drift, of the South of England: their Relation to the Valley-Drifts and to the Glacial Period; and on a late post-Glacial Submergence.—Part II." By Joseph Prestwich, D.C.L., F.R.S., F.G.S.

2. "The Pleistocene Deposits of the Sussex Coast, and their Equivalents in other Districts." By Clement Reid, Esq., F.L.S., F.G.S. (Communicated by permission of the Director-General of the Geological Survey.)

The following specimens were exhibited:—

Specimens from the Pleistocene Deposits of the Sussex Coast, exhibited by Clement Reid, Esq., F.L.S., F.G.S., in illustration of his paper, by permission of the Director-General of the Geological Survey.

March 9th, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Dugald Bell, Esq., 27 Lansdowne Crescent, Glasgow, and Joseph Leese, Esq., B.A., 74 Walmersley Road, Bury, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "The New Railway from Grays Thurrock to Romford: Sections between Upminster and Romford." By T. V. Holmes, Esq., F.G.S.

2. "The Drift Beds of the North Wales and Mid-Wales Coast." By T. Mellard Reade, Esq., C.E., F.G.S.

[Withdrawn.]

This paper is a continuation of papers by the Author on the Drift Beds of the N.W. of England and North Wales. The Author first treats of the Moel Tryfaen and other Caernarvonshire drifts; he describes the drifts of the coast and coastal plain, connecting his observations with those of the Moel Tryfaen drifts. The numerous mechanical analyses of the various clays, sands, and gravels form an important feature of the investigation. In all the samples but one, a large proportion of extremely rounded and polished quartz-grains have been found, which the Author maintains to be true erratics, and a certain sign of marine action. He shows that the Moel Tryfaen marine sands are in part overlain by typical till, composed almost wholly of local rocks with a small percentage of clay, whereas the sands and gravels are full of erratics including rocks from Scotland and the Lake District, numerous flints, Carboniferous Limestone, and crystalline schists. Throughout the drifts of the coastal plain he has found a greater or less proportion of granite erratics, as well as, in many cases, minute rolled shell-fragments. He maintains that these drifts are the result of two opposing forces, one radiating from Snowdonia, and the other acting from the sea to the southwards, and their characteristics change as the one or the other force preponderated.

The other divisions of the paper are taken up with a description of the Merionethshire drift and that of Mid-Wales, numerous sections being given. Attention is called to a remarkable glaciation of the rocks at Barmouth.

In a concluding part, giving inferences and suggestions, the Author discusses the land-ice and submergence hypotheses, and concludes that his observations distinctly strengthen the grounds for believing in a submergence of the land to an extent of not less than 1400 feet.

An Appendix contains details of nineteen mechanical analyses of tills, sands, and gravels, and a bibliography of papers, observations, and theories of the high-level drifts of Moel Tryfaen.

Discussion.

Mr. Lamplugh said that it did not seem to him necessary to suppose, as was often done, that the shelly gravels of Moel Tryfaen had been taken up by the ice-sheet in their present form and transported bodily. On the East coast there was convincing evidence that portions of the floor over which the ice moved had been caught up and carried forward to higher levels. Masses of Secondary rocks had frequently been transported in this manner, as well as portions of the sea-bottom. Under these conditions it was no more surprising that we should find shells intermingled with the detritus derived from the washing of the glacier, than that we should find, as in other instances, large numbers of well-preserved Secondary fossils. As for the sand-grains, if these are marine, any explanation which accounted for the shells would account for these also. He was inclined to think, however, that these rounded and highly-polished grains may have been derived from coastal sand-dunes which the ice had over-ridden—as in Yorkshire, where blown sands are seen to be cut out by the Boulder Clay.

Mr. J. W. Gregory understood that Mr. A. C. Nicholson no longer attached any value to the *Cardiniæ* and other Jurassic fossils from the Gloppa drifts (which had been alluded to by another speaker), these being of quite different preservation from the other fossils. They appear to have been introduced by the workmen, from whom they were obtained. But other evidence of glacial elevation in the area is available; thus, in the south of the Isle of Man, boulders of granite from Granite Mountain have been carried to the summit of South Barrule, a rise of over 800 feet in 1½ mile. He suggested that the alternation of beds with eastern erratics with those containing northern erratics migh be explained as due to differential flow in the glacier.

Mr. H. W. Burrows remarked that, since the Moel Tryfaen fauna was of a mixed character, there would appear to be considerable difficulty in accepting the theory advanced by Mr. Lamplugh. We should rather expect to find a comparatively pure fauna, if the shelly bed were the result of the washing of a glacier that had carried part of the sea-bottom over which it had travelled.

The President said the absent Author would learn that the engineer had been hoist with his own petard, since the earlier speakers considered he had supplied important facts in contradiction of his own conclusions. Whether we accepted the 'ice-shore' theory or the 'subsidence' theory, either drew largely on our faith, though these highest-level Drift-gravels had to be accounted for somehow. There was no difficulty in believing in the presence of two totally independent sources of supply, which might, to a certain extent, have acted synchronously. In the case mentioned by Mr. Whitaker it should be remembered that the lift by ice did not exceed 250 feet, whilst in the case of Flamborough the lift was not more than 400 feet [Mr. Lamplugh claimed that it might be more if the depth of the sea were added]. Whether they agreed or disagreed with the Author's conclusions, the thanks of the Meeting were due to him for a paper which had led to so interesting a discussion.

Messrs. Percy F. Kendall, J. E. Marr, C. Reid, R. Etheridge, W. Whitaker, and Prof. H. G. Seeley also spoke.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by T. Mellard Reade, Esq., C.E., F.G.S., in illustration of his paper.

Specimens of striated Chalk and Kimeridge Clay, exhibited by T. V. Holmes, Esq., F.G.S., in illustration of his paper

Specimen of glaciated Chalk-flint from the Boulder Clay, Finchley, exhibited by Horace B. Woodward, Esq., F.G.S.

Human skull found below silt and clay, and just above peat, in a section on the Manchester Ship Canal, exhibited by W. J. E. Binnie, Esq., F.G.S.

March 23rd, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

Theodore Gervase Chambers, Esq., Assoc.R.S.M., Goizueta, Navarra, por Irun, Spain; Walter D. Crick, Esq., 7 Alfred Street, Northampton; and William Marshall, Esq., Ashbourne, Ashfield, Sydney, New South Wales, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Occurrence of the so-called *Viverra Hastingsiæ* of Hordwell in the French Phosphorites." By R. Lydekker, Esq., B.A., F.G.S.

2. "Note on two Dinosaurian Foot-bones from the Wealden." By R. Lydekker, Esq., B.A., F.G.S.

3. "On the Microscopic Structure, and Residues insoluble in Hydrochloric Acid, in the Devonian Limestone of South Devon." By Edward Wethered, Esq., F.G.S., F.C.S., F.R.M.S.

The following specimens were exhibited:—

Specimens exhibited by R. Lydekker, Esq., B.A., F.G.S., in illustration of his papers.

Microscopic specimens and photographs, exhibited by E. Wethered, Esq., F.G.S., F.C.S., F.R.M.S., in illustration of his paper.

April 6th, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. "Geology of the Gold-bearing Rocks of the Southern Transvaal." By Walcot Gibson, Esq., F.G.S.

2. "The Precipitation and Deposition of Sea-borne Sediment." By R. G. Mackley Browne, Esq., F.G.S.

[Abstract.]

The Author discusses the mode of deposition of current-borne sediment upon the ocean-floor, and considers the effects of current-action in sifting the material and causing it to accumulate into stratified linear ridges having directions generally parallel with those of the currents—the dip of the strata varying according to the velocity of the currents. He considers that the conclusions deducible from his analysis appear to be in accord with the evidence afforded by the structure of ancient subaqueous sedimentary deposits.

Discussion.

Prof. Seeley and Prof. Hull spoke, and the Author replied to their observations.

April 27th, 1892.

Prof. J. W. Judd, F.R.S., Vice-President, in the Chair.

Arthur Frank Bowker, Esq., Halling Cottage, near Rochester, was elected a Fellow; and Dr. J. Lehmann, Kiel, and Prof. G. H. Williams, Baltimore, U.S.A., were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The Chairman announced that the Organizing Committee of the International Geological Congress have arranged to convene the sixth meeting of the Congress at Zürich, about the commencement of September 1894. Any communications should for the present be addressed to Prof. E. Renevier, University, Lausanne.

Prof. W. C. Williamson, F.R.S., exhibited the following specimens:—

Slab of Carboniferous Limestone from Bolland, illustrating the passage of a foraminiferal ooze into crystalline calcite;

Asteropecten Orion, Forbes, from the Kellaways Rock, near Pickering, Yorkshire;

and made the following remarks:—

The specimen before me is a slab of Carboniferous Limestone from the Bolland district of West Yorkshire. In its centre is a magnificent section of a large Nautilus—beautiful as a fossil, but still more important because of what it teaches. Its large terminal chamber is filled with foraminiferal ooze, the component objects of which are almost as perfect as when the organisms were living. The surrounding limestone is chiefly in an amorphous state; but it contains innumerable evidences that it also consists of foraminiferal ooze, largely reduced to the amorphous state by the agency of carbonic acid, now known to be so abundant in the depths of the ocean. The action of this acid upon the minute calcareous shells necessarily converted the water into a solution of carbonate of lime. In this state it percolated by osmosis through the shell of the Nautilus, penetrating its closed chambers, which it gradually filled with calcareous spar. The specimen is thus an epitome, within its limited area, of what has taken place on a gigantic scale in the deep sea. We have here first the organic mass, next its conversion into amorphous limestone, and lastly the production of the crystalline state of the same, so frequently seen filling the interiors of fossils.

The second object is the original type-specimen of Forbes's *Asteropecten Orion*, from a sandstone bed of the Kellaways Rock in the neighbourhood of Pickering, in Yorkshire. This starfish had lived upon and became buried in a sandy matrix which contained no lime. When the rock was split open, the space originally occupied by the starfish was hollow; for the sand contained no soluble material, like that which filled the chambers of the Nautilus. But in the lowest beds of the Coralline Oolite at Filey Brigg, on the Yorkshire coast, we long ago found another species of starfish, closely allied to the Pickering species. This was embedded in calcareous stone, which had once in all probability been foraminiferal ooze, and the processes which filled the chambers of the Nautilus also filled the cavity left by the decay of the starfish with crystalline carbonate of lime.

These specimens, studied collectively, illustrate two of the most important and common of the processes by which the mineralization of fossil remains has been effected.

The following communications were read:—

1. "Notes on the Geology of the Northern Etbai or Eastern Desert of Egypt; with an Account of the Emerald Mines." By Ernest A. Floyer, Esq., F.L.S., F.G.S.

2. "The Rise and Fall of Lake Tanganyika." By Alex. Carson, Esq., B.Sc. (Communicated by R. Kidston, Esq., F.R.S.E., F.G.S.)

May 11th, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The PRESIDENT announced that a bust of the late Sir Charles Lyell had been presented to the Society by Mrs. Katherine Lyell, through the intermediary of Prof. J. W. Judd, F.R.S., V.P.G.S.

The following communications were read:—

1. "On the so-called 'Gneiss' of Carboniferous age at Guttannen (Canton Berne, Switzerland)." By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.

2. "On the Lithophyses in the Obsidian of the Rocche Rosse, Lipari." By Prof. Grenville A. J. Cole, F.G.S., and Gerard W. Butler, Esq., B.A., F.G.S.

The following specimens were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., in illustration of his paper.

Rock-specimens and microscopic sections, exhibited by Prof. G. A. J. Cole, F.G.S., and G. W. Butler, Esq., B.A., F.G.S., in illustration of their paper.

Specimen of precious Opal from Queensland, exhibited by the President.

May 25th, 1892.

W. H. HUDLESTON, Esq., M.A., F.R.S., President, in the Chair.

The Rev. John Edward Shephard, Mountford Lodge, Barnsbury Square, N., was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On *Delphinognathus conocephalus* (Seeley) from the Middle Karoo Beds, Cape Colony, preserved in the South-African Museum, Capetown." By Prof. H. G. Seeley, F.R.S., F.G.S.

2. "On Further Evidence of *Endothiodon bathystoma* (Owen) from Oude Kloof, in the Nieuwveldt Mountains, Cape Colony." By Prof. H. G. Seeley, F.R.S., F.G.S.

3. "On the Discovery of Mammoth and other Remains in Endsleigh Street, and on Sections exposed in Endsleigh Gardens, Gordon Street, Gordon Square, and Tavistock Square, London." By Henry Hicks, M.D., F.R.S., Sec. G.S.

4. "The Morphology of *Stephanoceras zigzag*." By S. S. Buckman, Esq., F.G.S.

The following specimens were exhibited:—

Specimens of *Endothiodon bathystoma* and of *Delphinognathus conocephalus*, exhibited by Prof. H. G. Seeley, F.R.S., F.G.S., in illustration of his papers.

Specimens of Mammoth and other Remains found in Endsleigh Street, &c., exhibited by Dr. Henry Hicks, F.R.S., Sec. G.S., in illustration of his paper.

Specimens exhibited by S. S. Buckman, Esq., F.G.S., in illustration of his paper.

June 8th, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

William B. Scott, Esq., Professor of Geology in the University of Princeton, New Jersey, United States of America; Thomas Quintrell, Esq., Chief Inspector of Diamond Mines, Kimberley, South Africa; and Alexander Leslie, Esq., C.E., 5 Douglas Gardens, Edinburgh, were elected Fellows of the Society.

The names of certain Fellows were read out for the first time, in conformity with the Bye-laws, Section VI. Article 5, in consequence of the non-payment of arrears of contributions.

The List of Donations to the Library was read.

The President announced that the Accounts of the London Meeting (1888) of the International Geological Congress have now been made up, and there is found to be a deficit of £36. As this amount, if not raised otherwise, will require to be paid by the Members of the Executive Committee, it is suggested that the Fellows of the Geological Society be invited to assist them in clearing off the debt. Communications to be addressed to the Assistant-Secretary.

The following communications were read:—

1. "The Tertiary Microzoic Formations of Trinidad, West Indies." By R. J. Lechmere Guppy, Esq. (Communicated by Dr. H. Woodward, F.R.S.)

2. "The Bagshot Beds of Bagshot Heath (a Rejoinder)." By the Rev. A. Irving, D.Sc., F.G.S.

3. "Notes on the Geology of the Nile Valley." By E. A. Johnson Pasha and H. Droop Richmond, Esq. (Communicated by A. Norman Tate, Esq., F.G.S.)

The following specimens were exhibited:—

Specimens of deposits in Trinidad, exhibited by R. J. Lechmere Guppy, Esq., in illustration of his paper.

Microscopic preparations of specimens of Trinidad Rocks, exhibited by Dr. G. J. Hinde, F.G.S.

Marine Fossils from the Lower Bagshot Sands, Goldsworthy, near Woking, exhibited by R. S. Herries, Esq., F.G.S.

Photographs of recent Fumaroles in New Lavas of Vesuvius, photographed and exhibited by Dr. H. J. Johnston-Lavis, F.G.S.

June 22nd, 1892.

W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair.

James Fenn Clark, Esq., Clent House, Beauchamp Square, Leamington, was elected a Fellow of the Society.

The following names of Fellows of the Society were read out for the second time, in conformity with the Bye-laws, Section VI. Art. 5, in consequence of the non-payment of arrears of contributions:—

R. N. Boyd, Esq.; J. S. Crawford, Esq.; E. Easton, Esq.; M. W. B. Ffolkes, Esq.; H. Glenny, Esq.; D. G. H. Gordon, Esq.; Rev. G. W. James; C. Lane, Esq.; J. Martin, Esq.; Mirza Mehdy Khan; J. C. B. P. Seaver, Esq.; A. Simons, Esq.; J. Stirling, Esq.; H. Stopes, Esq.; and the Rev. H. A. Williams.

The List of Donations to the Library was read.

The following communications were read:—

1. "Contribution to a Knowledge of the Saurischia of Europe and Africa." By Prof. H. G. Seeley, F.R.S., F.G.S.

[Withdrawn.]

The Saurischia are defined as terrestrial unguiculate Ornithomorpha, with pubic bones directed downward, inward, and forward to meet in a ventral union. The forms of the pelvic bones vary with the length of the limbs, the acetabulum becoming perforate, the ilium more extended, the pubis and ischium more slender, and the sacrum narrower as the limb-bones elongate. The order is regarded as including the Cetiosauria, Megalosauria, and Aristosuchia or Compsognatha.

The Cetiosaurian pelvis has been figured in the Quart. Journ. Geol. Soc.; and a restoration is now given of the pelvis in *Megalosaurus*, *Streptospondylus*, and *Compsognathus*.

The characters of the skull are evidenced by description of the hinder part of the skull in *Megalosaurus* found at Kirtlington, and preserved in the Oxford University Museum. In form and proportions it closely resembles *Ceratosaurus*, and the corresponding region of the head in Jurassic Ornithosauria. The brain-cavity and cranial nerves are described, and contrasted with those of *Ceratosaurus*.

The skull in Cetiosauria, known from the American type *Diplodocus*, is identified in the European genus *Belodon*, which is regarded as a primitive Cetiosaurian.

Part 2 discusses the pelvis of *Belodon*, restored from specimens in the British Museum, and regarded as Cetiosaurian. A restoration of the shoulder-girdle is made, and found to resemble that in Ichthyosaurs, Anomodonts, and Dinosauria. The vertebræ in form and articulation of the ribs are Saurischian, the capitular and tubercular facets being vertical in the dorsal region, and not horizontal as in Crocodiles. The humerus shows some characters in common with that of *Stereorachis dominans*, in the epicondylar groove. In general character the limb-bones are more Crocodilian than the axial skeleton. The interclavicle is described, and regarded as a family characteristic of the Belodontidæ.

In the 3rd part an account is given of *Staganolepis*, which is regarded as showing a similar relation with the Megalosauria, to that of *Belodon* with the Cetiosauria. This interpretation is based chiefly upon the identification of the pubic bone in *Staganolepis*, which has the proximal end notched as in *Zanclodon* and *Streptospondylus*; and the inner ridge at the proximal end is developed into an internal plate. A note follows on the pelvis of *Aëtosaurus*, which is also referred to the Saurischia on evidence of its pelvic characters, approximating to the Cetiosaurian sub-order.

Part 4 treats of *Zanclodon*, which is regarded as closely allied to *Massospondylus*, *Euskelesaurus*, and *Streptospondylus*. It is founded chiefly on specimens in the Royal Museum at Stuttgart, and in the University Museum at Tübingen. The latter are regarded as possibly referable to *Teratosaurus*, but are mentioned as *Zanclodon Quenstedti*. The pelvis is described and restored. *Zanclodon* has the cervical vertebræ relatively long, as compared with *Megalosaurus*, and small as compared with the dorsal vertebræ, which have the same Teleosauroid mode of union with the neural arch as is seen in *Streptospondylus* and *Massospondylus*. The sternum, of Pleininger, is the right and left pubic bones; but there is much the same difference in the proximal articular ends of those bones in the fossils at Stuttgart and Tübingen, as distinguishes corresponding parts of the pubes in *Megalosaurus* and *Streptospondylus*. The ilium is more like that of *Palæosaurus* and *Dimodosaurus*. The limb-bones and digits are most like those of *Dimodosaurus*, but the teeth resemble *Palæosaurus*, *Euskelesaurus*, *Megalosaurus*, and *Streptospondylus*.

Part 5 discusses *Thecodontosaurus* and *Palæosaurus* upon evidence from the Dolomitic Conglomerate in the Bristol Museum. An attempt is made to separate the remains into those referable to *Thecodontosaurus* and those belonging to *Palæosaurus*. The latter is represented by dorsal and caudal vertebræ, scapular arch, humerus, ulna, metacarpals, ilium, femur, tibia, fibula, metatarsals, and phalanges. These portions of the skeleton are described. There is throughout a strong resemblance to *Zanclodon* and other Triassic types. A new type of ilium and the humerus originally figured are referred to *Thecodontosaurus*.

Part 6 gives an account of the South African genus *Massospondylus.* It is based partly upon the collection from Beaucherf, in the Museum of the Royal College of Surgeons, referred to *M. carinatus*; and partly upon a collection from the Telle River, obtained by Mr. Alfred Brown of Aliwal North, referred to *M. Browni.* The former is represented by cervical, dorsal, sacral, and caudal vertebræ; ilium, ischium, and pubis; femur, tibia; humerus, metatarsals, and phalanges. The latter is known from cervical, dorsal, and caudal vertebræ, femur, metatarsals, and bones of the digits. The affinities with *Zanclodon* are, in some parts of the skeleton, stronger than with *Euskelesaurus.*

Part 7 gives an account of *Euskelesaurus Browni,* partly based upon materials obtained by Mr. Alfred Brown from Barnards Spruit, Aliwal North, and partly on specimens collected by the Author, with Dr. W. G. Atherstone, Mr. T. Bain, and Mr. Alfred Brown, at the Kraai River. The former series comprises the maxillary bone and teeth, vertebræ, pubis, femur, tibia and fibula, phalanges, chevron bone and rib. The latter includes a cervical vertebra and rib, and the lower jaw. The teeth are stronger than those of *Teratosaurus,* or any known Megalosaurian. The anterior part of the head was compressed from side to side, and the head in size and form like *Megalosaurus,* so far as preserved. The pubis is twisted as in *Staganolepis* and *Massospondylus,* with a notch instead of a foramen at the proximal end, as in those genera; and it expands distally after the pattern of *Zanclodon.* The chevron bones are exceptionally long, and the tail appears to have been greatly elongated. The femur is intermediate between *Megalosaurus* and *Palæosaurus,* but most resembles *Zanclodon* and *Massospondylus.* The tibia in its proximal end resembles many Triassic genera; and in its distal end is well distinguished from *Massospondylus* by its mode of union with the astragalus. The claw-phalanges are convexly rounded, being wider than is usual in Megalosauroids. The lower jaw from the Kraai River gives the characters of the articular bone, and the articulation, as well as of the dentary region and teeth. The cervical vertebra is imperfect, but is remarkable for the shortness of the centrum, being shorter than in *Megalosaurus.*

In Part 8 an account is given of *Hortalotarsus skirtopodus* from Barkly East, preserved in the Albany Museum. It is an Euskelesaurian, and exhibits the tibia and fibula, and tarsus. There is a separate ossification for the intermedium, which does not form an ascending process; and the astragalus is distinct from the calcaneum. The metatarsals are elongated, and the phalanges somewhat similar to those of *Dimodosaurus.*

Part 9, in conclusion, briefly examines the relations of the Saurischian types with each other, and indicates ways in which they approximate towards the Ornithosauria. It is urged that the Ornithosauria are as closely related to the Saurischia as are the Aves to the Ornithischia; and that both divisions of the Saurischia approximate in *Staganolepis* and *Belodon.* Finally, a tabular statement is given of the distribution in space and time of the 25 Old-World genera which are regarded as probably well established. Eight of these are referred to the Cetiosauria, thirteen to the Megalosauria, and four to the Aristosuchia or Compsognatha.

2. "Mesosauria from South Africa." By Prof. H. G. Seeley, F.R.S., F.G.S.

3. "On a new Reptile from Welte Vreden, *Eunotosaurus africanus* (Seeley)." By Prof. H. G. Seeley, F.R.S., F.G.S.

Discussion.

The President observed that there could be no question as to the great value of these papers, the first of which especially was the outcome of years of experience and study on the part of the Author. It was only right to remark that the paper on Saurischia was received by the officers of the Society early in *April*. Since that date Prof. Marsh, in his Notes on Triassic Dinosauria (which did not appear till *May* 24th), had published, as regards *Zanclodon*, conclusions similar to those at which the Author (Prof. Seeley) had already arrived.

Mr. E. T. Newton also spoke.

Prof. Seeley drew attention to a photograph of *Hortalotarsus*, a reproduction of a sketch made at Barkly East, before the original specimen had been destroyed in the process of blasting the rock.

4. "The Dioritic Picrite of White Hause and Great Cockup." By J. Postlethwaite, Esq., F.G.S.

5. "On the Structure of the American Pteraspidian, *Palæaspis* (Claypole), with Remarks on the Family." By Prof. E. W. Claypole, B.A., D.Sc., F.G.S.

6. "Contributions to the Geology of the Wengen and St. Cassian Strata in Southern Tyrol." By Miss Maria M. Ogilvie, B.Sc. (Communicated by Prof. C. Lapworth, LL.D., F.R.S., F.G.S.)

7. "Notes on some New and Little-known Species of Carboniferous *Murchisonia*." By Miss Jane Donald. (Communicated by J. G. Goodchild, Esq., F.G.S.)

8. "Notes from a Geological Survey in Nicaragua." By J. Crawford, Esq., Geological Surveyor to the Nicaraguan Government. (Communicated by Prof. J. Prestwich, LL.D., F.R.S., F.G.S.)

[Abstract.]

The Author states that Nicaragua, geologically considered, can be divided, from north to south, into five zones, differing from one another in lithological, mineralogical, and structural characters.

The first division embraces the central mountainous parts, and contains Laurentian, Taconian, Cambrian, and Silurian rocks, also Devonian rocks unconformable to the last. The second division, parallel to that just named, and extending to within a hundred miles of the Caribbean Sea, contains sediments of Carboniferous,

Permian, and Mesozoic ages, covered unconformably by Cainozoic and modern formations. In some of the rivers of this division are rich gold-placers. The third division is the delta on the eastern coast. Evidence furnished by alluvial deposits and coral-reefs indicates recent subsidence until a few years ago, when elevation commenced. The fourth division is on the western side of the first (central) division. Its rocks are generally similar to those of the second division. In some places dykes are connected with lava-flows. In the valley of the Rio Viejo is a Tertiary mammaliferous deposit with Tillodonts, &c. The fifth division occupies Western Nicaragua, and contains several small crater-lakes of the Vicksburg, Yorktown, and Sumter periods; all the post-Mesozoic Nicaraguan volcanoes are in this division.

Details of the economic products, the volcanic phenomena, and the glaciation of the country are furnished, and the remains of Neolithic man are recorded.

9. "Microzoa from the Phosphatic Chalk of Taplow." By F. Chapman, Esq., F.R.M.S. (Communicated by Prof. T. Rupert Jones, F.R.S., F.G.S.)

10. "On the Basalts and Andesites of Devonshire, known as Felspathic Traps." By Bernard Hobson, Esq., M.Sc., F.G.S.

11. "Notes on Recent Borings for Salt and Coal in the Tees Salt-District." By Thomas Tate, Esq., F.G.S.

The following specimens were exhibited :—

Maxilla and other bones of *Euskelesaurus Browni* (Huxley), collected by Alfred Brown, Esq., of Aliwal North; Vertebræ of *Euskelesaurus* preserved in the Albany Museum; Lower jaw and cervical vertebra of *Euskelesaurus Browni*, collected at the Kraai River; Remains of *Massospondylus Browni* (Seeley), collected by Alfred Brown, Esq., at the Telle River; Hind-limb of *Hortalotarsus* from Barkly East, preserved in the Albany Museum; photograph of the Skeleton of *Hortalotarsus*; the *Mesosaurus tenuidens* from Albania, preserved in the South African Museum; and the Skeleton of *Eunotosaurus africanus* from Welte Vreden, exhibited by Prof. H. G. Seeley, F.R.S., F.G.S., in illustration of his three papers.

Rock-specimens and microscopic sections, exhibited by J. Postlethwaite, Esq., F.G.S., in illustration of his paper.

Rock-specimens and microscopic sections, exhibited by Bernard Hobson, Esq., M.Sc., F.G.S., in illustration of his paper.

Specimens of Carboniferous *Murchisonia*, exhibited in illustration of Miss Donald's paper.

Specimens from the Phosphatic Chalk of Taplow, exhibited by F. Chapman, Esq., in illustration of his paper.

Specimens of Tertiary (?) Plant-remains and Gasteropoda from the Thingadau Coalfield, Burmah, exhibited by Dr. Walter Saise, F.G.S.

ADDITIONS

TO THE

LIBRARY AND MUSEUM OF THE GEOLOGICAL SOCIETY.

Session 1891–92.

ADDITIONS TO THE LIBRARY.

1. Periodicals and Publications of Learned Societies.

Presented by the respective Societies and Editors, if not otherwise stated.

Adelaide. Royal Society of South Australia. Transactions and Proceedings. Vol. xiv. Parts 1 & 2. 1891.

S. Dixon. On a Subterranean Water-Supply for the Broken Hill Mines, 200.—C. Chewings. Geological Notes on the Upper Finke River Basin, 247.—R. Tate. Note on the Silurian Fossils of the Upper Finke Basin, 255.—E. H. Rennie and E. F. Turner. Note on a Volcanic Ash from Tanna, 256.—R. Tate. Descriptions of New Species of Australian Mollusca, Recent and Fossil, 257.—R. Tate. A Bibliography and Revised List of the Described Echinoids of the Australian Eocene, with Descriptions of some new species, 270.—M. C. Schlumberger. Description of a New Species of *Fabularia*, 346.—W. Howchin. The Foraminifera of the Older Tertiary; Kent Town Bore, Adelaide, 350.—W. Howchin. The Foraminifera of the Older Tertiary; Muddy Creek, 355.

Albany. New York State Library. Seventy-second Annual Report of the Regents for the year ending September 30, 1889. 1890.

——. New York State Museum. Bulletin. Vol. 2. No. 9. 1890.

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Amsterdam. Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië. Jaargang 1891. Wetenschappelijk Gedeelte. 1891.

J. W. Retgers. Mikroskopisch onderzoek eener verzameling gesteenten uit de afdeeling Martapoera, zuider- en ooster-afdeeling van Borneo, 5.

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Barnsley. Midland Institute of Mining, Civil, and Mechanical Engineers. Proceedings. Vol. xii. Part 101–107. 1891.

R. Russel. The Geology of the Southern portion of the Yorkshire Coal-field, 41.—J. Nevin. On the difference between the seams in the northern and southern parts of the Yorkshire Coal-field, as shown in some of the deeper sinkings, 123.

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R. Miller. On the Coal-field adjoining Barnsley, 153.

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J. F. Mostyn Clarke. The Geology of the Bridgewater Railway. A brief account of Lias cuttings through the Polden Hills in Somersetshire, 127.

Belfast. Natural History and Philosophical Society. Report and Proceedings. Session 1890–91. 1892.

R. Young. Some notes on the Geology of the Excavations for the Main Drainage Work [Belfast], 89.

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J. Cvijić. Der Flacheninhalt und die mittlere Höhe des Königreichs Serbien, 10 [6].—S. A. Radovanović. Beiträge zur Geologie und Paläontologie Ost-Serbiens, 17 [21].—M. T. Lecco und A. Amović. Technische Analysen einiger Erze aus Serbien, 65 [80].—A. Amović. Die chemische Zusammensetzung des Milanits, 76 [91].—Z. Jovičić. Analyses d'une série de serpentines, 90 [104].—Z. Jovičić. Analyses des micro-granulites de Srebrnica et Ljubovia, 94 [111].—Z. Jovičić. Analyse de l'eau de Bele Vode à Zarkovo, 95 [113].—J. M. Žujović. Sur la distribution des roches volcaniques en Serbie, 96 [115].—J. M. Žujović. Les euphotides de Serbie, 108.—J. M. Žujović. Contribution à l'étude géologique de l'Ancienne Serbie, 123.—J. M. Žujović. Note sur la crête Greben, 145.—J. Cvijić. Ueber die Prekonoger Höhle, 159 [272].—G. Jovanović. La Faune de la caverne Prekonoge, 181 [360].—M. S. Dinić. Sur quelques roches crystallophylliennes de la Bulgarie occidentale, 193 [477].—J. M. Žujović. Esquisse géologique des Balkans, 218 [145].

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J. Roth. Die Eintheilung u. die chemische Beschaffenheit der Eruptivgesteine, 1.—Otto Fromm. Petrographische Untersuchung von Basalten aus der Gegend von Cassel, 43.—E. Koken. Neue Untersuchungen an tertiären Fisch-Otolithen II., 77.—P. G. Krause. Die Decapoden des norddeutschen Jura, 171.—Carl Ochsenius. Ueber Loth, Pendel, Ocean-niveau und Beweglichkeit unserer Erdrinde, 226.—F. Rinne. Ueber den Dimorphismus der Magnesia, 231.—Cl. Schlüter. Verbreitung der regulären Echiniden in der Kreide Norddeutschlands, 236.—H. Eck. Bemerkungen über geognostische Profile längs württembergischer Eisenbahnen, 244.—R. Beck. Amphibolitisirung von Diabasgesteinen im Contact-bereich von Graniten, 257.—F. Zimmermann. Die Trias am Nordfuss des mittleren Thüringerwaldes, 263. — Kosmann. Der Unterschied zwischen sogen. Constitutions- u. Krystallwasser, 267. —E. Dathe. Die Discordanz zwischen Culm u. Waldenburger Schichten im Waldenburger Becken, 277.—Ebert. Die Lagerungsverhältnisse der oberschlesischen Steinkohlenformation, 283.—Rothpletz. Fossile Kalkalgen aus den Familien der Codiaceen und der Corallineen, 295.—A. Osann. Ueber den geologischen Bau des Cabo de Gata, 323.—K. A. Penecke. Die Mollusken-Fauna des untermiocänen Süsswasserkalkes von Reun in Steiermark (Sandberger's Horizont von *Helix Ramondi*, Brong.), 346. — O. Behrendsen. Zur Geologie des Ostabhanges der argentinischen Cordillere, 369.—P. Oppenheim. Beiträge zur Kenntniss des Neogen in Griechenland, 421.—A. Krause. Beitrag zur Kenntniss der Ostrakoden-Fauna in silurischen Diluvialgeschieben, 488.—Schreiber. Vorkommen fester Sandsteinbänke im mitteloligocänen Grünsand bei Magdeburg, 522. — R. Lepsius. Einige Fossilreste aus Griechenland, 524.—G. Klemm. Chiastolithschiefer und Hornblende-Porphyrit im Oberlausitzer Flachland, 526.—G. Boehm. Ueber *Lithiotis problematica*, 531.—O. Jaekel. Ueber Holopocriniden, mit besonderer Berücksichtigung der Stramberger Formen, 557.—F. Frech. Ueber das Devon der Ostalpen, ii., 672.—A. Osann. Beiträge zur Kenntniss der Eruptivgesteine des Cabo de Gata, ii., 688.—F. M. Stapff. Beobachtungen an den in Kreide eingebetteten Diluvialablagerungen Rügens, 723.—W. Müller. Ueber Contacterscheinungen am Glimmerschiefer der Schneekoppe, 730. —Eck. *Ceratites antecedens*, Beyr., von Wenden in Württemberg, 735. —R. Lepsius. Die erste Quarzporphyr-Effusiv-Decke in Saar-Nahe-Gebiete nachgewiesen, 736.—Eck. Bemerkungen über einige Encrinen, 739.—G. Boehm. Ueber eine Anomalie im Kelche von *Millericrinus mespiliformis*, 741.—P. Oppenheim. Bemerkungen zu G. Steinmann. Einige Fossilreste aus Griechenland, 744.—W. Deecke. Der Granitstock des Elsässer Belchen in den Südvogesen, 839.—R. Wagner. Ueber einige Versteinerungen des unteren Muschelkalks von Jena, 879.—G. Gürich. Ueber Placodermen und andere devonische Fischreste im Breslauer mineralogischen Museum, 902.—W. Schauf. Ueber die Diabasschiefer (Hornblendesericit-Schiefer K. Koch's) von Birkenfeld bei Eppenhain und von Vockenhausen im rechtsrheinischen Taunus, 914. —A. v. Strombeck. Ueber das Vorkommen *Actinocamax quadratus* und *Belemnitella mucronata*, 919.—P. Oppenheim. Die Gattungen *Dreyssenia*, van Beneden, und *Congeria*, Partsch, ihre gegenseitigen Beziehungen und ihre Vertheilung in Zeit und Raum, 923.—G. Gürich. Ueber einen neuen *Nothosaurus* von Gogolin in Oberschlesien, 967.

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O. Behrendsen. Zur Geologie des Ostabhanges der argentinischen Cordillere, 1.—H. Pohlig. Ueber das Valorsineconglomerat, 43.—K. Endrise. Zur Geologie der Höhlen des schwäbischen Albgebirges, 49.—C. Ochsenius. Die Bildung von Kohlenflötzen, 84.—C. Struckmann. Ueber den Serpulit (Oberen Purbeck) von Linden bei Hannover, 99.—F. Wahnschaffe. Mittheilungen über das Glacialgebiet Nordamerikas, 107.

—K. Futterer. Die Entstehung der Lapisinischen Seen, 123.—Schreiber. Ueber ein bei Magdeburg aufgedecktes altes Elbstrombett, 135.—Eck. Abnormer Kelchbau bei *Encrinus gracilis*, 138.—Eck. Schwerspath mit Zwillingslamellen von Schenkenzell im Schwarzwalde, 139.—Schütze. Bemerkungen über die angebliche Discordanz zwischen Culm und Waldenburger Schichten im Waldenburger Becken, 140.—R. Brauns. Hauyn in den Bimssteinsanden der Umgegend von Marburg, 149.—H. Pohlig. Ueber *Palæozoicum* von Australien, Persien, und Castilien, 151.

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