THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

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.*

VOLUME THE SIXTY-EIGHTH.

1912.

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EXPLANATION OF THE PLATES.

ERRATA.

P. cvi, *line* 4 *from the bottom*, p. cviii, *line* 9 *from the top*, & p. cx, *line* 24 *from the top*, *for* 'Procter' *read* 'Proctor.'

P. cxii, *line* 12 *from the top, the words* 'were given' should be added *after* 'lantern-slides.'

P. 661, *line* 6 *from the bottom*, for '*Themaropus*,' read '*Thenaropus*.'

PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES

BESIDES THOSE IN THE PLATES.

Dates of Issue of the Quarterly Journal for 1912.

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[With Nine Plates, illustrating Papers by Prof. T. G. Bonney & the Rev. E. Hill, Dr. T. F. Sibly, Mr. C. I. Gardiner & Prof. S. H. Reynolds, and Mr. J. Romanes.]

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THE

QUARTERLY JOURNAL

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THE GEOLOGICAL SOCIETY OF LONDON.

Vol. LXVIII.

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1. The Evolution of *Inoceramus* in the Cretaceous Period.

By Henry Woods, M.A., F.G.S., University Lecturer in Palæozoology, Cambridge. (Read November 22nd, 1911.)

Introductory Remarks.

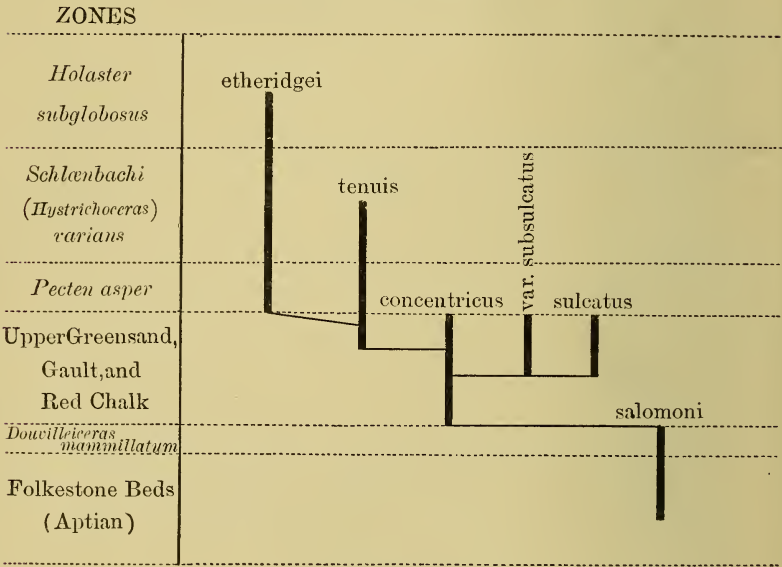
Although the genus *Inoceramus* is found in deposits as early as the Lias, yet it is represented by comparatively few species until the close of the Lower Cretaceous Period, after which it underwent rapid evolution so that many species and varieties were developed; but, so far as we know, none of these survived the Cretaceous Period or left descendants. From the evidence which has been furnished by a study of the variation of the species, their zonal distribution, morphological resemblances and development, and from the discovery of connecting links, it now seems possible to recognize the main lines of evolution in the *Inocerami* of the Cretaceous Period.

The species of *Inoceramus* found in the Gault, the Upper Greensand, and the Chalk appear to have originated from two stocks which occur in the Lower Greensand (Aptian), one being *I. salomoni* d'Orb., the other belonging to the type of *I. neocomiensis* d'Orb. and *I. ewaldi* Schlüt.

I. Species connected with *Inoceramus salomoni*.

We may first deal with the species which are connected with *I. salomoni*, namely:—*I. concentricus, I. concentricus* var. *subsulcatus*, *I. sulcatus*, *I. tenuis*, and *I. etheridgei*, of which the distribution and relationship are shown in the accompanying diagram (A).

Diagram A.—*Distribution and relationship of the species connected with* Inoceramus salomoni.

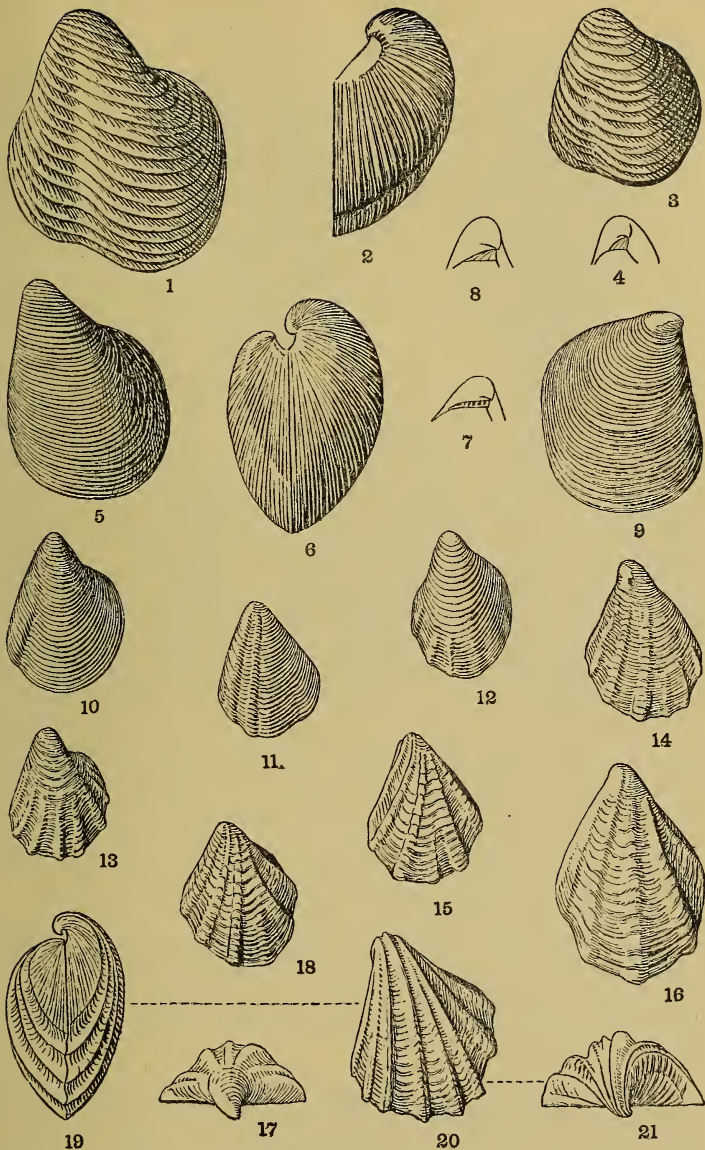


[The thick lines express the range of the species; the thin lines connecting them indicate what is believed to be the phylogeny of the species.]

I. salomoni d'Orb. (figs. 1–4, p. 3) is found in the Folkestone Beds (Lower Greensand) and in the *Mammillatum* Bed at the base of the Gault. The left valve is characterized by its subquadrate outline, the obliquely triangular hinge-area, the large anterior area bounded by a rounded ridge, the shallow radial sulcus which extends from below the umbo to the ventral margin and gives a sinuosity to the concentric ridges. In the early stage of growth the sulcus is not present, and the period at which it appears varies in different individuals.

I. concentricus Park. (figs. 5–9, p. 3)[1] ranges throughout the Gault and the Upper Greensand (with the exception of the zone

[1] For other figures, see H. Woods, 'Monogr. Cret. Lamellibr.' (Palæont. Soc.), vol. ii (1911) pl. xlv, fig. 11, pl. xlvi, figs. 1–10, & pl. xlvii, figs. 1–2.



Figs. 1–4. *Inoceramus salomoni* d'Orb., *Mammillatum* Bed; left valves: 2, anterior view; 4, umbo and hinge-area. 5–9. *I. concentricus* Park., Gault: 5, left valve; 6, anterior; 7 & 8, umbo and hinge-area; 9, right valve. 10–18. *I. concentricus* var. *subsulcatus* Wiltsh., Gault: left valves. 19–21. *I. sulcatus* Park., Gault: 19, anterior; 20 & 21, left valve. All @ two-thirds of the natural size.

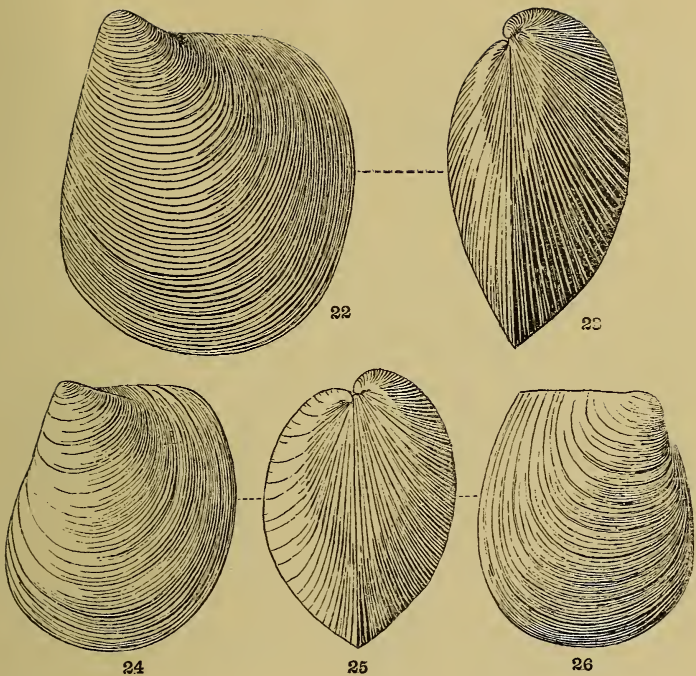
of *Pecten asper*), and is clearly of the same type as *I. salomoni*. In comparing it with *I. salomoni* we find that the early stage is similar, but of shorter duration; and after that stage is passed the left valve becomes more generally inflated, its axis of growth more oblique, the umbo narrower and more pointed, the anterior area smaller, the hinge-line shorter, and the hinge-area reduced in height. The radial sulcus is not developed. *I. concentricus* appears to have been derived from *I. salomoni* by the shortening of the hinge-line and the reduction in height of the hinge-area. Some forms of *I. concentricus* which possess a higher hinge-area (fig. 8, p. 3) and a rather larger anterior area than usual connect *I. concentricus* with *I. salomoni*.

I. sulcatus Park. (figs. 19–21, p. 3)[1] occurs in the Upper Gault, the Red Chalk, and the Upper Greensand (except in the zone of *Pecten asper*), and agrees closely with *I. concentricus*, notwithstanding the presence of strong radial folds which, at first sight, give it a very distinct appearance. Between these two species numerous intermediate forms (known as *I. concentricus* var. *subsulcatus* Wiltsh.) are found, in which every stage may be seen in the development of the radial folds (figs. 10–18, p. 3). The early part of the shell is identical with the adult shell of *I. concentricus*; in some cases this *concentricus* stage lasts for a considerable period (figs. 12 & 13); while in others it is of short duration (figs. 15–18), and in *I. sulcatus* (figs. 20 & 21) it is completely lost. The adult in some examples differs from *I. concentricus* only in the possession of a single radial fold (fig. 10); while in others two, three, or more (figs. 11–18) develop, until we get a type like *I. sulcatus*, in which the folds are sharp and numerous, and start from the apex of the umbo (figs. 20 & 21). On account of its strong radial folds, *I. sulcatus* has been placed by some authors in a separate genus or subgenus—*Actinoceramus*, Meek; but, since it has descended directly from *Inoceramus concentricus*, there is no reason for assigning it to a separate genus or subgenus.

I. tenuis Mant. (figs. 22 & 23, p. 5)[2] ranges from the Red Chalk (=Gault) to the Chalk Marl (*varians* zone), and possesses most of the features of *I. concentricus*, from which it has clearly been derived; the main differences are its longer hinge-line and the less prominent umbo of the left valve.

I. etheridgei Woods (figs. 24–26, p. 5)[3] extends from the zone of *Pecten asper* to the zone of *Holaster subglobosus*, and appears to have descended from *I. tenuis*. It possesses a similar concave anterior area and long hinge. The chief differences are found in the left valve, in which the umbo is less prominent, the postero-dorsal region is less compressed, and the valves are more nearly equal.

[1] H. Woods, *op. cit.* pl. xlvii, figs. 15–20.
[2] *Id. ibid.* pl. xlviii, fig. 1, & text-figs. 31–32.
[3] *Id. ibid.* pl. xlix, figs. 2–4.



Figs. 22 & 23. *I. tenuis* Mant., Red Chalk: 22, left valve; 23, anterior. 24–26. *I. etheridgei* Woods, *Holaster-subglobosus* Zone: 24, left valve; 25, anterior; 26, right valve. All @ two-thirds of the natural size.

II. Species connected with *Inoceramus neocomiensis*

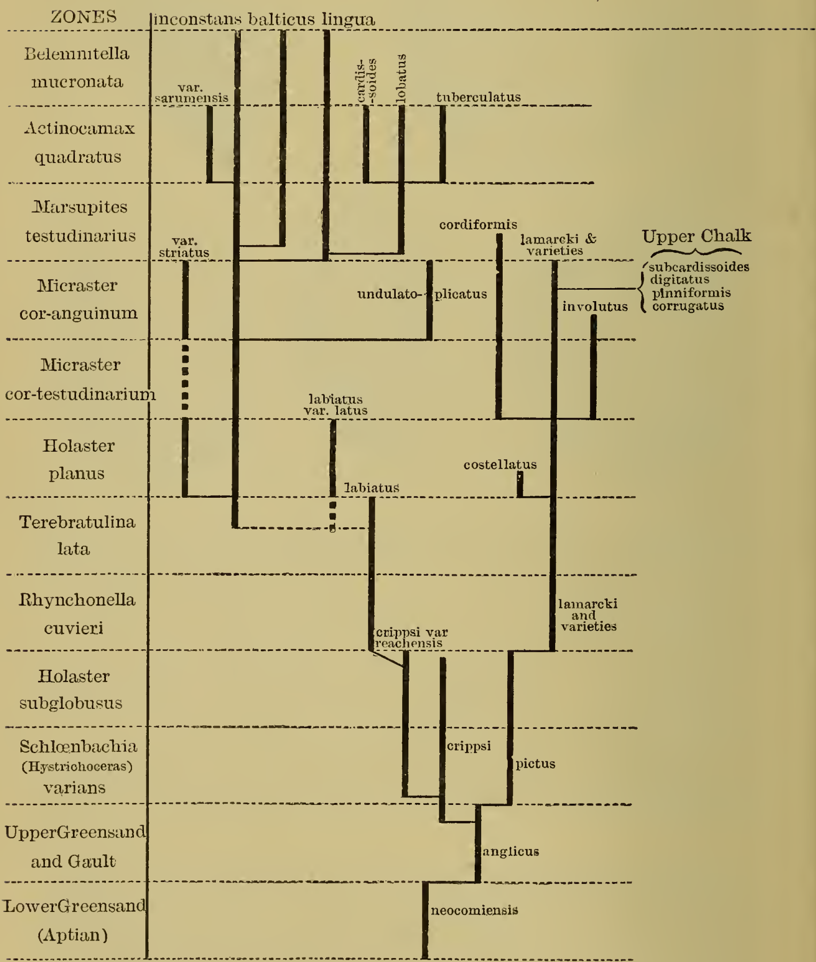
We may now consider the species which are believed to be connected with *I. neocomiensis*, the distribution and relationship of which are shown in the accompanying diagram (B, p. 6).

I. neocomiensis d'Orb. (fig. 27, p. 8) is found in the Lower Greensand, and a similar form (*I. ewaldi* Schlüt.) occurs in the Aptian of North Germany.

I. anglicus Woods (figs. 28, 29, 56, & 57)[1] occurs in the Gault, the Red Chalk, and the Upper Greensand, and appears to have arisen from a form of the type of *I. neocomiensis*. They agree in the general shape of the shell and in the type of ornamentation; but in *I. anglicus* the posterior part of the shell is more compressed, while the part ventral to the umbones is more convex than in *I. neocomiensis*; also in the former the ventral curvature of the ribs is sharper than in the latter. From *I. anglicus* two species seem to have arisen—*I. pictus* and *I. crippsi*.

[1] H. Woods, *op. cit.* pl. xlv, figs. 8–10, & text-fig. 29.

Diagram B.—*Distribution and relationship of the species connected with* Inoceramus neocomiensis.



[The thick lines express the range of the species; the thin lines connecting them indicate what is believed to be the phylogeny of the species.]

I. pictus Sow. (figs. 30 & 31, p. 8)[1] ranges from the Chalk Marl (*varians* zone) to the zone of *Holaster subglobosus*; it resembles the forms of *I. anglicus* which have more numerous and more regular ribs (figs. 28 & 29). In *I. pictus* the ribs have become smaller, more numerous, and more regular; the anterior area is better developed, and is concave or nearly flat; and the shell is relatively shorter and higher than in *I. anglicus*.

I. lamarcki Park. (figs. 32–41, p. 8) begins in the zone of *Rhynchonella cuvieri* and extends to that of *Micraster cor-anguinum*. Some early forms of this species (*I. lamarcki* var. *apicalis* Woods, figs. 32 & 33),[2] in which the valves are only slightly unequal, the concentric folds not much developed, and the posterior ear not sharply limited, closely resemble *I. pictus*, and seem almost certainly to have descended from that species.[3] *I. lamarcki* shows a great amount of variation,[4] so that many of the forms have diverged considerably from *I. pictus* owing to change in convexity, in the number, strength, and curvature of the concentric folds, in the size and distinctness of the posterior ear, and in the relative height of the shell, etc.

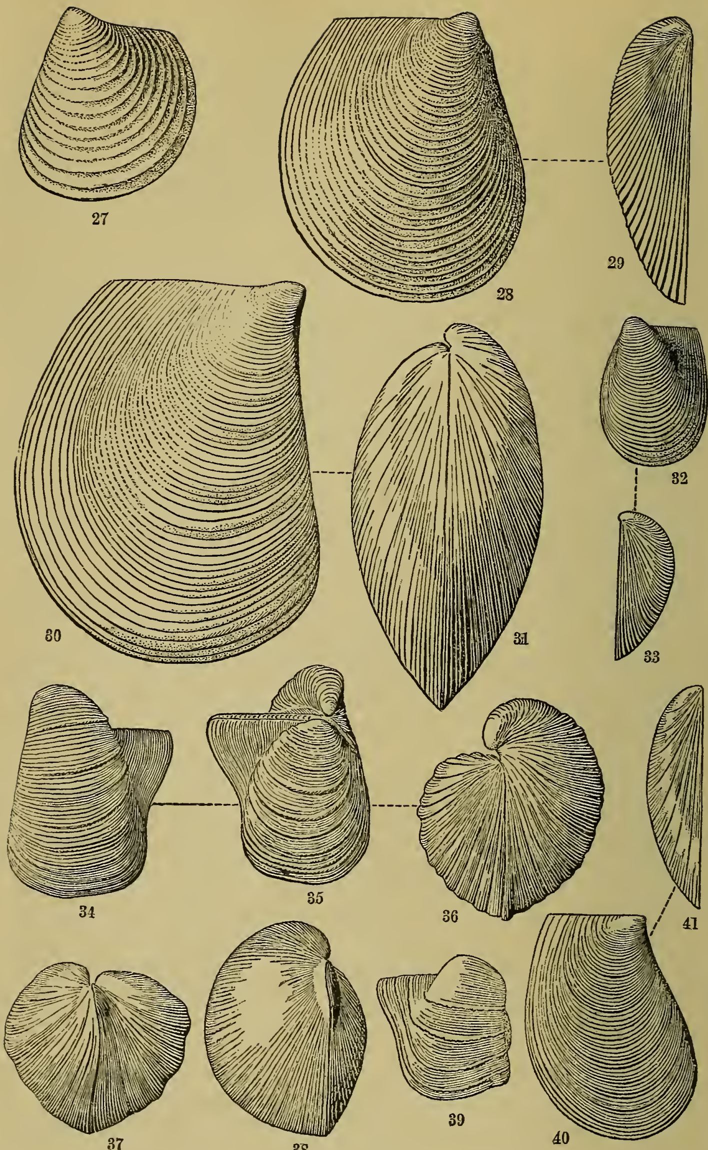
In *I. lamarcki* var. *cuvieri* Sow. (figs. 40 & 41),[5] which ranges from the zone of *Terebratulina lata* to that of *Micraster cor-anguinum*, the shell is high, with the valves only slightly convex and not very unequal, and with the concentric folds often absent or indistinct though sometimes becoming more or less strongly developed.

In forms like the type of *I. lamarcki* Park. (figs. 34–36) the valves are inflated and usually very unequal, the umbones prominent, the posterior ear sharply defined, and the concentric folds well-developed. Other similar forms have the posterior ear indistinctly limited, and the folds may be only poorly developed. The left valve is sometimes very much more convex than the right (fig. 38), and occasionally the two valves are of nearly equal convexity (fig. 37).

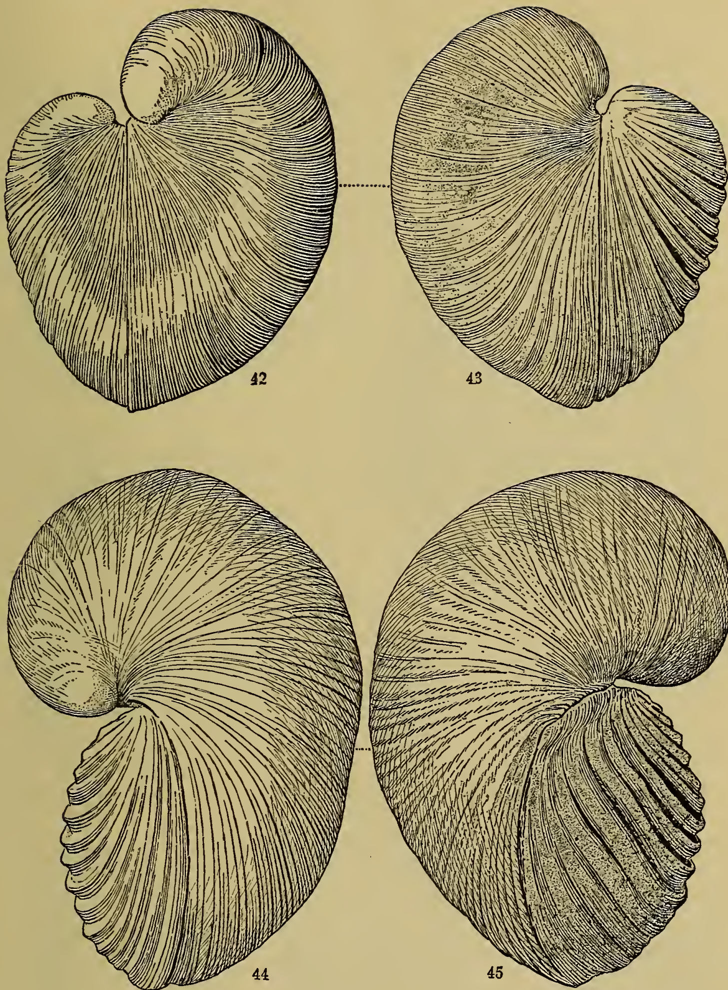
I. lamarcki var. *websteri* Mant. (fig. 39) occurs mainly in the zone of *Micraster cor-testudinarium*; it is an inflated form with the posterior ear not sharply limited, and is distinguished by the very thin shell and the sharp ridge-like character of the concentric folds.

I. involutus Sow. (figs. 44–47, pp. 9 & 10), found in the zone of *Micraster cor-testudinarium* and in the lower part of the zone of *M. cor-anguinum*, is shown by intermediate varieties (figs. 42 & 43, p. 9) to have descended from a convex form of *I. lamarcki*, by the increase in size and convexity of the left valve, its acquirement of a spirally curved umbo, the loss of concentric folds, and the loss of the

[1] H. Woods, *op. cit.* pl. xlix, figs. 5 & 6.
[2] *Id. ibid.* (1912) pl. liii, figs. 4–6.
[3] The resemblance is greater in the case of small forms of *I. pictus* than in the large example figured here.
[4] *Id. ibid.* pl. lii, figs. 4–6, pl. liii, figs. 1–7, & text-figs. 63–85.
[5] *Id. ibid.* text-figs. 73–84.



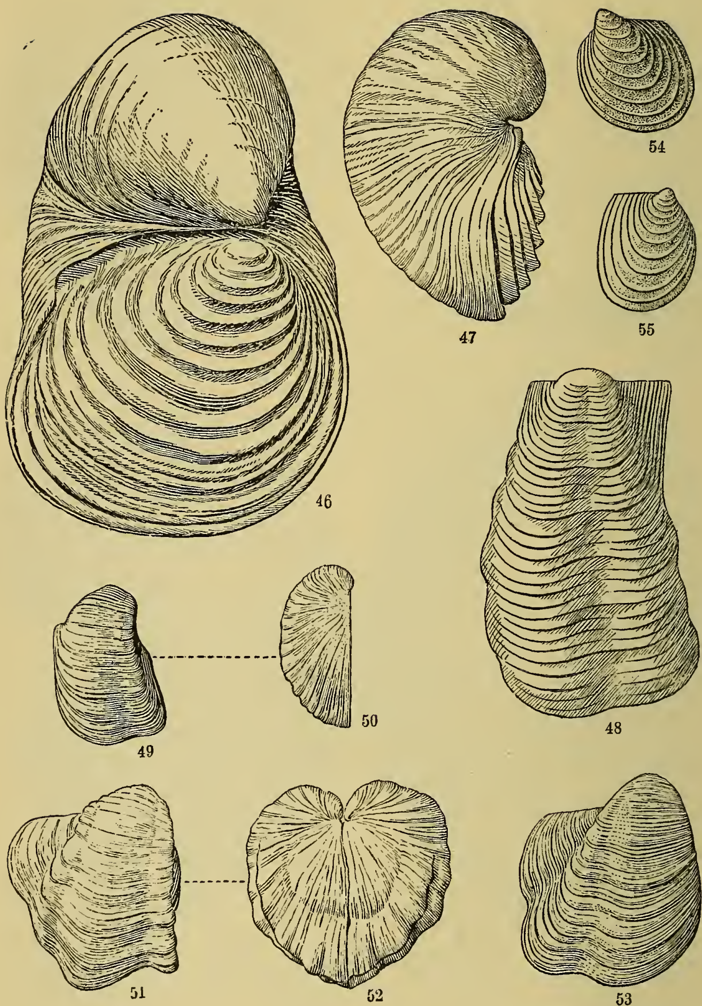
Figs. 27. *I. neocomiensis* d'Orb., Lower Greensand (Aptian): left valve. 28 & 29. *I. anglicus* Woods, Red Chalk: 28, right valve; 29, anterior. 30 & 31. *I. pictus* Sow., *Holaster-subglobosus* Zone: 30, right valve; 31, anterior. 32 & 33. *I. lamarcki* var. *apicalis* Woods, *Rhynchonella-cuvieri* Zone: 32, left valve; 33, anterior. 34–38. *I. lamarcki* Park., *Holaster-planus* Zone: 34, left valve; 35, right valve; 36, anterior; 37, 38, posterior. 39. *I. lamarcki* var. *websteri* Mant., *Micraster cortestudinarium* Zone: right valve. 40 & 41. *I. lamarcki* var. *cuvieri* Sow., *Terebratulina-lata* Zone: 40, right valve; 41, anterior. All @ half of the natural size.



Figs. 42 & 43. *Inoceramus* connecting *I. lamarcki* with *I. involutus,* Upper Chalk : 42, anterior ; 43, posterior. 44 & 45. *I. involutus* Sow., *Micraster cor-anguinum* Zone : 44, anterior ; 45, posterior. All @ half of the natural size.

anterior area which at first became concave and then decreased in size, ultimately disappearing (figs. 44 & 46). The right valve, in some forms of *I. involutus*, is moderately convex, with strong folds and a concave anterior area, and agrees with the right valve of one variety of *I. lamarcki*[1]; in other forms which have departed farther

[1] H. Woods, *op. cit.* p. 325 & text-fig. 85.



Figs. 46 & 47. *I. involutus* Sow., *Micraster cor-anguinum* Zone: 46, right valve and umbonal part of the left valve; 47, posterior view. 48. *I. lezennensis* Décocq, *Micraster cor-anguinum* Zone: right valve. 49 & 50. *I. lamarcki*; variety connecting *I. lamarcki* with *I. cordatus*, *Holaster-planus* Zone: 49, right valve; 50, anterior. 51–53. *I. cordiformis* Sow., *Micraster cor-anguinum* Zone: 51, 53, right valves; 52, anterior. 54 & 55. *I. costellatus* Woods, Chalk Rock: 54, left valve; 55, right valve. All @ half of the natural size.

from the *lamarcki* type, this valve becomes nearly flat (fig. 47, p. 10), the anterior area is lost, and the concentric folds increase in strength; the height of the shell decreases, and is often exceeded by the length.

From the large size and great thickness of the shell, and from the great difference in the form and size of the two valves, it seems evident that the characters which distinguish *I. involutus* from *I. lamarcki* were developed by the adoption of a more sedentary mode of life in which the animal rested on its left valve. The opercular character of the right valve, due to its decreased convexity and to the marginal growth around the hinge,[1] is in accordance with this view. Reasons for the short zonal range of *I. involutus* may be seen in the great size and thickness of the shell and in its specialized character.

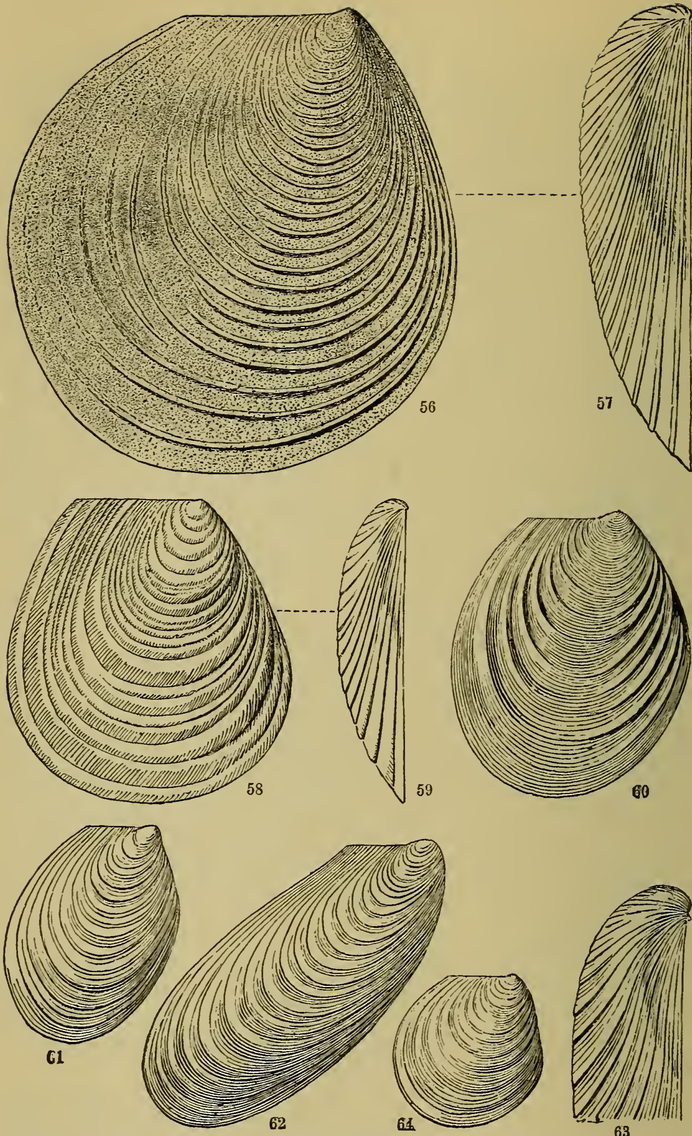
I. involutus has been placed by Stoliczka and some later writers in a separate genus or subgenus—*Volviceramus*; but, since that species has been shown to have descended from *I. lamarcki*, the separation which would be implied by the use of the name *Volviceramus* can no longer be maintained.

I. cordiformis Sow. (figs. 51–53, p. 10) is found in the zones of *Micraster cor-testudinarium* and *M. cor-anguinum*, and in the *Uintacrinus* Band of the zone of *Marsupites testudinarius*, also possibly in an earlier zone. It has been derived from an inflated form of *I. lamarcki* with nearly equal valves, with which it is connected by an intermediate variety (figs. 49 & 50). It differs from *I. lamarcki* in the equal size of the valves, the relatively longer hinge, the presence of a radial sulcus extending from behind the umbo to the postero-ventral extremity, and often also of another sulcus from the front of the umbo to the opposite ventral margin; when this sulcus is present the large anterior area is limited by a rounded ridge. In one variety of *I. lamarcki* (figs. 49 & 50) this anterior sulcus is found, but the shell is shorter than in *I. cordiformis.*

I. costellatus Woods (figs. 54 & 55, p. 10) is found only in the Chalk Rock (zone of *Heteroceras reussianum*), and has probably been derived from *I. lamarcki* var. *apicalis* by the axis of growth becoming more oblique to the hinge, accompanied by the development of a narrower and more prominent left umbo.

I. subcardissoides Schlüt.,[2] *I. digitatus* Sow.,[3] *I. pinniformis* Will.,[4] and *I. corrugatus* Woods,[5] from the Upper Chalk, are allied to one another and possess strong radial folds. No perfect specimen of these species showing the umbo and hinge has yet been found; but, from the character of the posterior ear and the curvature of the concentric folds, it seems probable that they have been derived from

[1] H. Woods, *op. cit.* fig. 94.
[2] Palæontographica, vol. xxiv (1877) p. 271 & pl. xxxvii.
[3] H. Woods, *op. cit.* text-fig. 95.
[4] *Id. ibid.* text-fig. 96.
[5] *Id. ibid.* text-fig. 97.



Figs. 56 & 57. *I. anglicus* Woods, Red Chalk: 56, right valve; 57, anterior. 58 & 59. *I. crippsi* Mant., *Pecten-asper* Zone: 58, right valve; 59, anterior. 60. *I. crippsi* var. *reachensis* Eth., *Holaster-subglobosus* Zone; right valve. 61–63. *I. labiatus* Schloth., *Rhynchonella-cuvieri* Zone: 61, right valve of incompletely-grown individual; 62, right valve of fully-grown individual; 63, anterior view of part of right valve. 64. *I. labiatus* var. *latus* Sow., *Holaster-planus* Zone; right valve. All @ half of the natural size, except fig. 62, which is a third of the natural size.

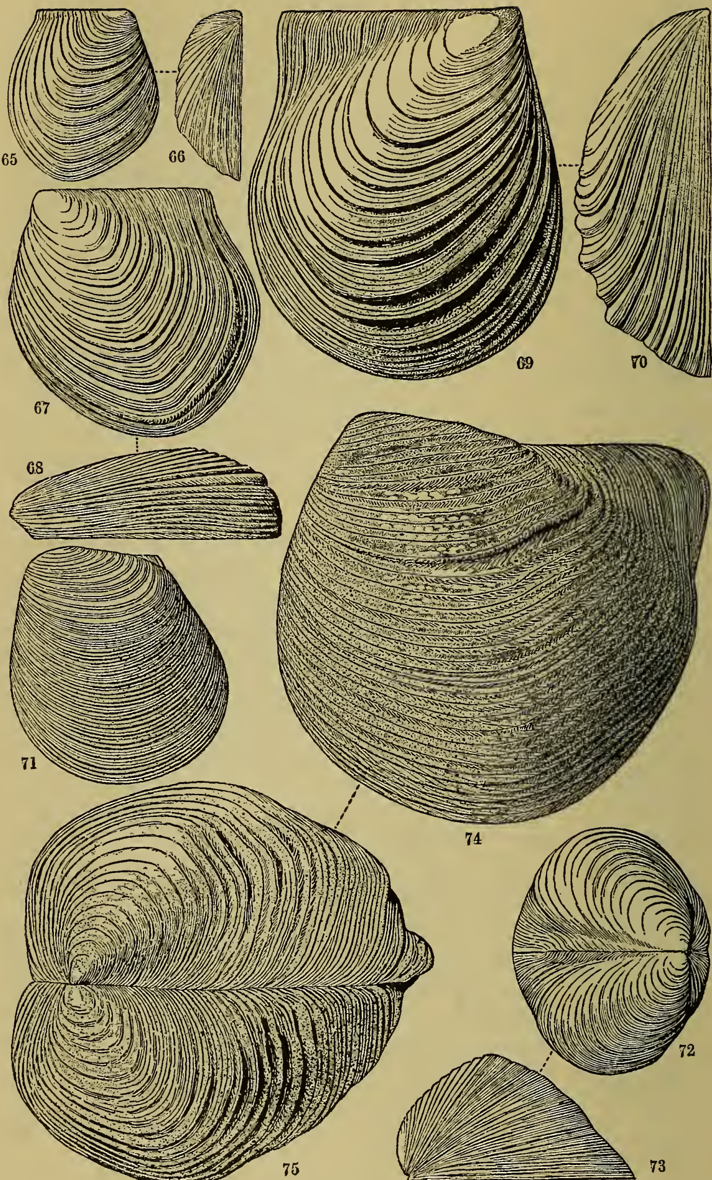
the less convex forms of *I. lamarcki* with concentric folds. That radial folds or corrugations, which give greater strength to the shell, can be developed in that stock is shown by the occasional presence of a fold in *I. lamarcki*, by the folds in *I. cordiformis*, and still more by the fold in *I. lezennensis* Décocq [1] (fig. 48, p. 10).

I. crippsi Mant. (figs. 58 & 59, p. 12) [2] ranges from the Upper Greensand to the zone of *Holaster subglobosus*. It appears to have been derived from the forms of *I. anglicus* which possess fewer and less regular ribs (figs. 56 & 57). It agrees in many respects with *I. anglicus*, but the shell is relatively shorter, the part of the valve between the umbo and the ventral margin is less convex (so that the postero-dorsal part of the shell is relatively less compressed), and the anterior area is smaller; the ribs are fewer, more irregular, and their posterior curvature towards the hinge-line is less strong. In *I. crippsi* var. *reachensis* Eth. (fig. 60),[3] ranging from the Chalk Marl (*varians* zone) to the zone of *Holaster subglobosus*, the shell, when fully grown, is relatively higher, and the posterior curvature of the ribs is greater than in *I. crippsi*.

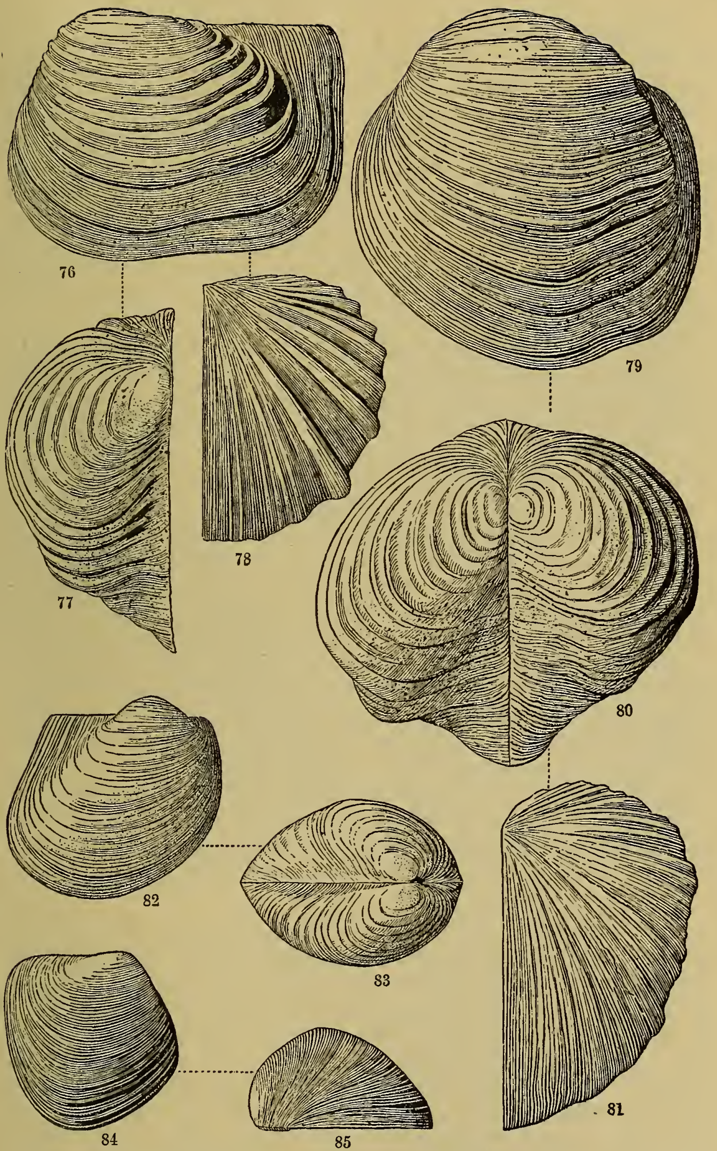
I. labiatus (Schloth.) (figs. 61–63, p. 12) [4] is found commonly in the zone of *Rhynchonella cuvieri*, and also occurs in the zone of *Terebratulina lata*. The curvature of the ribs, the similarity of the anterior area, and the fact that the anterior margin of the shell is at first perpendicular to the hinge,[5] make it most probable that this species has descended from *I. crippsi* var. *reachensis*. The main differences which appear in *I. labiatus* are due to the extensive growth of the shell in a direction oblique to the hinge-line, so that in fully-grown specimens (fig. 62) the form appears very different from that of *I. crippsi*. On account of this mode of growth, the resemblance between small specimens of *I. labiatus* (fig. 61) and the adult of *I. crippsi* var. *reachensis* is greater than in older specimens. Unfortunately, but few perfect specimens of *I. crippsi* and its variety *reachensis* have yet been found, so that their variation cannot be studied satisfactorily; and no forms intermediate between this species and *I. labiatus* have been seen.

I. labiatus var. *latus* Sow. (fig. 64, p. 12) [6] occurs in the zone of *Holaster planus*. The specimens of *I. labiatus* found in the zone of *Terebratulina lata* are often relatively longer and less high than the examples which occur in the zone of *Rhynchonella cuvieri*, and such forms pass gradually into *I. labiatus* var. *latus*, in which the length of the hinge-line has increased in proportion to the height of the shell; the axis of growth has become less oblique, the anterior margin more convex, and the ventral margin less sharply curved.

[1] C. Barrois, Ann. Soc. Géol. Nord, vol. vi (1879) p. 455 & pl. v, figs. 1–2.
[2] H. Woods, *op. cit.* pl. xliii, figs. 2–3 & text-figs. 33–35.
[3] *Id. ibid.* pl. xlviii, figs. 4–5 & pl. xlix, fig. 1.
[4] *Id. ibid.* pl. l & text-fig. 37.
[5] *Id. ibid.* pl. l, fig. 4.
[6] *Id. ibid.* text-figs. 38, 40, & 41 (*non* 39).



Figs. 65–75. *I. inconstans* Woods : 65–68, 71–73, *Holaster-planus* Zone ; 69 & 70, *Actinocamax-quadratus* Zone ; 74 & 75, Upper Clalk ; 65, 69, right valves ; 67, 71, 74, left valves ; 66, 68, 70, anterior views ; 72, dorsal view of 71 ; 75, dorsal view of 74. All @ half of the natural size.



Figs. 76–81. *I. inconstans* Woods, *Actinocamax-quadratus* Zone: 76, left valve; 77, dorsal view of 76; 78, anterior; 79–81, inflated form connecting *I. inconstans* with *I. inconstans* var. *sarumensis*; 79, left valve; 80, dorsal view of 79; 81, anterior. 82 & 83. *I. inconstans* var. *sarumensis* Woods, *Actinocamax-quadratus* Zone: 82, right valve; 83, dorsal. 84 & 85. *I. inconstans* var. *striatus* Mant., *Holaster-planus* Zone: 84, right valve; 85, posterior. All @ half of the natural size.

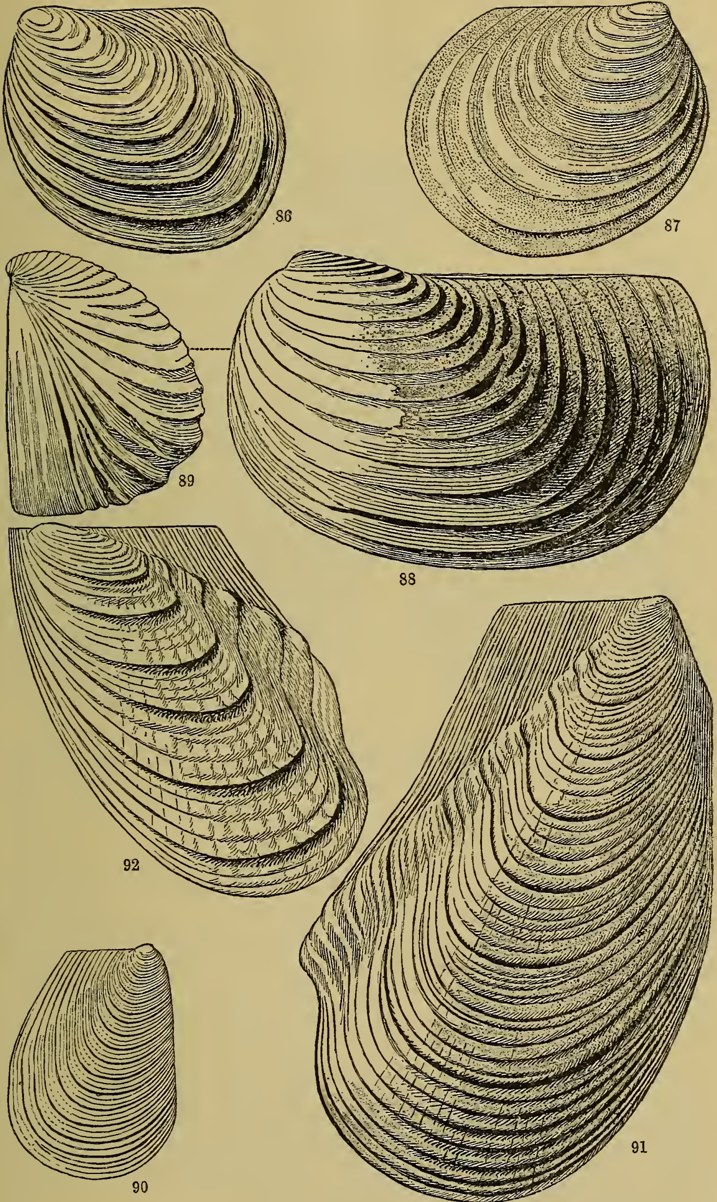
I. inconstans Woods (figs. 65–80 & 86, pp. 14–15 & 17)[1] extends from the zone of *Holaster planus* to the zone of *Belemnitella mucronata*, and perhaps occurs also in the zone of *Terebratulina lata.* It shows a large amount of variation. The less convex forms of this species approach very closely *I. labiatus* var. *latus*; but the hinge usually is relatively longer, the height of the shell less, the axis of growth more oblique to the hinge, the flattened area larger, the umbones less prominent, and the posterior ear more distinct. *I. inconstans* has undoubtedly been derived from the *labiatus* stock, and came probably from *I. labiatus* var. *latus*, but possibly from the longer and less high form of *I. labiatus* which occurs in the zone of *Rhynchonella cuvieri.*

From the variety of *I. inconstans* which throughout life is nearly flat or but slightly convex (fig. 67, p. 14), numerous varieties have arisen in which, sooner or later, the shell becomes convex or inflated owing to the later part growing towards the plane of the valves instead of nearly parallel to it: consequently the later-formed part curves more or less rapidly from the earlier part. The flat stage may last for a long (fig. 67) or a short period (figs. 71, 74), and in one variety (*sarumensis*, found in the *Actinocamax-quadratus* Zone, figs. 82 & 83, p. 15) disappears altogether, with the result that a regularly convex shell, without folds, is formed. Sometimes the change from the flat to the convex stage is abrupt, so that a sharp bend in the shell occurs (figs. 71–73, p. 14); in other cases, the change is gradual, and a dorso-ventral section of the shell is convex (figs. 74 & 75). When the flat stage is of short duration, the anterior flattened area becomes relatively shorter, and in the variety *sarumensis* (figs. 82 & 83, p. 15), in which the flat stage is lost, the anterior area is absent, and the umbo is not terminal.

I. inconstans var. *striatus* Mant. (figs. 84 & 85, p. 15),[2] found in the zones of *Holaster planus* and *Micraster cor-anguinum*, is another form in which the flat stage is absent; the valves are inflated, the folds indistinct, and the anterior area absent or indistinct.

I. balticus Böhm (figs. 87–89, p. 17)[3] ranges from the zone of *Marsupites testudinarius* to the zone of *Belemnitella mucronata.* In some examples of the slightly convex form of *I. inconstans* the hinge is relatively longer than usual (fig. 86), and these approach very closely the shorter and less convex forms of *I. balticus* (fig. 87) and also resemble the early stage of the large, convex form.[4] Other examples of *I. balticus* (especially older individuals) are much longer, and the axis of growth becomes more oblique to the hinge-line; the valves become much more convex, owing to the change in the mode of growth like that already described in *I. inconstans.* It seems clear that *I. balticus* has been derived from *I. inconstans* by an increase in the relative length of the shell.

[1] H. Woods, *op. cit.* pl. li, figs. 1–4 & text-figs. 39, 42–49.
[2] *Id. ibid.* pl. li, fig. 5 & pl. lii, fig. 1.
[3] *Id. ibid.* text-figs. 51–53.
[4] *Id. ibid.* text-fig. 53.



Figs. 86. *I. inconstans*, elongate form, Upper Chalk; left valve. 87–89. *I. balticus* Böhm, Upper Chalk: 87, right valve of slightly convex form; 88 & 89, left valve and anterior view of fully-grown convex form. 90. *I. lingua* Goldf., Upper Chalk: right valve. 91. *I. lobatus* Goldf., *Actinocamax-quadratus* Zone. 92. *I. cardissoides* Goldf., *A.-q.* Zone; left valve. All @ half of the natural size.

The 'genera' *Endocostea* Whitfield[1] and *Haenleinia* Böhm[2] have almost certainly been derived from *I. balticus* and should, I think, be included in the genus *Inoceramus*.

I. lingua Goldf. (fig. 90, p. 17),[3] from the zones of *Marsupites testudinarius*, *Actinocamax quadratus*, and *Belemnitella mucronata*, also appears to have descended from the flat form of *I. inconstans*, which it resembles closely. The principal differences seen in *I. lingua* are the greater relative height of the shell, giving more acute umbones, the rather less convex valves and consequently smaller anterior area. In *I. lingua* the flat stage appears to have continued throughout life.

I. lobatus Goldf. (fig. 91, p. 17),[4] from the zones of *Marsupites testudinarius* and *Actinocamax quadratus*, is very closely allied to *I. lingua*; but in it an angular ridge or carina between the umbo and the postero-ventral extremity has been developed, and in front of this is a sulcus: the ridge gives a definite line of separation to the posterior ear, and the sulcus causes the ribs to become sinuous. A further difference from *I. lingua* is generally seen in the more distinct differentiation of the ribs into two sizes.

I. cardissoides Goldf. (fig. 92, p. 17),[5] from the Upper Chalk (probably zone of *Actinocamax quadratus*), is closely related to *I. lobatus*; but radial ribs have been developed, and the concentric ribs have become stronger.

I. tuberculatus Woods (fig. 93, p. 19),[6] from the zone of *Actinocamax quadratus*, possesses the main characters of *I. lobatus* and *I. cardissoides*. It appears to have arisen from the former by the development of radial ribs which, in combination with the concentric ribs, give a tuberculate type of ornamentation.

I. undulato-plicatus Röm. (fig. 94, p. 19),[7] from the Upper Chalk, is of the same type as the flat forms of *I. inconstans*, especially in its early stages where concentric ribs only are present; but subsequently diverging radial ribs are developed. Athough no connecting-forms have been found, it seems probable that this species has descended either from *I. inconstans* or from some closely related form.

[1] 'Prelim. Rep. Palæont. Black Hills' (Powell's Geol. & Geogr. Surv. Rocky Mt. Region, 1877) p. 31; and 'Palæont. Black Hills of Dakota' (U.S. Geol. & Geogr. Surv. Rocky Mt. Region, 1880) p. 402. See also A. d'Orbigny, 'Pal. Franç.: Terr. Crét.' vol. iii (1846) p. 515 & pl. ccccix; H. E. Beyrich, Zeitschr. Deutsch. Geol. Gesellsch. vol. iv (1852) p. 151 & pl. v; & J. Böhm, Abhandl. d. k. Preuss. Geol. Landesanst. n. s. pt. lvi (1909) p. 48.

[2] J. Böhm, *ibid.* (1909) pp. 53–58 & pls. xiii–xiv.

[3] H. Woods, *op. cit.* text-fig. 56.

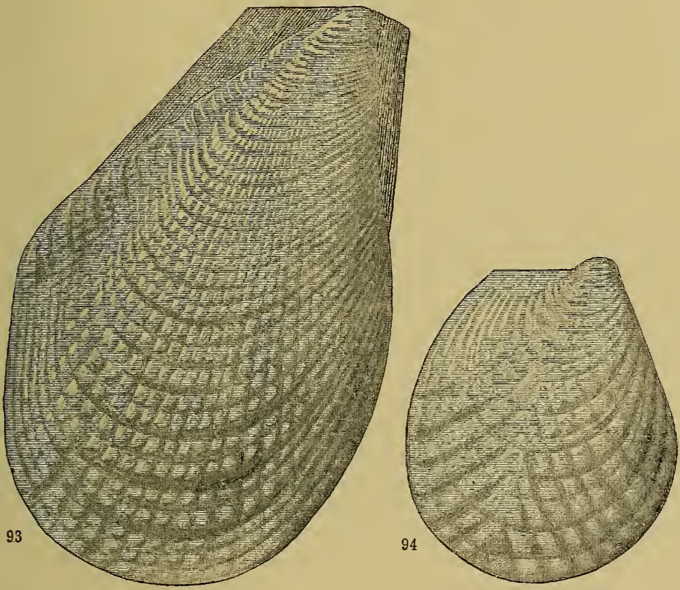
[4] *Id. ibid.* text-figs. 54 & 55.

[5] *Id. ibid.* text-figs. 57 & 58.

[6] *Id. ibid.* pl. liv, fig. 8 & text-fig. 59.

[7] *Id. ibid.* text-figs. 60 & 61.

I. undulato-plicatus var. *digitatus* Schlüt.[1] has the posterior ribs more strongly developed than in *I. undulato-plicatus.*



Figs. 93. *I. tuberculatus* Woods, *Actinocamax-quadratus* Zone; right valve.
94. *I. undulato-plicatus* Röm., Upper Chalk; right valve. Half of the natural size.

It is interesting to note that radial folds have been developed independently in several groups of Cretaceous *Inocerami*, namely: (1) *I. concentricus* var. *subsulcatus, I. sulcatus;* (2) *I. cordiformis;* (3) *I. subcardissoides, I. digitatus, I. pinniformis, I. corrugatus;* (4) *I. cardissoides, I. tuberculatus;* and (5) *I. undulato-plicatus.*

In conclusion, I wish to express my thanks to Dr. H. P. Blackmore, Mr. R. M. Brydone, Mr. C. P. Chatwin, Mr. G. E. Dibley, Mr. W. Hill, Dr. A. W. Rowe, and Mr. C. D. Sherborn for the loan of numerous specimens, without which this paper could not have been written. I am also indebted to Mr. C. P. Chatwin for placing his extensive knowledge of the zonal distribution of the Chalk *Inocerami* at my disposal, and for help in other ways.
The figures illustrating this paper have been drawn by Mr. T. A. Brock.

[1] Palæontographica, vol. xxiv (1877) p. 267 & pl. xxxvi.

Discussion.

Dr. F. A. Bather congratulated the Author on his success in arranging the numerous forms of British Cretaceous *Inocerami* in phylogenetic series, a task that had been impossible so long as the whole material lay confusedly before the museum-worker without stratigraphic detail. The addition of this knowledge enabled one to deal with the material group by group, and the comparison of each group with its immediate predecessor was placed on a secure basis by the application of the principle of recapitulation. Further collection and fresh details were, it appeared, required before all the series could be completed. But, when they were complete, then the palæontologist would only have reached the beginning of the truly scientific and philosophical aspect of his work. He would have the concrete facts, but their interpretation would still be to seek. What were the causes of the changes? What habits, what environment, or what impulse produced them? It was the answer to such questions that constituted the *logos* of Palæontology.

Mr. G. E. Dibley alluded to the Author's valuable work in connexion with the Palæontographical Society's Monograph of Cretaceous Lamellibranchia. *Inoceramus* and *Ostrea* afforded perplexing problems to the palæontologist, and the Author's lucid treatment of the genus *Inoceramus* deserved the gratitude of all field-workers.

2. *On the* Interglacial Gravel-Beds *of the* Isle of Wight *and the* South of England, *and the* Conditions *of their* Formation.

By Prof. Edward Hull, M.A., LL.D., F.R.S., F.G.S. (Read November 8th, 1911.)

[Abstract.]

The Author, after referring to the investigations of previous authors, especially of Mr. Codrington and the officers of the Geological Survey, with which he in the main agrees, points out that the origin and mode of formation of the gravel-terraces of the Isle of Wight and of the New Forest district are still open to discussion. He points out that the levels of the higher beds on both sides of the Solent, up to about 400 feet, indicate the amount of subsidence of the whole area at a time when the stratified gravels, composed mainly of rolled flints, were formed at the margin of the uprising ridges of the Chalk in the post-Glacial Epoch, for this part of England. Preceding this was the great uplift indicated by Godwin-Austen, by which the British Isles were joined to the Continent as land. By this uplift the English Channel was laid dry, and along its centre there ran a river from its source about the Straits of Dover to its outlet into the ocean through the Continental Platform. This river-channel is laid down on the Admiralty Charts under the name of 'the Hurd Deep' for a distance of 30 miles of its course, and has been named by the Author 'the English Channel River.'

The Author considers the gravel-beds of this region to be the representatives of the High-level Gravels of the Midlands and Cromer; also of the 'Interglacial Gravels' of Cheshire and Lancashire; and of the shell-bearing beds of the Denbighshire Hills, and of Moel Tryfaen in Wales, at levels of about 1200 feet above the sea.

Discussion.

Mr. W. Dale welcomed this communication as a reasonable explanation of the deposition of the high-level gravels of the New Forest and the Isle of Wight. He had worked for many years as an archæologist among the implementiferous gravels of the district found at lower levels, and was much surprised at the statement that the deposition of some of the lower terraces was actually going on down to the Roman period. This certainly could not be the case with Palæolithic gravels.

He also wished to submit that possibly the 100- or 150-foot gravels may have been laid down under sub-glacial conditions. He showed upon the screen four views of a gravel-pit at Dunbridge, 4 miles north of Romsey, in the Test Valley, at 146 feet above O.D. In this pit there is a lenticular mass of Woolwich and Reading Clay about a yard thick in the middle, lying between the gravel and the Tertiary sand, which looks very much like the result of ice-work. The sand itself also, in the opinion of several geologists who have seen it, presents so irregular a surface as to suggest that it was frozen hard before the gravel was deposited upon it.

The Rev. E. C. Spicer drew attention to an exposure near Carisbrooke, where the gravels lie upon the upturned edges of the Tertiary beds. The whole mass of gravel, while creeping down hill by 'solifluction,' had dragged over the tops of the vertical Tertiary beds into curves. There was evidence in the gravels themselves of this mass-movement in their curving lines of stratification. All the stratification of these gravels might perhaps be associated with this kind of mass-drag. An interesting point in connexion with the Author's diagram of crustal movements might be found in the gravels above Shide, where the exposures showed a thickness of many feet of perfectly clean flint-gravel resting immediately upon a thick section of dark iron-stained gravel on the top of which was evidence of peaty deposit. A gravel sheet would be formed during the Interglacial submergence, uplifted by the post-Glacial elevation, covered with soil and heath, producing in the stagnant water hydrated iron-oxide which stained the mass. When this subsequently sank, the clean gravel would be deposited upon it. The whole would then be raised to its present position, showing in section the clean gravel resting upon the stained, while the pinching and contortion of the Chalk on which it rests may be explained by the mass-flow of the gravel, making ice-action an unnecessary explanation.

The Author, in reply to a question put by Mr. Whitaker, stated that he considered that the streams descending from the north of Hampshire into Southampton Water and Spithead ultimately entered the English Channel River and formed one of its tributaries (as did also other rivers flowing from the South of England), and, with the Seine from France, produced a large river at its entrance into the ocean where it crossed the margin of the Continental Platform due south of Land's End.

3. *The* Glacial Sections *round* Sudbury (Suffolk). By the Rev. Edwin Hill, M.A., F.G.S. (Read December 20th, 1911.)

The sections round Sudbury are called in the Geological Survey Memoir of 1885 'perhaps about the finest in any inland spot in East Anglia.' They are described in the Survey Memoir on North-West Essex (1878); and there are further notes in that on Ipswich, Hadleigh, etc. (1885).

There is a paper by Dr. Marr in Geol. Mag. 1887 (p. 262); there have been excursions to the neighbourhood on the occasion of the Geological Society's Centenary in 1907, and by the Geologists' Association in 1898 and 1910, of which brief descriptions have been published. I know of nothing else. Since publication of the two Survey Memoirs some pits have been closed; some new ones opened; and many extended considerably. These changes have disclosed facts of considerable interest, which deserve to be put on record.

I. The Principal Pits.

I will name the position and contents of the principal pits, giving numbers to them for use in this paper and notes of references to them in the Survey Memoirs.

Beginning with those on the high road leading eastwards from the town, Green's Pit (1) has been filled in, but the singular contorted sands [1] are still visible. On the south side of the road two pits (2) called Victoria on the Ordnance Map and in the Geological Survey Memoirs,[2] now joined at the top, show Chalk, Thanet Sands, Crag, gravels, and a patch of Boulder Clay. Farther out along the road, on Gallows Hill,[3] two brickworks (3), called California on the Ordnance Map, show bedded silts and upon these Boulder Clay.

The high road which runs out of the town south-east towards Newton, passes on its left (north-east) side, Whorlow's (4) Chalk-pit[4] (Chalk, Thanet Sands, Crag, Glacial Gravels, and clay) and next, the entrance to the Alexandra Brickworks. Here are two pits[5]: the outer (5),[6] nearest to the road, contains Thanet Sands, Crag, Glacial Gravels, Boulder Clay; the inner (6),[7] half a mile from the road, very large, shows bedded silts and Boulder Clay, like those in the Gallows-Hill Pits (above, 3), which are indeed across

[1] Geol. Mag. dec. 3, vol. iv (1887) p. 262.

[2] 'Geology of N.W. Essex, &c.' Mem. Geol. Surv. 1878, fig. 15, p. 54; 'Geology of the Country around Ipswich, Hadleigh, &c.' *ibid.* 1885, pp. 132–33.

[3] *Ibid.* 1878, p. 53: 'On the hill North-East of Sudbury'; see also *ibid.* 1885, p. 132.

[4] *Ibid.* 1878, p. 55: 'Touching the eastern side of the cemetery'; see also *ibid.* 1885, p. 132.

[5] Apparently opened since the publication of the Survey Memoirs.

[6] Mem. Geol. Surv. 1878, p. 55: 'Eastward of the cemetery.'

[7] Apparently opened since the publication of the Survey Memoirs.

a field barely 100 yards off. About a mile from the town, also on the left (north-east) side of the road, is a sandpit (7) which shows bedded sands and Glacial Gravel.

The high road running southwards from the town, to Great and Little Cornard, passes a large chalk-pit (8) near the railway-station,[1] with Chalk, Thanet Sands, Crag, Glacial Gravel, and clay. Farther on, a road to the left (Cat Lane on the Ordnance-Survey 6-inch Map) skirts the remains [2] of an extensive quarry (9). This is much overgrown, but Chalk can still be seen at its southern end, and beyond its northern end Crag is seen at the back of the Mauldon Gray Inn, not far from (5), but south-west of the high road.

In Great Cornard, a lane beside the church leads near to a pit (10) in a field about 300 yards east of the rifle-butt[3]; this shows a deep section in red sands, which I suppose to be Crag.

Leaving the town by way of Ballingdon Bridge, and taking a road southwards on the right bank of the Stour, we pass on the right the great Ballingdon Chalk-pit (11), described in the Survey Memoirs.[4] Now, only Chalk and Thanet Sands are seen, with occasionally a trace of Woolwich and Reading Beds; over these is some late gravel. A little farther, on the left, is an entrance to the Ballingdon-Grove[5] Brickworks (12). These contain Boulder Clay, gravels, and sands. The clay has been washed for brick-making, and in the residues some far-travelled rocks have been found. Much of the clay has now been dug away, and gravel is worked; below this Thanet Sands have been disclosed (also, a pit about 50 yards south of the western end is chiefly in these).

The high road leading south-westwards from Ballingdon Bridge, as it mounts Ballingdon Hill, passes on the left (east) the entrance to an extensive sand-pit (13) in the field.[6] This shows a great thickness (perhaps over 40 feet) of false-bedded sands, with Boulder Clay lying upon them.

The Victoria Brickworks (14), north-west of Ballingdon Bridge,[7] are chiefly in late gravels, but some Thanet Sands are visible at the south-western end, up towards the mill.

All the above-named pits are within a mile of Sudbury. About 2 miles south of the town, the brickworks (15) in Little Cornard contain Thanet Sands, a considerable thickness of false-bedded sands and gravels, some grey clay, and in this clay very large transported masses of Chalk. A few hundred yards up an adjacent lane (Chapel Lane, on the Ordnance 6-inch Map) a small excavation (16) affords the only section[8] at present known to me of Woolwich and Reading Beds.

[1] Mem. Geol. Surv. 1878, p. 16, fig. 4?
[2] *Ibid.* 1878, p. 15: 'East of Sudbury is a line of Chalk-pit[s].'
[3] Apparently opened since the publication of the Survey Memoirs.
[4] Mem. Geol. Surv. 1878, p. 14, fig. 3.
[5] *Ibid.* 1878, p. 57: 'At the great brickyard east of Balingdon.'
[6] Apparently opened since the publication of the Survey Memoirs.
[7] Mem. Geol. Surv. 1885, p. 132.
[8] Apparently opened since the publication of the Survey Memoirs.

II. Sands and Silts.

Since the date of publication of the Survey Memoirs additional aids have been furnished in the Ordnance Maps, by their larger scale, and by their contour-lines.

Six of the above-named pits lie on or near the 200-foot contour. In the two pits on Gallows Hill (3), and in the adjacent inner Alexandra Pit (6), is exposed a thick series of finely-bedded sandy silts, of which more than 30 feet can be seen. About half a mile east, at the same level, in the sand-pit on the Newton Road (7), is an exposure of at least 20 feet of bedded sands—chiefly pure sand, but in two or three beds a little clay is present.

Across the river, at the same level, in the sand-pit on Ballingdon Hill (13), are nearly 40 feet of somewhat current-bedded, stoneless sands, similar to the last, except that clayey sand occurs only at the top. Sands of similar character seem to occur not far off, in the parish of Middleton. In all these pits, except that on the Newton Road (7), Boulder Clay overlies the beds.

The sand-pit north of Great Cornard Church (10), east of the rifle-butt, is just below the 200-foot contour. It is in red sands, which are, I think, a remnant of Crag. Similar red sands can be traced at short intervals up to the pit (2) in which Mr. W. Whitaker recognized Crag.

There seems, then, to have been at Sudbury an extensive deposit of sediments, sands, and silts, reaching nearly up to 200 feet above Ordnance datum. They are all somewhat current-bedded. Do they not indicate deposition in water which was shallow, and affected by only moderate currents? This level of 200 feet O.D. is 120 feet above the alluvial meadows at the bottom of the valley.

III. Boulder Clay.

In the Gallows-Hill (3) and inner Alexandra (6) Pits, upon the bedded silts lies Boulder Clay. This forms a sheet which is exposed continuously for several hundred yards. The ground behind the pits rises gradually into the plateau of Boulder Clay, which attains an altitude of nearly 300 feet O.D., and covers several square miles. The clay is found in wells to have a thickness of sometimes over 100 feet. We may deduce that these sections show a true base of the clay.

Its junction with the silts can be scrutinized, touched, tested. The passage from silts into clay is seen to be continuous: there is no sudden break. There are coarser beds in the upper foot or so of the silts, finer bands in the lowest foot of the clay. Flints are not abundant in the lowest part of the clay; where they cease to occur, the bed can hardly be assigned definitely to either division. The chalk-pebbles in the clay are rounded: smaller rounded chalk-pebbles are found at several horizons in the silts. It seems that the process which produced the silts changed by a gradual transition into the process which produced the Boulder Clay.

It may be mentioned that bedded silts are also seen lying under

Boulder Clay in brickyards at Woolpit, about 8 miles east of Bury St. Edmunds (also at about 200 feet O.D.), and in the Culford Brickyards, about 4 miles north-north-west of Bury (here at only about 100 feet O.D.). Sands under Boulder Clay have been proved at various levels (generally under 200 feet O.D.) in various well-sinkings, as, for instance, Brettenham Park and Felsham.[1]

Along an extensive visible transition-line the action which produced the clay has left the silts perfectly undisturbed: it exerted on them neither thrust nor drag. In the lower of the two Gallows-Hill Pits (3) and in the inner Alexandra Pit (6), at its south-western end, the silts are seen to bend down into hollows[2] 10 or 20 feet deep, occupied by the clay. The beds are neither thickened nor thinned, they lap over as sheets. I am inclined to look on them as deposited on the sides of pre-existing hollows; but the hollows may be due to subsequent subsidence below. Some tiny step-faults may be explained on either view, and I have found no evidence which is decisive.

IV. Gravels and Isolated Clay.

The Stour Valley seems to be pre-Glacial. Boulder Clay was found in its bed in a boring at Glemsford, about 4 miles above Sudbury.[3] The boring appears to show that the ancient valley-bottom there lies 470 feet below the present floor. It may be conjectured that this indicates a buried channel, and that such channel lies buried all along the present valley. If so, the old valley about Sudbury was deep and, in places, remarkably narrow. However, all known sinkings have reached Chalk at moderate depths.

Whatever may have been the shape of the old valley, a great mass of Boulder Clay must have been removed after deposition. Thus we find the thickness of over 100 feet on the plateau reduced to a few feet about the 200-foot contour: and at lower levels find it sometimes absent altogether, as at the Ballingdon Chalk-pit (11), the Ballingdon Victoria Brickworks (14), and the Little Cornard Brickworks (15), each at about 100 O.D.

The bedded sands and silts described in § II (p. 25) are absent from all pits below the 200-foot contour. Those pits that are called in the Geological Survey Memoirs 'Victoria Pits east of the town' (2) lie at a level below that of the Gallows-Hill (3) and inner Alexandra (6) Pits. They show Chalk, presenting a horizontal upper surface; over it Thanet Sands, somewhat eroded at the top; upon these again Crag, with an extremely-eroded upper surface; and, finally, on this coarse gravels and sands, violently current-bedded. Though only a quarter of a mile from the higher-level pits mentioned above, with their 40 feet of silts, no silt is here seen. In the coarse gravels lies a sheet, about 10 feet thick

[1] 'The Water-Supply of Suffolk' Mem. Geol. Surv. 1906, pp. 32, 52.

[2] Mem. Geol. Surv. 1878, p. 53: 'At the southern end. . .'

[3] *Ibid.* 1906, p. 58.

and several yards long, of Boulder Clay. It is banded for a foot or two at its base, but above is normal tough clay. This sheet terminates at its south-western end in a contorted mass of yellow and white sand, which is rolled up into the clay. Gravels lie round the whole.

These pits are situated on the south side of a lateral valley. At about the same level, on the north side, is Green's Pit (1) with the contorted mass of sand described and figured by Dr. Marr. Across the Stour, the Ballingdon-Grove Pits (12) are at their western end now chiefly sand, though, at one time, masses of clay and masses of sand were here intermingled confusedly. The clay has been mostly removed; but early in 1911 I found that a block of clay was being dug, some 20 feet broad and 10 or 12 deep, with sand on each side. A few weeks later all the clay had been removed, and the block was seen to have been embedded in fine sands, which dipped, not riverwards, but away from the valley.

At the eastern end of these same Grove Pits, in the digging of coarse gravel, two sheets of Boulder Clay have been cut through. One was 40 feet long, 4 to 8 feet thick, abruptly cut off at one end; the shape of the other end was hidden by a little talus.

In the outer Alexandra Pit (5) there is a sheet of the clay resting upon gravels. At first, appearances were not inconsistent with deposition *in situ*; but, as excavation progressed, the clay was seen to lie on a ridge of the gravels, and to bend down over this on each side. Further cutting has revealed it to be a sheet, 40 or 50 yards long by about 4 feet in thickness, ending abruptly against the gravels, which lie around it, above as well as below.

These isolated sheets and masses cannot have been formed *in situ*; they are as much boulders as any mass in the gravel; plainly they have been transported. All of them lie at levels below the base of the Boulder Clay, as seen in the Gallows-Hill (3) and inner Alexandra (6) Pits, and far below the higher parts of the plateau: their transport would be down hill. All of them lie on slopes of the present river-valley; and it will be remembered that clay can slip down very moderate slopes. At the brickyard near Ballycastle Railway-Station (Antrim), for instance, I saw Boulder Clay slipping down the hillside, though the slope was only 1 in 8. The excavation was shallow, but the turf for many yards above it was rent and fissured. The contorted sand and clay in the Victoria Pits (2) bend as they would be bent by a slip down a hillside. The jumble at the western end of the Ballingdon-Grove Pit (12) may be fallen masses, on a steeper slope, or down a cliff where the river had been undermining. Ice may have assisted in transporting the sheets. The coarse and strongly current-bedded gravels which lie around or adjacent indicate violent and varying water-action.

In the Railway-Station Chalk-pit (8) and Whorlow's Chalk-pit (11), which are about 300 yards apart, and each at about 150 feet above Ordnance-datum, clay is seen to rest upon irregular gravels. This, however, does not seem to be normal Chalky Boulder Clay; I think that it may be remanié. Such would naturally often be formed during the re-excavation of the valley.

V. Isolated Masses of Chalk.

The brick-pits in Little Cornard (15), about 2 miles south of Sudbury, lie on and above the 100-foot contour. They show at the entrance some Thanet Sands. Against these, on a slope which seems to be a bank of a former lateral channel of the ancient river, lies a mass of violently current-bedded sands and gravels. Against these gravels, still farther from the present valley, comes a stretch of grey stoneless clay, now mostly worked away. In this grey clay, at the farther side of the pit, lie several large masses of Chalk. They are very large: one, oval in shape, is not less than 30 feet long, by 10 feet in height. They contain no flints: they appear to be not original Chalk, but remanié Chalk, as are some of the Cromer masses. They lie embedded in the clay, which wraps round them and fills fissures. The clay itself looks as if it may be a mud washed from Boulder Clay.

The valley is wide and open above, but here is contracted by a spur of the plateau to about a third of its former breadth. These masses lie at the end of the spur. Were they stranded here? The gravels, against which their enwrapping clay rests, indicate powerful currents at levels 20 to 40 feet above the present valley-floor.

VI. General Remarks.

This paper is the fruit of some words from Mr. Harmer, spoken when showing some Norfolk sections. He remarked on the light which might be thrown on the origin of Boulder Clay by the beds that immediately preceded it. I had almost relinquished Glacial studies, but the new idea roused me to a re-examination of West Suffolk sections.

The foregoing descriptions show that close to Sudbury, on each side of the existing Stour Valley, at or just below the level of 200 feet O.D., which is 120 feet above the present valley-floor, there are extensive deposits of sands and silts, such as appear to be aqueous deposits, laid down in shallow waters [1]; and that these pass by a continuous transition into normal Chalky Boulder Clay: also that their undisturbed condition negatives the existence, during that transitional period, of any action such as thrust or drag.

Again, close to Sudbury, at levels of about 170 feet O.D. and below, on the sloping sides of the valley, are sands and gravels, often very coarse, generally presenting strong current-bedding, such as indicates torrential water-action. These gravels contain transported sheets and blocks of previously-formed Boulder Clay, some of which have shapes such as would be the consequence of slip down slopes. There has been some action able to deposit also, at the same level as some of these gravels, Chalk masses which weigh hundreds of tons.

It may be noticed that the foregoing deductions, made for the

[1] Compare the suggestion of an extra-Glacial lake, Proc. Geol. Assoc. vol. xv (1898) p. 454.

immediate neighbourhood of Sudbury, agree with the course of events probable if a submergence preceded the deposition of the Boulder Clay, and an emergence followed it.

Discussion.

Mr. W. Whitaker said that, when making the geological survey many years ago, he found no record of the fine sections at Sudbury, the finest inland sections of Drift in the Eastern Counties. These sections had been constantly changing, and luckily some years later the new developments were noticed by Dr. Marr. It was fortunate that the Author had continued the record.

He was disposed to look on the peculiar mass of Glacial Drift at the sides and bottom of the valley as belonging to a series of deposits older than the Boulder Clay of the plateau, and belonging rather to the 'Lower Glacial' of Searles V. Wood, an infilling of an early Glacial (or pre-Glacial) channel.

The thickness of the deposits in some of these channels was too great to allow of the explanation by land-slipping—it being greater than that of any other Drift deposits in the country, as much as 470 feet in the valley of the Stour some miles above Sudbury. Moreover, these deposits reached down to below sea-level, and obviously could not result from any process going on with the land at its present level. The Boulder Clay certainly was well adapted for land-slipping; but that could hardly be to the great extent pointed out. Besides, the Drift-channels contained various other materials as well as Boulder Clay.

The Secretary read the following remarks, received from Prof. T. G. Bonney:—

'Unfortunately an engagement on Wednesday evening, made before I knew that this paper would then be read, prevents me from being present. That I very much regret, since, as the Author has taken me over all the sections (as I believe) described in his paper—in most cases two or three times at least—I should have liked to have expressed the opinions which I have independently formed. These are in full agreement with those set forth in his paper, so far as I can gather from the abstract. In the Sudbury sections at about 200 feet above O.D., a quite normal 'Chalky Boulder Clay' is seen overlying well-stratified silts and sands, with occasional false-bedding. These present every appearance of having been deposited under water, which was moving very gently and steadily. Their stratification shows no disturbance as it approaches the base of the Boulder Clay, and the latter does not in any way scoop or dig into it; but we find, not seldom, signs of a real, though rapid, transition from the one to the other.

'But, from about 180 to 100 feet O.D., that is more or less on the flanks of the Stour Valley (which the Glemsford boring has shown to be pre-Glacial)—sand, gravel, and Boulder Clay (normal) show great disturbance and strange associations,—masses of the last material occurring in the others, like large irregular erratics. Their mutual relations are not suggestive of a ploughing-up by the snout of a glacier (which, had it deposited the Boulder Clay, would by this time have retreated from the district), but a downslipping of the older materials and a mixture of them with coarser gravels of more local origin.

'I may add that, sometimes in the Author's company, sometimes with others, I have seen this orderly succession of silt, sand (more or less gravelly), and Boulder Clay, in other parts of the Eastern Counties, and not in them only.

Thus, while I am fully conscious of the difficulties presented by the hypothesis of the subaqueous deposition of Boulder Clay, that which regards it as the direct product of an ice-sheet seems to me to involve yet more serious difficulties, at any rate in our Eastern Counties.'

The AUTHOR, in reply, agreed with Mr. Whitaker as to the existence of Boulder Clays of more than one age. But the sheets described in these gravels were not contemporaneous lenticles; they had tolerably uniform thickness and abrupt ends. Without the aid afforded by the 6-inch maps and contour-lines, the paper could not have been composed. Photographs had been taken, but these materials do not readily give clear results.

4. Petrological Notes *on* Guernsey, Herm, Sark, *and* Alderney.

By Prof. T. G. Bonney, Sc.D., LL.D., F.R.S., and the Rev. Edwin Hill, M.A., F.G.S.[1] (Read November 22nd, 1911.)

[Plate I—Microscope-Sections.]

Contents.

During the nineteen years which have passed since we visited the Channel Islands, our friend Mr. John Parkinson has examined parts of Jersey with results described in four valuable papers contributed to this journal.[2] He then turned his attention to Northern Guernsey, and in a short but very important summary of his work on its diorites,[3] announced his conclusion that the syenite, hornblende-gabbro, and diorite, which had been separated by the older observers, were not genetically distinct, but were related to each other as the products of the differentiation of a single magma. Our brief visits to the island in 1888 and 1891 had shown us that the above-named distinctions could hardly be maintained, and prepared us for some such conclusion as that just mentioned.

The principal object of our visit in September 1910 was to make a further examination of this question and to study some of the numerous dykes a little more fully than Mr. Hill had been able to do when drawing up his sketch-map and general account of the geology of Guernsey.[4]

We also spent two full days in Alderney, an afternoon in Herm (both unknown to one of us), and twice visited Sark, in order to re-examine some specially interesting sections.[5]

I. The Gneiss.

The gneiss, which occupies the larger half of Guernsey, forming the grand crags and beautiful bays of its more southern shores,

[1] Mr. Hill wishes to state, with regard to this paper, that he has taken part only in the field-work.

[2] Q. J. G. S. vol. liv (1898) p. 101; vol. lv (1899) p. 430; vol. lvi (1900) pp. 307, 320; also vol. lvii (1901) p. 218.

[3] Geol. Mag. dec. 5, vol. iv (1907) p. 74.

[4] A map of Guernsey, on the scale of 2 miles to the inch, prepared by the Ordnance Survey, was published in 1902.

[5] This paper was completed, with the exception of one section, by the spring of this year (1911), but examination of the rock-slices brought out a point of much interest, to clear up which Mr. Hill (the other author being unable to accompany him) went to Guernsey after Easter, and again in September.

was described by Mr. Hill in his paper on this island,[1] to which Prof. Bonney contributed some petrographical notes.

At that date the authors still assumed gneiss to be, as they had been taught in their youth, the extreme result of metamorphism in a sedimentary rock, though the latter of them called attention to the very frequent signs of mechanical disturbance. On their joint visit to these islands in 1888, they were convinced that the foliation in the gneiss of Guernsey was a result of pressure, and that the rock had been originally granite more or less porphyritic—thus being almost everywhere a variety of what is now called 'augen-gneiss,' a conclusion announced by Mr. Hill[2] in the following year.

This visit and a passing glance in 1891 showed that, making the necessary modifications required by the new interpretation of the 'gneissic' structure, the statements in Mr. Hill's first paper were substantially correct, so it may suffice to say that porphyritic felspars, which sometimes are about a couple of inches in diameter, were almost always constituents of the original granite.[3] These and most of the smaller felspars in the matrix are usually red, but the rock is locally greyish-white: the alteration in colour being probably due to the change, in disseminated minute granules, from magnetite to hæmatite. Biotite has been present, but it is more generally altered into a chloritic mineral.

The foliation, which is, of course, at right angles to the pressure, is roughly north and south. It is the same at St. Malo, and near Coutances is between this direction and north-north-east, while about Cape La Hague it is north-east and south-west. These indicate very ancient (probably pre-Cambrian) movements, almost at right angles to the widely-extended Armorican folding.

II. The Diorites.

This rock is now much more largely quarried than when Mr. Hill was at work in Guernsey, the excavations being more numerous and carried to a greater depth. The latter change, however, does not facilitate examination, as the floor of the pit often can only be reached by ladders, not easy of access, and the quarry, when abandoned, is before long converted into a pool. In such cases we had to be content with a view from above, and with an examination of the heaps of material which were awaiting

[1] Q. J. G. S. vol. xl (1884) p. 404.

[2] E. Hill, 'The Rocks of Alderney & the Casquets' Q. J. G. S. vol. xlv (1889) p. 389.

[3] It is possible that further scrutiny may show that there is more than one mass. Mr. Hill, during his visit in April 1911, found a variety, bearing some superficial resemblance to a diorite, in a quarry opposite Rocquaine Castle. A slice shows it to be holocrystalline; the quartzes, composite and not very abundant; felspars, rather irregular in outline, a considerable amount plagioclase; decomposition, shown by minute white micas, setting in; biotite, fairly plentiful, composite, a little altered, containing between its cleavage-planes rather elongated crystallites (? sphene). So the rock is a gneiss that has undergone pressure-modification.

removal. We think, however, that in the course of one visit or another, we have seen all the principal varieties.

They were grouped by Ansted as diorite and syenite, to which a third, hornblende-gabbro, was added in the paper of 1884; but we incidentally showed, in 1891, the close connexion of two of them, and thus agree with Mr. Parkinson's[1] conclusions that these are the results of differentiation in a single magma.

The diorite varies generally from a rather fine-grained rock, which, when unweathered, is almost black, to one in which the principal minerals are the size of a hemp-seed, or occasionally even slightly larger: the latter kind being often a little richer in felspar, which assumes a whitish colour from incipient decomposition. A third variety,[2] called 'birdseye' by the quarrymen, is more local. In this a number of roundish crystals of hornblende, commonly about 0·4 inch in diameter, are scattered in a matrix, usually more like that of the first-named variety, though occasionally it becomes more felspathic and speckled in aspect. A variety termed 'long grain' exhibits a slight foliation, the hornblende crystals becoming rather elongated and assuming a rudely parallel arrangement. This is sometimes streaked (as described in 1891) with the greyer kind.[3]

Occasionally the 'birdseye' develops a very coarse structure. We picked up some fragments exhibiting it on the floor of a pit entered from Delancey Lane (north of St. Sampson's), and found a remarkable case in certain skerries in Bellegrève Bay.[4] Here a streaky and 'spotty' diorite (in close relation with both fairly normal speckled and 'birdseye' types) becomes locally so coarse that the hornblende-crystals are sometimes nearly 2 inches long.[5] Two extreme varieties also claim notice: the one, related to the second of those mentioned above, but with much less hornblende and more coarsely crystalline in structure, being generally conspicuous from some distance by its yellowish-white tint; the other very dark in colour from the abundance of hornblende. Of this we know only two instances, one at the bottom of the descent into Bon Repos Bay, and another on the south-west side of Fort Albert in Alderney. The latter[6] one can be distinguished from the more normal diorite by its blackness some hundreds of yards away. Here, as a rule, it is simply divided, but with a perfect

[1] Geol. Mag. dec. 5, vol. iv (1907) p. 74.

[2] It dominates, as shown in Mr. Hill's map, for about half a mile inland from the coast between a little north of Vale Castle and a couple of furlongs south of Hougue à la Perre.

[3] Q. J. G. S. vol. xlviii (1892) pp. 134–37.

[4] Near an old battery and some 50 yards north of a low causeway going down to the sea.

[5] Even larger hornblende-crystals were obtained, prior to 1884, by Mr. Hill in an otherwise normal 'birdseye' from a quarry near Baubigny Mill. These larger crystals often show a pœcilitic structure (felspar).

[6] The microscopic structure is described in Q. J. G. S. vol. xlv (1889) p. 384. The larger hornblende-crystals measure sometimes about half an inch in diameter.

weld, from the paler more normal rock. On the more southern side this dark kind appears occasionally in patches, with irregular outlines, among the more normal diorite, which itself is rather variable in coarseness. All are cut by veins of the exceptionally felspathic kind. This rock from Fort Albert was described in 1889 [1] as closely related to the picrites, but a slice, made from an apparently average specimen collected last year, shows less olivine, and distinctly more felspar: so the extreme basicity, as at Little Knott,[2] is obviously local.

In the field the rock is irregularly jointed, weathers with rather rounded edges, and varies in both the amount of felspar and the size of its hornblende-crystals, which sometimes reach half an inch in diameter. Here and there it much resembles the Guernsey 'birdseye,' and passes on either side into a normal 'speckly' diorite. Commonly the junction between the two varieties is sharp, a little wavy, and with a perfect weld; but occasionally it is irregular. We consider the normal diorite to be the intruder, for now and then, near a junction, it contains streaks, sometimes almost 'wisps,' occasionally forking, of 'picrite' or a solitary hornblende, quite half an inch in diameter; while one of the streaks, less than an inch thick and a few inches long, may contain felspar, in a way that suggests an impregnation from the other rock.

All these varieties are veined by the rather cream-coloured felspathic one, mentioned above, in which the hornblende is about the size of a mustard-seed. Thus we infer that the 'picrite' had only just crystallized when it was followed or carried up by the diorite, and that both were still at a high temperature when the more felspathic material was injected. Diabase dykes, like those common in Guernsey, cut the mass, and at Bibette Head, granite,[3] as was described by Mr. Hill, is clearly intrusive in the ordinary diorite. The former rock is of normal coarseness at the junctions, and sends a vein into the other which is about 3 inches thick.

In the Guernsey instance, at Bon Repos Bay, a rather broad mass of diorite, obviously intrusive in the gneiss, passes from a coarse, very hornblendic form (in the lowest part of the cliff) to a fairly normal one, the intermediate zone being now and then very like the 'birdseye.' In the field the first rock much resembles the dark one at Fort Albert, but under the microscope it proves to contain more felspar (plagioclase) and some quartz, occasionally forming an intercrystalline mosaic with hornblende. The latter mineral is abundant, and is often associated with small flakes

[1] Q. J. G. S. vol. xlv, p. 384, where the results of the microscopic examination are given.

[2] *Ibid.* vol. xli (1885) p. 511.

[3] A slice shows it to consist of quartz, felspar (not very well-preserved, but in part at least orthoclase), biotite, dominating over hornblende (though often closely associated with it, as if formed at its expense), a little sphene, and iron-oxide.

of biotite, as if that were in some way derived from it. Acicular prolongations of the green hornblende suggest a slight secondary growth. Grains and granules of iron-oxide are present; but apatite is inconspicuous, and sphene probably absent. Thus the rock, notwithstanding its aspect in the field, is only rather a basic diorite.

Ten slices have been cut from specimens of diorite collected during our late visit; and those described in 1884 [1] have been again examined. As a minute description of the microscopic details would unduly lengthen this paper and have no general interest, we shall confine ourselves to indicating the more characteristic features of the chief varieties.

A specimen of 'birdseye' from Hougue à la Perre, slightly more felspathic than the one previously described, contains hornblende, brown and green, some of which, if not all, has been formed by paramorphic change from a very pale-brown augite. The larger grains are rather irregular in outline and studded with small crystals of felspar, which cause the conspicuously pœcilitic aspect of the larger hornblendes in this rock. Their extinction-angles, and those of the felspar in the body of the rock, suggest labradorite or in some cases andesine.

A specimen from the Bouet quarry, dark in colour, with its hornblendes tending to be parallel ('long grain'), shows that mineral to be the more abundant (see Pl. I, fig. 1). It is of a rich brown tint, and associated with a little pale brownish-grey augite, from which it probably has been formed; the felspar is hypidiomorphic, and similar to that in the last-named rock; a little quartz is present.

A dark, rather fine-grained variety, cutting 'birdseye,' as described, at Hougue à la Perre, shows a tendency to porphyritic structure in the hornblende, which is more abundant than the felspar, and has its larger crystals spotted with that mineral. A little brownish augite may be seen in process of conversion into hornblende, and a grain or two of free quartz. (See Pl. I, fig. 2.)

A specimen from one of the light-coloured veins, near Hougue à la Perre, consists largely of felspar. This is in bad preservation, but most of it is plagioclase, though some orthoclase may also be present. The ferromagnesian constituent is small, irregular in outline, and often occurs in tiny groups, suggestive of chloritized biotite rather than of hornblende. With this is associated a colourless or faintly yellow material, with fairly-high refractive index and bright polarization-tints, probably epidote. A little iron-oxide is visible, but neither quartz, nor sphene, nor apatite.

The diorites of Fermain Bay and Castle Cornet, both of normal kind, were described in 1884, and we have again examined the slice—besides a new section from the former, and one showing the 'birdseye' type from the latter place; but, as all are in poor preservation, they do not call for special notice.

[1] Q. J. G. S. vol. xl, p. 425.

We may, however, mention a variety from the north of the causeway to Lihou Island, because it is the only instance in which we remember to have found a true dyke (generally under 2 yards in width) of this rock in the gneiss.[1] A rather compact-looking dull-green ground-mass is spotted with darker hornblende-grains, rounded in form, and about a fifth or a quarter of an inch in diameter. The slice shows them to be rather irregular in outline and pœcilitic in structure, enclosing a small mineral, not felspar. Much of it may be some kind of augite, the remainder is a rounded mineral; in colour rather brown, with dark bands, possibly indicating the former presence of an olivine. The ground-mass is in still worse preservation; hornblende, however, is rather abundant, dominating the (much decomposed) felspar.

These varieties, as well as the more normal granular diorite, may be found among the specimens described in 1884, in which the hornblende is commonly green, and the felspar (plagioclase) too decomposed for further determination; sometimes the latter is fairly idiomorphic, and sometimes a trace of fluxion-structure is perceptible.

Examples come from quarries west of Vale (the darker variety), at Hommets (east of Cobo Bay), near Fort Doyle, in Delancey Hill, the shore under Mont Crevelt, the northern end of Bellegrève Bay, west of St. John's Church, at Castle Cornet, and Fermain Bay. Now and then we find a little biotite or free quartz, especially in the slices from the more northern localities.

Two specimens, from Grand Havre, may be mentioned as representative of the most northern and acid type of the Guernsey diorites, both being fairly coarse-grained. The one is from the rocky shore of a promontory (near a tower) on the west side of that inlet. A slice shows the felspar (in moderate preservation) to be fairly idiomorphic, much of it being a plagioclase with rather small extinction-angles, probably oligoclase, but some of it bears more resemblance to an orthoclase. There is a fair amount of hornblende and biotite closely associated: the former occasionally including small crystals of felspar, the latter sometimes associated with its companion in a way that is suggestive of production at its expense. There is a fair amount of quartz, which has been the last to crystallize; also a little iron-oxide and some small apatites. The rock, in fact, is a t o n a l i t e.

The other specimen represents the lighter rock in a quarry west of Vale Church, and may also be called a tonalite. The hornblende is rather irregular in outline, with pœcilitic felspar in the larger crystals; the biotite is similar in shape and habit, and sometimes contains rather minute inclusions of a green mineral which much more resembles ill-preserved residual hornblende than a local chloritization of the biotite. In fact, the two minerals are often so related as to suggest that the latter has replaced the former after the rock had become very nearly, if not wholly, solid. The

[1] Mentioned by Mr. Hill, Q. J. G. S. vol. xl (1884) p. 417.

felspar, fairly idiomorphic, is not well preserved, but apparently corresponds with that seen in the other specimen; so does the quartz, which sometimes shows slight strain-shadows.

This rock was intrusive in a micaceous diorite of fairly normal character, and probably is identical with the lighter (intrusive) rock in a junction-specimen mentioned in Mr. Hill's paper of 1884.[1]

General Conclusions regarding the Diorites.

The foregoing description shows these diorites to be the products of a magma, which was subject to differentiation more or less local; the one extreme being represented by the very basic form at Fort Albert, the other either by the coarser felspathic intrusions, or by the tonalites in the Grand Havre district. The diorites of Guernsey, as was noticed by Mr. Parkinson, contain more quartz and biotite towards the north or north-west of the island, the microscope sometimes showing the presence of the former material where the aspect of the rock did not lead one to suspect it.

Where the magma has undergone a marked differentiation, the more basic portion seems to have been the earliest extruded; and, the later the date is, the more acid is the material. That also holds good in Alderney, where at least three forms occur, one of them sometimes very basic. But is it not possible that some of the granites may also be residual products of the same magma? The one at Bibette Head, Alderney (intrusive in diorite), is distinctly hornblendic, and in it also the biotite often seems to have been formed at the expense of the other mineral. Besides this, it is not very rich in quartz, and contains a fair amount of plagioclase. Both the 'granites' of Sark, as described in 1892,[2] are hornblendic, and the southern one is really a tonalite.

The granites of Herm and Jethou are distinctly hornblendic,[3] and so are those of Guernsey, especially that of Lancresse (intrusive in diorite). It is, therefore, possible that these also may be yet more acid terms in a differentiation series.

III. The Acid Dykes.

These are often of a light brick-red, inclining sometimes to a pinkish red, sometimes to a buff colour. Occasionally they may attain a thickness of 12 or 15 feet, but are more often less than 3 feet thick, and may even 'dwindle' to less than an inch. In texture, they vary from compact to finely granular (the more common); in composition, from aplites to microgranites: a ferro-magnesian constituent being very seldom conspicuous, and their edges rarely showing any appreciable chilling. Usually they are

[1] Q. J. G. S. vol. xl, p. 415. The slice, however, shows less biotite, and perhaps no hornblende, but only a small piece of it represents this rock, the remainder belonging to the other, which is a normal diorite (? traces of augite) with a little biotite.

[2] *Ibid.* vol. xlviii (1892) p. 130.

[3] *Ibid.* vol. xliii (1887) p. 333.

sharply, but irregularly, jointed, so that it is difficult to obtain specimens of a fair size and shape.

In Guernsey they are nowhere common in the diorite, and sometimes altogether wanting, as on the shore north of St. Peter's Port. One or two, however, may be seen in the Delancey-Lane quarry and in the micaceous diorite on the south-western margin of Grand Havre; and they cut the granite in the south-eastern part of Lancresse Bay, though none have been noticed in that of the eastern horn of the Mont-Cuet promontory.[1] In the gneissic region they are abundant, as on the shore opposite to Lihou, at the foot of Pleinmont, in Bon Repos Bay, about La Corbière, in Fermain Bay, to the south of St. Peter's Port, and abundantly at Castle Cornet, where they afford, as will presently be described, some special features of interest. They have not been identified with certainty in Sark,[2] but they are far from rare in the diorite of Alderney, being numerous at its south-western end.[3]

To obtain materials for a complete account of these dykes would be so expensive a task that we must leave it (if it be worth undertaking) to the officials of some future Geological Survey. We have, therefore, contented ourselves with examining under the microscope (in addition to those from Castle Cornet, which can be more conveniently described separately) some dozen specimens (ten of them new preparations), as illustrative of the more conspicuous varieties. But as a minute description of even these would be wearisome, we shall condense our notes into a general statement, only entering into particulars in exceptional cases.

The dominant minerals are quartz and felspar. Both are apt to vary in size (in one or two cases, from about ·08 to ·0015 of an inch), the smaller grains sometimes forming a sort of mosaic setting for the larger,[4] or filling up a crack in them, while in other instances the grains are more nearly of a size. The larger are apt to have rather irregular boundaries, and occasionally are very slightly elongated in one direction. The felspar is generally rather turbid: but orthoclase, a plagioclase (perhaps oligoclase), and microcline can be recognized. The last is commonly water-clear, though containing a little (residual) dust. A third constituent is a more or less chloritized biotite, generally small and infrequent, though occasionally (as in a dyke on the north side of Fermain Bay) it is large enough to give the rock a rather spotted aspect; but here also it is considerably decomposed. Other minerals are practically absent, except a few small grains of iron-oxide, to which, in an ultra-microscopic condition, the frequent red colour must be due.[5]

[1] That is, on the west side of Lancresse Bay; see Guernsey N. H. Soc. Trans. 1898, p. 255.

[2] E. Hill, Q. J. G. S. vol. xliii (1887) p. 332. There are doubtless many reddish aplitic dykes in that island, but such evidence as can be obtained seems to point to an earlier date for these.

[3] Near Fort Clonque one of them, as will be described, is cut by a later dyke rather similar in composition.

[4] For instance, a dyke about 24 feet thick, near Fort Tourgies in Alderney.

[5] To this group belong 20 & 21, in the appendix to Mr. Hill's paper of 1884, Q. J. G. S. vol. xl, p. 423.

IV. Rocks at Castle Cornet.

This fortress, now occupied as military barracks, stands on a rocky island, joining the southern pier of the harbour at St. Peter's Port. The rocks between the walls and the sea are easily traversed at low water and afford excellent sections. Gneiss, of which this is the northern extremity, is the oldest rock. Diorite is intrusive in this, acid dykes of a reddish colour cut both, and dark basic dykes traverse all three. Without a large-scale map it would be impossible to depict and tedious to enumerate the numerous and complicated outcrops of these rocks, so we shall be content to draw attention to a few points of special interest.

The gneiss is reddish in colour; it varies slightly in coarseness, the augen-structure not being always equally conspicuous, and the cleavage-foliation is more or less soldered up near the contact with an intrusive rock.

The diorite is usually composed mainly of about equal quantities of dark-green hornblende and felspar (neither well preserved), in slightly irregular grains measuring about an eighth of an inch in diameter; but this common variety assumes over a limited area the 'birdseye' character.[1] At a junction-surface the diorite is either closely welded to the gneiss, or occasionally has partly melted it down. In the latter case the diorite, for a few inches, assumes a slightly streaky and porphyritic structure, being studded with felspar-crystals (rather rounded in outline) which increase in size as they approach the gneiss. They are, however, always distinctly less than the larger 'augen' in that rock, so that we are justified in inferring the latter to have been partly, and the smaller constituents wholly, melted down. The larger felspars may be traced for perhaps 4 or 5 inches from the indubitable gneiss, and the smaller to quite double that distance. The diorite occasionally includes a strip of gneiss, 4 or 5 inches thick, which may also have a fused border.

In a slice from about the middle of a 'fusion-band' the rock presents a rather fragmental aspect. The principal constituents are quartz, felspar, hornblende, and biotite, which are irregular in form and variable in size. The quartz, although fairly abundant, generally occurs in rather small grains; the felspars range downwards from about ·25 inch. The larger are sometimes fractured, the crack being filled by minute ground-mass. None are well preserved, but a plagioclase and some orthoclase can be recognized. The hornblende and the biotite (the last altered to a pale-green mineral, with extrusion of iron-oxide) are generally smaller in size than in the ordinary diorite or gneiss, and are curiously associated, sometimes almost intermixed.[2] Thus the inference from field-work is confirmed by the microscope.

The numerous red dykes often indicate no small shattering of the mass composed of the two older rocks. A very few of these

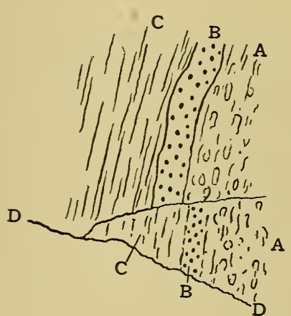
[1] It is in the middle of a slight recess in the rock on the west side, near its northern end.

[2] There is also some iron-oxide and a little apatite.

may reach or even exceed a dozen feet in width; many are not 6 feet wide, and they may thin down to less than an inch and yet be quite distinct. Most of them are microgranitic in structure, consisting of quartz and a red felspar with, as a rule, a minute sparsely-distributed greenish material; and thus they are practically finely-grained aplites. One or two, however, are a little more distinctly granular, with a ferromagnesian constituent more obviously present.[1]

Near the north-western angle is a very compact instance, and one or two dykes [2] a little farther south have chilled edges; but, as a rule, no change in texture is obvious on approaching a junction. That is generally clean, with a close weld, but now and again these dykes have locally melted down both the gneiss and the diorite, and have incorporated some of their material. Of the former rock, the felspars more or less survive, as in the diorite already described, though distinguished with more difficulty owing to similarity of colour; while the micaceous constituent gives rise to a green streaking. One of the appended diagrams represents a junction-surface of dyke and gneiss (fig. 1); the other (fig. 2, p. 41) an inclusion of the latter which, in the upper and thinner part, loses its porphyritic character, as if it had been more or less fused *in situ*.

Fig. 1.—*Junction-surface of dyke and gneiss.*



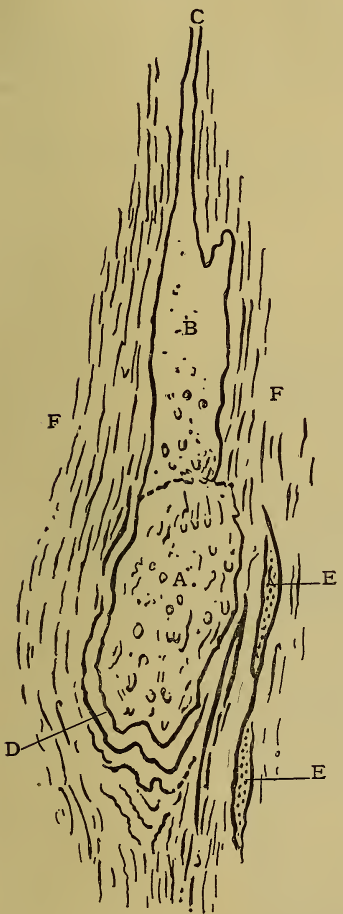
[A=Augen-gneiss; the augen are not quite so large as usual.
B=Border, about 2 inches broad, on the whole more like gneiss.
C=Red rock, rather streaky.
D=Edge of a diabase dyke.]

As, however, the streaking of the 'red dyke' extends for a few feet from the junction, that structure may have been mainly acquired in another way. The magma seems to produce fusion in the diorite more readily than in the gneiss, though here also clear closely-welded junctions often occur. The two may be seen in different stages of incomplete mixture. Sometimes we find an elongated, shuttle-shaped patch of 'greenstone' ending in a streak. When the piece is a few inches thick, the inner part resembles a rather fine-grained diorite. Both the outer part and the thicker streaks, which, however, generally do not exceed a couple of inches, are minutely granular; the outsides and the thinner streaks (from 1 inch downwards) look quite compact. These alternate for a short distance with fairly-clean red bands; while the rest, or even

[1] Mr. Hill, in September 1911, came upon a dyke, which was a marked example of this variety, at low tide on the harbour side of the breakwater.

[2] As will be presently shown, further work makes it probable that these are later in date than the others.

Fig. 2.—*Gneiss-inclusion, porphyritic in the lower but not in the upper portion.*



[A=Gneiss, felspars measuring not more than half an inch; maximum thickness, about 6 or 7 inches.
B=Gneissoid, after the break granular rather than porphyritic.
C=Inclusion continued for about 2 feet apparently by a granular streak.
D=' Clean' band of 'red' dyke.
E, E=Granular streaks.
F, F=Streaked red dyke-rock.]

the whole of a dyke, exhibits the slightly wavy sage-green streaks. Here and there is a thin band of uniformly red rock, which, in one or two cases, seems as if some clean magma had broken into the 'dirtied' one, while the latter was solidifying. Sections have been prepared to illustrate these structures. One, in which are not only green streaks but also the above-mentioned granular bands, is found to consist of quartz, and felspar in rather elongated, irregular grains, and an altered biotite (Pl. I, fig. 3). The felspar is rather decomposed, but Carlsbad twins of orthoclase, microcline, and a plagioclase, with rather small extinction-angles, can be recognized. The biotite is now altered in colour to green, and has extruded some iron-oxide in the usual way: the flakes being sometimes about ·01 inch long, but generally less (down to about ·002 inch). Where these are more conspicuous, the felspar distinctly exceeds the quartz in quantity. The slice contains also a little iron-oxide and apatite. Another specimen, from a dyke 5 or 6 yards thick, with alternating streaks of red and greyish green (the former dominating), exhibits constituents generally similar in nature and shape; but the altered biotite is less in amount and smaller in size. A third slice is from a dyke about 10 feet wide, rather compact in structure, and in colour a fairly bright red, with curving dull green streaks, not exceeding 0·1 inch in thickness, recalling the fluxion-structure of a rhyolite. This consists of the above-named minerals, but locally shows a slight tendency to become 'graphic.' A fourth slice represents an offshoot, rather over an inch in thickness, from a dyke in gneiss. Its minerals are as above, but distinctly more irregular in form and size, some felspars being as much as ·125 inch in length, while others do not exceed a tenth of this. A fifth example is cut from the indefinite boundary between a red dyke and partly-fused gneiss. The structure, under the microscope, is very irregular, the felspar-grains (of the usual kinds) differ much in size, and it recalls in some parts a dyke, in others the gneiss.

Fig. 3.—*Streaky red and green aplitic rock from Castle Cornet (Guernsey). Natural size.*

An outcrop of the red rock, bounding the side of the above-named little bay, shows two or three irregular patches of a rather compact dark rock, about a yard in diameter, looking like huge ink-spots. In the field we suspected these to be lumps of diorite, not sufficiently melted to mix appreciably with the other rock (for that is not streaked); and microscopic examination of a small fragment shows the darker part to consist of felspar, granular to hypidiomorphic (in which, though decomposed, plagioclase is recognizable), and of a rather pale hornblende, in which the extinction-angles are smaller than is usual, and transverse sections are few (both suggestive facts). The rock is finer in grain than the normal diorite, from which it has probably been broken, but has perhaps been almost re-melted. The red part is mainly felspar, variable in size, the larger grains being hypidiomorphic. It is decomposed, but microcline and plagioclase are recognizable. Also present are a fair amount of a pale yellowish-green mineral, rather irregular in outline, with high refractive index, probably epidote, quartz (not much), and the usual little flakes of greenish mica, which in the hand-specimen are hardly visible. (See Pl. I, fig. 4.)

We come, lastly, to two dykes which present some rather marked differences in structure from the others. One is an unstreaked dyke about 12 feet thick, just north of the angular bastion on the western side of the castle. A slice from the middle part contains only a few flakes of altered biotite. Quartz and felspar occur porphyritically: the former often retaining its prism-angles, the latter fairly idiomorphic, varying in length from ·1 inch to ·05 inch, and, as usual, decomposed, though generally with clear borders. The ground-mass often exhibits a rather spherulitic structure, irregular in its outline, somewhat brush-like in growth, and apparently connected with one or two of the larger minerals (see Pl. I, fig. 5). The remainder of it is a mosaic of the same minerals, the granules being about ·005 inch in diameter, mixed with some flakelets of a white mica. Some peculiar, thin, granular, elongated bodies are perhaps only cracks subsequently filled up. Another slice, cut from the chilled edge about 2 inches from the exterior, shows quartz, felspar, and altered biotite much as before, in a quartzo-felspathic ground-mass, the constituents of which measure not more, and generally less, than ·001 inch in diameter; under a high power it shows a tendency to a spherulitic or graphic structure, and some minute belonites, rather irregularly shaped and of a pale yellowish-green colour.

Another very compact dyke, of a purplish colour, almost flinty in structure, with small phenocrystals of quartz and felspar, occurs at the north-western corner of the Castle-Cornet rock near the pier-bridge.[1] We were at first inclined to suppose it an offshoot from a thick dyke of normal character, which for some reason had cooled more rapidly, but further study excited suspicions which were strengthened by microscopic examination; and Mr. Hill, on his last visit, satisfied himself that the dykes were independent, although for part of their course they occupy the same fissure. Here then, as in one or two other places,[2] there has been a second and later intrusion of acid rock.

[1] It is described in the paper of 1884 at pp. 416 & 423.

[2] For instance, near Fort Clonque in Alderney and Fort Regent in Jersey.

V. The Basic Dykes.

Basic dykes, which the older geologists would have called 'greenstones,' are abundant in the Channel Islands. Mr. Hill in 1884 gave a general description of those in Guernsey,[1] including, however, among them one or two intrusive masses, which, on closer examination, seem more nearly related to the diorites; and he mentioned in 1889 an interesting example in Alderney.[2] During our late visit we paid some attention to those in Guernsey, but found them to be so numerous and in many cases so difficult of access that we soon gave up the idea of collecting materials for a complete study, which could only be done by a residence of some months in the island. We therefore contented ourselves with examining a few of the more representative varieties.

We take first one that, strictly speaking, ought not to be included. It is from a dyke, about 4 feet wide, cutting the gneiss of L'Erée Point, opposite to Lihou Island. In the field it resembled a somewhat decomposed diorite, rather less coarse-grained than the normal 'speckled' variety of that rock; but the microscope shows porphyritic crystals of hornblende, felspar, and quartz, scattered in a microcrystalline ground-mass. The first mineral is variable in size, sometimes fairly idiomorphic, sometimes composite, the grains averaging about ·01 inch in diameter, with a somewhat 'flaky' structure and extinguishing at angles rather uniformly low. The second is a plagioclase, the extinction-angles suggesting a somewhat basic oligoclase. The third (quartz) is not common, and is much corroded by the ground-mass. A few grains of iron-oxide are also present. The ground-mass is a mosaic of clear minerals, probably to a large extent felspar (untwinned and perhaps reconstituted), with occasional interstitial belonites of hornblende and flakelets of a very pale brown tint—possibly another form of the same mineral. One or two cracks are largely cemented by epidote. So this rock is very possibly more nearly related to the diorites than to the material of the ordinary basic dykes.

The next specimen is also rather abnormal. It cuts gneiss, cropping up irregularly on the rocky shore to the north of the causeway leading to Lihou Island, seldom so much as 6 feet thick, and often less than 3. It contains numerous crystals of hornblende fairly idiomorphic, sometimes nearly an inch long, in a rather compact speckled greenish matrix. In one place it is distinctly cut by a fairly thick dyke of diabase (with small phenocrystals of felspar) which runs up into the headland; in one or two more it appears to be cut by and welded to a rather compact diabase, but in others it has a chilled edge in which the porphyritic hornblendes become smaller and fewer until they disappear (which suggests that these may have been, at least to some extent, formed *in situ*).

The larger hornblendes, under the microscope, prove to be only

[1] Q. J. G. S. vol. xl (1884) pp. 416-18.

[2] *Ibid.* vol. xlv (1889) p. 384. Those of Sark are briefly noticed in vol. xliii (1887) p. 332, and again by the present authors in vol. xlviii (1892) p. 140.

imperfectly idiomorphic, are generally brown in colour, but sometimes green; in one case the former includes rounded grains of the latter, but in another (the larger crystals) the enclosures are composite—the small constituents giving rather exceptionally high polarization-tints.[1] The ground-mass is microcrystalline, consisting of much-decomposed felspar, small grains of augite or hornblende, and many granules of iron-oxide. This rock not improbably represents an offshoot from the 'birdseye' variety of the diorites.

The next specimen is from a dyke on the north side of Fermain Bay, 3 to 4 feet thick, which runs up the cliff from the shore, cutting gneiss. This is chiefly interesting because it is cut by a thin aplitic dyke. Very near it, eastwards, is a mass of diorite, and westwards are two diabase and other aplitic dykes, a thin vein from one of the former distinctly cutting a similar vein of the latter.

Under the microscope the structure is microcrystalline. The pale-green hornblendes, with occasional rusty stains, prismatic in form (more abundant than the felspar), suggest a slight fluxion-foliation. The felspar is granular and interstitial, not twinned, rather decomposed, and the clear parts may sometimes be reconstituted. Iron-oxide is small and not very abundant. Perhaps this dyke also is an offshoot of the diorite.

The following specimens represent the more ordinary types. We take first a compact dyke, which cuts the gneiss at the south end of Vazon Bay. The hand-specimen is of a greenish-black colour, very minutely granular. A slice shows the rock to be microcrystalline. It contains numerous prismatic, sometimes almost acicular, greenish crystals exhibiting a general resemblance to hornblende but often granular in structure, especially towards the centre, so that it is difficult to observe the extinction-angles. There are small grains of iron-oxide. An interstitial mineral, probably felspathic, possibly a devitrified glass, contains numerous belonites (? hornblende).

The next specimen is from a dyke on the east side of Petit Bot Bay. The hand-specimen, a dark blackish-green sub-porphyritic diabase, is minutely granular, and contains specks of pyrite. The microscope shows a fair amount of a plagioclastic felspar, measuring up to about three-fifths of an inch in length, tending to occur in groups, but not well preserved. The ground-mass consists of a felspar, also too altered for determination, with augite, almost replaced by the filmy hornblende described above, and a little iron-oxide. A few grains of calcite occur, perhaps slightly dolomitic and probably secondary.

The next specimen, from a dyke about 9 feet wide, on the side of the Lihou causeway, is selected to represent the more porphyritic examples. The ground-mass (somewhat minutely ophitic) consists of decomposed plagioclase and rather small augites partly replaced by 'viridite,' together with little grains of iron-oxide, resembling magnetite. In this are scattered crystals of

[1] This may signify that the enclosed mineral was once an augite, poor in iron, like diopside.

plagioclase, measuring up to nearly ·1 inch in length, not well preserved, which enclose occasionally small felspars and even augites. Some larger grains of iron-oxide (? magnetite) are also present.

The greenstone dyke in the Mannez Quarry, Alderney, is in one respect interesting, for it cuts the Grès feldspathique. A brief description of it is given in Mr. Hill's paper on that island, but another slice has been examined, because it has been called an andesite by Prof. Bigot. This, however, as it happens to represent a slightly more compact state of the rock, adds little to our knowledge. In it the grains of iron-oxide assume a slightly club-like form, the small felspars are fairly idiomorphic, and there is a considerable amount of a rather minute greenish material, perhaps both chlorite and secondary hornblende; some larger grains of iron-oxide (? magnetite) are also present. Though the hand-specimen is a little pale in colour, we still think that the rock should be classed with the diabases[1] rather than with the andesites. Two or three more specimens from other localities in these islands have been examined, but those described may suffice to show that the basic dykes are for the most part either ordinary or hornblendic diabases.

VI. Mica-Trap[2] Dykes. [E. H.]

In Mr. Hill's paper of 1884 two occurrences of these rocks are noticed. Since then they have received attention from the Guernsey Society of Natural History, and the following list is compiled chiefly from its 'Transactions.'[3] The localities are given in order round the coast, starting southwards from the Harbour.

Putron Village.—Below Mr. Ozanne's property, in the face of the rock. About 1 foot wide. (1892, p. 186.)

Bec du Nez.—Some distance north of.—Two close together; one 10 feet wide with mica in rather large flakes: erosion of it has given rise to a cave. (1894, p. 331.)

Bec du Nez.—One, some way south of this, is mentioned in Q. J. G. S. vol. xl (1884) pp. 418, 426.

St. Martin's Point.—In the cave below and north of the battery. 18 inches wide. (1892, p. 186.)

Monument Bay.—South of the so-called 'Marble Caves.' [These names are not on Guérin's map. The spot is said to be under Doyle's monument on Jerbourg.] Very wide. (1894, p. 331.)

Moulin Huet.—One in this bay is mentioned by us.[4] Q. J. G. S. vol. xl (1884) pp. 418, 426.

Cliffs west of Les Thielles.—West of the junction between two varieties of gneiss a mica-trap dyke occurs, at least 20 feet wide. (1897, p. 150.)

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[1] I disagree with some modern petrographers, and think diabase (in Hausmann's sense) a convenient term for more or less altered basalts—a hornblende-diabase being the same thing as a proterobase (J. J. H. Teall, 'British Petrography' 1888, pp. 134, 135); epidiorite is a similar rock, the formation of which is a consequence of crushing. [T. G. B.]

[2] I retain the old name mica-trap, though some exception might be taken to the latter half, because I think it better than the modern lamprophyre, in which the corresponding part is absolute nonsense. [T. G. B.]

[3] The references, unless otherwise described, are to their volumes.

[4] There are apparently two outcrops, one of which is distinctly less micaceous than the other.

L'Erée Promontory.—A mica-trap vein, striking north-east and south-west, cuts three veins of felsite which cross the porphyritic gneiss from north-north-west to south-south-east. (1895, p. 23.) In 1910 we noticed here two small mica-trap dykes, both south of the Lihou causeway, visible only in a few outcrops, and too decomposed to be worth slicing, but did not notice that they cut felsite or greenstone veins. The southern one was some 4 feet thick; the northern about half that amount. The latter not only cuts the gneiss, but also encloses a piece about a foot thick, one of the branches being only 6 or 7 inches.

Fort La Crocq and Richmond.—One about 2 feet wide just below the small fort, running north-eastwards down the rocks. A similar dyke was found on the south-west of Richmond, probably a continuation. (1891, p. 126.)

Hommet [north of Vazon Bay].—A similar dyke, on the east side of the fort. (*Ibid.*)

Albecq Cutting.—On the land side, through the red granite: thin. (*Ibid.*)

Long Port, Vazon. [Guérin's map marks Long Port in Cobo Bay.]—In places fully 6 feet wide: colour, redder than usual: divides into two branches. (1892, p. 186.)

Grandes Rocques.—Similar to that at Fort La Crocq. (1891, p. 126.)

Port Soif.—Similar. (*Ibid.*)

Fort Doyle.—In the quarry near the fort, three veins of undoubted mica-trap: respective widths=3 feet, 1 foot, and 8 inches. (1893, p. 270.)

Point Norman.—In a cleft of the rocks at this Point; close to the quarry, but rather on its southern side. (1891, p. 153.) We have noticed this one.

Homtole, and Hommet Paradis.—Two are suspected on these islets. (1893, p. 270.)

St. Sampson's Harbour.—One which occurs near the mouth of the Harbour has been mistaken for a sandstone. (1890, p. 36.) Subsequently it was cut through in drainage-excavations. 'A remarkable feature was the inclusion in it of nodules of diorite, many of which were so rounded, and separated so cleanly from the matrix, as to resemble pebbles.' (1893, p. 270.)

Herm and Jethou.—Mr. Hill mentioned one on Jethou in Q. J. G. S. vol. xliii (1887) p. 333. The 'Guernsey Transactions' say that they 'abound,' and give a list of ten (1894, p. 331): one 10 feet wide, one 12, and one 14. But not one has so far been recorded from the adjacent and larger island of Herm.

Sark.—It does not appear that any have been added to those mentioned in our paper of 1892. (Q. J. G. S. vol. xlviii, 1892, p. 142.)

Alderney.—Mr. Hill mentions one in the Mannez Quarry. (Q. J. G. S. vol. xlv, 1889, p. 384.) Another has been noticed in La Chue Sandstone Quarry on the south coast. (1902, p. 123.)

Mica-trap dykes have, therefore, been noticed in every variety of rock, except (up to the present time) the Lancresse granite.

VII. The Pleinmont Grit.

In Mr. Hill's paper (1884)[1] a rather fine-grained dark rock is mentioned as forming the whole cliff of Pleinmont Point, which he regarded as an exceptionally large mass ('fully half a mile in length') of the dyke-forming diabase.

We gave it a passing glance in 1888, when Prof. Bonney put it down in his notes as 'a compact diabase, rather schistose and close-jointed.' In September 1910, wishing to see its relations, if any, to the microgranitic dyke-rock, we walked up its northern slope near Fort Pezeries until we found a 'red dyke'[2] cutting it.

[1] Q. J. G. S. vol. xl, p. 417.

[2] Described below, A, p. 49.

On that occasion Prof. Bonney wrote in his diary that, on the whole, the rock reminded him more of a dark felsite, like some in Wales, than of a diabase. Nothing in its aspect suggested a sedimentary origin, but he observed, when collecting a specimen for microscopic examination, that it was exceptionally hard, and had a more irregular fracture than is usual with igneous rocks of similar texture. The first glance at a slice showed that we had been deceived, and we afterwards found that the late Father Noury had recognized the clastic origin of the rock, for in a sketch-map of Guernsey, contributed to the third edition of Ansted's 'Channel Islands,'[1] he marks it as schiste. We subsequently came upon a remark in his 'Géologie de Jersey' 1886, p. 127, which had escaped our notice:—

> 'La pointe ouest de Guernesey contient cependant, au sud du Fort Pezeries, un petit massif de schiste semblable à celui de Jersey et durci par les granites qui forment cette extrémité de l'île.'

But these granites can only be the gneiss, which we have no doubt is the older of the two, and, notwithstanding the lax use of the term schiste, we should say that, as a rule, it was hardly applicable to the Pleinmont rock.

Mr. Hill paid two short visits this year (1911) for further examination. The grit forms cliffs and slopes for about half a mile, from the small bay west of Fort Pezeries to somewhere near the spot marked Pleinmont Point. In the bay there is, on the east, gneiss; on the west, grit: at high-water mark these are separated by shingle; they come together in the rocks bared at low tide, but are much masked by seaweed. Some hundred or so yards from the shore a dark crystalline dyke[2] is seen, crossing both gneiss and grit; also, a pink dyke (described below, B, p. 50), some 12 feet broad, cutting all three. On a small knoll in the shingle he came upon a junction of a rock, rather resembling a gneiss, with grit; but the former proves, as will be seen, to be a variety of the 'red dykes' (described below, C, p. 50).

On land the boundary between gneiss and grit can be followed southward by outcrops. From a high level it descends somewhat suddenly to the sea, and at a spot which can be reached a contact is seen. The grit here for a few inches contains small fragments, and shows a slight banding (see below, p. 49). The gneiss at this spot lies on the grit: not far south all the rocks are gneiss; and opposite the contact-spot, only 20 yards seaward (west), there is again gneiss. A cleft, no doubt a fault, forms the seaward boundary between the two rocks here, and as far as it was followed north. There has apparently been great disturbance.

[1] Revised by E. T. Nicolle (1893), the first edition being in 1862.

[2] A slice shows the rock to be mainly composed of a small prismatic green hornblende, rather acicular in structure, with colourless needles, apparently the same mineral, piercing a water-clear ground-mass, probably a secondary felspar. Here and there is a little epidote, sometimes rather impure. As the structure is very likely a result of pressure, the rock may be named an epidiorite.

The above-mentioned specimen of Pleinmont rock shows a distinctly clastic structure. It consists of rather numerous grains, subangular to fairly rounded (from about ·008 inch in diameter downwards), of quartz, with rather wavy edges, and of felspar (plagioclase recognizable) and some dark-brown, barely translucent grains of iron-oxide. These are embedded in a mosaic of a clear material mixed with films of a mica, greenish to colourless, which vary much in size and occasionally are almost equal in length to a diameter of the larger grains. Crossing the nicols shows the clear material to be granular, a mixture, probably, of quartz and reconstituted felspar; but its individuals are so minute that it is very difficult to be certain (see Pl. I, fig. 6). Slices have since been examined from five other specimens collected by Mr. Hill at earlier and later visits. They differ only in details one from another and from that just described, two or three indicating a certain amount of fracture and recementation; but one specimen (that which shows a slight banding and small fragments) is interesting, as bearing on the relation between the grit and the gneiss. Under the microscope it appears to be distinctly fragmental, some of the quartz-grains being fairly rounded, others rather angular. In most respects it resembles the others, but one part of the slice is considerably finer in grain, and the remainder contains sundry composite grains (those of larger size consisting of quartz and rather elongated felspars, in which plagioclase is recognizable). One or two of these fragments are only quartz, the constituent grains, four or five in number, being elongated and a little 'ragged' in outline, as is frequent in a gneiss. The altered biotite occurs sometimes in larger grouped flakes, and a small chlorite is present. The specimen fully confirms the general evidence, namely, that the gneiss is anterior to the Pleinmont rock.

Two specimens of Brioverian rock from Bec-au-Fry (Brittany), given several years ago by Prof. Barrois to Prof. Bonney, have been sliced for comparison, as they presented a certain resemblance to the Guernsey grit. One, which contains a little epidote and has a slightly more micaceous ground-mass (one flake measuring about ·05 inch), shows a small vein, filled with quartz and some mica, which is slightly faulted. The other, a little more cracked, is slightly more coarse-grained than the first, and has some of the larger felspar-like fragments replaced by a fairly clear microgranular mineral, rather like some of the ground-mass. The mineralogical changes in both these and the Pleinmont specimens are rather more conspicuous than is usual in such Cambrian grits as Prof. Bonney has examined, but less than in those of Huronian age near Sudbury (Canada), and in the finer materials of the conglomerate at Obermittweida (Saxony), and he is disposed to regard it as an effect of old age rather than of contact-metamorphism.

The three 'red dykes' mentioned above have been examined under the microscope. That above Fort Pezeries (A) appears in the hand-specimen to be rather more compact than the ordinary red dykes. The ground-mass is cryptocrystalline to microcrystalline, showing in many parts a tendency to spherulitic structure, in crystallites more or less 'bunched'; but in parts it is almost a micropegmatite. A little quartz is present, generally in clustered granules; some small rather altered biotite, similarly aggregated; also granules of decomposed iron-oxide, and one or two which may be an impure sphene. Prof. Bonney inclines to regard this rock as a quartz-porphyrite rather than a quartz-felsite, but a chemical analysis alone could settle that point.

The dyke on the shore (B) shows a crowd of very minute plagioclases (species indeterminable), perhaps set in a cryptocrystalline 'paste,' and rather numerous minute flakes of mica, white and brown. Of larger minerals, there are felspars, several of fair size and idiomorphic, mostly plagioclase with rather small extinction-angles; quartz-grains, not numerous and composite; biotite, rather altered, sometimes into a chlorite; and a little iron-oxide, which is associated occasionally with (possibly) a secondary sphene. This rock is a quartz-porphyrite.

The rather gneiss-like dyke (C) presents a cryptocrystalline ground-mass, with phenocrystals of felspar, some rather rounded, others idiomorphic, most of them certainly plagioclase, with rather low extinction-angles; also some quartz and a moderate amount of altered biotite, and some iron-oxide. This rock belongs to the same group as the last one. It shows signs of having suffered somewhat from pressure, both ground-mass and felspar being rather cracked.

A specimen from Rocquaine Castle, described in 1884, much resembles the grits from Pleinmont. Macculloch[1] speaks of 'a stratum of argillaceous schist . . . . at the lower parts of the bay,' and Ansted[2] of 'a small patch of clay slate.' South of the Fort, the shore-rocks below high-water mark are (nearest to the land) gneiss; farther out is a fine-grained rock which includes patches and pockets of a coarser one, apparently gneiss. Over a few square yards this fine-grained rock resembles a slate. It extends seawards, and often meets portions of coarse rock in a manner resembling igneous contact. But the outcrops are much shattered, and in one clean face the shapes of the coarser included patches, and a mottling in the fine-grained ground-mass, strongly suggest crush.

Two specimens in this locality were described and discussed in 1884[3] with the result that, although the one was almost impossible to distinguish from a grit, the other, in which a small part had an almost identical structure, seemed in the rest to be a crushed gneiss. We then inclined to regard both as much-crushed gneiss, and this view has been confirmed by a third specimen, collected by Mr. Hill in April 1911: part of this slice much resembling the Pleinmont grit, the rest almost certainly being crushed gneiss. His field-work, as described above, suggests that this slaty rock

[1] Trans. Geol. Soc. ser. 1, vol. i (1811) p. 10.
[2] In a note, 1st ed. (1862) p. 257; 3rd ed. (1893) p. 208.
[3] Q. J. G. S. vol. xl, p. 427 (Nos. 40 & 47).

of Rocquaine Castle is really only a case of extreme crushing.[1] It is perhaps needless to add that the large area occupied by, and the general uniformity of, the Pleinmont rock, make this explanation impossible for it, so that Guernsey does contain one very ancient sedimentary rock.

VIII. Notes on some Paramorphic and other Changes. [T. G. B.]

The following alterations in minerals which have been mentioned incidentally in the foregoing description deserve a little further notice:—

(*α*) The conversion of augite into hornblende.—I called attention to this change in 1877,[2] and have since then recorded other instances.[3] In the case of uralite, the change observed eighty years ago[4] was strictly paramorphic; but, as the term 'uralitization' has been applied by modern writers in an extended sense, it may be worth recording the several forms that have come under my observation. Beginning with an augite (or diallage) which in thin sections is almost colourless, we find that it changes (1) into a rich brown hornblende, with no alteration in external form. (2) This may be changed into a green hornblende, which, however, may perhaps sometimes form directly from the augite. (3) The latter mineral may be replaced by a group, the outline of which does not correspond with the original one, of small hornblendes, either prismatic or acicular in form. The latter phase may be locally subsequent to one of the others, pale-green actinolitic needles forming like a fringe at the margin of the larger crystals (4); but, when the whole of the new mineral assumes this form, often becoming rather coarser in structure, that is probably a result of pressure-metamorphism.

The change from an almost colourless to a richly-tinted mineral is rather surprising, especially in the first case. Probably some ultra-microscopic iron-salt is developed,[5] from which by further action of water a hydrous iron-silicate (green) is formed. Stage (3) probably indicates some irregularity in the operation of the transforming agent, and (4) a greater activity of water. But, though hornblende is often a result of change, paramorphic or otherwise, in augite, we cannot doubt that in many cases it has been an original constituent of a rock.

(*β*) The conversion of hornblende into biotite.—In 1892 we described at some length cases of this change, as a con-

[1] The changes which pressure can produce in a gneiss are extraordinary; see Geol. Mag. dec. 2, vol. x (1883) pp. 509–11.

[2] Q. J. G. S. vol. xxxiii (1877) pp. 895, 909, 912, 915.

[3] As in Min. Mag. vol. ii (1879) p. 5.

[4] By G. Rose, Pogg. Ann. vol. xxii (1831) p. 321.

[5] Perhaps a slightly hydrous iron-oxide, for that (with a little manganese) is the main constituent of umber-brown tints.

sequence of the action of an aplitic magma on an almost pure hornblendite,[1] and I have noted since then other instances of similar change. The streaked red dykes of Castle Cornet afford, as I believe, frequent examples, for in many of them it cannot, I think, be doubted that the small biotites have been produced by the melting-down of the hornblendic constituent of the diorite; but in the latter rock, elsewhere in Guernsey, biotite sometimes seems to replace part of a hornblende-crystal, either by taking the place of about half of it, or by enclosing a core of it, more or less completely. These cases, like some described in 1898,[2] suggest occasionally that the biotite-molecule has been substituted for the hornblende-molecule in building crystals of the latter. If, however, there has been a subsequent change, this would require the removal of lime and the addition of a moderate amount of alkaline silicate; which, perhaps, would not be a very difficult matter if the rock were still at a high temperature.[3]

(γ) Structure of the acid dykes.—In the acid dykes the relations of the felspar and the quartz differ from those in an ordinary granite. In the latter, as a rule, the felspar is more or less rectilinear in outline; in these dykes it is rather irregular, and the rock assumes a granular structure. Full thirty years ago I drew attention to the possible significance of this structure,[4] and since then have more than once pointed out that it is sometimes accompanied by a slight elongation of the grains and indication of a fluxion-structure, being probably the result of a little movement in the later stages of crystallization.[5] The occasional presence of an interstitial mosaic of fine-grained quartz and felspar accords with that explanation, for it suggests the more rapid crystallization of a small amount of residual magma, which has acted like a lubricant to the grains in the nearly consolidated mass, and then has been either divided between the nearest crystals of the principal constituents, or sometimes, perhaps, has locally approached an eutectic mixture, and thus has rather suddenly solidified. The structure, as I remarked in 1885, is common in a vein-granite; it is noteworthy in the 'granulitic' group of the Lizard, and in a rather similar group in Sark, both of which are now believed to be

[1] Q. J. G. S. vol. xlviii (1892) pp. 129–32.

[2] *Ibid.* vol. liv (1898) pp. 366 & 369.

[3] If we take, for purposes of comparison, the ferromagnesian constituents of these two minerals as unity, this gives, in an average (aluminous) hornblende, the proportion of silica as also about 1, of alumina ·5 or ·6, of lime about ·6; in a biotite, silica about 1·3, alumina ·5, potash (or alkalies) ·3. Both biotite and hornblende seem to form rather rapidly as secondary minerals in a rock that has been much affected by pressure. See Q. J. G. S. vol. xlix (1893) p. 104; and T. G. Bonney & C. A. Raisin, in 'Climbing & Exploration in the Karakoram Himalayas,' by W. M. Conway, 1894, vol. ii, p. 54.

[4] I then thought that this irregularly-outlined structure (like that of some quartzites) might distinguish gneiss, which was regarded as the extreme stage of metamorphism in a sedimentary rock, from a normal granite.

[5] Q. J. G. S. vol. xxxvi (1880) p. 97; vol. xli (1885) Proc. p. 64; also 'Foundation-Stones of the Earth's Crust' 1888, p. 8.

produced by the mixture of an acid with a more basic and perhaps already solid material. The structure of these Guernsey dykes, and the conversion into biotite of the hornblende in the diorite, where it has been to some extent melted down, confirms the interpretation already given of those banded 'granulites'; and indicates that many of the Laurentian gneisses, though igneous in origin, owe their distinctive structures to the fact that they cooled in a different way from a normal granite.[1]

IX. Age of the Eruptive Rocks in the Channel Islands. [T. G. B.]

Dykes of mica-trap, in most of the Channel Islands, break only through gneissoid and igneous rocks, but in Alderney one cuts the Grès feldspathique (Upper Cambrian), while in the Rade de Brest and in the south-west of Britain[2] they are intrusive in Lower Carboniferous strata.

They all are probably of Permian or but slightly earlier[3] age. In Alderney two greenstone dykes also cut the Grès feldspathique; but in the other islands we can only say that these dykes (with two exceptions) appear to be later than any other crystalline rock.[4] In Cornwall and Devon the intrusive 'greenstones' are generally earlier than the acid dykes ('buff elvans'), but the numerous basic dykes at the Lizard, which must have been intruded when the peridotite (serpentine) and the gabbro were comparatively cool, may imply two ejections of similar magma at widely-separated intervals.[5] A few acid dykes (the compact), such as those at Fort Clonque (Alderney), Fort Regent (Jersey), and one or two at Castle Cornet and three at Pleinmont (Guernsey), may be quite late, because the first-named of these cuts not only a micrograniitic but also a greenstone dyke, and one of the last cuts a basic dyke.

Still, as similar compact felstones occur as pebbles, rather abundantly, at the base of the Grès feldspathique both in Alderney and in the Omonville district, and as the rock has a considerable resemblance to the acid lava-flows of Eastern Jersey, which are now admitted to be below the Grès pourpré (basal Cambrian), we should naturally suppose them to be of the same age. If so, they are much older than the acid dykes of Cornwall.

Another fact points to a rather marked gap between the ages of these Channel-Island rocks. The diabase dykes, so far as we have seen, are not coarsely crystalline, and frequently have chilled edges[6];

[1] To put it briefly, the normal granite came to rest as a liquid, and then crystallized: the gneissoid granite of 'Laurentian' type crystallized as it was coming to rest.

[2] J. J. H. Teall, 'British Petrography' 1888, p. 350.

[3] Sir A. Geikie, 'Ancient Volcanoes of Great Britain' vol. ii (1897) p. 96.

[4] Except, of course, the mica-trap.

[5] This, of course, may indicate that our preliminary assumption is not always valid.

[6] This statement, although the number of instances is few, holds also of the smaller group of acid dykes mentioned above.

but the granites and the diorites, which are rather coarse-grained rocks, run up to a junction with little, if any, change of structure; and even the microgranitic dykes not only appear to have cooled uniformly and have a close weld, but also in some cases have actually melted the adjacent rock, as though it too, when they were intruded, had been at a high temperature. Besides this the fact that, wherever they may occur, they vary little in texture, indicates that, although they cooled when the underground temperature was too low for them to crystallize as ordinary granite, it was fairly uniform in all parts of the islands. But the small group of acid dykes, mentioned above, seems to have been injected into comparatively cool rocks, which is another reason for regarding them as rather late in date.

The granite is intrusive in sediments of Brioverian age (Schistes de St. Lô) in Jersey as well as in Normandy, as, for instance, at Avranches in the south-west and Vire in the south-east. In this province also granite-pebbles occur in a conglomerate beneath the Grès armoricain.[1] Thus it cannot well be earlier than the close of the Archæan Era, and the micrograuites must be rather later; while the diorites are more ancient, and the granite, now represented by gneiss, oldest of all.[2] The relation of these to the hornblende-schists of Sark and the Lizard must be reserved for a subsequent discussion.

That rocks very similar in chemical composition should differ widely in geological age need not be an insuperable difficulty. The ejections of basic magma in the South-West of England must have continued, at intervals, from Archæan to early Permian times. In Scotland similar discharges were abundant in Carboniferous (perhaps also Permian) and Tertiary ages. Some of the Scottish granites are Archæan, others Devonian, and others Tertiary. So we need not be surprised if, in the Channel Islands, a diabase dyke is occasionally cut by an acid one, though the bulk of them are distinctly younger than the latter.

The prevalence of soda-bearing felspars in the granites and microgranites, as well as in the more basic intrusions, suggests that all these rocks may be results of differentiation from a magma, the separation of which began at a very early period—the most basic product among the diorites being represented by the 'picritic' rock of Fort Albert (Alderney) and that of Bon Repos Bay (Guernsey); the most acid by the tonalites of the Grand Havre district and of Little Sark. The latter are related to the granites, and these to the microgranites: the more ordinary diorite affording about four varieties, and becoming on the whole more acid towards the north

[1] A. de Lapparent, 'Les Roches Éruptives de l'Ile de Jersey' Ann. Soc. Sci. Bruxelles, vol. xvi, pt. 2 (1892), a very valuable paper. See also his 'Traité de Géologie' 5th ed. vol. iii (1906) p. 1746. A paper by Mr. J. A. Birds (Geol. Mag. dec. 2, vol. v, 1878, p. 79) contains some acute observations, though it has suffered from the misleading influence of Ansted.

[2] Their crystalline condition, as described above, suggests that the diorites, granites, and microgranites were not separated by very long intervals of time.

in Guernsey (as pointed out by Mr. Parkinson in 1907) and towards the north-east in Alderney. Thus the Channel Islands form a kind of petrographical province, characterized by richness in soda-bearing felspars and by a fair amount of ferromagnesian minerals in all but the most acid type of rocks.

The hornblende-schists of Sark and the Lizard are practically identical, and the granulitic group in the one closely resembles that in the other, but with this important difference, that it underlies those schists in the former district and overlies them in the latter. It is also produced in a similar way, though not altogether from the same material. In Sark an aplite has broken into and partly melted down a coarse-grained hornblendite; at the Lizard a rather more normal granite has similarly affected the hornblende-schist. The last rock, however, may in both cases represent incipient differentiation in a magma, the extreme products of which are hornblendite and aplite; for a few small lumps of the former rock occur, though very rarely, in the hornblende-schists of the Lizard. The main difference appears to be that, in Sark, the basic portion of the magma became completely separated, and even solidified, while the acid residue remained liquid; so that the latter, in consequence of earth-movements, shattered and carried upwards the former, with local melting-down. Following this came the less perfectly differentiated residual mass, which is represented by the hornblende-schists. But, at the Lizard, the process of differentiation became most complete in the later stage.[1] We think, as stated in our paper on Sark in 1892, that the fairly coarse, slightly foliated gneiss, which is seen beneath the above-named groups on both sides of the island, is really an intrusion somewhat, though perhaps not much, later in date.

The gneiss of Southern Guernsey must be the oldest rock in the islands, for it had already been made by pressure from a porphyritic granite, prior to the intrusion of the diorite; and the same may be said of the gneissoid rocks (also locally porphyritic) between Cherbourg and Cape La Hague. In fact, as Prof. Bonney pointed out in 1887,[2] many of the foliated rocks on the eastern side of the English Channel are very similar to those in the Lizard district. Further examination has confirmed this opinion, so it may suffice to call attention to one point of some importance—that the structure of the gneissoid rocks in Guernsey and Normandy indicates very early and important earth-movements acting almost at right-angles to those which gave rise to the great Armorican chain.

The latter produced as their ultimate result a great extrusion of acid rocks, beginning with the granites in the South-West of England and in Brittany, followed by more limited ejections of basic rocks

[1] But, as the hornblendite was often easily melted by the aplite, these stages may have followed in rather quick succession.

[2] Q. J. G. S. vol. xliii (1887) p. 320.

(including mica-traps). Is it possible that the diorites, granites, and aplitic dykes of the Channel Islands may be the consequences of a much more ancient, even pre-Cambrian, set of movements, of which our Charnian axis, with its associated intrusives, is a relic?

EXPLANATION OF PLATE I.

[All the figures are drawn with ordinary light, and magnified 20 diameters.]

Fig. 1. Diorite, from Bouet Quarry (Guernsey). Two grains of unchanged augite lie on a line drawn south-south-westwards from the numeral 1. Rising from the upper one and in the left-hand segment are hornblendes (darker in tint). (See p. 35.)

2. 'Birdseye' diorite, from Hougue à la Perre. Several grains of augite (tinted as in the last specimen), some of which are partly altered into hornblende (darker in tint). (See p. 35.)

3. Streaky red dyke, under Castle Cornet. The small dark-tinted prisms are the biotites or hornblendes of the green streaks. The white is quartz; the pale tints represent felspar. (See p. 41.)

4. Black rock, enclosed in red dyke, east of the breakwater, St. Peter Port. The lighter-tinted grains are the pale hornblende, the darker part felspar, rather decomposed. (See p. 43.)

5. Quartz-felsite dyke, Castle Cornet. The colourless grain on the right is quartz, the darker on the left decomposed felspar. Traces of a spherulitic structure can be seen. (See p. 43.)

6. Pleinmont rock [specimen 5, E. Hill]. The colourless grains are the larger fragments of quartz. (See p. 49.)

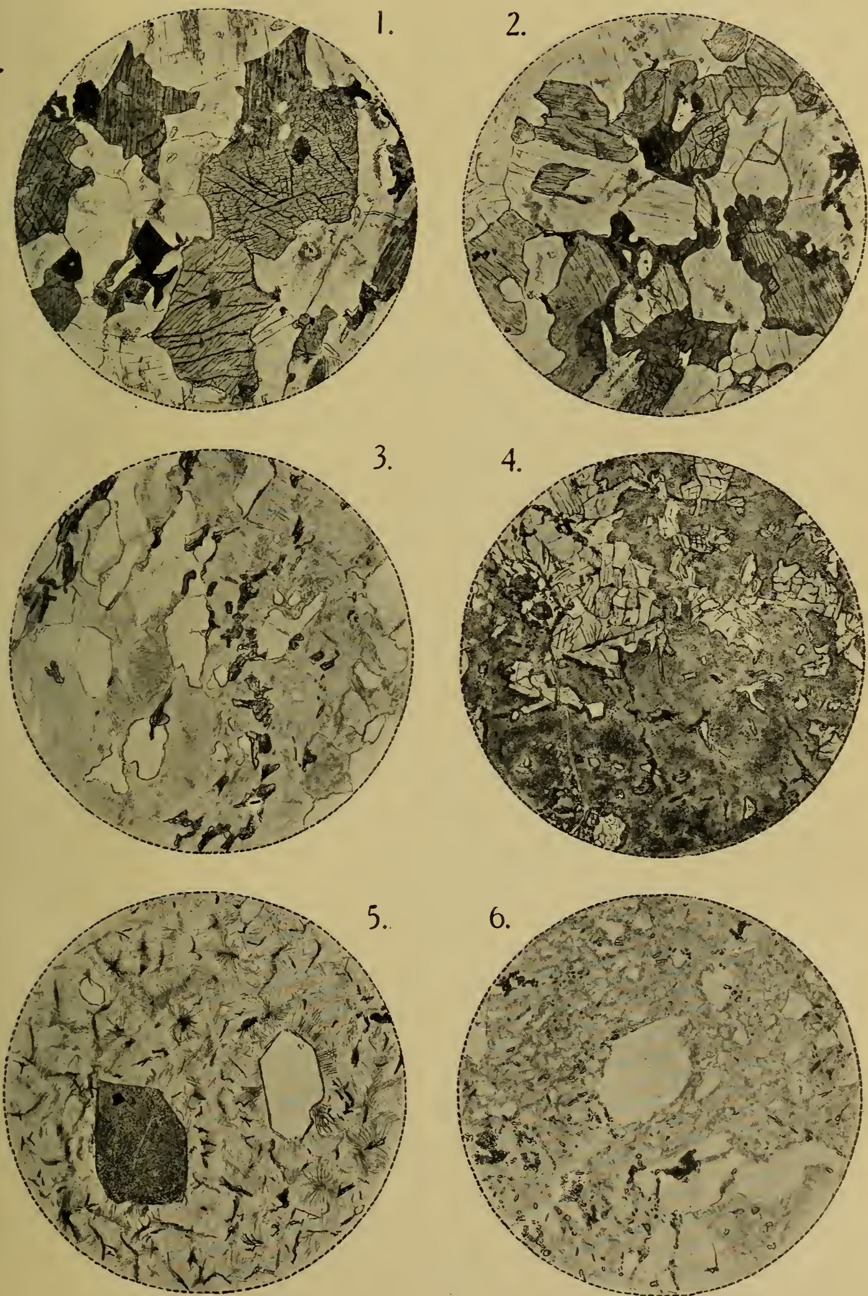
[Fig. 3 on p. 42 is a reproduction of a drawing, made from a specimen in Prof. Bonney's collection by Miss Ethel Wetherall.]

Discussion.

Dr. J. W. Evans remarked on the large number of different igneous rock-types described by the Authors as succeeding each other through a long period of the earth's history. He suggested that they might be divided into groups, the members of each of which belonged to a separate cycle of intrusions. The diorites were, for instance, followed by the hornblende-granites, showing the usual succession from basic to acid in plutonic rocks; while the microgranite and diabase-dykes showed the contrary order, which is normal in minor intrusions. He asked the Authors whether there was any evidence of the character of the distribution of the products of the segregation of the diorites. Did the basic material gather to the margins, as was usually the case in comparatively small igneous reservoirs; or did it form the lower portion of the mass, as appeared to happen in those of greater dimensions?

Mr. T. O. Bosworth enquired whether the contact between the granite and the diorite was as simple as suggested by the line on the map, or whether there occurred any of that intricate penetration so frequent where diorite and granite are associated.

The Rev. E. Hill said, in regard to the remark on the number of varieties of intrusive rocks, that on the tiny area of Castle



V. G. S. del.

Diorites, Quartz-Felsite, etc., from Guernsey.

Cornet, measuring perhaps only 300 yards by 100, there were not less than five. As to geographical arrangement in varieties of diorite, it should be remembered that Guernsey showed what is probably only a small part of a very large area. He desired to express his regret at the abandonment of Guernsey work by Mr. J. Parkinson, and the loss to Channel-Island geology incurred by the death of the late Father Noury.

Prof. Bonney said, in reply to Dr. Evans's question, that, as was explained in the paper, the very basic type of Fort Albert (Alderney) and of Bon Repos Bay (Guernsey) seemed to be the oldest; the porphyritic dark type seemed to come next, but it was rather mixed up with the normal diorite, of which there was a darker and a lighter variety; and very distinct from all was a felspathic diorite in veins. Also, the more normal diorite became more quartzose towards the north-west and towards the north in Alderney.

5. *The* FAULTED INLIER *of* CARBONIFEROUS LIMESTONE *at* UPPER YOBSTER (SOMERSET). By THOMAS FRANKLIN SIBLY, D.Sc., F.G.S. (Read December 6th, 1911.)

[PLATES II–V.]

CONTENTS.

I. INTRODUCTION.

THE faulted inliers of Carboniferous Limestone at Luckington, Upper Vobster, and Tor Rock, Vobster, respectively, are three small masses lying in the Coal Measures of the southernmost portion of the East Somerset Coalfield, at distances varying from about a mile and a quarter to half a mile north of the main outcrop of the Carboniferous Limestone in the Eastern Mendips.

The highly disturbed condition of the Carboniferous strata in this coalfield is well known. Throughout the district east of Nettlebridge, in which these inliers are situated, the strata of the Coal Measures are overfolded and in places greatly contorted, as was shown by Buckland & Conybeare in 1824.[1]

The anomalous position of these masses of Carboniferous Limestone has given rise to much comment and speculation by geological writers. Since attention was drawn to two of them by Buckland & Conybeare,[2] the inliers have been the subject of several papers, apart from many incidental references made to them. The contributions of Mr. H. B. Woodward and Mr. James McMurtrie[3] are particularly noteworthy, on account of the conflicting theories advanced by these authors to explain the position of the masses. Mr. Woodward has invoked a fan-shaped anticline broken by

[1] Buckland & Conybeare, 1824, pp. 255–56. See also McMurtrie, 1869, pp. 140–44; Anstie, 1873, pp. 55–63 & figs. 13–17; McMurtrie, 1902, pp. 327–29 & pl. xiii, fig. 3. For details of references see the Bibliography, § V, p. 72.

[2] Buckland & Conybeare, 1824, p. 228 & pl. xxxii, fig. 1 c.

[3] H. B. Woodward, 1871, 1876, 1891; McMurtrie, 1877. See also Winwood, 1891, pp. clxxviii–clxxxvi & figs. 3–5.

faults to explain the phenomena. Mr. McMurtrie, strongly combating this explanation, has elaborated an 'overthrow theory' in its place. The latter writer has given descriptive notes on each of the three inliers, and recorded many important facts in regard to them.

Two papers[1] by the Rev. H. H. Winwood, which give the details of a quarry-section and a tunnel-section exposed in the Upper Vobster mass in 1882, are especially valuable, because the tunnel-section, now almost entirely concealed, gives the key to the structure of this inlier. Further reference will be made to these and other papers.

The present paper is limited to a description of the Upper Vobster mass. This inlier, intermediate in position, is not only by far the largest of the three, but also the only one in which any satisfactory exposures are at present available.

With reference to the wider subject of the large tectonic features to which these masses of Carboniferous Limestone owe their present position, no discussion is offered here. We may conclude with tolerable certainty, as will be shown in the sequel, that the occurrence of these inliers is due to thrust-faulting[2] connected with the proved overfolding of the Coal Measures; but a proper discussion of the structural problem must await the re-survey of the whole district.

My thanks are due to Mr. J. W. Tutcher and Prof. S. H. Reynolds for their kindness in furnishing the photographs (reproduced in Pls. III–V) which illustrate this paper.

II. Extent of the Inlier. [Map & Section, Pl. II.]

Horizontal Extent.

The rocks forming the Upper Vobster inlier consist mainly, but not entirely, of Carboniferous Limestone. On the south and west their outcrop is bounded by that of the surrounding Coal Measures: on the north and east, however, the outcrop of the Carboniferous Limestone is cut off by the Lias, and a considerable portion of the inlier may be concealed by the thin covering of this latter formation. The position of various small mounds of shaly débris which mark the sites of trials for coal, indicates that on the north, beneath the Lias, the Carboniferous Limestone is soon cut off by Coal Measures; but no such evidence is available to indicate the limit of the inlier beneath the Lias on the east.

With reference to the question of the eastern limit of the inlier the following facts are, however, worthy of consideration. Less than half a mile north-east of the exposed portion of the Upper Vobster inlier are situated the old workings of Mells Colliery,

[1] Winwood, 1885, 1893.

[2] This explanation was suggested, many years ago, by Mr. W. A. E. Ussher. See Ussher, 1889, 1891.

abandoned in 1876. Large faults encountered at the eastern limit of these workings appear to have determined the cessation of work in this colliery: these faults have a south-westerly trend. Now, mapping indicates that, at the eastern visible limit of the Upper Vobster inlier, the southern boundary-fault is acquiring a north-easterly trend. These facts lead us to suspect that the southern boundary-fault of the Upper Vobster inlier may be continuous with the above-mentioned faults proved in the Coal Measures on the north-east.[1] Should this be the case, the area of Carboniferous Limestone concealed by Lias on the east would be comparatively small.

The actual junction between the Carboniferous Limestone and the surrounding Coal Measures is nowhere exposed, and I have not succeeded in tracing the boundary between the two formations with much precision. Approximately, however, the *proved* east-and-west extent of the Carboniferous Limestone is 1100 yards; and the maximum width of the inlier from north to south is probably little, if at all, greater than 400 yards.

Vertical Extent.

Evidence recorded by previous writers appears to prove that the vertical thickness of the Upper Vobster mass of Carboniferous Limestone is small as compared with its horizontal dimensions, and that the whole inlier is practically a thin cake of Carboniferous Limestone and other beds, superimposed upon the strata of the Coal Measures.

Thus Anstie stated,[2] with reference to this inlier, that

> 'There is a shaft close to its southern edge from which a level was driven many years ago, completely under the Limestone, to another pit on the north side of it, thus proving it to be a detached block.'

Anstie did not indicate the precise position of this shaft, but Mr. McMurtrie is undoubtedly referring to the same shaft when he writes [3] :—

> 'In the corner of a field adjoining the coal-yard at Bilboa, on the south of the patch [of Carboniferous Limestone], are the remains of an old shaft, and I have been informed upon reliable authority that its workings passed beneath the Limestone. At a depth of eighty yards from the surface a branch or gallery was driven north more than 100 yards, and the men who worked in this branch are said to have been within hearing of the workmen in the Dunny Drift vein at Upper Catch pit situated in the northern side of the patch.'

The position of the shaft in question is shown on a geological map accompanying the paper from which the above is quoted. The site of the shaft, now marked by a mound of shaly débris on which conifers are growing, is indicated on my map (Pl. II).

[1] I have to thank Mr. Herbert H. Thomas for this suggestion, and also for kind assistance in consulting the plans of Mells Colliery, deposited in the Home Office.

[2] Anstie, 1873, p. 61.

[3] McMurtrie, 1877, p. 297.

On this evidence it would appear to be established that Coal Measures have been proved for a considerable distance under the eastern part of the Upper Vobster inlier, and at no great depth from the surface.

Other statements by Mr. McMurtrie, also pointing to the conclusion that the Carboniferous Limestone of Upper Vobster is no more than a superficial mass, are of interest. Referring to the southern margin of the western portion of the inlier, this author writes:—

'In a garden, behind some cottages at Upper Vobster, marked A on plan, a well was sunk many years ago by Mr. Richard Edgell, a bailiff at the Vobster Colliery. It began in Mountain Limestone, but at a depth of 22 feet from the surface it passed into Coal Measures, in which it was continued 4 feet, making a total depth of 26 feet. This information I have obtained from Mr. Edgell himself, who is prepared to vouch for its accuracy, and who has also communicated another important fact. At the time the well in question was sunk, the workmen at Upper Vobster Quarry [Vobster Old Quarry] having followed the Limestone a little deeper than usual, at a point marked B, passed through it into shale, and it was ascertained, by levelling the ground, that the shale at the bottom of the well A was on a level with the shale met with at the bottom of the quarry.' (*Loc. supra cit.*)

III. Essential Structure of the Inlier.

The inlier comprises three portions, namely, two masses of Carboniferous Limestone separated by a band of grits and shales which is faulted in between them. These may be termed respectively: (1) The Northern Limestone Mass, (2) the Southern Limestone Mass, and (3) the Grit-&-Shale Mass.

Many years ago, quarrying operations were confined to the limestones of the Southern Mass. A long quarry running east and west (Vobster Old Quarry) was gradually extended northwards in the Carboniferous Limestone of the Southern Mass, until the Grit-&-Shale Mass was encountered. This quarry was then abandoned, and a tunnel was driven northwards through the Grit-&-Shale Mass until the Northern Limestone Mass was reached, when quarrying was resumed. A huge quarry (Vobster Quarry) has since been excavated in the Northern Limestone Mass, and is still being actively worked. The structure of the inlier has thus been exposed to a remarkable degree.

The characters of the rocks, and other features of the chief sections, will be described in some detail below. For the sake of clearness, however, a summary of the main conclusions arrived at may be given here, as follows.

General Conclusions.

(1) The Upper Vobster Inlier is apparently a lenticular mass of Carboniferous Limestone, and Grits and Shales, superimposed upon overfolded Coal Measures by thrust-movements.

(2) It comprises (*a*) a Northern Limestone Mass, and (*b*) a Southern Limestone Mass, separated by (*c*) a Grit-&-Shale Mass.

(3) The great bulk at least of the exposed Carboniferous Limestone belongs to the *Seminula* Zone and the Lower *Dibunophyllum* Zone.

(4) The beds of the Grit-&-Shale Mass are in faulted relation with the Carboniferous Limestone, on both sides.

(5) On the northern side of the Grit-&-Shale Mass, the immediately adjacent beds of Carboniferous Limestone represent part of the *Seminula* Zone. On the southern side, in Vobster Old Quarry, the adjacent beds belong to the Lower *Dibunophyllum* Zone. On both sides the limestone beds are considerably disturbed.

(6) In the Northern Limestone Mass, Vobster Quarry exposes over 500 feet of limestones belonging to the *Seminula* Zone. The whole succession is here inverted, the beds dipping northwestwards at an angle of about 135°.

(7) In the Southern Limestone Mass, where portions of the Lower *Dibunophyllum* Zone and of the Upper *Seminula* Zone are exposed, the strata are locally overfolded northwards.

(8) The beds of the Grit-&-Shale Mass include quartzites which must certainly be assigned to the Millstone Grit. They also comprise shales, with intercalated fine-grained sandstones, of considerable thickness. Possibly this mass includes the lowest beds of the Coal Measures, in addition to a part of the Millstone Grit.

(9) In most of the sections of Carboniferous Limestone, signs of the immense stresses to which the rocks have been subjected are very evident. The strata are often distorted, while slickensides and calcite-veins are extensively developed on both a large and a small scale.

IV. Detailed Description.

(*a*) The Northern Limestone Mass.

Vobster Quarry. (Pl. III & Pl. IV, fig. 1.)

(i) General features.—The Carboniferous Limestone is well exposed along the western, northern, and eastern sides, where quarrying is in progress; but on the southern side, where great quantities of Liassic limestone-rubble have been tipped, it is concealed by piles of this material, except near the mouth of the tramway-tunnel.

From east to west the quarry is approximately 250 yards long, and the distance from the mouth of the tunnel northwards to the present northern face of the quarry is about 190 yards. If the present rate of quarrying should be maintained, the northern limit of the Carboniferous Limestone will probably be reached in the course of a few years.

At the western end the Carboniferous Limestone comes to the surface (Pl. III); but on the eastern side and along nearly the whole of the northern face it is overlain by a thin covering of yellow, rubbly, Liassic limestone. The Lias here rests upon a perfectly level-planed surface of Carboniferous Limestone [1] (Pl. IV, fig. 1).

Along the northern face of the quarry the dip of the Carboniferous Limestone is found to vary a little in direction and amount, since the beds are slightly curved in places. The average apparent dip has been found to be about 45°, E. 35° S.; and a calculation based upon this estimate gives 520 feet as the approximate total vertical thickness of Carboniferous Limestone exposed in this quarry.

This quarry-section represents a great part of the *Seminula* Zone. As the result of a single visit in 1905, the writer concluded, wrongly, as will be shown, that the upper portion of S_1 and the lower part of S_2 were here represented in normal succession from west to east. The fossil evidence merely indicated S, without justifying any subdivision of the zone; but the lithological characters of certain beds in the eastern half of the quarry were observed to be those of the middle portion of the *Seminula* Zone, and the conclusion stated above was based upon this observation.

When the section was studied more carefully in the summer of 1910, it became evident that the succession was abnormal, since the beds in the western part of the quarry were discovered to possess the remarkable lithological characters of the upper portion of S_2: but no further fossil evidence was forthcoming.

In April 1911, however, it was found that a recent westward extension of the quarry had exposed fresh beds, underlying those hitherto seen; and these beds yielded fossils which indicate the summit of the *Seminula* Zone. The inversion of the strata suggested by the lithological succession being thus confirmed by fossil evidence, we must conclude that Vobster Quarry exhibits over 500 feet of *Seminula* Limestones overfolded and dipping north-westwards at 135°.

The development of slickensides and calcite-veins in the limestones of this quarry is remarkable. Hand-specimens can be obtained showing both these features, which are also developed on a very large scale. Near the eastern end of the north face of the quarry, the limestone is so largely replaced by masses of coarsely crystalline calcite, and so much cut up by irregular slickensided joints, that the stratification is very obscure (Pl. IV, fig. 1).

Further effects of the powerful forces that acted on this mass of limestones are to be found in the disturbed condition of the beds as the Grit-&-Shale Mass on the south is approached. Mr. Winwood's section [2] shows that the limestones at the mouth of the tunnel, closely adjacent to the Grit-&-Shale Mass, are much disturbed; and signs of distortion can still be seen in the rather poor exposures of limestone situated around the tunnel-mouth. In the mouth of the tunnel itself, about 8 yards

[1] The Lias of this quarry has been described by Mr. L. Richardson, Proc. Geol. Assoc. vol. xxi (1909–10) p. 222. Mr. Richardson notes that occasional small patches of Rhætic rock are to be found adhering to the surface of the Carboniferous Limestone.

[2] Winwood, 1893, folding plate.

from the faulted junction with the Grit-&-Shale Mass, the limestones are vertical (section, Pl. II). The south-western corner of the quarry, shown in Pl. III, fig. 1, affords an excellent exposure of the disturbed limestones. Here, apparently, we are on the margin of the greatly-disturbed belt adjacent to the Grit-&-Shale Mass.

(ii) Western end of the quarry: the summit of the *Seminula* Zone (Pl. III, fig. 2).—The lowest beds seen, those lying at the present western extremity of the quarry, are dark-grey compact limestones. Their weathered edges, exposed where the soil had been removed on the brink of the quarry, yielded the following fossils:—

Productus aff. *giganteus* (Mart.), 'mut. D_1' Vaughan; common.
Carcinophyllum θ Vaughan; common.
Koninckophyllum aff. θ Vaughan.
Syringopora cf. *distans* Fischer.

As to the horizon of these beds, the common occurrence of the two first-named fossils indicates either the summit of the *Seminula* Zone or the Lower *Dibunophyllum* Zone. But, since both *Dibunophyllum* and *Cyathophyllum murchisoni*, fossils characteristic of D_1, appear to be absent, and since the immediately overlying (that is, older) strata undoubtedly belong to S_2, the beds in question must be assigned to the top of S_2 rather than to the base of D_1. The exposed thickness of these beds was about 15 feet.

(iii) Northern and eastern sides of the quarry: the main *Seminula* Zone.—The section given by the northern and eastern faces of Vobster Quarry is a very fine one, and by far the most extensive exposure of *Seminula* Beds to be found in the eastern Mendip area.

Lithology.[1]—The development of dark-grey or black limestones, compact in texture and breaking with a conchoidal or splintery fracture, is a conspicuous feature here, as in the *Seminula* Zone throughout the South-Western Province. Limestones of this general character form most of the western half of the section: with them, in the westernmost part, shaly partings are frequently intercalated.

Among these limestones the following different types are conspicuous:—

(*a*) 'Horny' limestones, with a perfectly smooth, conchoidal fracture.[2]

(*b*) Very compact but not 'horny' limestones, appreciably crinoidal, and breaking with splintery rather than conchoidal fracture. In these the individual beds often break readily into layers measuring from half an inch to 2 inches in thickness, owing to the development of shaly carbonaceous films at intervals.

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[1] Compare the lithology of the main *Seminula* Zone in the Burrington-Combe section, recently described by Prof. S. H. Reynolds, Q. J. G. S. vol. lxvii (1911) pp. 344–47, 'Upper *Seminula* Zone.'

[2] These are identical with the type of limestone termed 'china-stone' by Dr. A. Vaughan, Proc. Bristol Nat. Soc. ser. 4, vol. i (1904–07) p. 94. They are included in the 'calcite-mudstones' of Mr. E. E. L. Dixon, Q. J. G. S. vol. lxvii (1911) p. 516.

(*c*) Brecciated bands, consisting of rounded and subangular fragments of compact horny limestone set in a foraminiferal and shelly limestone-matrix. The fragments are of all sizes up to an inch in diameter. Here and there these brecciated beds contain thin lenticular bands of horny limestone, identical in character with the fragments; and the prevalent brecciated character of the beds doubtless resulted from the penecontemporaneous brecciation of such layers. Brecciated beds occur only at the western end of the section.

In addition, some beds are mottled, and show a well-marked 'concretionary' structure.

Towards the middle of the northern face, nodular black chert occurs in a few beds of compact limestone.

To the east of this, the predominant rock-type is a brownish-grey limestone, which proves under the microscope to be richly foraminiferal and almost completely recrystallized.

In the eastern face itself, much of the limestone is oolitic, and some bands of pure oolite occur. Here the beds have suffered local dolomitization. Calcite-veining is very extensive, and the dolomitization appears to be connected with the lines of maximum calcification. One specimen of dolomitic rock, examined in thin section, was found to be an oolitic and foraminiferal limestone in which not only is the matrix almost completely dolomitized, but most of the ooliths also have been attacked.

Palæontology.—Altogether, the lithological development is fairly typical of the major upper portion of the *Seminula* Zone in the Mendips. In the comparative scarcity of fossils, however, this section appears to present a distinctly abnormal development. Occasional bands crowded with *Seminula ficoides* Vaughan or *Lithostrotion martini* Ed. & H., can be found, but such beds are far less conspicuous than is usually the case. The other fossils recorded in this section include papilionaceous *Chonetes*, *Athyris* cf. *expansa* (Phill.) Dav., *Productus* aff. *cora* d'Orb., and *Alveolites septosus* (Flem.): among these, only the two former shells are occasionally common. *Seminula ficoides* is more abundant in the compact limestones at the western end of the quarry than in the overlying beds on the east.

With reference to this scarcity of fossils, however, the absence of weathered rock-surfaces throughout most of the quarry should be noted. The detection of fossils is difficult on freshly-broken surfaces of the dark-grey limestones which here predominate.

The occurrence of *Serpula* in a specimen of limestone obtained from the S_2 beds near the western end of the quarry is a fact worthy of special mention. The calcareous annelid-tubes occur sparingly in a mottled 'concretionary' limestone of compact, horny texture. I have recently found *Serpulæ* to be extremely abundant in certain compact, horny limestones of calcite-mudstone [1] type which are intercalated with the *Modiola*-phase deposits of the *Cleistopora* Zone in the Mitcheldean district (Gloucestershire). The same fossils might be expected to occur in the shallow-water beds of similar character, so well developed in S_2 of the South-Western Province. At the latter horizon, however, they appear to be very rare; but, in addition to this specimen from Vobster, I have recently collected a single specimen of compact limestone, crowded with *Serpula*, from the S_2 beds of the Avon Section.

[1] E. E. L. Dixon, Q. J. G. S. vol. lxvii (1911) p. 516.

(iv) Zonal extent of the Vobster-Quarry section.—The total thickness of Carboniferous Limestone exposed in Vobster Quarry, amounting to some 520 feet, is considerably greater than the thickness of S_2 in the typical Mendip section of the *Seminula* Zone, namely, the Cheddar-Gorge section [1] in the Western Mendips. At Cheddar, where the *Seminula* Zone as a whole has a thickness of about 700 feet, the thicknesses of S_1 and S_2 are about 300 and 400 feet respectively. Having found no evidence of an expansion in the thickness of the *Seminula* Zone as a whole in the Eastern Mendips, I am led to conclude that the Vobster Quarry-section extends below S_2 and includes part of S_1. I have failed, however, to discover any palæontological evidence establishing the presence of S_1 here. If, as I believe to be the case, we have here a portion of S_1 from which the distinctive fossils are absent, then the Vobster section affords an interesting parallel to the Burrington-Combe section. At Burrington Combe, certain distinctive elements of the S_1 fauna are apparently absent, and consequently a subdivision of the zone into S_1 and S_2 on the typical faunal basis cannot there be established.[2]

(*b*) The Southern Limestone Mass.

Exposures in this mass are numerous, occurring in many disused workings and in cuttings on the mineral railway. Those afforded by Vobster Old Quarry are of particular interest, since they show beds of fossiliferous limestone, highly disturbed in places, in contact with the strata of the Grit-&-Shale Mass.

The workings of Vobster Old Quarry extend east and west of the tramway-tunnel. Farther west, the Carboniferous Limestone is seen in abandoned workings in several cottage gardens. Farther east, it is exposed at various points in the railway-cutting.

The beds of Carboniferous Limestone exposed in the face of Vobster Old Quarry and also in the yards and gardens to the west are abundantly fossiliferous, and can be assigned definitely to D_1, as the following list of fossils shows :—

Cyathophyllum murchisoni Ed. & H.	Abundant.
Productus aff. *giganteus* (Mart.), 'mut. D_1' Vaughan.	Abundant.
Productus hemisphericus Sow.	Abundant.
Alveolites septosus (Flem.).	Common.
Carcinophyllum θ Vaughan.	Common.
Lithostrotion martini Ed. & H.	Common.
Daviesiella aff. *comoides* (Sow.).	Common.
Dibunophyllum φ Vaughan.	
Athyris cf. *expansa* (Phill.), Dav.	

A section in Vobster Old Quarry, which shows the faulted junction of these D_1 beds with the strata of the Grit-&-Shale Mass, is described immediately below.

[1] T. F. Sibly, Q. J. G. S. vol. lxii (1906) p. 347; and Proc. Geol. Assoc. vol. xx (1907–08) p. 68.

[2] T. F. Sibly, Proc. Bristol Nat. Soc. ser. 4, vol. i (1904–07) p. 36; and A. Vaughan, Q. J. G. S. vol. lxvii (1911) p. 370.

Vobster Old Quarry. (Pl. IV fig. 2, Pl. V, & text-fig. p. 68.)

West of the tunnel, the quarry-face gives a good section of D_1 limestones overlain by grits and shales. This section, the eastern part of which is seen in Pl. IV, fig. 2, extends from the western extremity of the quarry as far as a prominent bluff about 50 yards west of the tramway (*efg* on the map, Pl. II). Throughout the section the beds have a general northerly dip; but, in consequence of synclinal folding, the greatest thickness of Grit-&-Shale beds is found near the middle of the section, while at the western end a mere capping of grit-&-shale débris overlies the limestone.

Immediately overlying the Carboniferous Limestone beds, which are hard grey limestones for the most part, are the Grit-&-Shale beds.

These latter, examined at the point where they occupy a maximum depth of a little more than 20 feet of the quarry-face, were found to comprise the following beds, in descending order [1]:—

(*c*) Compact pink and yellowish quartzites: in part very fine-grained; in part of coarser grain, and speckled with rusty ferruginous spots. [And débris of same to top of section.]

(*b*) Fine-grained, greenish, argillaceous sandstones.

(*a*) Blue-black micaceous shales, much ironshot, and containing lenticles of fine-grained sandstone.

The combined thickness of (*a*) and (*b*) is about 8 feet.

This junction of Carboniferous Limestone with Grit-&-Shale beds is undoubtedly a faulted one; and, although the section is much overgrown, it can be seen that the stratification in the two formations is not precisely concordant. In the bluff at the eastern end of the section the limestone-beds are distorted and broken.

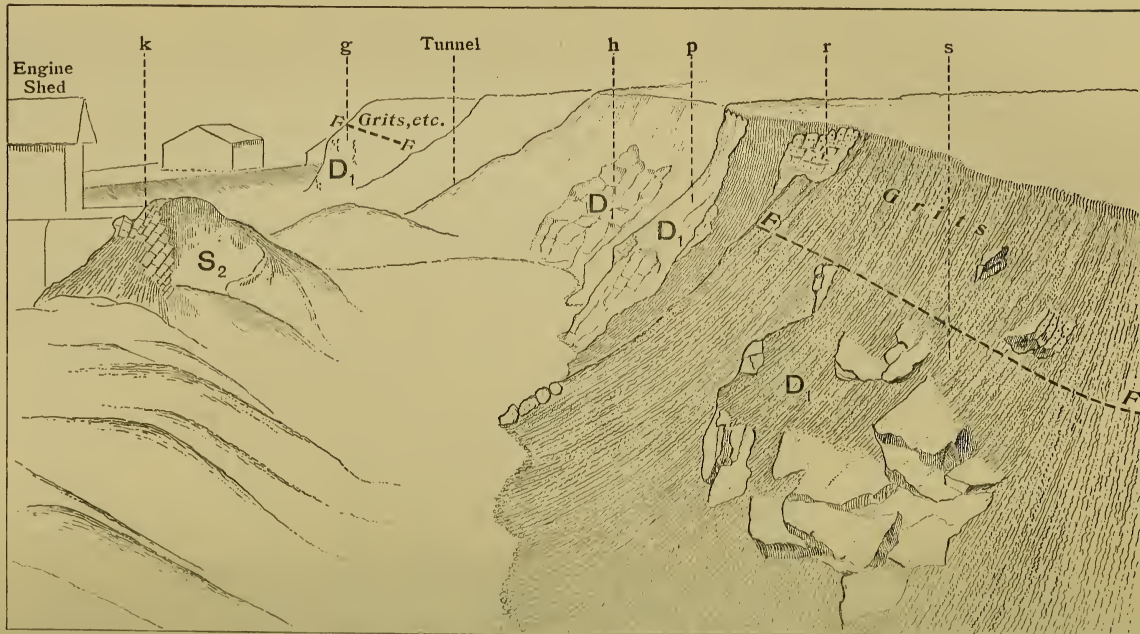
East of this bluff (*g*), débris now obscures the rocks as far as the tunnel and for some distance beyond it. Thanks to Mr. Winwood's description [2] of the tunnel-section, however, we know that in the mouth of the tunnel the Carboniferous Limestone appears to dip steeply s o u t h w a r d s, and is underlain on the north by shales and quartzites which have nearly the same angle of dip. Here, then, the succession of limestones, shales, and quartzites already seen in the quarry-face to the west is inverted, and the fault-plane between the Carboniferous Limestone and the Grit-&-Shale beds hades southwards instead of northwards. Our section (Pl. II) crosses the junction at this point.

We must conclude that the beds of Carboniferous Limestone, where they are inclined southwards, as in the tunnel itself and at various points in Vobster Old Quarry on the east, are inverted. The evidence leading to this conclusion is as follows.

About 35 yards east of the tunnel the bare surfaces of some limestone-beds, steeply inclined southwards, form the lower part of the quarry-face (*h* on the map, Pl. II, and in the text-figure,

[1] This section was described by the Rev. H. H. Winwood, 1885, p. 30.
[2] Winwood, 1893.

Vobster Old Quarry: general view, looking westwards. Key to Pl. V.



[The lettering of the exposures (*g*, *h*, *k*, etc.) corresponds with that on the map, Pl. II. At *g*, grits and shales in faulted superposition on D_1 limestones; at *h*, D_1 limestones overfolded; at *k*, S_2 limestones overfolded; at *p*, D_1 limestones overfolded and contorted; at *r–s*, grits in faulted superposition upon D_1 limestones, the latter overfolded. For further description of these exposures, see pp. 67–70.]

F......F=Faulted junction of the Southern Limestone Mass with the Grit-&-Shale Mass.

p. 68). Fossils are extremely abundant on the weathered rock-surfaces here, and prove that the beds belong to D_1. Proceeding south-eastwards from this point, across the level floor of the quarry, we reach a mass of limestone left by the quarrymen on the northern side of the engine-shed, and against which a limekiln has been built (*k* on the map, Pl. II, and in the text-figure). Here are well-bedded limestones also inclined at a high angle almost due south. These limestones, which now overlie the D_1 beds just seen at *h*, are identical in character with certain beds near the summit of the *Seminula* Zone in Vobster Quarry. They are dark-grey and black rocks, perfectly compact in texture, and occasionally brecciated in structure. Partings and lenticles of black shale are developed. Although I have failed to discover any fossils in these beds, I have no doubt that they belong to the uppermost part of the *Seminula* Zone, and that the strata of the Carboniferous Limestone are here inverted.

Slightly lower horizons in the *Seminula* Zone are exposed in cuttings on the mineral-railway, close to the engine-shed. The sections lie (1) beside the low-level rail and immediately east of the engine-shed (*l* on the map, Pl. II); and (2) on the south side of the high-level rail, underneath the road-wall (*m–n* on the map, Pl. II). The latter section extends east and west of the engine-shed, and is about 130 yards long. In each section the beds have the same steep southerly inclination, so that a very small vertical thickness of limestones is exposed. The limestones are, for the most part, dark grey, and very compact in texture. Fragments of *Productus* and of *Seminula (?)*, not specifically determinable, were seen in these beds.

This inversion of the Carboniferous Limestone, giving the strata an apparent dip towards the south, appears to prevail throughout that area of Vobster Old Quarry which lies east of the tramway-tunnel. Westwards from the tunnel, however, the prevailing dip is found to be either northerly or north-easterly in all the exposures of limestone; and in this western tract the observed succession of lithological types, taken in conjunction with the palæontological evidence, suggests that the succession of Carboniferous Limestone beds is a normal one.

It has been seen that, along the great fault between the Southern Limestone Mass and the Grit-&-Shale Mass, which coincides approximately with the northern edge of Vobster Old Quarry, the disposition of the strata is variable. Thus, west of the tunnel the strata dip northwards, and the beds of the Grit-&-Shale Mass overlie the Carboniferous Limestone at the fault-plane with slight but distinct discordance of bedding. At the tunnel itself the apparent dip is southerly, and the succession of beds reversed: here, according to Mr. Winwood's section, there is no great discordance of bedding, and no distortion of the strata, along the faulted junction of the two formations.

Farther east, however, the relation of the beds along the fault is evidently more complex. The eastern half of the face of Vobster Old Quarry is much overgrown, and also obscured in places by the presence of slipped masses of rock. Attention may, however, be directed to the following features.

A precipitous rock-face, about 85 yards east of the tunnel (*p* on the map, Pl. II, and in the text-fig. p. 68), shows sharply-folded limestones in its highest part and distorted beds of limestone, with *Productus* aff. *giganteus* in great profusion, below. Here the whole quarry-face is formed of limestone. A little farther east (*r* and *s*), however, only the lower part of the quarry-face consists of limestone, the upper portion being formed of quartzites. Apparently the limestones here dip steeply southwards, while the superincumbent quartzites dip northwards, into the cliff. This is the last exposure of beds belonging to the Grit-&-Shale Mass. The recess at the eastern extremity of the quarry shows beds of limestone much broken and veined with calcite.

Other Exposures.

(i) Sections in the railway-cutting. — A lamellibranch-fauna in the Upper *Seminula* Beds.—With one exception, the remaining exposures of Carboniferous Limestone, all of which lie to the east of Vobster Old Quarry, present no features of special importance. The exception is afforded by a small section of the highest *Seminula* Beds, which lies in the northern bank of the railway-cutting, about 60 yards west of the bridge on which the road crosses the railway (*t* on the map, Pl. II).

This section is one of many small exposures that are to be found in the railway-cutting east of Vobster Old Quarry: exposures showing disturbed beds of Carboniferous Limestone with no constant direction of dip. Its importance lies in the discovery in it of a band of limestone yielding numerous lamellibranchs. These fossils occur in a thin band of light-grey compact limestone, in association with abundant casts of an expansiform Athyrid.

The lamellibranchs collected were submitted to Dr. Wheelton Hind, who has kindly reported on them.

Dr. Hind remarks that 'The specimens are very difficult to determine. Frequently the umbo and hinge-line are not exposed.' He determines the following:—

Schizodus sp., 'not unlike *Sch. truncatus* King.'	*Tellinomorpha (?)* sp.
Cypricardella sp.	*Grammatodon (?)* sp.
	Cf. *Pleurophorus costatus* Brown.

So far as I am aware, this is the only record of a lamellibranch-fauna in the *Seminula* Zone of the South-Western Province. The horizon of the band is fixed as follows:—(1) a bed lying about 3 feet higher in the section yields *Lithostrotion martini*, *Carcinophyllum θ*, and *Productus* aff. *giganteus*; and (2) not more than 6 yards away from this section, in the opposite bank of the cutting (*u* on the map, Pl. II), is a buttress composed of grey compact limestones, in part brecciated and 'concretionary,' and yielding *Seminula ficoides*. This evidence fixes the horizon at the top of the *Seminula* Zone.

(ii) Old quarries.—In the disused quarry which lies in the north-western angle of the cross-roads, the rocks are not only much overgrown, but also, since the quarry is full of water, largely inaccessible. No fossils, other than crinoid-fragments, were seen in the beds of grey limestone examined on the northern side of this quarry.

The easternmost exposure of the Carboniferous Limestone is found in another long-disused quarry, adjacent to the buildings named Bilboa. Here, quarrying has exposed the strata beneath a thin covering of Lias. As in Vobster Quarry, the Lias rests upon a level-planed surface of Carboniferous Limestone. Since the quarry is filled with water and its sides are precipitous, close examination of the Carboniferous Limestone is impossible. No determinable fossils were seen in the few beds accessible at the southern end of the quarry. The dip of the beds appeared to be in a direction west of north.

(*c*) The Grit-&-Shale Mass.

As regards this mass, there is little to add to the description of the beds given by Mr. Winwood. Reference should be made to the admirable section which illustrates his second paper on Vobster.[1] The complete tunnel-section is given there; and I find that the succession of beds traversed from south to north between the two masses of Carboniferous Limestone was as follows (the appended section, Pl. II, follows this line):—(1) Shales, about 15 feet[2]; (2) Millstone Grit, about 44 feet; (3) Shales, about 50 feet.

The beds of (1) and (2) are inclined southwards at a high angle; those of (3) appear to be folded anticlinally, dipping southwards in the middle portion of the tunnel, and northwards in the northern part.

Beds representing portions of (1) and (2) are seen in the face of Vobster Old Quarry to the west of the tunnel, and have been described above (p. 67). It is there found that the shales (1) include shales and fine-grained sandstones, and that the Millstone Grit (2) is formed of quartzites.

The tunnel is now bricked up almost from end to end, but small portions of the section can still be seen in three archways within the extent of the brickwork, the positions of which are shown in Mr. Winwood's section. In the southernmost of these three archways, quartzites belonging to (2) are exposed. In the two northern archways portions of the shale-series (3) are seen; and it is found that fine-grained greenish sandstones are here intercalated with shales. In addition, there is a very small exposure of the contact between the shales (3) and the Carboniferous Limestone of the Northern Mass. This occurs within the tunnel, just at the northern end of the brickwork. Here a very thin seam of coal and a thin band of red sandstone intervene between the black shale of (3) and

[1] Winwood, 1893, folding plate.
[2] The figures stated here represent vertical thickness.

the Carboniferous Limestone, as described by Mr. Winwood. The junction between the shales and the limestone is here a fault-plane dipping northwards at about 60°. The nature of the faulted junction between the Grit-&-Shale beds and the Carboniferous Limestone of the Southern Mass has been discussed above (p. 69).

Beyond these tunnel-exposures and the sections in Vobster Old Quarry already described (pp. 67, 70), there is no further exposure of the beds of the Grit-&-Shale Mass. The east and west extension of the Grit-&-Shale beds shown in my map (Pl. II) is based upon the evidence of rock-débris in the soil of the fields.

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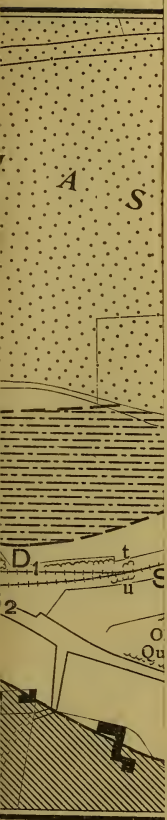

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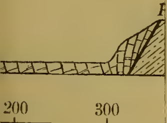

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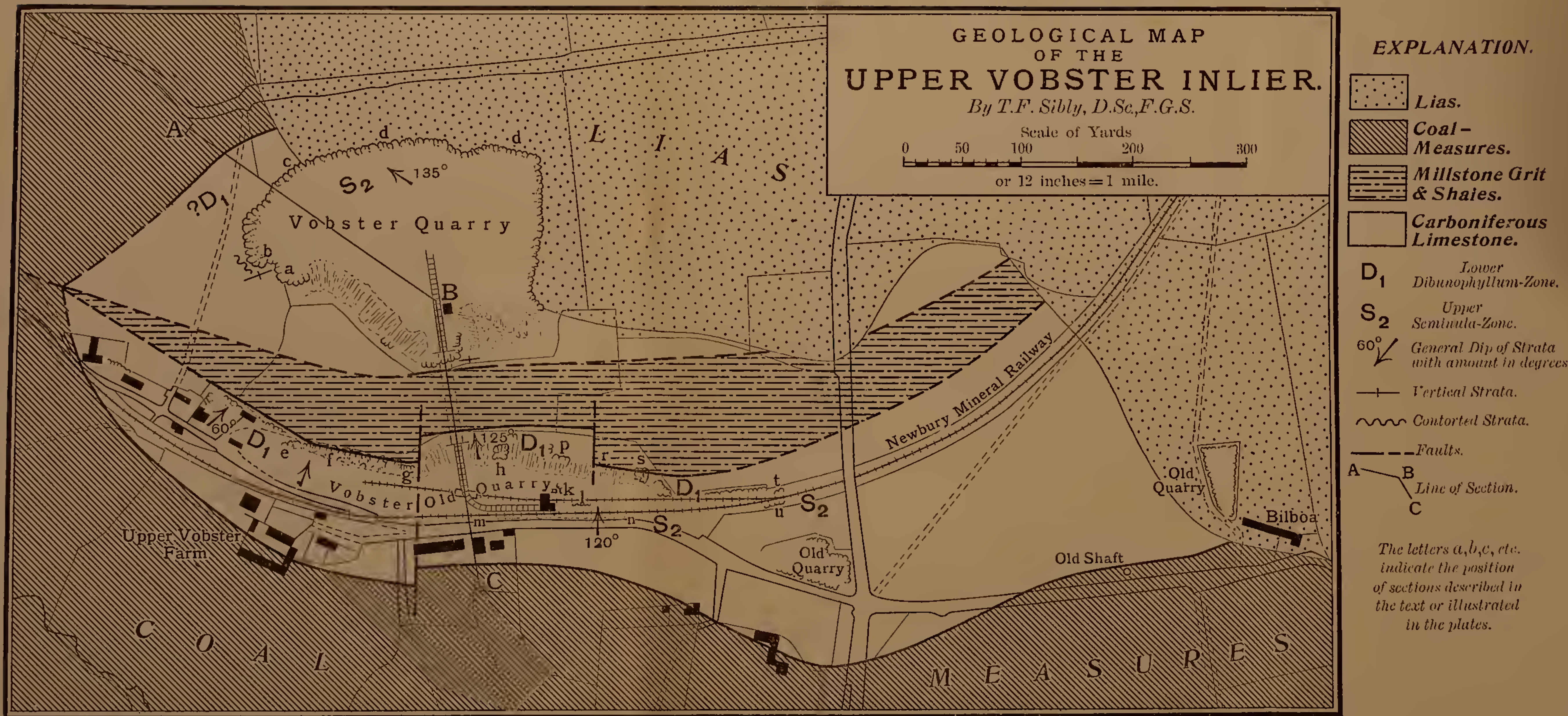
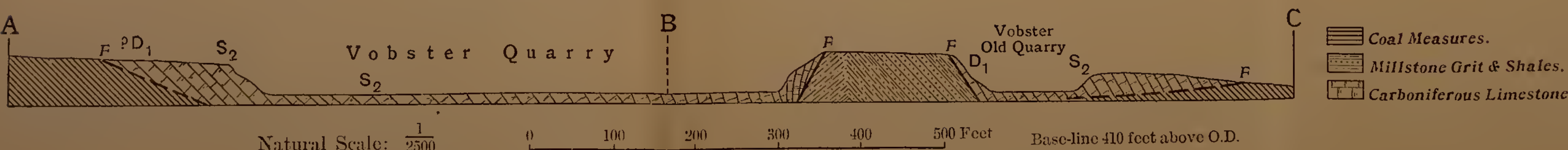


Section along the line ABC on the map.



Note:- The representation of dip is diagrammatic as regards the Coal Measures, the strata of which are probably much disturbed.

Fig. 1.

VOBSTER QUARRY: western end, south side.
Highest *Seminula*-Beds vertical and overfolded.

J. W. Tutcher, Photo.

Fig. 2.

VOBSTER QUARRY: western end.
Highest *Seminula*-Beds overfolded.

J. W. Tutcher, Photo.

Bemrose Ltd, Collo., Derby.

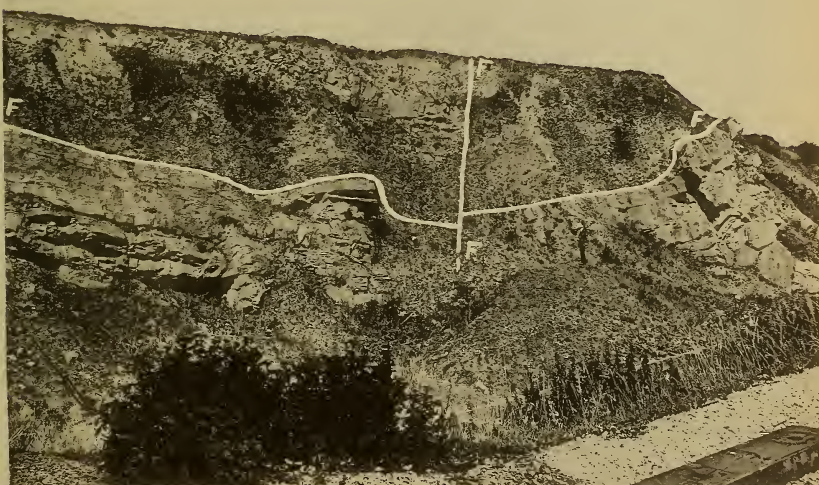
FIG. I.

VOBSTER QUARRY: EASTERN PART OF NORTHERN FACE.
OVERFOLDED *SEMINULA*-BEDS CAPPED BY LIAS.

S.H. Reynolds, Photo.

FIG. 2.

VOBSTER OLD QUARRY: WEST OF THE TRAMWAY-TUNNEL.

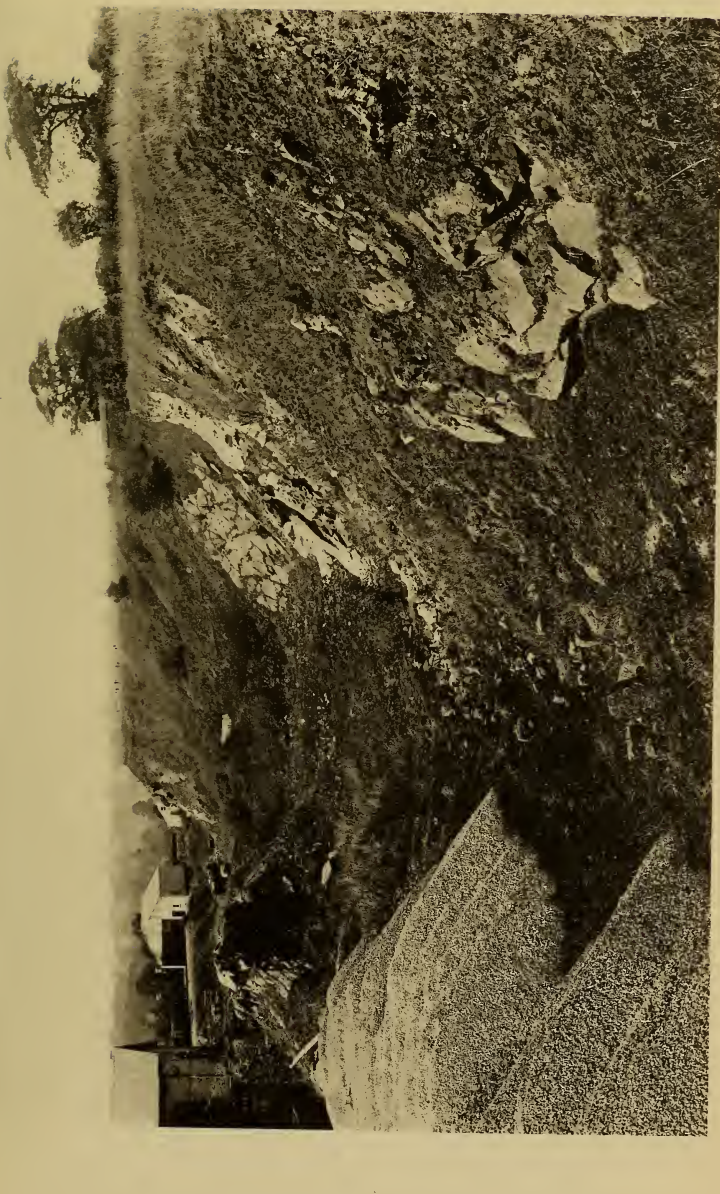


[F, F = Faults.]

J. W. Tutcher, Photo.

Bemrose Ltd, Collo., Derby.

VOBSTER OLD QUARRY: GENERAL VIEW, LOOKING WESTWARD.



S.H. Reynolds, Photo.

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EXPLANATION OF PLATES II–V.

Plate II.

Geological map of the Upper Vobster Inlier, on the scale of 12 inches to the mile, or 1 : 5280; and horizontal section along the line ABC on the map, on the scale of 1 : 2500. [The map is oriented north and south.]

Plate III.

Fig. 1. Vobster Quarry: western end, south side, August 1911. Highest *Seminula* Beds—inverted and sharply folded in the corner of the quarry on the observer's right; vertical in the bluff on the left. *a* to *b* on the map (Pl. II). (See p. 64.)

2. Vobster Quarry: western end, August 1911. Highest *Seminula* Beds, overfolded; *b* to *c* on the map (Pl. II). The white, weathered rock-surfaces on the brink of the quarry, on the observer's left, yielded fossils characteristic of the summit of the *Seminula* Zone. (See pp. 63, 64.)

Plate IV.

Fig. 1. Vobster Quarry: eastern part of the northern face, August 1911; *d* to *d'* on the map (Pl. II). Inverted *Seminula* Beds, capped by Lias. Bedding in the Carboniferous Limestone obscured by calcite-masses and slickensides, at the eastern end of the section. (See pp. 62–63.)

2. Vobster Old Quarry: face of the quarry west of the tramway-tunnel; *f* to *g* on the map (Pl. II). Beds of the Grit-&-Shale Mass in faulted superposition upon limestones (D_1) of the Southern Limestone Mass. (See p. 67.)

Plate V.

Vobster Old Quarry: general view, looking westwards. For explanation and description of the sections, see text-figure, p. 68, and pp. 67–70.

Discussion.

Mr. G. Barrow congratulated the Author on his paper, and drew attention to its important bearing on the increase in intensity of post-Carboniferous earth-creeps, or overthrusts, as one proceeds southwards. In the North of England these are but feebly, if at all, represented. In North Staffordshire the Coal Measures are locally thrown on end, and occasionally broken up by such movements. In the South-West of England they are no longer local, they are regional; and the Author's work deals with an area between the two. The speaker said that he would welcome further evidence of the age of the sandstones or grits that were shown in the diagram, projecting into, or breaking through, the limestone.

Mr. W. A. E. Ussher said that he had published an explanation of the phenomena by overthrust-faulting in a paper on 'Coal Prospects South of the Mendips,' communicated twenty years ago [1891] to the Somerset Archæological & Natural History Society. The illustration showed the shifting of the crest of a normal anticline. Mr. McMurtrie's work, however, especially a paper communicated to the Institution of Mining Engineers in 1901, showed the prevalence of reversed dips in the Coal Measures (about Luckington and Vobster), justifying the view sketched on the blackboard of an inverted anticlinal crest shifted by thrust-faulting and stepped by cross-faulting.

The AUTHOR explained, in reply to Mr. Barrow, that the quartzites of the Grit-&-Shale Mass were assigned to the Millstone Grit, on account of their distinctive lithological character. These beds, seen to a thickness of about 40 feet in the tunnel-section described by Mr. Winwood, were compact pink quartzites. In reply to Mr. Ussher, he stated that the contributions to the literature of Luckington and Vobster, made by that speaker and containing the earliest suggestion of an overthrust, were duly noticed in the paper. He had attempted no discussion of the general tectonic problem of this area to the north of the Mendips, because he thought that the data collected up to the present were inadequate. As to the tectonic theories elaborated by Mr. H. B. Woodward and Mr. McMurtrie to explain the occurrence of the Luckington and Vobster masses of Carboniferous Limestone, those theories were mentioned in the paper, but not discussed. The extensive overfolding of the Coal Measures in this area was clearly demonstrated by Buckland & Conybeare as early as 1824.

6. *The* Ordovician *and* Silurian Rocks *of the* Kilbride Peninsula (Mayo).

By Charles Irving Gardiner, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S. (Read December 20th, 1911.)

[Plates VI & VII.]

Contents.

I. Introduction.

The Kilbride area with which this paper deals lies some 5 miles to the south of the Glensaul area described by us in 1910. Its limits are very sharply defined. It forms a peninsula bounded by two long inlets from the south-western corner of Lough Mask, the northern one being known as Derry Bay or Derrypark Bay, the southern as Kilbride Bay. It has a length from east to west of about 4½ miles, and a breadth of about a mile and a half. It ends to the west in the alluvial tract through which the Finny River runs. From this low ground the land rises rapidly to a ridge which attains its highest point at Knock Kilbride (1230 feet). Farther east is another eminence (Knocknamuck), and then the ground sinks slowly through Fox Hill to the shore of Lough Mask. The descent from the high ground to Derry Bay on the north is far steeper than that to Kilbride Bay on the south, a fact intimately associated with the geological structure of the country.

Little has been written about the geology of this area. Some description of it is given in the Memoirs of the Geological Survey.[1] The igneous rocks are referred to as being everywhere felsite; the presence of ash is mentioned; and allusion is made to the finding of Llandovery fossils at several points on the southern side of the peninsula.

In the 'Annual Report of the Geological Survey for 1896' (pp. 49–51) a general account of the igneous and associated rocks of the Tourmakeady, Glensaul, and Lough Nafooey districts is given; and, in his 'Ancient Volcanoes of Great Britain,' Sir Archibald Geikie (vol. i, 1897, p. 251) briefly alludes to the Lough Nafooey district, but gives no details. The papers by Mr. J. R. Kilroe[2] 'On the Silurian & Metamorphic Rocks of Mayo & North Galway'; by Messrs. R. G. Carruthers & H. B. Maufe[3] on 'The Lower Palæozoic Rocks around Killary Harbour'; and by the authors of the present communication upon the neighbouring districts of Tourmakeady[4] and Glensaul[5] have some bearing upon the Kilbride district.

At the meeting of the British Association for the Advancement of Science at Dublin in 1908, a Committee was appointed[6] to investigate the igneous and associated rocks of the Glensaul and Lough Nafooey districts (Galway); and, following a report on the Glensaul district presented at Winnipeg[7] in 1909, a preliminary account of the geology of the Kilbride peninsula was read at the Sheffield[8] meeting of the Association in 1910. The substance of the general account of the structure of the peninsula there given may be repeated in a slightly amplified form here.

The southern and eastern part of the peninsula consists in the main of Llandovery and Wenlock grits and flags, dipping with great regularity in a direction varying from east to south-south-east. These strata are associated with a large intrusion of lime-bostonite, some smaller ones of labradorite-porphyrite, and an extensive series of small dolerite sills. Some of the beds are exceedingly fossiliferous, these being on the same horizon—Upper Llandovery—as those to which we referred,[9] in our paper on the Tourmakeady district, as occurring in the neighbourhood of Trean. The northern and western parts of the peninsula consist principally of a great series of igneous rocks—quartz-felsite, pillow-lavas (spilites), and coarse tuffs or breccias. These rocks are clearly comparable with the igneous series of the Tourmakeady and Glensaul areas, and a further resemblance lies in their association with cherts and beds

[1] Mem. Geol. Surv. Ireland, Explan. Sheets 93 & 94, with part of Sheets 83, 84, & 103 (1878) pp. 114–16; also Explan. Sheet 95 (1870) pp. 43–45.

[2] Proc. Roy. Irish Acad. vol. xxvi, sect. B, no. 10 (1907) pp. 129–60.

[3] 'Irish Naturalist' vol. xviii (1909) pp. 7–11.

[4] Q. J. G. S. vol. lxv (1909) pp. 104–53.

[5] *Ibid.* vol. lxvi (1910) pp. 253–79.

[6] Consisting of Prof. W. W. Watts, Mr. H. B. Maufe, and the authors of the present paper.

[7] Rep. Brit. Assoc. (Winnipeg) 1909, p. 163.

[8] *Ibid.* (Sheffield) 1910, p. 110.

[9] Q. J. G. S. vol. lxv (1909) p. 126.

containing Arenig graptolites. In the south-eastern corner of the peninsula is an area of gneissic rocks, presumably Archæan, against which the highest member of the Silurian series is faulted. At the north-eastern corner of this gneissic area a second development of the lower members of the Silurian System is met with, the dip here being northerly and easterly.

II. The Sedimentary and Volcanic Arenig Rocks.

Under this head we group the great series of breccias and spilites, together with a relatively small development of grits, shales, and cherts, these sedimentary beds being confined to the northern part of the district.

Only at one point have Arenig fossils been found; but we consider that we are justified in regarding the whole series of rocks alluded to above, and in addition the intrusive felsites, as of Arenig age, on account of the general resemblance which they bear to those of the Tourmakeady and Glensaul districts. There are, however, many important differences, which will be summarized in the sequel. The most marked feature of the Kilbride series is the immense development of pillow-lavas (spilites).

The general structure of the area north-west of the Silurian outcrop, and west of the great felsite-mass of Glenbeg, is difficult to make out, and there has clearly been much faulting. Throughout a belt stretching westwards along the crest of the ridge from the top of Knock Kilbride to the neighbourhood of Lough Mweelaun, the strike of the Arenig rocks is east-north-easterly, in conformity with that of the neighbouring Silurian rocks; and the same strike is met with in the rocks immediately to the west of the Glenbeg felsite. But two important faults cut these rocks off from those in the western part of our map, occupying the country between Finny and the end of Derry Bay, and throughout this part of the area the strike when ascertainable is found to be south-easterly. Of these faults, one, the exact position of which is not ascertainable, lies to the east of Lough Mweelaun and strikes in a north-north-easterly direction, meeting a second which we propose to call the Oak Island Fault: this latter lies not far west of the great Glenbeg felsite-mass, and strikes the coast to the south of Oak Island.

(*a*) The Sedimentary Arenig Rocks.

(1) A small but interesting exposure is seen at a point nearly half a mile north-east of the top of Knock Kilbride. Here thinly-bedded black cherts, with shaly partings. are overlain by quartzose grits. Unfortunately, the exposure is entirely surrounded by peat, and consequently the relations of the rocks are not clear. The strike, however, is east-north-east, in conformity with that of all the Arenig rocks (so far as it is possible to observe this point) east of the Oak Island Fault. The cherts and grits probably form

a band interbedded with the spilites or breccias, patches of which protrude through the peat at various points in the neighbourhood.

In the cherts and shales we found the following graptolites :—

Didymograptus extensus Hall.
Didymograptus protobifidus=*nanus* Lapw. (common).
Tetragraptus sp.

Also a single specimen of what Dr. H. Woodward considers to be a new species of phyllocarid crustacean ; this is described in the Appendix (p. 99). The graptolites, which have been kindly examined by Miss G. L. Elles, D.Sc., indicate that the Kilbride beds belong to the same horizon as the graptolite-bearing beds of Lettereeneen in the Glensaul area, that is, the zone of *Didymograptus extensus.*

Though radiolaria are not so well seen in the cherts from Kilbride as in those from Tourmakeady and Glensaul, they are undoubtedly present in a rock (89)[1] from opposite Oak Island.

(2) A band of grit some 15 feet thick occurs among the spilites south of Oak Island ; it is truncated on the east by the Glenbeg felsite, and bisects the more westerly of the two smaller felsitic intrusions.

The narrow sedimentary bands, which occur in places interbedded among spilites or breccias, are best described with the rocks with which they are associated.

(*b*) The Breccias.

In the western part of the Kilbride district, as in that of Glensaul, coarse breccias play a prominent part. In the country west of the Glenbeg felsite-mass bands and areas of breccia are associated with the spilites. East of the Oak Island Fault, and to a less-marked extent south-east of Lough Mweelaun (where the strike is west-south-westerly), and north and north-west of Lough Mweelaun (where the strike is south-easterly), the breccias form fairly well-marked bands ; while in the district north and west of Finny the breccias occur in more irregular masses. It is possible that certain of these breccia-masses may mark the position of vents, as, for instance, the great mass in the south-western corner of the district ; but of this we are not confident. South and west of Lough Mweelaun a very coarse breccia stands up in great ice-worn elevations, in a very striking and characteristic fashion.

The breccias are of two distinct types : in the one, and far the commoner case, the fragments are of felsite, in the other of spilite. As a rule, the two varieties are not intermingled, but sometimes they are. The felsitic type of breccia, though generally distributed, is especially prevalent in the district west of Lough Mweelaun.

In addition to these two types of breccia, both of which are of

[1] These numerals in parentheses indicate the localities marked on the map (Pl. VI) where specimens were collected.

explosive origin, flow-breccias are not unfrequently met with in the spilites.

The coarseness of the breccias renders it, as a rule, impossible to ascertain their dip and strike, but occasionally interbedded fine bands give the direction: as, for example, at a point 400 yards north-east of Lough Mweelaun, a band of grit interbedded in the breccia has a north-westerly and south-easterly strike, while 250 yards west-south-west of this point very thin bands of chert and fine ash strike in the same general direction.

The numerous little patches of breccia mapped among the spilites may often be larger than is indicated in the map, the ground being much obscured by peat. An important feature in which the Kilbride district differs from those of Tourmakeady and Glensaul is the complete absence of limestone-breccias—in fact, of calcareous Ordovician rocks of all kinds.

It is noteworthy that the breccias to the south-west of Lough Mweelaun show the introduction of a considerable amount of chert, which has been deposited round the felsite-blocks so as sometimes to enclose them completely. This fact is of importance, in connexion with the method of introduction of chert among the spilites. No chert-fragments were noticed among the tuffs of the Kilbride district, although such fragments are common among the limestone-breccias of the Tourmakeady district.

(*c*) The Spilites (Pillow-Lavas).

In our earlier paper on the rocks of the Tourmakeady district, we described as intrusive certain spilites—fine-grained rocks of andesitic character, and quoted (Q. J. G. S. vol. lxv, 1909, p. 136) Dr. J. S. Flett, who, subsequently to the reading of the paper, kindly examined the rocks, as pointing out their strong resemblance in microscopical structure to certain pillow-lavas. In the Tourmakeady district these rocks, which are very poorly exposed, apparently form small intrusions and show no pillows. But rocks of the same type exhibit a vastly greater development in the Kilbride area, forming its most remarkable feature; and at very numerous points a pillow-structure is finely seen, the diameters of the pillows generally varying from 18 inches to about 3 feet.

Spilites cover a larger area than any other rock in the Kilbride peninsula. Commencing at a point near the top of Knock Kilbride, they extend westwards in a broad band, interrupted in places by patches of breccia, to the Finny River, where their outcrop has a width of half a mile. The rocks between the Oak Island Fault and the felsite-mass of Glenbeg are also predominantly spilites, and are here interbedded with breccia and with a band of grit which bisects the westernmost of the two smaller felsite-masses in this area.

Although, as a rule, there is no clear line of strike to be observed in the spilites, this is commonly obtainable from the interbedded bands of breccia, and in several cases from the trend of the bands of pillows. Less frequently, information is afforded by the associated bands of sediment, as in the following five cases:—

(i) The spilites west of the Oak Island Fault are underlain by a narrow band of grit, seen immediately to the west of the more westerly of the two small felsite-intrusions.
(ii) Half a mile east-north-east of Lough Mweelaun bands of chert occur interbedded with spilites.
(iii) A band of chert, occurring about 150 yards north-west of Lough Mweelaun, close to the boundary of the lower spilite-band and overlying breccia, strikes parallel to the line of junction between the two rocks and proved, like some of those of the Glensaul area, to be fine silicified tuff.
(iv) About 350 yards east-north-east of the exposure just mentioned a band of grit is seen.
(v) Chert and crushed shales occur in the bed of the stream a third of a mile north-north-west of Finny Chapel, along the line of fault between the spilite and the felsite.

In the area west of the Oak Island Fault and west of the Lough Mweelaun Fault there are again large areas of spilite.

The spilites are green or purple rocks, generally dark but sometimes of a light colour. They are very commonly vesicular, often markedly so, and when the pillows are exposed in section they are frequently seen to be more vesicular round the margin than towards the centre, or to have bands of concentrically-arranged vesicles (see Pl. VII, fig. 1). In many cases, however, the vesicles are irregularly scattered throughout. The most readily accessible spot where the pillows are well seen is near where the rough track to Derrypark leaves the Finny road. Fairly good examples occur in the enclosure behind the priest's house at Finny. Pillows are also finely seen at a number of points along the northern outcrop of the broad band of spilite which stretches north-westwards from near Lough Mweelaun, and east and west of the prominent dolerite-dyke which runs up the hillside about a third of a mile south-east of this Lough. Here the pillows are intimately associated with spilite-breccia—a clear case of flow-brecciation. Such brecciation, in this case unaccompanied by pillow-structure, is well seen at a spot on the left bank of the stream a third of a mile north-north-west of Finny Chapel.

An important feature, in which these pillow-lavas resemble those of the Ballantrae district, is their close association with chert, which is very frequently plentiful. The method of occurrence varies: as a rule, the chert forms a series of irregular strings and patches (see Pl. VII, fig. 2). But it may occur filling the spaces between the pillows, or between spheroidal masses of lava isolated by jointing, or else forming a more or less rectangular network around brecciated fragments; while, very rarely, a relatively large mass of chert is found occupying the centre of a spheroid.

A careful examination of the chert-masses described above leads us to the conclusion that they are all the product of deposition subsequent to the consolidation of the rocks with which they are associated, and that the great majority of them are due to infiltration. One of the best spots for observing these varieties of chert is near the point where the rough track to Derrypark leaves the Finny road.

Allusion may here be made to certain large veins or masses of red chert, or of quartz, which may be observed in various parts of the district. The following are the most important exposures :—

(i) A band about a quarter of a mile long and some 3 feet thick strikes in a north-westerly direction between the breccia and spilite, a third of a mile south-west of Lough Mweelaun. This runs parallel to the dolerite-dyke (120).

(ii) A mass appears through the peat, a third of a mile north-east of the top of Knock Kilbride.

(iii) A patch surrounded by spilite is found half a mile due west of the top of Knock Kilbride.

(iv) Much red chert occurs to the west of the dolerite dyke (137), where the latter traverses breccia and the basal Silurian conglomerate.

At one point only has a variolitic structure been observed in the spilites: this was at a spot (111) about a quarter of a mile north of Lough Mweelaun, where the spilite rests upon the breccia.

III. The Silurian Rocks.

(*a*) The Main Outcrop.

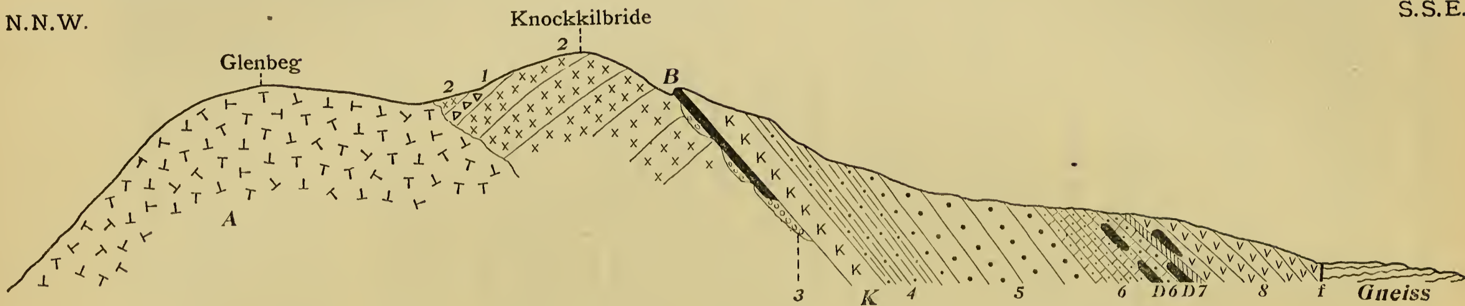
As has been already mentioned, except for an area of gneiss, the whole of the southern and eastern part of the Kilbride Peninsula is formed of Silurian strata and their associated intrusive rocks. Except in the Barnarinnia area, between Bird Hill and St. Bridget's Well, which requires separate treatment, the Silurian strata have a general dip varying from east to south-south-east. At the northern end of the outcrop, east of Knocknamuck, the dip is easterly or east-south-easterly; but, south-west of the Kilbride burial-ground, it becomes south-easterly and then south-south-easterly, this direction being maintained until the area ends at the Finny River.

Although careful mapping shows that the outcrop is shifted by numerous cross-faults, the general succession is perfectly easy to ascertain, and is as follows, in descending order :—

		Thickness in feet.
Wenlock	6. Doon Rock Grits	2000 seen.
? Tarannon Shale (equivalent)	5. Purple sandy shale	75
Llandovery	4. Finny School Beds (calcareous flags)	600
	3. Annelid-Grits	900
	2. Red sandstone	700
	1. Basal conglomerate	75

The thicknesses are very variable, and the maximum observed in each case is given.

Fig. 1.—*Section through Knock Kilbride.* *(Scales, horizontal: 4 inches = 1 mile; vertical: 1 inch = about 1,000 feet.)*



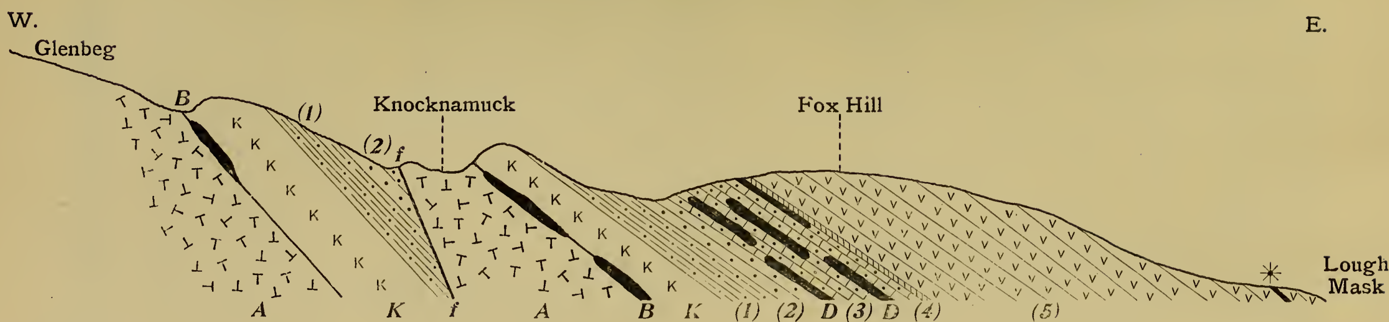
1 = Breccia, 2 = Spilite } Arenig Series.

3 = Conglomerate, 4 = Red Sandstone, 5 = Annelid-Grits, 6 = Calcareous Flags, 7 = Purple sandy shales (Finny School Beds) } Llandovery Series.

8 = Doon Rock Grits { Wenlock Series.

A = Quartz-felsite.
B = Labradorite-porphyrite.
K = Lime-bostonite.
DD = Dolerite sills.
f = Fault.

Fig. 2.—*Section through Fox Hill.* (*Scales, horizontal: 4 inches = 1 mile; vertical: 1 inch = about 200 feet.*)



(1) = Red Sandstone.
(2) = Annelid-Grits.
(3) = Calcareous Flags (Finny School Beds).
(4) = Purple sandy shales.
(5) = Doon Rock Grits.
* = Black-slate layers containing *Monograptus vomerinus.*

A = Quartz-felsite. B = Labradorite-porphyrite. K = Lime-bostonite. D = Dolerite. *ff* = Fault.

(1) The Basal Conglomerate.

The oldest Silurian rock is a coarse conglomerate, which is very impersistently exposed. It crops out at several points when it occurs in juxtaposition to specially hard rocks, such as the coarse porphyrite and the dolerite dyke a third of a mile south-east of Lough Mweelaun; but the exposures are relatively few, and the conglomerate frequently gives rise to a narrow tract of smooth grass between the rugged outcrop of the breccias on the north, and of the coarse porphyrite or lime-bostonite on the south. The best locality to observe the conglomerate is in the neighbourhood of the dolerite dyke just mentioned, and for about a quarter of a mile to the east thereof. In the immediate neighbourhood of the dyke the conglomerate is seen in close relationship to the coarse Arenig breccia, and at one point seems to dip below it; the explanation is probably that here the upturned base of the conglomerate rests upon a very uneven surface of breccia. The pebbles of the conglomerate, which are thoroughly well rounded, may reach a length of 10 inches, and consist chiefly of pink quartzite, but include also granite, felsite, quartz, and chert.

(2) The Red Sandstone.

This is a somewhat current-bedded sandstone, very uniform in character, and with its component quartz-grains cemented together by ferric oxide. It is exposed all along the southern slopes of the Knock Kilbride ridge from near Finny Chapel to the eastern slopes of Knocknamuck. With the exception of an ill-preserved coral, no fossils have been found in it. It occasionally becomes conglomeratic, and may then include well-rounded pebbles of red quartzite rather larger than a hen's egg. In rare cases it includes small patches of red shale. Only at a single point, a spot north of Kilmore, have we found it penetrated by one of the dolerite dykes which are so abundant in some of the overlying rocks. The maximum width of outcrop (about 300 yards) is met with east of the summit of Knock Kilbride: at Kilmore the width of outcrop is reduced to about 100 yards.

(3) The Annelid-Grits.[1]

The red sandstones are overlain by yellowish or reddish-purple grits, which very frequently have the bedding-planes covered by numerous slight elevations rather less than a quarter of an inch in diameter, which are seen in longitudinal section to be filled-up tubes. The rock closely resembles the Serpulite-Grit of the Durness area. The yellowish and purple grits pass up into a series

[1] The occurrence of these Annelid-Grits is mentioned in the Annual Rep. Geol. Surv. for 1896 (1897) p. 50, where they are stated to resemble the 'pipe-rocks' in the Sutherland quartzite. The age of all these Silurian deposits is stated, however, to be Wenlock.

of very hard white grits, occasionally containing quartz-pebbles. The beds are readily recognized in the field. They are overlain by flaggy sandstones which are sometimes seen, where weathered, to be highly fossiliferous. We obtained the following fossils from exposures north and north-west of the Doon Rock:—

Lindstrœmia bina Lonsd.
L. subduplicata var. *crenulata* M'Coy.
Palæocyclus preacutus (?) Lonsd.
Streptelasma elongatum Phill.
Cyathophyllum (?) sp.
Heliolites interstinctus Linn.
Favosites aspera d'Orb.
F. forbesi (?) M.-Edw.
Aulopora sp.
Orthis calligramma Dalm.
O. rustica var. Sow.
O. crassa Lindstr.
O. elegantula Dalm.
O. equivalvis (?) Dav.
Leptæna rhomboidalis Wilck.
Camarotœchia llandoveriana (?) Dav.
C. stricklandi (?) Sow.
Chonetes striatella Dalm.
Pentamerus oblongus Sow.
Cœlospira hemispherica Sow.
Illænus barriensis Murch.
I. maccallumi Salt.
Phacops elegans Sars & Bœck.
Calymene blumenbachi (?) Brongn.
Encrinurus punctatus Brünn.
Proetus latifrons (?) M'Coy.
Beyrichia klœdeni (?) M'Coy.
Tentaculites anglicus Salt.
Ctenodonta anglica d'Orb.
Horiostoma globosum Sow.
Loxonema sp.
Orthoceras (?) sp.
Crinoid stem-joints.

Encrinurus punctatus is locally very abundant.

The grits pass up into the Finny School Beds (4).

(4) The Finny School Beds—Calcareous Flags.

These highly fossiliferous beds form one of the most interesting features of the Silurian development, not only in the Kilbride Peninsula, but throughout the country immediately south-west and west of Lough Mask. They are dark-grey fissile flags, much used for building purposes, and are frequently quarried. In the Kilbride Peninsula their outcrop extends in an east-north-easterly direction from near Finny School to a point north of the Doon Rock, and then north-north-eastwards over the shoulder of Fox Hill and down to the shore of Derry Bay. They include two profusely fossiliferous horizons. The lower one is crowded with corals, such as *Favosites*, *Halysites*, *Heliolites*, and *Lindstrœmia*, which often cover large slabs of rock and present a remarkable appearance. These beds are well seen at many points, as on the north and west of the Doon Rock, and at a small promontory east of Knocknamuck. In some cases the massive corals are enclosed in calcareous concretions, and this probably was formerly the case with them all; but, as a rule, the rock has been almost completely decalcified. At a somewhat higher level is the second highly-fossiliferous horizon, a bed crowded with brachiopods, chiefly *Orthis calligramma*, which occurs in innumerable large and singularly perfect specimens. This bed is well exposed near the northern shore-line, a short distance east of the outcrop of the coral-bed. The complete list of fossils from the Finny School Beds is as follows:—

Lindstrœmia bina Lonsd.
L. subduplicata M'Coy.
L. subduplicata var. *crenulata* M'Coy.
Palæocyclus sp.
Ptychophyllum patellatum Schloth.
Streptelasma elongatum Phill.
Cyathophyllum sp.
Heliolites megastoma M'Coy.
H. murchisoni M.-Edw.
H. interstinctus Linn.
Propora tubulata (?) Lonsd.
Plasmopora petaliformis Lonsd.
Halysites catenularia Linn.
H. escharoides Lamk.
Favosites gothlandica Fougt.
F. forbesi M.-Edw.
F. bowerbanki (?) M.-Edw.
F. aspera D'Orb.
F. cristata (?) Blum.
Favositella sp.
Cœnites intertextus Eichw.
Thecia swinderenana Goldf.
Lingula parallela (?) Phill.
Orthis calligramma Dalm.
O. elegantula Dalm.
O. rustica Sow.
Orthotetes pecten Linn.
Chonetes striatella Dalm.
Leptæna rhomboidalis Wilck.
Plectambonites transversalis Wahl.
Wilsonia wilsoni Sow.
Camarotœchia llandoveriana (?) Dav.
Pentamerus undatus Sow.
P. oblongus Sow.
Cœlospira hemispherica (?) Sow.
Spirifer plicatellus Linn.
Atrypa reticularis Linn.
Atrypina barrandei Dav.
Meristella cf. *angustifrons* M'Coy.
Fenestella sp.
Pterinea subfalcata Conr.
Modiolopsis sp.
Ambonychia striata var.
Triblydium sp. nov.
Orthoceras ludense Sow.
Cyrtoceras approximatum Sow.
Gomphoceras æquale (?) Blake.
G. imbricatum Barr.
G. sp.
Beyrichia klœdeni M'Coy.
Trinucleus sp.
Proetus latifrons M'Coy.
Encrinurus punctatus Brünn.
Crinoid stems.

The most noteworthy feature in the foregoing list is the occurrence of *Trinucleus* in Llandovery strata. The specimen was not found actually in place, but was collected from a block built into a wall. The matrix is precisely that of the Llandovery rocks of the neighbourhood, and the following fossils were collected from the same block:—*Lindstrœmia subduplicata* var. *crenulata*, *Favosites forbesi*, *Spirifer plicatellus*, *Leptæna rhomboidalis*, *Pterinea subfalcata*, and *Encrinurus punctatus*.

(5) The Purple Sandy Shale.

This narrow band of shale is remarkably persistent throughout the whole outcrop, from a point north-east of the Doon Rock westwards to the Finny River; and, owing to the readiness with which it could be recognized, it proved of considerable service in mapping. From the neighbourhood of the Kilbride burial-ground northwards no permanent exposure of the shale occurs. It was exposed, however, in 1911, in a trench immediately to the west of the Kilbride burial-ground, and fragments occurring on the beach north of Foxhill indicate that it here strikes the shore-line. No fossils were found in these shales, despite prolonged search.

(6) The Doon Rock Grits.

These massive grits attain a greater thickness, and cover a larger area than any other Silurian formation in the district. They are well seen along the southern shore of the peninsula for about a mile to the west of the gneiss, whence they run north-eastwards past the Doon Rock to Kilbride Church. They also form Fox Hill and the entire eastern and northern shores of the peninsula in the neighbourhood of that hill. Bands of them strike with great persistence through the woods of Barnarinnia. The lower beds are in the main grey quartzose grits; but fine dark grit-bands also occur in the strip of ground that extends from Kilmore to Kilbride Church.

North of Kilbride Church the outcrop of the grit widens greatly; this is due partly to a lower dip, but chiefly to the upper beds being cut out by faulting in the Kilmore-Kilbride exposure. The northern shore-line yields good exposures, and the grit-bands succeed one another with great regularity. Occasionally, however, there is evidence of disturbance in the form of bands of breccia, and about 200 yards short of the extreme point there is some folding. At the point the grit-bands are separated by very thin partings of black shale, in which numerous fragments of badly preserved graptolites have been found. Among these Miss Elles has determined *Monograptus vomerinus* Nich. and *M. vomerinus* var. *gracilis* Elles & Wood. These beds are overlain south of the point by grits, with occasional large calcareous concretions, these being the highest beds in the district.

Doon Rock Grits are also exposed along the eastern coast-line almost as far south as Kilbride Rock, and in various scattered exposures to the west of this line of coast.

(*b*) The Barnarinnia Area.

Reference to the map (Pl. VI) will show that the south-eastern portion of the Kilbride peninsula is occupied by gneissic rocks, against which the Silurian strata with a southerly and easterly dip are faulted. From the shore of Kilbride Bay to a point about a third of a mile north-east of the Doon Rock, Doon Rock Grits with a south-easterly dip are faulted against the gneiss; but farther east the other members of the Silurian series, with the exception of the basal conglomerate, are all met with, the lime-bostonite being also present. These rocks, which have in the main a northerly dip, appear to represent part of the southern limb of a big syncline, the northern limb of which is represented by the main Silurian outcrop. They are, however, much faulted, and are swung out of their normal line of strike. The badness of the exposures makes mapping very difficult, and it is uncertain whether the lowest member (the lime-bostonite) rests upon the gneiss or is faulted against it. It appears that four cross-faults traverse these rocks and the adjacent gneiss, dividing the Silurian strata into four blocks. In the two westerly blocks lime-bostonite, Red Sandstone, Annelid-Grits, and Calcareous Flags are all exposed, but the Red and Purple Shales were not detected. In the third block, counting from the west, only the lime-bostonite and the Red Sandstone were seen. In the easternmost band the Red and Purple Shale was exposed at two points (as indicated on the map). In the western exposure the normal northerly dip occurs, but in the eastern exposure on the small peninsula opposite Kilbride Rock the dip of the exposed rocks is southerly. We regard this as a local inversion.

On Kilbride Rock the Calcareous Flags are seen, and we have thought it best to map them to the south of the red-shale outcrop on the mainland, despite the fact that they have not been detected there, and although certain large blocks doubtfully *in situ* appear to bear a greater resemblance to the Red Sandstone.

The greater part of the area between Bird Hill and Kilbride Rock is occupied by a fine development of the Annelid-Grits, which show the characteristic tubes probably as well as anywhere in the Kilbride Peninsula. The rocks betray signs of disturbance, and discordant dips are noted. In the neighbourhood of Bird Hill the Annelid-Grits are faulted against lime-bostonite and red sandstone, which strike in a north-north-easterly direction.

IV. Field-Relations of the Intrusive Igneous Rocks.

(*a*) The Felsites.

Felsite is intruded only in the Arenig rocks, for at Knocknamuck (the only place where it is found in contact with the Silurian sediments) the junction is almost certainly a faulted one; and west of Knocknamuck lime-bostonite has been intruded at the base of the Llandovery strata, separating them from the felsite on which they were doubtless originally deposited. Felsite occurs principally in one enormous mass of very coarsely-quartzose rock, which stretches along the southern shores of Derrypark Bay from Knocknamuck to above Red Island. Although it does not form the summit of Knock Kilbride, the highest point in the area, it gives rise to some of the steepest and most rugged country. Two small masses of the same type of felsite, each having a length of some 250 yards, lie to the west of the main mass, the more westerly being bisected by a band of grit and cut off on the west by the Oak Island Fault.

Three very small intrusions of the somewhat coarsely-quartzose felsite penetrate the spilites or breccias near the top of the watershed south-east of Lough Mweelaun; while two other small intrusions occur on the borders of the breccia and spilite a third of a mile south-west of this Lough.

Felsite of a type somewhat different from those just mentioned, and devoid of conspicuous quartz-crystals, forms Red Island and a narrow strip on the shore south and west of it. A mass of felsite, about 300 yards long and 200 yards broad, occurs north of Finny: it is of a type similar to the felsite of Red Island.

(*b*) The Lime-Bostonite.[1]

A much-faulted band of this rock extends for nearly 3 miles from the Finny River to Knocknamuck, where it is faulted against felsite. A second band, which appears to be faulted off from the northern end of the main band, extends along the eastern base of Knocknamuck down to the shore of the lake. The southern and western boundaries of this latter band are formed by faults. In the Barnarinnia area four small patches of lime-bostonite occur. Wherever the lime-bostonite occurs throughout the district, it is overlain by red sandstone. The most noteworthy feature of the lime-bostonite is its remarkable variability in width of outcrop. South of the summit of Knock Kilbride the outcrop is only some 25 yards wide; while, in the neighbourhood of the labradorite-porphyrite intrusion south-east of Lough Mweelaun, the width increases to about 275 yards. This remarkable variation in width of outcrop depends mainly on variation in thickness, not on difference of dip. The maximum thickness is about 600 feet. The lime-bostonite is a very resistant rock, and frequently stands up forming steep crags. In view of the marked variation in the thickness of the lime-bostonite, its non-association with tuffs, and the absence of evidence in this or any other Irish area (with the exception of the Clogher-Head district of Kerry) of the existence of volcanic rocks of Silurian age, it seems clear that the lime-bostonite, like the coarse porphyrite, is a sill intruded at the base of the red sandstone. It is noteworthy that the line of least resistance followed by the intrusions was not always that of the unconformity, as the basal Silurian conglomerate, where it is seen, lies beneath the lime-bostonite.

(*c*) The Labradorite-Porphyrite.

This rock is entirely unrepresented in the Glensaul and Tourmakeady areas. It forms four intrusive masses, all of which occur in close relation to the lime-bostonite and near the base of the Silurian strata. The principal intrusion is a sill, having a probable thickness of about 100 feet, which occurs immediately south of the top of Knock Kilbride. It strikes north-east and south-west, and can be followed with slight breaks for rather over half a mile. About 300 yards from its south-western end it is interrupted by a fault, which alters its strike from south-west to south-south-west. The north-eastern end is also separated by a fault from the main mass. A second band of porphyrite of about the same thickness, having a length of about a third of a mile, commences about 500 yards to the west of that just described. It resembles the first band in its relations to the other rocks, and in the fact that it is shifted by a fault. It is intersected by a dolerite dyke.

[1] [As British writers seem to confine the term keratophyre to lavas, we have thought it advisable to call this rock a lime-bostonite, especially as it is so similar both chemically and microscopically to the Abercastle bostonite.—*C. I. G. & S. H. R., Feb. 16th, 1912.*]

A third band can be traced for some 250 yards in a north-north-easterly direction along the eastern base of Knocknamuck. All these three bands are clearly sills. A fourth, but much smaller, intrusion occurs at the western end of Knocknamuck. These sills are all on the same horizon.

(*d*) The Dolerites.

Thirty-three dolerite intrusions have been mapped, and it is probable that others may not have been detected. Of these, seventeen are in the Calcareous Flags (Finny School Beds), and seven in the overlying Doon Rock Grits. Five occur in the spilites, two in the breccia, and one in the Red Sandstone; lastly, a dyke starting in the breccias penetrates the basal Silurian conglomerate and one of the labradorite-porphyrite sills ending in the bostonite. The great majority of these intrusions occur in the area north and west of the Doon Rock.

The dolerites are readily divided into two groups: a larger group, the strike of which ranges from west-south-west to south-south-west; and a smaller group striking south-east or south-south-east. All these rocks are dark green or grey on the freshly broken surface, and weather to a rusty brown.

Group (*a*). Those with a west-south-west to south-south-west strike.—The great majority of these occur in the Calcareous Flags and overlying grits, especially in the region west of the Kilbride burial-ground and north of the Doon Rock; none were met with in the western part of the outcrop of these rocks nearer Finny. These intrusions, which vary in length from a few yards up to some 300 yards, are probably all sills. Their thickness is inconsiderable, 35 feet being probably the maximum, and they have not produced any appreciable alteration in the adjacent strata. In rare cases doleritic intrusions belonging to group (*a*) are met with in rocks other than the Calcareous Flags and grits. Thus, one occurs in spilite a quarter of a mile south-west of the top of Knock Kilbride; a second in breccia half a mile west-south-west of the same point; and a third in red sandstone half a mile north-east of Finny School.

Group (*b*). Those with a south-easterly or south-south-easterly trend.—These are in the main dykes, not sills, and occur principally in the spilite. They are far less numerous than group (*a*). About 300 yards south-east of Lough Mweelaun a dyke 8 feet wide is seen running up the hillside, which is here very steep. Being covered with white lichen, it contrasts strongly with the other rocks and forms a prominent feature. It is intruded into spilite, and shows well-marked chilling at the edges.

On the southern side of the ridge, almost on the line of strike of the dyke just described, occurs another equally well-marked one, which is particularly interesting on account of the variety of rocks that it intersects. Commencing in breccia, it traverses the basal Silurian conglomerate and a labradorite-porphyrite sill ending in lime-bostonite. This dyke, like that just described, is about 8 feet wide, and shows marginal chilling.

Both dykes strike south-south-eastwards, and may really be part of the same intrusion.

A third intrusion occurs about half a mile north of Finny School, and runs for some 300 yards in a north-westerly direction between spilite and breccia, parallel to a very large red quartzose vein; whether this is a dyke or sill is not clear. Two small intrusions of similar rock are seen near Finny, the one in spilite at the western angle of the wood north of Finny Chapel, the other in coarse breccia a third of a mile north-west of the village. Another small intrusion occurs in spilite, about 800 yards west-north-west of Knock Kilbride.

V. Petrographical Details.

(*a*) The Felsites.

The great quartz-felsite intrusion which extends westwards from Knocknamuck consists of a well-marked rock, much resembling those that form the 'green and brown' felsite-intrusions of the Tourmakeady district and the great sill of the Glensaul district. It is characterized by large crystals of quartz which in hand-specimens often show crystal faces, embedded in a matrix usually of a reddish-purple colour, but becoming yellowish-green near the western border of the mass. Few sections were cut of this rock, but these showed an abundant felsitic ground-mass, through which were scattered crystals of quartz, often strongly corroded, and a few much-weathered felspars. The last-named include both orthoclase and plagioclase, the plagioclase, as pointed out by Dr. Flett, being often albite. The specific gravity of four specimens of this rock gave an average of 2·65.

West of this great intrusion are two smaller masses of the same rock, which, it can scarcely be doubted, have (or once had) a subterranean connexion with the larger mass. A section taken from the more westerly of these two masses shows a still further resemblance to the intrusive felsites of Glensaul and Tourmakeady, in the presence of numerous pseudomorphs either entirely in a green chloritic mineral, or partly in this, partly in calcite; many of the green pseudomorphs are certainly after rhombic pyroxene. This rock has a specific gravity of 2·74. The felspars, which are rather less weathered than those in the sections examined from the great intrusion on the east, include both orthoclase and plagioclase. Magnetite is rather plentiful.

A very felspathic type of felsite, containing much magnetite and abundant green pyroxene-pseudomorphs (72), occurs at Red Island and along the shore to the south and south-west. The small felsite patches which are seen south-east and south-west of Lough Mweelaun show no features of special importance.

Allusion may here be made to an exceptional rock-type seen only at (30), a spot about a quarter of a mile south of Knocknamuck, where it appears to be intruded between the lime-bostonite and the Red Sandstone. In a hand-specimen it is a pinkish rock, with pale-green felspar-phenocrysts and small ill-defined dark patches. Sections show the rock to be principally composed of almost square felspars with simple twinning. Scattered through the ground-mass are larger weathered felspars. Albite is present; but the majority of the felspars, large and small, are orthoclase. The dark patches prove to be chloritized pseudomorphs after hornblende. Epidote and calcite are also present as alteration-products. The rock may be called a hornblende-felsite.

(*b*) The Lime-Bostonite.

This retains a very uniform character throughout the whole length of its outcrop. It is a purple or pinkish rock, very compact and fine-grained, and hardly ever showing any phenocrysts. The scarcity or abundance of its amygdules is its sole varying characteristic in the field. As a rule, only a few small scattered amygdules are seen; but sometimes, especially near the base of the sill, as at (134), they are very plentiful. Quartz is by far the commonest mineral forming the amygdules. In thin sections the lime-bostonite is very uniform in character, consisting of a felted mass of small felspar-needles associated with much iron-oxide (sometimes magnetite, sometimes hæmatite), much of which in either case is probably secondary. This is, as a rule, very evenly distributed through the sections in small patches; but it sometimes occurs interstitially, and may, like certain ill-defined patches of calcite which are sometimes (49) seen, represent ferromagnesian minerals, no sign of such minerals in an unaltered state having been observed in these rocks.

The felspar was determined as albite by Dr. Flett, who pointed out that these Kilbride bostonites are more felspathic than the spilites, containing from 60 to 70 per cent. of felspar. Felspar phenocrysts in a much-weathered state are only rarely met with, and no sign is seen of a glassy base. There is little trace of flow-structure. These rocks show a considerable resemblance to the lime-bostonite described by Dr. J. V. Elsden[1] from the district north-east of St. David's Head and still more to the keratophyre described by Mr. Herbert H. Thomas[2] from Skomer.

We have said that our lime-bostonite resembles microscopically the St. David's rock described by Dr. J. V. Elsden (*op. cit.* p. 595). The similarity in chemical composition is shown by the analyses of the two rocks:—

[1] Q. J. G. S. vol. lxi (1905) pp. 594–99.
[2] *Ibid.* vol. lxvii (1911) pp. 193–95.

	I.	II.	III.
SiO_2	54·20	55·38	56·50
Al_2O_3	21·00	18·34	18·14
Fe_2O_3	2·60	1·13	3·12
FeO	4·32	5·86	2·86
MnO	trace	......	......
CaO	3·80	3·25	3·38
MgO	2·02	3·47	1·22
K_2O	0·42	0·22	1·60
Na_2O	6·58	7·12	5·28
TiO_2	2·60	0·90	0·85
P_2O_5	0·04	trace	......
CO_2	1·57	2·00	5·11
Water at 110° C.	......	0·48 }	1·26
Water (combined)	1·23	2·39 }	
Totals	100·38	100·54	99·32
Specific gravity =	2·68	2.73	

I. Lime-bostonite from Kilbride (analysed by J. Weintraube).
II. Lime-bostonite from St. David's (analysed by J. V. Elsden).
III. Lime-bostonite from Mæna, W. C. Brögger, Q. J. G. S. vol. 1 (1894) p. 26.

Calculating the percentages of albite and anorthite from the soda and lime, Dr. Elsden gets for his felspar :—

Albite	60·26
Anorthite	16·12,

which amounts to 76·38 per cent. of a plagioclase between Ab_4An_1 and Ab_3An_1.

For the Kilbride rock we get :—

Albite	55·61
Anorthite	18·86,

which amounts to 74·47 per cent. of a plagioclase corresponding to the formula Ab_3An_1.

If we calculate the amounts of silica and alumina needed to form felspars with the lime and alkalies, we arrive at the following result :—

	Ab.	An.	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$.	Total.	Observed.
SiO_2	38·21	8·14	1·61	49·48	54·20
Al_2O_3	10·32	6·92	0·46	18·20	21·00
Na_2O	6·58	...	...	6·58	6·58
K_2O	...	...	0·42	0·42	0·42
CaO	...	3·8	...	3·8	3·8

It will be observed that the silica and alumina needed for the above suppositions are less than the observed amounts. The excess of these oxides is no doubt due to some of the silica and alumina being combined with magnesium and iron in the chloritic mineral which is present.

Finally, it is worth recording that in the three (Kilbride, St. David's, and Mæna) areas, the three similar rocks are all accompanied by a porphyrite. In the Kilbride area there is no direct evidence of transgression to prove which rock was the earlier, but the occurrence in the field suggests that the porphyrite was the later of the two. In the Mæna area Prof. W. C. Brögger finds bostonites and camptonites as complementary rocks, that is, differentiation-products of one and the same magma.[1] Although no camptonites occur in the Kilbride area, it is interesting to note that we have found some intrusions of hornblende-lamprophyre in the Arenig rocks of Tourmakeady.[2]

(*c*) The Labradorite-Porphyrite.

This rock is very constant in character. The extensive fine-grained ground-mass is always purplish brown in colour, and is crowded with large fresh, pale-grey, platy crystals of labradorite, having an average length of about 5 millimetres and a breadth of about 1 mm. Their outline is commonly somewhat rounded. The specific gravity of this rock is 2·72. The ground-mass is seen in section to be principally composed of felspar-laths, which are less fresh than the phenocrysts and give a smaller extinction-angle. Fresh augite sometimes (85) occurs, and as a rule chloritic and other pseudomorphs, apparently after rhombic pyroxene, are present. Very small vesicles filled with chlorite and chalcedony are of frequent occurrence.

(*d*) The Dolerites.

These include mica-dolerites, in addition to the ordinary augite-dolerites.

(i) The augite-dolerites.—These are dark or nearly black rocks, of medium grain as a rule, the texture in the larger dykes becoming finer towards the margin. In some hand-specimens no crystals are apparent; but in some cases (58, 62) large augites are seen, and in others porphyritic felspars (60, 62). Pyrite is occasionally seen, and small calcite-filled vesicles are not uncommon. The average specific gravity of sixteen specimens was 2·82.

In section, most of the rocks are seen to be normal dolerites—consisting of a felted mass of plagioclase-laths with augite and magnetite. No olivine has been definitely recognized; but pseudomorphs in carbonate, perhaps after olivine, are occasionally met with, as, for instance, in the mica-dolerite (66). The size of the felspar-laths varies a good deal, being generally greater in the dykes in the south-western part of the area with a south-easterly trend, than in the sills associated with the Calcareous Flags. These dykes also tend to be fresher than the sills.

[1] W. C. Brögger, Q. J. G. S. vol. l (1894) p. 26.
[2] C. I. Gardiner & S. H. Reynolds, Q. J. G. S. vol. lxv (1909) p. 131.

Phenocrysts of felspar are conspicuous in sections of (62); and in (122) the weathered felspar is seen to be bordered by fresh secondary material.

The augite is, as a rule, granulitic in character; but in some cases (58, 62) large well-terminated crystals of augite occur. Less often, as in (136), a specimen taken from the centre of the big dyke south-east of Lough Mweelaun, the augite is ophitic.

As for accessory minerals, magnetite is generally distributed. Chlorite and calcite are common as alteration-products or filling small vesicles, and epidote is occasionally met with (58). A specimen (60) taken from the eastern end of the big dyke north of the Doon Rock has a very fine-grained ground-mass, and its characters in microscopical section are rather those of an augite-porphyrite than of a dolerite. Its specific gravity, however, is 2·81. In addition to the idiomorphic augites, it contains chloritized pseudomorphs, probably after rhombic pyroxene.

(ii) The mica-dolerites occur west of the Kilbride burial-ground and north of the Doon Rock. They differ from the other dolerites only in the presence of numerous flakes of biotite. Dr. Flett points out the presence of albite in these rocks, and that the association of albite-diabases with spilites occurs in Mid Argyll and is universal in Cornwall. Although these two rocks occur in the Kilbride district, they can hardly be said to be associated, since the spilites are of Arenig age, while the mica-dolerites are post-Llandovery intrusions. Apatite is present as an accessory in the rock from (66).

(*e*) The Spilites (Pillow-Lavas).

These are rocks of fine and uniform grain, consisting principally of small lath-shaped felspars which often show fluxion-structure, or are arranged in a divergent sheaf-like manner. Occasionally a subvariolitic structure may be observed. The felspar is practically always albite. Porphyritic felspars are rather rare; they sometimes (29) contain prehnite, and were probably not originally albite but lime-bearing plagioclase. Occasionally pseudomorphs which seem to be after pyroxene are present, but no unaltered ferromagnesian minerals are preserved. Some of the felspars are replaced by carbonate. Iron-ore (sometimes magnetite, sometimes ilmenite) is often present, as small patches uniformly distributed over the section and probably secondary. Vesicles are numerous, and may be filled with carbonates, quartz, chalcedony, or chlorite. Dr. Flett, to whom we are indebted for many of the observations recorded above, alludes to the resemblance which the Kilbride rocks present to the Ordovician pillow-lavas of the South of Scotland, Megavissey and Mullion Island in Cornwall. The resemblance to the Devonian and Carboniferous spilites of Devon and Cornwall is less marked.

We quote below an analysis of one of the Kilbride spilites, and for comparison add two analyses of British spilites as quoted by Mr. Dewey & Dr. Flett in their paper on British pillow-lavas in the 'Geological Magazine'.[1]

	I.	II.	III.
SiO_2	49·80	47·56	51·31
TiO_2	1·70	2·40	1·92
Al_2O_3	17·94	14·27	12·67
Fe_2O_3	2·37	1·63	0·54
FeO	6·74	6·80	7·99
MnO	...	0·30	0·45
CaO	9·00	10·95	8·17
MgO	4·02	4·90	2·19
Na_2O	4·03	4·61	5·21
K_2O	0·20	0·27	0·54
P_2O_5	...	0·19	0·90
CO_2	1·28	2·95	6·15
Water at 105° C.	0·10	0·42	0·04
Water (combined)	3·54	2·65	2·31
Totals	100·72	99·90	100·39

I. Spilite from Kilbride, analysed by J. Weintraube.
II. Pillow-lava, Tregedden (South Cornwall): omitting (CoNi)O 0·08, FeS_2 0·22, Fe_7S_8 0·05. Anal. E. G. Radley.
III. Pillow-lava, Argyllshire: omitting FeS_2 0·30, Fe_7S_8 0·17. Anal. E. G. Radley.

A comparison of these analyses shows how similar the Irish spilite is in composition to the Cornish rock.

It is interesting to recall that we found small intrusions of a spilitic rock in the Arenig Series in the Tourmakeady area, which Dr. Flett, after microscopical investigation, stated to have the essential features of the Mid-Devonian lavas of the Plymouth area.[2]

(*f*) The Tuffs.

Few sections were cut of these rocks, their interest lying chiefly in features which may be observed in the field. As compared with those of Tourmakeady and Glensaul, the most interesting characters are negative ones, namely the absence of limestone-breccias and the slight development of gritty tuffs. The coarse breccias so extensively developed at Kilbride differ from those of Glensaul, in the fact that the blocks consist of spilite nearly as frequently as of felsite. In many of the fine tuffs, also, the little ashy particles are frequently of spilite. Only at one point (109), a small exposure a third of a mile north-north-east of Lough Mweelaun, occur silicified tuffs similar to those found in the Mount Partry Beds of Glensaul.

[1] Geol. Mag. dec. 5, vol. viii (1911) p. 206.
[2] Q. J. G. S. vol. lxv (1909) p. 136.

VI. Comparison of the Rocks of the Tourmakeady, Glensaul, and Kilbride Areas.

	Tourmakeady.	Glensaul.	Kilbride.
Arenig Rocks.			
Shangort and Tourmakeady Beds (Zone of *Didymograptus hirundo* and perhaps higher beds).	Well-developed, including grits, bedded limestones and limestone-breccias.	Well-developed, including grits, tuffs, bedded limestones, and limestone-breccias, also beds containing graptolites of the *D.-hirundo* Zone.	Unrepresented.
Mount-Partry Beds (Zone of *Didymograptus extensus*).	The upper beds are well seen, and include cherts and shale containing *Didymograptus extensus* and other fossils, quartzose grits, and tuffs. Coarse breccias are not prominent. The lower beds (coarse conglomerate) are well seen.	The upper beds are well seen, and include cherts and shales containing *Didymograptus extensus* and other fossils, tuffs, and coarse breccias. Quartzose grits are not very prominent. The lower beds (coarse conglomerate) are well seen.	The upper beds include chert and shale containing *Didymograptus extensus* and other fossils, but they are not well seen. The same is the case with the gritty tuffs, but coarse breccias are very greatly developed. No coarse conglomerates occur.
Igneous rocks.			
Felsites and rhyolites.	Two large boss-like masses of intrusive felsite occur, and a great number of small intrusive masses. There is also a great mass of probably contemporaneous rock of similar character (rhyolite) occurring at the base of the Shangort Beds.	A large sill of felsite occurs in the Shangort Beds, but only a very few small intrusions.	A very large mass of felsite penetrates the Mount-Partry Beds, and there are a good many smaller intrusions.
Lime-bostonite.	Unrepresented.	Unrepresented.	A large sill occurs intruded at, or near, the base of the Silurian rocks.
Labradorite-porphyrite.	Unrepresented.	Unrepresented.	Several sills of considerable size occur at, or near, the base of the Silurian rocks.
Hornblende-lamprophyre.	Several small dykes occur.	Unrepresented.	Unrepresented.
Spilite.	Several small intrusions penetrate the Arenig beds.	Unrepresented.	Extensive lava-flows of spilite showing well-marked pillow-structure occur in the Mount-Partry Beds.
Dolerite.	Several small intrusive masses occur, either in the Arenig beds, or between them and the basal conglomerate of the Carboniferous. Some are olivine-bearing.	Unrepresented.	Numerous sills and a few dykes occur intrusive in various rocks, but principally in the Silurian. Some contain biotite, some albite.

VII. General Summary and Conclusions.

The stratigraphical succession in Arenig times is not nearly so complete in the Kilbride area as at Tourmakeady and Glensaul, neither the coarse conglomerate towards the base of the Arenig deposits nor the Shangort Beds near their summit being seen. The lowest Arenig bed at Kilbride is a spilite-flow with some accompanying breccias, upon which rest quartzose grits, with black cherts and shales containing *Didymograptus extensus*, these being almost the sole representatives of the Arenig sedimentary deposits in the area. A most extensive series of spilite-lavas accompanied by felsite and spilite-breccias follows: the coarseness of the breccias indicating the highly explosive character of the eruptions, and the large blocks of felsite in the breccias proving the presence of an acid magma at no great distance, although no acid lavas have been found in the area and as yet no acid intrusions had taken place.

Later on, but almost certainly in Arenig times, occurred the upwellings of the acid rock which now forms the great felsite-intrusion of Glenbeg and the smaller felsite-masses elsewhere in the area. At what exact period the extensive fracturing of the Arenig beds took place is not evident. It is probable that it occurred in post-Arenig times, and was connected with the uplift which brought these rocks under the influence of the Llandeilo sea.

The Kilbride area contains no Llandeilo rocks; but an enormously thick series of grits, with a coarse basal conglomerate containing blocks of a quartz-felsite exactly like the Glenbeg rock, rests upon the Arenig beds along the western margin of the Kilbride area, and forms the northern shore of Kilbride Bay. These rocks are similar to the grits and conglomerates to which we refer in our Tourmakeady and Glensaul papers as of Bala (?) age, but according to Mr. H. B. Maufe and Mr. R. G. Carruthers they are of Llandeilo age.

If these beds ever extended over the Kilbride Peninsula, they were removed by erosion in pre-Llandovery times, as the Llandovery Beds rest directly upon the Arenig Series.

Llandovery Beds some 2350 feet thick, succeeded by about 2000 feet of Wenlock grits, occur in the area; but no Ludlow Beds are seen, *Monograptus vomerinus* being found in the very highest strata.

Probably at an early post-Silurian date came intrusions of lime-bostonite and of coarse porphyrite. Then followed a period of important earth-movement, connected in all probability with the Caledonian movements of other regions. The whole area was folded into a syncline, the axis of which trended roughly north-east and south-west; and, perhaps owing to the presence of the rigid block of the Glenbeg felsite, the rocks in adjusting themselves were traversed by numerous cross-faults, which shifted the outcrops of the lime-bostonite and coarse-porphyrite intrusions as well as those of the Silurian strata. The important fault bringing the Silurian deposits against the gneiss in the south-eastern part of the area is probably also of this date.

An interval of erosion, perhaps corresponding to the Lower Old-Red-Sandstone Period, followed, and then came the conglomerates of Upper Old-Red-Sandstone or Lower Carboniferous age, which are to be seen towards the eastern end of the peninsula at the lake side,[1] and of which a small remnant containing a block of coarse porphyrite is seen resting on the lime-bostonite west of Fox Hill.[2] If the dolerite intrusions, as seems probable, are of the same period as those of Tourmakeady, we may regard them as of post-Old-Red-Sandstone age. They are clearly later than the cross-faulting which shifted the outcrop of the Silurian rocks.

In conclusion, our sincerest thanks are tendered to Mr. F. R. Cowper Reed, M.A., for naming the great majority of our fossils; to Miss G. L. Elles, D.Sc., for examining the graptolites; to Dr. J. S. Flett, M.A., for much help in the examination of the igneous rocks; to Mr. Herbert H. Thomas, M.A., for the loan of rock-sections; and to Prof. G. A. J. Cole for 6-inch Ordnance Survey maps.

Appendix.

Note *on a new* Species *of* *Caryocaris* (*C. kilbridensis*) *from the* Arenig Rocks *of the* Kilbride Peninsula. By Henry Woodward, LL.D., F.R.S., V.P.Z.S., F.G.S.

Early in the present year I received from my friend Prof. S. H. Reynolds a very interesting little phyllopod crustacean obtained in the Arenig rocks of Kilbride (Mayo), with a request to subjoin a note upon it to the paper which Mr. Gardiner and he were reading to the Geological Society.

This form approaches the *Caryocaris wrightii* of Salter, a species which also occurs in shales of Arenig age on the Firth of Clyde and at many localities near Keswick (Cumberland), etc.[3]; but the carapace in *C. wrightii* is narrower in proportion and less arcuate on its ventral margin, while the posterior border is truncated and not produced into a latero-posterior spine as in the Kilbride example.

The Irish phyllocarid has both the impression and counterpart of the carapace preserved (both being marked by the authors as 55) and exposed on the surface of a rather coarse dark-brown shale, exhibiting a good side-view of the carapace and three caudal segments displaced and bent upwards dorsally.

The carapace is 25 millimetres in length, 5 mm. in depth at its anterior end, and increases to 10 mm. in depth near the posterior ventral border. The anterior margin is truncated, and its border is fringed by ten or twelve minute spines about 1 millimetre long directed forwards (resembling in appearance the oral cirri in

[1] These large masses of conglomerate are not demonstrably in place; but it is impossible to doubt that they are almost in position.

[2] This patch is too small to show in the map (Pl. VI).

[3] See T. R. Jones & H. Woodward, Monogr. Pal. Soc. pt. ii (1892) p. 89 & pl. xiv, cf. fig. 15 &c.

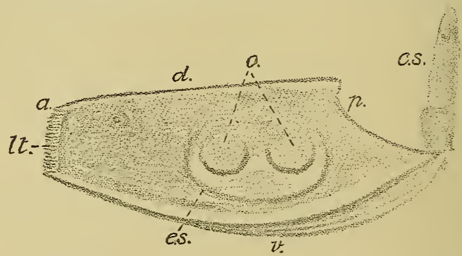
Amphioxus)—the longest being next the dorsal line of the carapace.

The dorsal margin is straight, and is 17 mm. long; its posterior margin is strongly incurved or emarginated, but produced backwards where it unites with the ventral border to form a strong projecting spine.

The ventral margin is 25 mm. long, and very arcuate, terminating posteriorly in an acute spine.

The caudal segments measure together about 15 mm. in length and lie close to the posterior margin, being displaced and bent upwards.

Fig. 3.—Caryocaris kilbridensis, *sp. nov.* (*Twice the natural size.*)



[*a* = Anterior border.
l t. = Labial tentacles or spines.
o = Ova.
d = Dorsal border.
v = Ventral border.
p = Posterior border.
e.s. = Ephippial shield.
c.s. = Three caudal segments.]

What appears to me to be of great interest in this specimen, is the presence, near the centre of the carapace, and evidently, as it seems to me, enclosed within it, at its broadest part, of two round bodies (each measuring about $2\frac{1}{2}$ mm. in diameter) which appear to be eggs, and may possibly be homologous with the pair of ephippial eggs, so often observed in *Daphnia*, especially protected to retain their vitality by their additional covering during the cold of winter—or when the water in which the parent lived had been dried up by evaporation, leaving the mud containing the eggs to solidify, and so remain imprisoned, until, after a more or less protracted period of drought, the arrival of the rainy season again sets them free—when the eggs are duly hatched out.

I may mention that, many years ago, I received by the favour of Mr. Clement Reid, F.R.S., a number of these small ephippia, which he had picked out of the ancient Freshwater Bed at Mundesley on the Norfolk coast, attesting the almost indestructible nature of these minute siliceous envelopes.

I have myself hatched out a number of these ephippial eggs sent to me which had been obtained from the dried-up mud of a stream in the Orange Free State, after some years' imprisonment in a dry box in the British Museum (Natural History).

The late Dr. W. Baird, in a similar manner, brought to life quite a number of Entomostraca from a sample of dried-up mud which

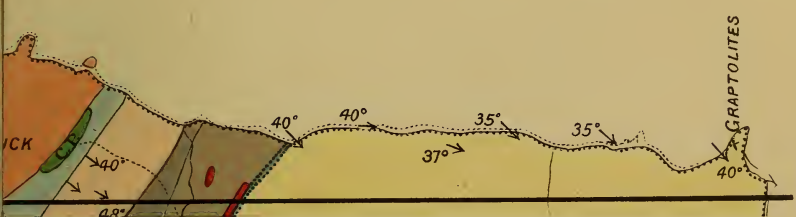
ƎEOLOGICAL MAP

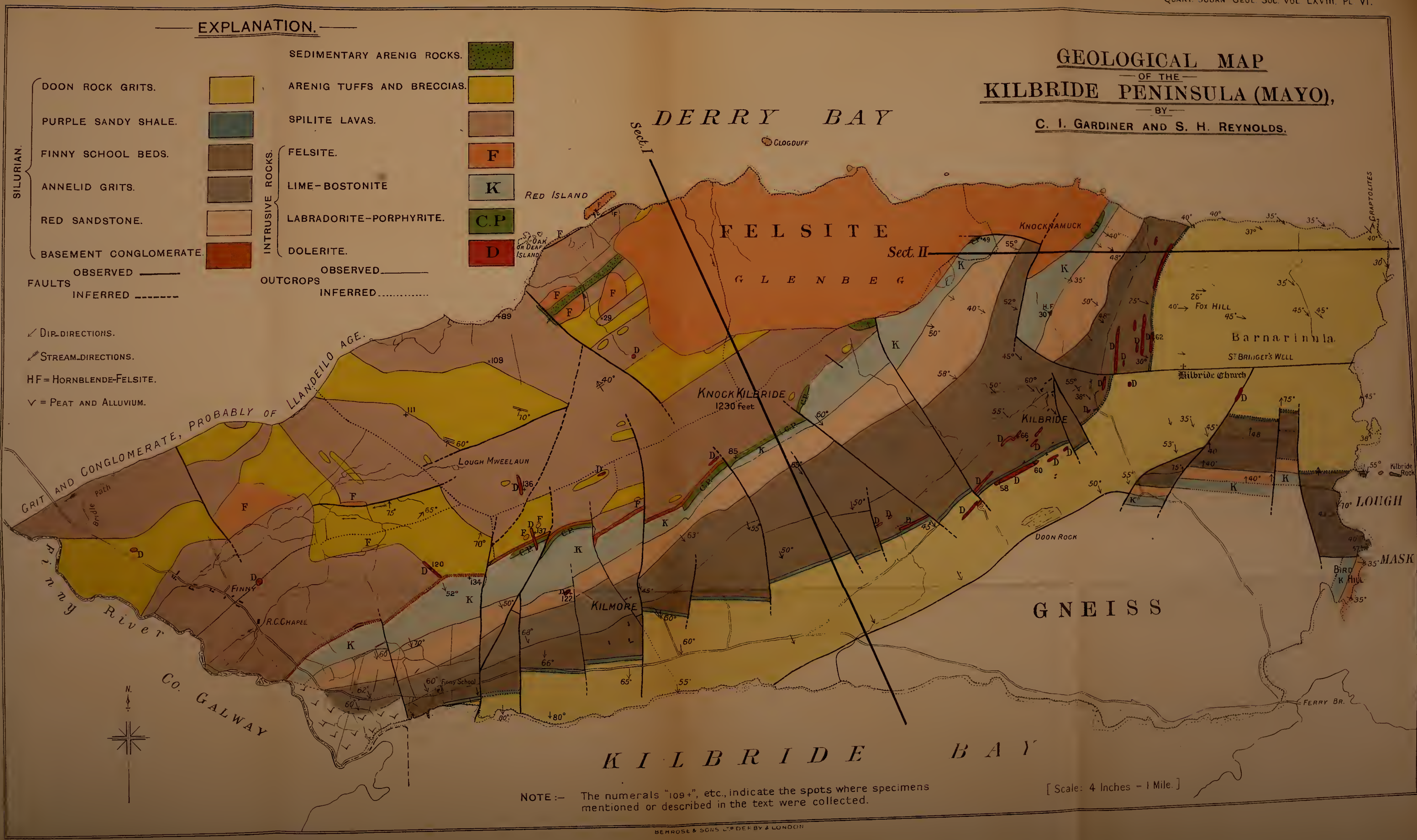
OF THE

IDE PENINSULA (MAYO),

BY

Gardiner and S. H. Reynolds.





GEOLOGICAL MAP
OF THE
KILBRIDE PENINSULA (MAYO),
BY
C. I. GARDINER AND S. H. REYNOLDS.
EXPLANATION.
SILURIAN.
DOON ROCK GRITS.
PURPLE SANDY SHALE.
FINNY SCHOOL BEDS.
ANNELID GRITS.
RED SANDSTONE.
BASEMENT CONGLOMERATE.
SEDIMENTARY ARENIG ROCKS.
ARENIG TUFFS AND BRECCIAS.
SPILITE LAVAS.
INTRUSIVE ROCKS.
FELSITE. F
LIME-BOSTONITE. K
LABRADORITE-PORPHYRITE. C.P
DOLERITE. D
FAULTS OBSERVED
FAULTS INFERRED
OUTCROPS OBSERVED
OUTCROPS INFERRED
Dip directions.
Stream directions.
HF = Hornblende-Felsite.
V = Peat and Alluvium.
DERRY BAY
Clogduff
Red Island
Oak or Deaf Island
Sect. I
Sect. II
FELSITE
GLENBEG
Knockramuck
Fox Hill
Barnarinnla
St. Brigget's Well
Kilbride Church
Graptolites
Knock Kilbride 1230 feet
Kilbride
Kilbride Rock
Lough Mweelaun
GRIT AND CONGLOMERATE, PROBABLY OF LLANDEILO AGE.
Bridle Path
Finny
R.C. Chapel
Finny River
Co. Galway
Finny School
Kilmore
Doon Rock
GNEISS
LOUGH MASK
Bird Hill
Ferry Br.
KILBRIDE BAY
N.
NOTE:— The numerals "109+", etc., indicate the spots where specimens mentioned or described in the text were collected.
[Scale: 4 Inches = 1 Mile.]
Bemrose & Sons Ltd Derby & London.

FIG. I.

SPILITE (PILLOW-LAVA), SHOWING THE CONCENTRIC ARRANGEMENT OF THE VESICLES IN REGARD TO THE MARGIN OF THE PILLOWS.

S.H. Reynolds, Photo.

FIG. 2.

CHERT, ASSOCIATED WITH SPILITE, IN THE FORM OF IRREGULAR STRINGS AND PATCHES.

S.H. Reynolds, Photo.

Bemrose Ltd, Collo., Derby.

had been sent to him by a friend from the deserted pool of Gihon, near Jerusalem.[1]

I believe this is the first ancient Phyllocarid in which traces of eggs have been observed within the bivalve shell of the parent. Eggs (in clusters) called *Parka decipiens* have been noticed with remains of *Pterygotus* in the Old Red Sandstone of Trimpley, north of Bewdley.[2]

The curious fringe of cirrus-like spines on the anterior (oral) border of the carapace has not, I believe, been before observed in any species of Phyllopod, and deserves especial notice.

I venture to designate this interesting Phyllocarid as *Caryocaris kilbridensis*, after the locality where it was discovered by Mr. Gardiner and Prof. Reynolds, to whose kindness I am indebted for the privilege of examining it.

EXPLANATION OF PLATES VI & VII.

Plate VI.

Geological map of the Kilbride Peninsula, on the scale of 4 inches to the mile or 1 : 15,840.

Plate VII.

Fig. 1. Spilite, showing the concentric arrangement of the vesicles in regard to the margins of the 'pillows.' (See p. 82.)

2. Chert, associated with spilite, in the form of irregular strings and patches. (See p. 82.)

Discussion.

The President (Prof. Watts) congratulated the Authors on this addition to the important series of papers which they had presented on the Palæozoic rocks of the West of Ireland. He enquired whether the *Trinucleus* said to occur in Silurian strata was not a derived form, and cited an analogous occurrence of *Trinucleus* in the Silurian of the Onny-River district of Shropshire, where it was undoubtedly derived.

Dr. A. Wade, after congratulating the Authors upon this further development in their very important work in the West of Ireland, said that the point of special interest to himself was the close parallel which existed between the succession of the beds, from the Llandovery Conglomerate to the base of the Wenlock, in this area and in the Welshpool District. This similarity became more marked when one considered the bostonite-like rocks intruded near the base of the Silurian. Some complex faulting made the position of the Welshpool Dyke somewhat obscure, but the speaker had come to the conclusion that it occupied a position very similar to that held by the keratophyres described by the Authors. The microscope slides and descriptions showed how closely the rocks resembled

[1] See Annals & Mag. Nat. Hist. ser. 3, vol. iv (1859) pp. 280–83 & pls. v–vi [*Estheria gihoni*, *Daphnia atkinsoni*, *Cypris celtica*, *C. orientalis*, & *Diaptomus similis*]; and in a second paper, *op. cit.* vol. viii (1861) pp. 209, 210 & pl. xii [*Branchipus eximius*].

[2] See H. Woodward, Monogr. on Merostomata, Pal. Soc. 1871, p. 79 & pl. xvi, figs. 10–11.

one another, the only difference being perhaps a little coarse texture in the case of the Welshpool bostonite.

It was a most unsatisfactory circumstance that, in practically every case where *Trinucleus* had been recorded from Silurian rocks, something was left open to doubt. Here it had turned up in a wall-fragment. It was, however, of such importance that he thought it would be very advisable for the Authors to give a separate list of the fossils associated with it in the fragment.

Dr. H. Lapworth said that he was interested in the comparison of the Llandovery rocks in the West with their equivalents in the North-East of Ireland. In the former region they appeared to be of the arenaceous type as developed at Llandovery itself, along the Welsh Borders, and in the Girvan area in Scotland; in the other region they were of the graptolitic-mudstone facies, as found in North-West Wales, the Lake District, and the Southern Scottish Uplands. With further work in Ireland and Wales, it would become possible to trace approximately the limits of the original deep-sea trough.

With reference to the Authors' geological map, he was struck by the amount of detail inserted along the faulted southern margin, and on what he assumed was a 6-inch plan. He would be interested to know whether the exposures were so numerous as to enable the Authors with certainty to develop the detailed structure shown.

Dr. J. V. Elsden called attention to the resemblance mentioned in the paper between the Kilbride keratophyre and the lime-bostonite described by him from Abercastle, in Pembrokeshire. From his examination of the specimens exhibited, he thought that, while there seemed to be points of similarity, there were also important differences. He would like to see a chemical analysis of the Kilbride rock. The felspar in this rock was described as albite, while that in the Abercastle variety seemed to be oligoclase. Referring to the general question of the nomenclature of these rocks, he had submitted specimens of the Abercastle rock to Prof. W. C. Brögger, who, while not denying its general mineralogical and chemical resemblance to the typical mænaite or lime-bostonite of the Gran district, was disposed to exclude the Abercastle specimen from that class on account of its associated rocks. In the speaker's opinion, however, the introduction of genetic affinities greatly increased the difficulties of rock-nomenclature.

Mr. C. I. Gardiner thanked the President and Fellows for the way in which they had received this communication. He assured them that the paper would include chemical analyses. As attention had been drawn to the large number of more or less parallel faults, which were seen on the 6-inch map to displace the Silurian strata, he pointed out that, owing to the fact that there was a red sandstone near the base and higher up in the series dark calcareous flags covered by purple shales, it was a comparatively easy matter to map in the faults represented, as the exposures were very numerous. The Authors were quite confident that the faults really existed as mapped.

7. Geology *of a* Part *of* Costa Rica.

By James Romanes, M.A., F.G.S., Christ's College, Cambridge. (Read December 6th, 1911.)

[Plates VIII & IX.]

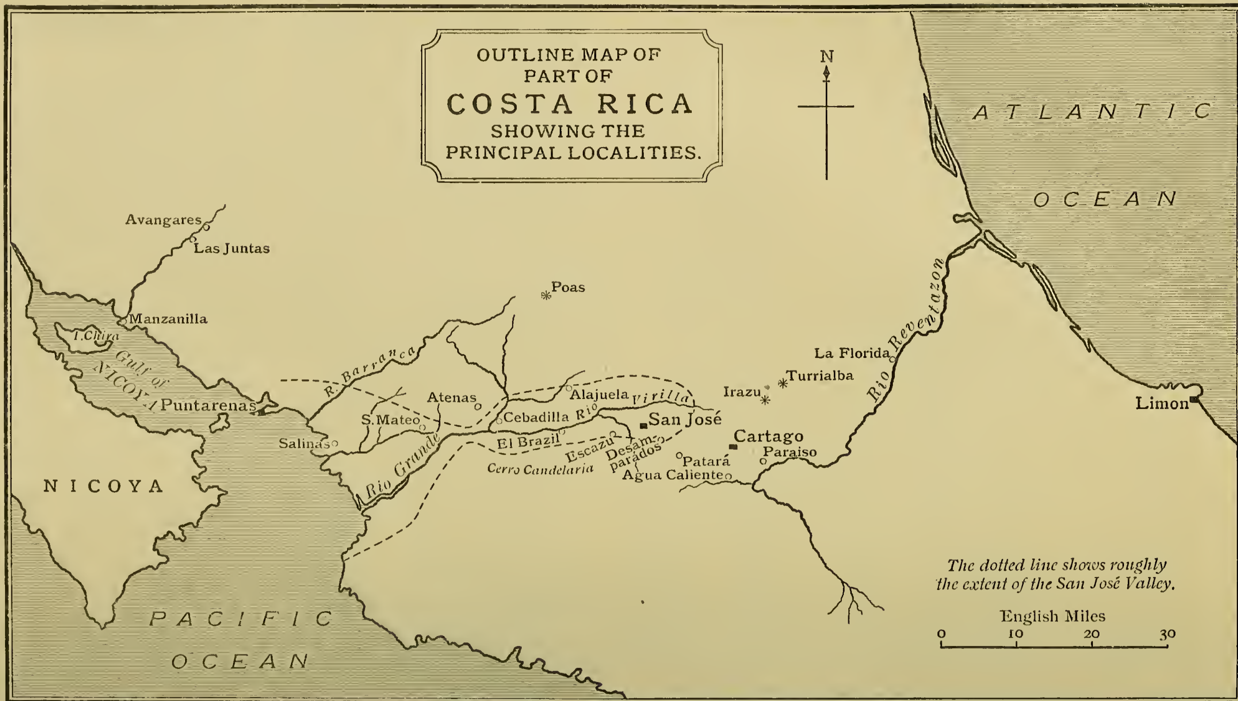
Contents.

I. Introduction.

At the suggestion of Mr. W. J. Le Lacheur, F.G.S., and Dr. J. E. Marr, F.R.S., and assisted by a grant from the Worts Fund, I undertook at the beginning of the year 1910 a journey to Costa Rica, with the view of studying the geology of parts of that country. Most of the time was spent on the Pacific slope, on which even less work of a detailed nature seems to have been done than on the Atlantic side. Towards the end of my visit I was able to devote a short time to certain parts of the Atlantic slope: unfortunately the box containing all the most important specimens from that area was lost in transit. The present paper, therefore, deals principally with the country lying to the west of San José, down to the Gulf of Nicoya.

In a region comparatively so little known geologically, and of which the maps are on a very small scale and not altogether reliable, detailed work in the three months which I had at my disposal was out of the question. Therefore, the account of my work which follows is not meant to represent any completed investigation, but simply a description of the formations and exposures met with, published in the hope that it may prove of use to future workers. I trust at some later date to be able to publish a more complete account of the palæontology of the fossiliferous deposits than appears in this paper, and to deal more fully with their bearing on the wider questions of Central American geology.

Fig. 1.—[*The asterisks indicate active volcanoes.*]



II. Previous Literature.

Reference has been made by many writers to Costa Rican geology; but, as might be expected, the literature is very scattered and difficult to trace. Many of the papers deal almost exclusively with the chain of recent volcanoes, a subject not dealt with in these pages; though I cannot claim to have been able to cover, in any sense completely, the previous writings on Costa Rican geology in general, it appears that comparatively few of these make direct reference to the part of the country which is about to be described, and, as this communication is essentially confined to descriptive work, the following list is restricted to those papers which have a direct bearing on the area in question. From this point of view the undermentioned are the most important papers:—

Attwood, G. 'The Geology of a Part of Costa Rica,' with appendix by W. H. Hudleston. Q. J. G. S. vol. xxxviii (1882) pp. 328–39.

Gabb, W. M. 'Notes on Costa Rica Geology' Am. Journ. Sci. ser. 3, vol. ix (1875) pp. 198–204, 320.

Sapper, K. 'Ueber Gebirgsbau & Boden des südlichen Mittelamerika' Peterm. Mitth. Ergänzungsb. xxxii (1906) No. 151, pp. i–vi, 1–82.

Church, G. E. 'Costa Rica' Geogr. Journ. vol. x (1897) pp. 56–84.

Hill, R. T. 'The Geological History of the Isthmus of Panama & Portions of Costa Rica' Bull. Mus. Comp. Zool. Harvard, vol. xxviii (1898) pp. 151–285.

It is unnecessary to give a synopsis of the work of the authors enumerated above, since throughout the following pages reference is made to their observations as occasion arises; while occasionally allusion is made to other memoirs dealing less directly with the subject under investigation. If there have been any omissions, which I am afraid may be the case, I can only trust that due allowance will be made for the difficulties encountered in dealing with so wide and varied a subject.

III. Geology of the Cerro Candelaria.

The Cerro Candelaria is the range of mountains forming the southern boundary of the wide valley[1] in which San José is situated. This range rises with surprising abruptness from the level floor of the valley to a height of some 3000 feet above it, while the general trend of the range in the San José area is east and west. These mountains are typical of the hill topography which characterizes the country. The slopes are steep, often culminating in almost vertical cliffs, while the sides of the mountains are scored by deep narrow ravines separated from each other by sharp saddle-ridges. The whole surface is thickly clothed in dense scrub, making it almost impossible to leave the recognized trails. The topography is precisely what would be expected during the early stages of denudation, when easily eroded rocks are exposed to rapid and often violent stream-action.

[1] For the sake of convenience, this valley will throughout these pages be termed the 'San José Valley'; as will be explained later, it is not a river-valley, and to refer to it as the 'Rio Grande Valley' might be misleading.

These mountains, situated almost in the centre of the isthmus, afford many interesting geological problems, since there is a considerable number of formations represented; and in them I have been able to trace marine sediments to a height of at least 6000 feet above sea-level.

From a study of the localities which I was able to visit, the geology may be divided into three main parts:—(*a*) The sediments; (*b*) the volcanic rocks; and (*c*) the plutonic rocks.

(*a*) The Sedimentary Series.

This may again be divided into two main groups, according to lithological character:—(i) Limestone, and (ii) marl and sandstone.

(i) The limestone is described by Mr. R. T. Hill as forming the foothills of the Cerro Candelaria (or Sierra Candella, as he calls this range) and is named by him the San Miguel Beds. From a somewhat brief description of its fauna he assigns it to the Cretaceous Period, saying that it provides the only example of rocks of this age throughout the isthmian region.

This limestone, which I shall term the San Miguel Limestone, apparently stretches continuously from the village of Patará (some 9 miles south-east of San José) eastwards to Agua Caliente, which lies about 2 miles south of Cartago, and thus crosses the Atlantic-Pacific watershed a few miles west of Cartago. Exposures are only to be found where the rock is being quarried, otherwise the formation is entirely concealed by vegetation. Good sections are to be seen in the quarries of Patará, Tres Rios, and Cartago. In these the limestone varies considerably in appearance, owing to the different degrees of alteration which it has undergone.

The least altered type is a hard, compact, bluish-grey limestone, with a considerable amount of impurity, and largely composed of fragmental organic remains the nature of which will be considered more fully on a subsequent page.

The Patará quarries furnish a good example of this type. In the lower of the two quarries the limestone is seen to be very much jointed, so that dip and strike are difficult to determine; but it seems to strike at about south 40° east, with a dip of 40° north-eastwards. The limestone itself shows considerable recrystallization, and slickensiding is seen not only along the joint-faces, but also in the internal structure. The effects of tropical weathering are well illustrated here. The limestone passes up into 8 or 10 feet of loose material, in general appearance rather like some parts of the Chalky Boulder Clay of Britain. The weathering first affects the rock along the joints, until only scattered fragments of the weathered limestone remain, and these finally disappear in the upper part of the clay. Another larger quarry may be seen a little higher up the hill; and here the limestone presents much the same appearance, but is perhaps a little more recrystallized and slickensided, while the strike is east and west with a southward dip of 65°.

Passing eastwards, the next sections are seen in the foot-hills immediately south of the town of Tres Rios. Here again there are two quarries, the one some 50 feet above the other, at an altitude of about 4200 feet above sea-level.

In the upper quarry the limestone is exactly similar in lithological character to that of Patará; but in the lower one it is totally recrystallized, and no trace of organic remains is visible. The dip and strike in the two cases are about the same (strike north 30° east, steep dip southwards), but the abrupt change in lithological character strongly suggests that a fault or thrust exists between them. The weathering of this limestone is curious; it is very impure, and so the leaching-out of the calcareous matter leaves a loose sandstone-like material which cannot be recognized as limestone, except by actually tracing the gradual change.

The same type of rock is found in several quarries at Agua Caliente, some 2 miles south of Cartago. Here, also, the limestone is almost completely recrystallized. At this place, as the name implies, there occur hot springs; these rise through the limestone, highly charged with calcareous matter which is deposited round them as sinter. The bedding of the rocks here is very clearly marked, the strike being north and south, with a gentle varying dip to the east. An examination of this rock under the microscope shows an impure crystalline limestone, with a very few traces of organic remains. The impurities consist of angular fragments of quartz and a few small crystals of plagioclase, together with numerous fragments of what appears to be a yellow volcanic glass, which in certain cases shows some devitrification; thus it is evident that, during the deposition of the limestone, volcanic action must have been in progress at no very great distance.

The exposures are too few and too wide apart to enable any opinion to be formed as yet, as to the general structure of the belt of limestone; but there can be no doubt that it is intensely crushed, folded, and faulted in such a way that the actual dip and strike observed in the few isolated exposures are probably of little value.

The limestone where not altered is richly fossiliferous, but rather by virtue of an extraordinary number of individuals than by a great variety of species.

As mentioned by Mr. R. T. Hill[1] the most conspicuous fossil is a large species of *Pecten*, which occurs in all the exposures where unaltered limestone is found. The larger specimens measure some 6 or 7 inches across; they are almost equivalve, and ornamented with strong and rather widely-separated ribs. A smaller species, averaging about 2·5 inches across, is also abundant; it has the ribs rather widely separated, as in the larger species, but is much more convex. Neither of these species have I been able as yet to identify with described species. These, together with some small specimens of *Ostrea*, are the only visible fossils in the lower Patará

[1] Bull. Mus. Comp. Zool. Harvard, vol. xxviii (1898) pp. 226–27.

quarry. In the upper quarry and at Tres Rios, however, the rock is seen to be largely composed of cirripede-remains. These agree with *Balanus*, both in external form and in the characteristic complex structure of the shell, as shown by a thin transverse section (see Pl. IX, fig. 1). In some specimens they are so crowded together that they have been forced to assume a polygonal outline; and, where they have been broken across by joints and weathered, the appearance almost suggests a very large compound coral possessing no internal structure.

The microscope also reveals numerous badly-preserved foraminifera, which in general form suggest *Orbitoides*, as also a few indeterminable corals. Mr. R. T. Hill records that, by polishing the limestone, it is seen to consist largely of *Inoceramus* and *Rudistes*, and therefore he calls it Cretaceous. An examination of a large number of specimens entirely fails to confirm this statement: the only structures that might suggest *Inoceramus* being the cross-sections of *Pecten*.

The occurrence of such vast numbers of *Balani* makes it extremely improbable that the rock could be pre-Tertiary, while a Tertiary age would be more in accordance with the idea of contemporaneous volcanic action to which reference was made above.

(ii) Marls and sandstones.—In his work on Central America, Dr. Sapper[1] mentions a sandstone apparently underlying the San Miguel Limestone, and records the impression of a *Pecten* in it; but this appears to be almost the only reference to sediments other than limestone in this area. I have been able to discover several different localities in which marls or sandstones are exposed; from two of these fossils have been obtained. As a general rule, there appears to be a belt of argillaceous and arenaceous rocks lying between the San Miguel Limestone and the level floor of the valley. The cart-track from the village of Patará to the limestone quarries passes over this belt, and several good roadside exposures are seen. The deposits here vary from a loose friable sandstone often stained bright red, to a very fine-grained pale-yellow marl, this latter being in places fairly fossiliferous. In all the exposures seen these rocks have been so affected by irregular jointing, that they are reduced to quite small angular fragments: this, together with a certain amount of staining by infiltration, has entirely obliterated the bedding, so that no definite clue can be obtained to the probable relation between these beds and the San Miguel Limestone, although it is more probable that they underlie than that they overlie the limestone.

The marl contains an assemblage of fossils entirely different from those of the limestone; there is a much more varied fauna, but, unfortunately, the fossils are very fragmentary and badly preserved: the genera *Pectunculus*, *Astarte*, *Arca*, and *Pyrula* are represented.

[1] Peterm. Mitth. Ergänzungsb. xxxii (1906) No. 151, p. 29.

The best development of the sandstone is seen along the road that winds up the hills from the village of El Higuito, a few miles to the west of San Miguel. Just above El Higuito, at a height of about 4000 feet above sea-level, sandstone begins to be exposed along the roadside; this is exactly similar to some of the Patará deposit. It is a fine-grained friable sandstone with an extraordinary range of bright colours—white, yellow, red, and brown being the commonest. The colouring imparts to the rock a very mottled and banded appearance and the colour-banding often shows a distinctly concentric form, corresponding with the type of weathering described by Mr. Hayes in Nicaragua,[1] and this has generally masked completely any bedding which may have originally been present. When the least evidence of bedding is visible, the beds appear to be highly contorted.

The sandstone is chiefly formed of extremely angular fragments of quartz, many of which show fresh fractures and no trace of subsequent rounding; along with the quartz-grains are fragments of felspar and devitrified volcanic glass. The cement is a red oxide of iron. This rock, while of undoubted marine origin, strongly suggests that deposition has been rapid, and that explosive volcanic action has taken part in the preparation of the material.

At an altitude of about 4500 feet a thin dark band of carbonaceous shale is interstratified with the sandstone. This band contains some very fragmentary plant-remains, and strikes north 70° east, dipping 70° south-eastwards. At a height of 5300 feet is a good cliff-exposure by the roadside; here the rock has rather a different character, resembling nothing so much as a badly-burnt gault-brick, with much brown iron-staining along the joint-faces. This exposure has yielded some fossils, namely, casts of *Pecten*. The species is much smaller than that from the San Miguel Limestone, measuring only about 3 inches across. Still higher, at 5500 feet, occurs a much-jointed band of very fine, compact, dark grit, about 50 feet thick.

In a small stream a short distance below this, I found a fragment of this rock on which was the cast of a small *Pecten*. From this point right up to the watershed (6300 feet) the only rock exposed in place is the sandstone, with the exception of a very decomposed greenish tuff at the altitude of 5800 feet, which appeared to be horizontally bedded.

The sandstone is thus continuously exposed on this road through a vertical height of some 2300 feet; but it is, of course, quite impossible to give any estimate of its true thickness. A remarkable feature of this traverse is that not a trace of the San Miguel Limestone is encountered, and I was unable to obtain any evidence as to where its outcrop lies west of Patará.

Passing now to Tres Rios, somewhat similar deposits are seen in the roadside sections below the limestone-quarries. Immediately

[1] C. W. Hayes, Bull. Geol. Soc. Amer. vol. x (1899) p. 325.

below the quarries the road cuts through a pale sandstone precisely similar to that described above. A short distance farther down a deep-yellow marl is exposed, showing very clear bedding (strike east and west; dip 45° northwards).

This deposit yielded no fossils, but exhibited a very remarkable resemblance to a yellow marl, to be mentioned later, in the gorge of the Rio Virilla at El Brazil. Lying on the top of the road-embankment here was a huge rectangular mass of quartzite, about 10 feet square and some 2 feet thick. It was quite unrounded, and had probably suffered little transport.

(*b*) The Igneous Rocks.

Exposures of igneous rocks are not plentiful in the Cerro Candelaria, and those that do occur are by no means easily accessible. I was able, however, to collect a number of boulders, some of which cannot have travelled far, and a study of these gives a very fair indication of the rock-types which a more detailed examination of the range may eventually reveal.

The most interesting rocks are the plutonic types, and, so far as I am aware, these have never been previously described. In the village of Escazu, about 4 miles south-west of San José, there are several large boulders lying by the roadside. These must weigh several tons each, and consist of an even, coarse-grained, grey, syenitic rock. The same type of rock is found in the gravels of the Tiribi at Anonas, and farther down the valley in the gravels of the Rio Virilla at El Brazil. As plutonic rocks are of very rare occurrence in the sierras of Costa Rica, a rather full description of these will perhaps not be unwelcome.

The Escazu boulders.—The hand-specimen shows a coarse-grained, even-textured, plutonic rock of a greenish-grey colour. Upon examination with a lens, it is seen to consist largely of felspar, together with brown biotite and some augite. The felspar is partly fresh and colourless, and partly stained and pale yellow. The fresh felspar shows very distinct albite-twinning, while the biotite occurs in characteristic lustrous brown plates. Under the microscope the rock is seen to consist of quartz, felspar, augite, and biotite, together with several accessory minerals. The structure is coarse, but many of the felspars have too pronounced a lath shape for the true granitic structure. Free quartz is present, though in small quantity; it forms small irregular grains with minute liquid inclusions. The bulk of the rock is made up of felspar, two kinds being present. The most plentiful is a plagioclase in well-formed lath-shaped crystals showing very narrow twin lamellæ on the albite law, and in some cases pericline-twinning also. The extinction-angle measured from the twin plane is 16°, while the refractive index is higher than that of quartz, showing the felspar to be andesine. It is quite fresh, and free from any products of decomposition. The other felspar is orthoclase, which is present in considerable quantity. It is much more decomposed than the andesine, and has crystallized at a later stage, so that it tends to form large plates completely or partly enclosing the lath-shaped plagioclase-crystals. The ferromagnesian minerals are represented by biotite and augite. The former is of a rich brown colour, and intensely pleochroic. The augite is colourless, and usually builds very irregular crystals; although in a few cases more or less idiomorphic individuals are present. The biotite and augite have crystallized almost simultaneously, either together with or just after the andesine. The accessory minerals are apatite and magnetite.

This rock shows a most striking similarity to the typical monzonite of Monzoni, both in structure and in component minerals; in particular the relationship between the orthoclase and the plagioclase is identical with that which characterizes the type-rock (see Pl. IX, fig. 2).

Boulders from Anonas.—These vary to a certain extent in texture and mineralogical composition. They are slightly more basic in character, but all show the same monzonitic structure as those already described.

All these types indicate a very close genetic relationship, and might well have come from a single plutonic mass. There can be little doubt that this mass must be exposed in the hills somewhere above Escazu: probably at no great distance, to judge by the very large size of the Escazu boulders; while there is no agent except water-action to account for their transport.

A few specimens which I obtained from the Cerro Candelaria strongly suggest, from their petrographical character, a hypabyssal origin. About a quarter of a mile below the village of Patará on the San José road, is a small exposure of rock which I think is practically in place, although there are no other exposures near it to indicate its relation to anything else. The fresh rock is green and rather fine-grained, and weathers almost pure white. A microscopic examination of this rock shows at once that it is of extreme interest, as it is clearly allied to the plutonic rocks. In mineralogical content and in structure it is similar to the normal monzonites, but the texture is very much finer, and the rock might well be named a micromonzonite. The plagioclase is oligoclase, quite fresh and undecomposed. The orthoclase, as in the plutonic type, is rather turbid and of later crystallization, partly enclosing the plagioclase. A considerable quantity of free quartz occurs interstitially to the felspar. The ferromagnesian mineral is a pale green augite, in small more or less idiomorphic grains, sometimes showing slight pleochroism. Magnetite is abundant, and a little apatite is present. This rock is distinctly more acid than the plutonic types, as regards both the plagioclase and the amount of free quartz, and it seems probable that it may be of the nature of an aplitic modification of the normal monzonite.

Another type which strongly suggests a hypabyssal origin occurs as numerous boulders, in a small stream which crosses the road above El Higuito. In the hand-specimen it is a dark rock, in which felspar, augite, and pyrites may be easily distinguished. It is a typical olivine-dolerite, the olivine being represented by pseudomorphs of carbonates. A curious feature of this rock is the occurrence of pyrites in interstitial patches, often partly enclosing the lath-shaped crystals of labradorite; this pyrites has been apparently the last mineral to crystallize. This may, of course, be secondary; but, if so, it is difficult to see what is replaced, and there is no evidence in the slice of such an alteration having taken place.

The volcanic rocks which I obtained from the Cerro Candelaria do not show any points of special interest. The majority are the ordinary pyroxene-andesites so common in other parts of the country. For convenience, the following description is given as typical of the great majority of the pyroxene-andesites of the country; subsequent descriptions will, as far as possible, only refer to the more important variations from this type. The andesitic lavas are generally rather dark, often mottled, and more or less vesicular. The hand-specimens show well-formed crystals of plagioclase and pyroxene in a fine ground-mass. Under the microscope the felspar is seen to be labradorite, which builds large tabular crystals generally strongly zoned and showing both albite and Carlsbad twinning. The pyroxene is mainly augite, colourless to pale green, and often with complex twinning. Some rhombic pyroxene (hypersthene or enstatite) is occasionally present. The ground-mass consists of small lath-shaped crystals of labradorite, and granules of augite and magnetite in a glassy base. In those under consideration a little red biotite is often present as an accessory mineral, together with magnetite and pyrites. In certain cases the structure is more of a doleritic type, the ground-mass being a holocrystalline aggregate of minute lath-shaped felspars. In one specimen of this type glomeroporphyritic structure is well marked; the rock contains aggregates of felspar-crystals showing distinct plutonic structure. The felspar in these cases is principally orthoclase. In the same specimen there is a curious secondary deposit of quartz and hornblende, the former containing long needles of the hornblende.

In a stream-section above Escazu are some very thick beds of an almost black fine-grained rock; in the hand-specimen are seen a few fragments of felspar and a little pyrites in a structureless ground-mass. A microscopic examination of the rock shows that it consists of broken crystals of felspar and some pyrites in a fine matrix of felspar and magnetite-dust. The felspar, which is absolutely fresh, is chiefly orthoclase, with Carlsbad twinning, and some plagioclase. The rock is undoubtedly a fine-grained volcanic tuff, and such rocks probably have a wide distribution in these mountains, as many of the boulders in the streams appear to be of a similar nature.

IV. Cartago and the San José Valley.

The drainage-system of the Rio Grande and its tributary streams stretches from El Alto, some 10 miles east of San José, almost due westwards to the Pacific Ocean. The Cartago area drained by the head-waters of the Rio Reventazon, and therefore belonging to the Atlantic slope, presents, however, such close similarity to the topography of the San José Valley that they are most conveniently considered together. The topography is very striking, and shows much the same features for a considerable distance on either side of the watershed. A brief description of the San José Valley will give some idea of the main points. On the south this valley is bounded by the Cerro Candelaria, and on the north by the great chain of recent volcanoes, Poas, Irazu, etc. Between these two chains is a vast valley, which at San José cannot be less than 12 or 14 miles wide. It is remarkable for its extraordinarily smooth flat surface; it is, in fact, a great plain dipping gently to the west as far as Atenas, where the Cerro Candelaria and the Aguacate Hills converge, and between these the Rio Grande flows in a magnificent gorge. On the south the mountains rise with surprising abruptness from the floor of the valley, presenting almost the appearance of a mountainous coast-line rising from the sea. The northern boundary of the valley is very different; the ground rises at first almost imperceptibly from the valley, the slope gradually increasing to culminate in the magnificent range of active volcanoes.

Between Alajuela and San José, however, this even grade is broken by an abrupt escarpment 300 or 400 feet high, which forms a great terrace along the lower slopes of the volcanoes. Various writers [1] have regarded this and other similar terraces as due to the former existence of large lakes, while Dr. Sapper [2] has put forward a totally different theory to account for this feature. He regards the San José Valley as having been partly filled up by material coming from the recent volcanoes on the north, which spread southwards and was banked up against the Cerro Candelaria; he supposes that, during periods of volcanic quiescence, river-action has cut down the general level of the surface, leaving a steep terrace on the north side of the valley. He sums up by saying that it is the same action on a very large scale as that which causes the formation of river-terraces in alluvial deposits. This seems to involve river-erosion on a scale altogether disproportionate to the possibilities of the case; and at present the effect of river-action is not to lower appreciably the general surface-level, but to cut deep vertical gorges with but little evidence of lateral erosion. I was not able to examine this terrace in any detail; but, from the general appearance, I should like to suggest the possibility of its being a fault-scarp. Considering the immense amount of material which has been rejected by these

[1] G. Attwood, *op. cit.* p. 332; R. T. Hill, *op. cit.* pp. 225–26.
[2] Zeitschr. Deutsch. Geol. Gesellsch. vol. liii (1901) p. 28.

recent volcanoes, a certain amount of subsidence in their vicinity might well be expected, and in the absence of any detailed and accurate observations on this well-marked feature, this seems to be the most plausible explanation (see fig. 2).

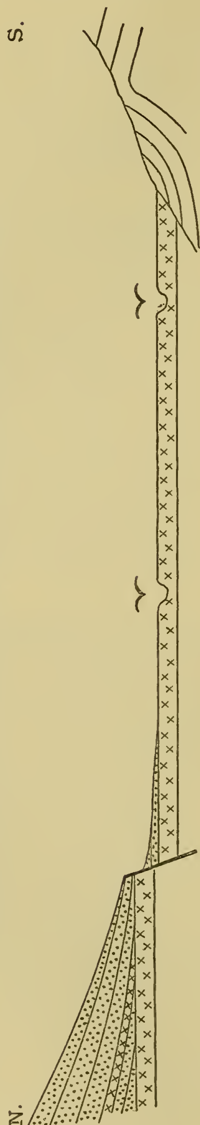


Fig. 2.—*Diagrammatic section from the slopes of Barba across the San José Valley to the Cerro Candelaria, showing the formation of the terrace by means of an east-and-west fault.*

The valley between the two above-mentioned mountain-ranges is drained by the Rio Grande and its numerous tributaries. These rivers all flow in deep gorges, which often have almost perpendicular sides. The result is, that in a general view of the area from any of the high ground surrounding it, the rivers are quite invisible; and the general effect is that of a huge waterless valley sloping gently to the west. Exposures in an area such as this are naturally not very plentiful; but some idea of the geological structure is obtained from a study of the river-gorges, where there are some very fine exposures. In every case the surface of the ground seems to be occupied by a lava-flow or flows of great extent, and it is only well to the west of San José that any deposits under the lavas are exposed. It is in this area that Mr. R. T. Hill[1] describes the occurrence of 'bolsons' or old lake-basins: one at Cartago, another at San José, and a third at Alajuela. The Cartago bolson is especially well marked, and the ground there is evidently a great alluvial flat. These lakes must have been caused by inequalities in the surface-lavas forming dams across the valley, and giving rise to large but shallow sheets of water. These would have but a brief existence, as they would be rapidly silted up by the volcanic ash and mud brought down from the volcanoes, giving rise to flat alluvial tracts covered by redeposited volcanic ash, and such appears to be the case in these areas.

The evidence of a lava-dam is clearest in the instance of the Cartago area. At the eastern end of that bolson the ground is covered by huge boulders of lava, which are worked for building-stone under the name of 'Cartago Granite.' These seem to have been generally regarded as transported

[1] Bull. Mus. Comp. Zool. Harvard, vol. xxviii (1898) p. 225.

masses, but I think that the evidence is against this supposition. An examination of a large number of the boulders showed an extraordinary similarity in lithological character. The only difference that can be observed is, that while some are grey, others are of a dull red: now, if any collection of transported boulders is examined, for example, in the river-gravels, one of the most striking facts is the great range in character of the rocks. Even when most of them are petrographically similar, the range in colour and texture is very great, and consequently it is difficult to understand why the Cartago boulders, if transported, should show so little variation in character. I have no doubt whatever that these huge boulders represent a single lava-flow, which has weathered out in place; and I believe that it was this lava-flow which dammed back the water to form the Cartago lake. Similar collections of boulders produced in the same way may be seen on the surface in several places west of San José, often forming distinct hummocks.

I shall now pass on to a more or less detailed description of the rocks met with in the area under consideration.

(*a*) Cartago.

The rocks collected near Cartago are mainly from the large boulders which have been mentioned above. The most plentiful are those used for building purposes. The rock is grey or dull purple, very rough to the touch, and exhibits a pronounced vesicular structure and a slight banding due to the parallelism of the felspar-phenocrysts. They differ mainly from the type described (see p. 112) in containing corroded crystals of deep red biotite, while the augite is quite subordinate to the hypersthene. Glomeroporphyritic structure is well developed, consisting of aggregates of felspar and hypersthene, which simulate a fine-grained norite.

Rocks collected about 2 miles west of Cartago, though of the same andesitic character, show some well-marked differences. They are hornblende-bearing andesites. The hornblende is of a rich brown colour, strongly pleochroic with a dark resorption-border. A very little fresh olivine is present. The most curious feature of these rocks is the occurrence of numerous pseudomorphs after some ferromagnesian mineral. These have generally a border of magnetite, while fibres of magnetite sometimes extend inwards at right angles to the external edges. The mineral composing them is colourless, with a high refractive index, strong double refraction, and shows no cleavage. The form of these pseudomorphs suggests original hornblende, but the absence of cleavage is against this. The probability is that they represent original olivine, replaced by a mineral of the nature of iddingsite.

About 2 miles west of Cartago is a small quarry, on one of the slopes rising from the alluvial flat. The rock here exposed is decomposed almost beyond recognition, but it contains in parts much microcrystalline silica; it is probably a silicified volcanic ash, and may belong to the Cerro Candelaria series.

(*b*) San José.

A good exposure of the recent lavas is seen in the gorge of the Rio Virilla about 4 miles north of San José, where that river is crossed by the Alajuela Railway. The gorge of the river is here some 50 feet deep with vertical sides, and for about a quarter of a mile down-stream there are more or less continuous exposures of lavas which show in the hand-specimens a considerable variation in structure and colour. The rock exposed directly below the railway-bridge is darkish, and has a mottled appearance; it corresponds exactly with the type, except for the absence of rhombic pyroxene. The other lavas of this gorge are petrographically very closely allied to the above, but many are highly vesicular.

About 2 miles west of San José the lavas are again well exposed in the Rio Tiribi, at the Anonas Power-Station of the San José Electric Light Company. Here they belong to a type very different from those in the Rio Virilla, as they are practically non-porphyritic, and all show a very markedly banded structure; thin purple and black lamellæ alternate in a highly contorted fashion, evidently a complex flow-structure. In places bands of a curious breccia are intercalated with the lavas; but, as these breccias are much better developed at El Brazil, the description of them will be deferred to a later page. A microscopic examination of these lavas is rather disappointing, as they show extremely little structure. They are largely glassy, consisting of minute slender crystals of felspar, magnetite dust, and a brown micaceous mineral set in a glassy ground-mass. This brown mineral, which undoubtedly is closely allied to biotite, is scattered plentifully throughout all the slides examined; it often assumes a spherulitic structure, and its general appearance strongly suggests a secondary origin. In composition these rocks probably differ little from the normal andesites.

A similar rock may be obtained from a roadside exposure just below Escazu.

(*c*) El Brazil.

El Brazil, where a new power-station is being erected for the Electric Light Company, is on the Rio Virilla, immediately below the junction of that river with the Rio Oruca, and lies about 7 miles south-west of San José. The river is here flowing in a deep gorge which cuts right through the lava-flow and down into the underlying sediments, and as this locality is just at the foot of the Cerro Candelaria, I was able to see very clearly how the lava-flow terminates against the rising ground.

The geology here may be divided into two main parts: (i) The overlying lava, and (ii) the underlying sediments.

(i) The l a v a - f l o w shows several points of interest. In the first place, it has the appearance of a single great flow, possibly some 200 feet thick, and, unlike the previously described cases, it presents extreme uniformity throughout.

The upper surface forms the level plain of the San José valley, which stretches away eastwards to the range of recent volcanoes. The lower surface of the lava is extremely uneven, in places it is 70 or 80 feet above the bed of the river, while at other points the gorge has failed to cut through it. The relation of the lava to the sediments appears to be that of a great flow which has buried the lower spurs of the Cerro Candelaria, filling up the valleys between them with a solid mass of lava. The present river is now cutting down through these buried spurs. Petrographically, the lava here differs but slightly from those which are exposed in the Rio Virilla north of San José. It is a typical augite-andesite. A noticeable feature about this rock is the very well-marked glomero-porphyritic structure, which forms patches wherein augite and felspar show subophitic intergrowth, and produce a coarse doleritic structure.

The lava-flow itself presents some curious features, especially as regards the types of jointing. One of these types is well seen in the cliff over which the cataract falls some distance below the intake-station. The lava here occurs in great concentric shells, due to a circular type of jointing, the diameter of the outer shells being as much as 30 to 40 feet (see Pl. VIII, fig. 1). This structure I believe to consist rather of concentric cylinders than of spheres. Unfortunately, it is not possible to investigate this exposure closely; but, so far as can be seen, the lava appears to be perfectly fresh, and the concentric structure is not due to the spheroidal weathering which such a structure might naturally suggest in a tropical climate. Associated with this structure is a deposit which, at first sight, looks like a river-gravel interbedded with the lava. This, however, on closer examination is seen to consist entirely of rounded masses of a very vesicular lava with little or no matrix; this I take to represent the scoriaceous surface of the lava-flow broken up and modified by incorporation in the flow when part thereof was still liquid.

It is a fact worthy of record that these scoriaceous intercalations always occur in close proximity to the places where the lava shows the most fantastic jointing. These intercalations must be due to a sort of over-rolling of the lava, and this might well have given rise to circular flow-lines which on cooling have determined the formation of this remarkable structure.

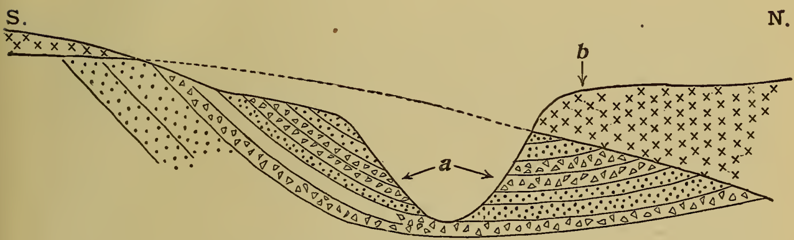
Another noticeable type of jointing consists of a kind of horizontal columnar structure, and this causes the lava to protrude from the sides of the gorge in great bunches of massive blades. These blades are roughly square in cross-section and generally taper to one end. Along with this kind of jointing the scoriaceous intercalations are also found. This type of fragmental deposit is also recorded from the Rio Tiribi, at Anonas, and from the lavas exposed in the Rio Avangares just below the gold-mines.

(ii) Sedimentary deposits of El Brazil.—In this area are several good exposures of sediments which are seen to underlie the lava-flow. They all exhibit a very shallow-water character, and in many cases are richly fossiliferous. A few exposures are visible in the river-banks between the cataract and the lower end of the pipe-line. At the junction of the creek and the main river is an exposure of some fine conglomerate, striking north 70° west and dipping 35° southwards. I did not see any fossils *in situ* in this deposit; but some large boulders of the same type, containing fragments of *Pecten*, may be seen in the river-bed. The rock has a general purple colour, with in places a white calcitic matrix. Many boulders more richly fossiliferous also occur in the river-bed, and these evidently come from a point some 80 yards farther up stream where similar rocks are seen practically in place. The exposure, owing to landslides, is, however, very bad, and dip and strike are not determinable. These rocks are of a distinctly greenish colour and much finer-grained than the conglomerates. Lithologically they are volcanic ashes, and in a slice much of the rock is seen to consist of fresh basic plagioclase, together with devitrified glass and an indeterminate fine-textured matrix. These deposits are crowded with fairly well preserved Pectens which are evidently closely allied to the smaller type of *Pecten* in the San Miguel Limestone.

At the intake station the sedimentary rocks are much better exposed, occurring on both sides of the river. The dip here is about 15° northwards, but this when the beds are traced down stream soon falls off to 2° or 3°. The lowest bed seen is a massive, grey, volcanic agglomerate, containing a few highly carbonized wood-fragments. The constituents of this rock are considerably decomposed; it contains numerous broken crystals of a fairly acid plagioclase, together with many angular fragments of a felsitic character. Above this comes about 20 feet of well-bedded fossiliferous ash. This rock is of a bright green colour, and consists of broken felspar-crystals and the felsitic fragments noted above. Fossils are rare, and occur principally in the lowest bed exposed. They are mostly small and rather badly-preserved gasteropods, while scattered through these beds occur many fragments of wood; but these are quite carbonized and show no structure. Overlying the ashes is another coarse agglomerate, always extremely weathered. These bedded ashes, when traced down stream, disappear below the lava-flow about 200 yards below the intake-station, and the lava comes right down to the level of the river. The actual junction of the two is obscured by river-gravel, the lowest part of the lava-flow visible being a scoriaceous volcanic conglomerate, and above this the lava shows the remarkable 'bladed' jointing mentioned above. As we ascend the south side of the gorge, we find the coarse agglomerate overlain by a fine olive-yellow marl, which in lithological character corresponds exactly with the yellow marls of Tres Rios. An important point is that the northward dips are found to increase rapidly to about 30°, when followed southwards from the river.

One other exposure is worthy of record. The road down the creek to the lower end of the tunnel cuts through some fossiliferous deposits. These are highly-weathered ashes of a deep rusty brown, and contain a considerable amount of iron and phosphate. The dip here is 30° northwards, which carries the beds underground; but, if this dip be continued, they ought to be exposed again near the bottom of the gorge; and so they are probably the same as the fossiliferous ashes which crop out along the river. The most characteristic fossil of this weathered bed is a *Pecten* which Mr. R. B. Newton has kindly examined; he says that it is very closely allied to *P. hemphilli* Gabb. It is also somewhat similar to the casts of *Pecten* obtained from the marl above El Higuito.

Fig. 3.—*Section across the gorge of the Rio Virilla at El Brazil, showing the probable relation of the fossiliferous ashes to the lava-flow.*



[*a*=Fossiliferous ashes; *b*=Lava.]

The general succession of the El Brazil beds appears to be as follows:—

Lava-flow.
Yellow marls, comparable with those of Tres Rios.
Coarse weathered agglomerate.
Fossiliferous ashes.
Massive agglomerate.

On the north side of the river-gorge, opposite the intake-station, the sedimentary rocks can be seen cropping out horizontally under the lava-cap, which is here very thin, but thickens rapidly on either side. There can be no doubt that these sediments formed a spur of the Cerro Candelaria, which has been buried under the lava-flow and subsequently dissected by river-erosion. Detailed work here would probably throw some valuable light on the succession in the Cerro Candelaria, as it is the only example of a dissected spur that I saw, although no doubt others occur in less accessible places. The rapid increase of dip in the beds, as they are traced southwards from the river, is probably a very significant fact. It suggests, at any rate, that the San José Valley consists of a series of almost horizontal Tertiary sediments (marine ashes) overlain by lava, and that southwards they pass laterally into a region of intense folding, of which the Cerro Candelaria forms the northern part.

(*d*) Cebadilla.

This locality lies some 25 miles west of San José, on the Rio Grande. A very short distance to the west the San José Valley narrows to a magnificent gorge, with the Cerro Candelaria on the south and the Aguacate Hills on the north. At Cebadilla the river flows in a deep gorge, which affords a splendid section right through the great lava-flow. Unfortunately, no Tertiary or older sediments are exposed below the lava, but there is instead a thick deposit of river-sands and gravels; and obviously the river is here re-excavating its old course, instead of cutting through a spur of the mountains—as it is doing at El Brazil. The rocks exposed in the Cebadilla gorge fall naturally into the following succession:—

(3) Lava-flow.
(2) River-sands and gravels.
(1) 'Bed-rock' or older volcanic series.

(1) The older volcanic rocks are exposed in but a few places along the river-bed. They almost certainly form part of the volcanic complex of the Aguacate Hills, through which the old river cut its valley and subsequently laid down its gravels and sands. These volcanic rocks have been very considerably weathered, but their andesitic character is still clearly visible.

Some bands of this series have originally been highly vesicular, and these vesicles have been subsequently infilled with calcite and cryptocrystalline silica, the latter often showing beautiful spherulitic structure. All these rocks have been very largely replaced by calcite, and no trace of ferromagnesian minerals remains. The lavas are traversed by several small dykes averaging about 3 feet in width, and having a general east-and-west trend; but this is very variable, as folding has evidently taken place subsequently to their intrusion. These dykes are petrographically indistinguishable from some of the lavas through which they have been intruded. The series illustrates well the rapidity of tropical weathering: during the dry season the surface for 2 or 3 inches becomes quite soft and friable, and this layer is entirely removed during the floods—leaving a fresh surface to be attacked.

The surface of this old valley-floor is very uneven, and when a road was cut along the side of the river several peaks were encountered rising up into the overlying deposits. At the junction of the Rio Virilla with the Rio Grande, where the river-level is about 200 feet lower than at Cebadilla, the bed-rock extends about 50 feet above the present river-level, so that the grade of the old valley appears to have been less steep than that of the present Rio Grande.

(2) The sands and gravels.—Resting upon the irregularly eroded surface of the bed-rock is a great series of river-deposits, which vary from a coarse conglomerate (containing blocks 3 or 4 feet in diameter) to a thinly-bedded river-sand or silt. The thickness of this series naturally varies somewhat, but it attains a maximum

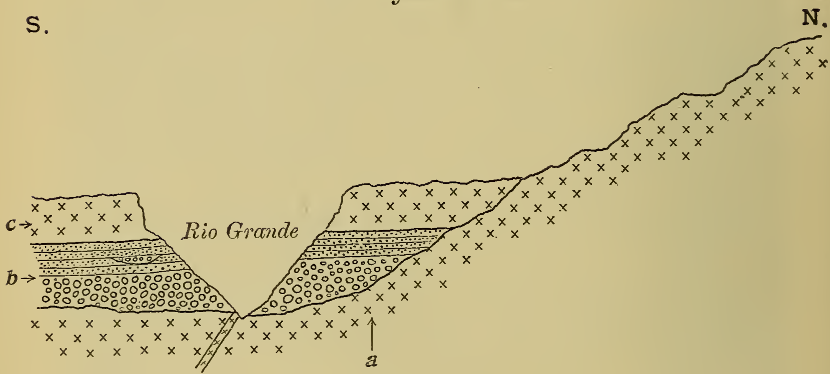
of about 100 feet. The lower part of the series is almost entirely conglomeratic, and a tunnel connecting bends of the river is driven for 1000 yards entirely through this coarse conglomerate. The boulders are subangular to rounded, and even in the coarsest parts there are distinct traces of horizontal bedding. The boulders are entirely volcanic rocks, chiefly dark, basic porphyritic andesites; the majority are compact, but a few are highly vesicular. In this basal portion, which is about 50 feet thick, the boulders are practically in contact, with just a little clayey sand filling the interstices between them. Above the conglomerate comes a thick bed of sand, which shows good horizontal bedding and rests upon a very uneven surface of the conglomerate. In places the sand immediately after deposition has evidently been scooped out by strong current-action, and the resulting hollow has been filled up by conglomerate. These finer deposits show slight, but only slight, traces of false-bedding, and they consist of much purer quartz-sand than the matrix of the conglomerates. Numerous fragments of wood are embedded in these accumulations, especially when the arenaceous facies is replaced by a more clayey one. For example, about half-way down the pipe-line the deposit has almost the consistency of Gault, and from this quite large roots and other plant-remains can be obtained; in this locality a large spur of the older volcanic series rises into the conglomerate which rapidly thins out against it.

In the gorge of the Rio Alajuela, about a mile above its junction with the Rio Grande, the same general structure may be seen, but here the detrital deposits are of an entirely different character. The thickness of the deposits is about the same as at Cebadilla, but boulders are comparatively rare and so far as can be seen perfectly angular, although owing to the steepness of the gorge a close inspection is impossible: the great mass seemed to consist of a fine-grained sandy clay which showed only the merest traces of bedding. It certainly appeared to me that in this section the deposits are of the nature of old mudslides rather than true river-deposits, and correspond on a larger scale to similar patches in the 'boulder-clay' of the Rio Reventazon which are clearly due to landslides: these are referred to in § VI, on the 'Boulder Clays of Costa Rica' (see p. 134).

(3) The lava-flow.—Cebadilla provides another section through the great lava-flow, but petrographically the rocks here are very different from the typical andesite. The lava forms a great escarpment at the top of the Rio-Grande gorge, and the average thickness exposed cannot be less than 150 feet. The upper surface, as usual, forms the floor of the San José Valley, and on the surface are many large boulders which probably represent the weathering-out in place of part of the lava. The actual junction of the lava with the underlying sands is exposed on the side of a small track, which leads northwards from the works towards the intake-station. The igneous rock here is very dark and quite compact; a curious

feature of the junction is, that although the loose sand is baked and bleached to a depth of 18 inches, the sand itself is quite undisturbed by the overlying lava. A slice of this basal portion of the lava shows it to be almost entirely glassy, with a few small phenocrysts and some small rock-fragments which were evidently incorporated by the lava while still fluid. The glass which comprises the bulk of the rock is of a peculiar and distinctive purple colour, contains a considerable amount of indeterminate opaque dust, and shows extraordinarily complex flow-structure. Enclosed in this glass are small crystals of very fresh labradorite, often corroded and containing glass inclusions. Ferromagnesian minerals are represented by a few, very small, colourless crystals of enstatite, together with a little brown biotite. The included fragments are either glass, or consist of a dark andesitic rock with felspar-microliths.

Fig. 4.—*Section through the Rio Grande gorge at Cebadilla to the Aguacate Hills.*



[*a*=Older volcanic rocks of the Aguacate Series; *b*=Old river-gravels and sands; *c*=Recent lavas.]

Above this basal modification comes the main mass of the lava, which generally shows well-marked columnar structure and weathers brown where exposed to the atmosphere. The rock presents a very heterogeneous appearance, quite different from the ordinary andesites of the country.

The matrix is dark grey, with many small and glassy-looking plagioclase-crystals. Scattered through the rock are dark masses and streaks of a very brittle black glass, which impart to the rock a slightly banded appearance: on a weathered surface very intricate flow-structure is seen, although on a fresh surface not a trace of this can be made out. On the whole, the macroscopic characters of the rock are much more like those of a tuff than those of a true lava; but I have no doubt that this rock is really a lava, though certainly a very highly brecciated one.

Under the microscope the character of the rock is clearly seen: the chief constituent is the purple glass, which forms the basal portion of the flow: it is present in large irregular fragments which may be distinguished one from the other by slight colour-differences. These fragments of glass are singularly free from any crystals; only very occasionally are labradorite or enstatite found embedded in them. The rest of the rock consists of a crushed mass of glass in which are embedded crystals, often broken, of labradorite, augite, and rhombic pyroxene. In addition to these occur fragments of more normal andesites, which have been picked up by the lava while still molten.

Another good section of the lava is seen in the gorge of the Rio Alajuela, a short distance above the junction of that stream with the Rio Grande, where it overlies the old mudslides previously mentioned. The rock here is of the brecciated type, and contains intercalations of volcanic conglomerates exactly similar to those that occur at El Brazil. The lava is also well exposed in the Rio Virilla near its junction with the Rio Grande, and here it shows beautiful columnar structure. This peculiar brecciated type of lava has also been found in the lower part of the gorge at Anonas, and again near the bridge over the Rio Virilla, on the road between San José and Escazu.

Westwards from Cebadilla, as mentioned before, the San José Valley narrows between the northern and the southern mountain-ranges. In places, however, patches of the old level surface of the valley may be seen as broken terraces along the side of the gorge. Still farther west the valley opens out again, into what Mr. R. T. Hill speaks of as 'the San Mateo peneplain'; and this appears to slope gradually down with no abrupt change of level to the top of the cliffs along the Pacific coast, which attain heights of 100 to 200 feet. As far as is known, this plain, to within a short distance of the sea, is occupied by lavas and ashes; but time did not permit me to investigate any of this area, except the part right down on the coast.

V. The Pacific Coast.

(*a*) Barranca.

In this and the following paragraphs attention will be confined to a description of the rocks exposed in the localities visited, the general description of the coastal topography being left for a later section. The coast-line south-eastwards from the mouth of the Rio Barranca provides many good exposures of rocks, which form bold headlands and sea-cliffs. These are most typically seen on that part of the coast where the new railway is taken along the shore, close to the headland known as the Carballo. Here the cliff presents a vertical face over 100 feet high, and in it are exposed a great variety of sediments many of which are richly fossiliferous.

These vary from rocks presenting the appearance of a fine purple mudstone to a fairly coarse ashy sandstone, and were recorded by the late Mr. Attwood, and petrographically described by the late Mr. Hudleston[1] as consisting largely of kaolinized soda-felspar. The finer-grained types have a striking resemblance to some of the deposits at El Brazil. The strata forming the Carballo are striking north and south, and have a gentle dip of 10° eastwards. The same series is well exposed at the mouth of the Rio Barranca, on the south side in natural cliffs and on the north side in a new railway-cutting. The strata here have the same dip and strike as at the Carballo, and within a very small radius show an extraordinary variety in appearance. On both banks of the river the rock is of a brilliant yellow-white speckled colour, often mottled with vivid red owing to iron-staining. When these beds are followed south-eastwards along the shore, it is found that in 50 yards they have changed to a friable fossiliferous ash, and in another 100 yards to a very compact, greenish, shelly deposit, all this taking place without the least break of any sort. The fauna of these beds shows the same peculiarity, the dominant forms changing rapidly from place to place: all of which points strongly to these beds being of an extremely shallow-water character.

On the road from Barranca Bridge to the camp at Barranca Tunnel are several exposures of these sediments rising from the alluvial flats of the river. These show, again, considerable diversity of lithological character along this road. The dip and strike vary greatly from place to place. In the first exposure the strike is west 20° north, dip 30° southwards; about a quarter of a mile farther on the strike is east and west, with a dip of 20° southwards. In this latter exposure the upper bed is a coarse brown ash, showing remarkably clear spheroidal weathering; below this comes a thin intercalation of shale overlying a coarse greenish ash. At the mouth of the tunnel the strata are striking north 50° east and dipping 80° northwards. Nowhere is any violent folding to be seen, and so probably the beds are much faulted, giving rise to block structure on a small scale.

Petrology of the Barranca sediments.—All these different types of deposits have one important feature in common. They are all ashes, but with different texture and composition which determine their appearance and special mode of weathering. Specimens from the very pale beds at the mouth of the Barranca appear in a slice to consist largely of fragments of chert, or at least some form of cryptocrystalline silica, set in an earthy or ferruginous matrix. Broken crystals of felspar and quartz are present, but are by no means common in this type. Many of the siliceous fragments contain irregular patches of calcite, and so they may perhaps represent silicified limestone. These ashes contain some badly preserved specimens of *Globigerina*.

[1] In G. Attwood, Q. J. G. S. vol. xxxviii (1882) p. 339.

Good examples of the coarser and darker types were obtained in a very fresh condition from the Barranca tunnel. The coarsest type consists very largely of slightly-rounded, dark-green, isotropic grains. These sometimes contain small lath-shaped crystals of labradorite, and appear to be a very dark volcanic glass somewhat decomposed. This forms the bulk of the rock, but isolated crystals of labradorite and augite are fairly plentiful. The matrix is calcareous, and has recrystallized into large crystals of clear calcite which enclose the grains in pœcilitic fashion.

A rather finer type from the same locality shows a much larger proportion of plagioclase and augite-crystals, along with fragments of cryptocrystalline silica and glass. This type of rock is fairly rich in small foraminifera, and has yielded *Globigerina*, *Rotalia*, and *Orbulina*.

The finest types, which have the appearance of mudstones and are generally by far the most fossiliferous, consist of the same aggregate of minerals in a much finer state of division.

These fossiliferous beds can be traced for only a short distance inland, and they are soon replaced by a coarse, unfossiliferous, and unstratified volcanic agglomerate, which contains in places enormous blocks of volcanic rocks. These agglomerates are well seen in the numerous cuttings along the new railway between Cascajal and Cambalache, and in no case have any traces of organic remains been observed in them.

One of the commonest and most characteristic fossils in the Barranca deposits is a species of *Venus*, which appears to be identical with *V. meridionalis*, recorded by Charles Darwin from Patagonia. It is also closely related to *V. walli*, from the Lower Miocene of Trinidad, and to *V. ebergenyii* Bœse, recorded from the Pliocene of Mexico. The following list gives approximate identifications of the dominant fossils from these beds:—

Mactrinula macescens Guppy.
Dosinia cf. *orbicularis* Edw.
Clementia dariena Conrad.
Turritella cf. *gatunensis* Conrad.
Pyrula reticulata Lam.
Solarium cf. *villarelloi* Bœse.
Arca sp.

This assemblage points to a Miocene age for these beds, and they may easily prove to be more or less contemporaneous with some of the fossiliferous ashes farther inland.

(*b*) The Avangares Mines—Manzanilla.

The gold-mining district of Avangares lies on the south-western borders of a vast expanse of volcanic rocks which stretches unbroken eastwards to the Aguacate Hills and from there is probably continued across the Rio Grande as the Cerro Candelaria.

Igneous rocks.—The lavas in this district show little difference from the andesites so common all over the country, and to describe them in detail without careful mapping would involve useless repetition. The majority are basic pyroxene-andesites, some containing only augite, while others carry hypersthene in addition. Some of these rocks appear to form large dykes, as, for example, a very dark rock, collected at the 10th-level tunnel, which forms a great band some 400 feet wide apparently cutting through the other lavas; however, even where the field-relations of the rocks show them to be hypabyssal, the microstructure is essentially volcanic. Many of these lavas show very perfect columnar structure, as, for example, on the banks of the Rio Avangares about half a mile below the mines. I noticed here intercalations of the same volcanic conglomerate as that which has been recorded from El Brazil and Anonas. The boulders forming the conglomerate are of a very vesicular augite-hypersthene-andesite, the vesicle being in almost every case lined with a thin coating of a brightly polarizing mineral, showing the initial stages of infilling.

There is one type of lava from Avangares which merits description, as it is quite unlike any other lava that I have seen in the country. The specimen was collected from a large angular block in the railway-cutting between Avangares and the Boston Mine; and, although it was unfortunately not in place, it cannot have been transported far. In the hand-specimen the rock is of a bluish-green colour, with well-formed black crystals of hornblende scattered through it. The ground-mass is cryptocrystalline or glassy, and has undergone some silicification and calcification. The felspar is labradorite in large porphyritic crystals, showing considerable alteration along the cleavage-lines; this has gone on in certain cases to such an extent that merely isolated unaltered kernels of felspar remain. Hornblende is well developed; this specimen, together with one to be described later, forming a conglomerate at Manzanilla (see p. 130), and the boulders from Cartago (see p. 115) comprise the only hornblendic rocks that I have collected in Costa Rica. The hornblende in this lava is olive-green, with sometimes a brownish tinge; it shows well-developed prismatic cleavage and strong pleochroism: the extinction-angle is about 12°.

A short distance north of the mines coarse volcanic agglomerates are largely developed. These are very compact, greyish-green, and contain large angular fragments of lava. Little or no bedding is visible, and they probably represent the site of one of the vents through which the lavas and ashes were erupted.

The auriferous quartz-veins in this district have a general parallelism, striking about north 20° to 30° east. Many of them occur along lines of intense brecciation, and some of the veins represent crush-bands recemented by quartz, so that fragments of the 'country-rock' are scattered right through the vein. A slice cut from a specimen of the very rich Tres Hermanos vein shows the quartz to be in a microcrystalline or cryptocrystalline state: along with the quartz very numerous small crystals of pyrites are visible; these latter carry the gold. The formation of these veins probably represents a final phase of the igneous action, and in the case of at least one vein warm mineral waters are still coming up through the partly-filled fissure.

Weathering in the Avangares area.—The weathering of the lavas in this district shows some special features. In all cases, as would be expected in a tropical climate, a large amount of surface-weathering is evident, giving rise in its final phase to brown clays. Below this weathered crust, however, the igneous rocks are remarkably fresh. In other cases, a very different type of alteration has affected the rocks. This decomposition has apparently gone on throughout great masses of rock, and is just as complete many feet below the surface as near it. These rocks are represented by material which, though quite soft and friable enough to be dug with a spade, yet retains very perfectly the structure of the original lava. The colour is greyish, and betrays none of that brown staining which is never absent when oxidation has played any part in the alteration.

This is strongly suggestive of something more than mere surface-weathering, and it is much more probably due to some type of pneumatolytic action which affected the rocks in question soon after their consolidation: it may well represent another phase of the aqueo-igneous action which led to the formation of the auriferous veins. In this connexion an exposure on the southern bank of the Rio Avangares just above the mines may be recorded where a rock has been somewhat similarly acted on, and in it is seen a large amount of well-crystallized calcite, while the rock is impregnated with iron and a greenish-blue mineral of a chloritic character.

Ashes and sediments.—Between the Avangares Mines and the coast of the Gulf of Nicoya is a comparatively low-lying coastal belt of country occupied by a series of well-bedded ashy sediments, which are fossiliferous in certain places; these I have termed the Manzanilla Beds. They are well exposed at Manzanilla on the coast, and it is only at this place that fossils have as yet been found in them. As will be mentioned later, many of these deposits are composed entirely of volcanic débris, but in other cases non-volcanic material contributes largely to their composition; and, as they lie in an area so well marked off from the volcanic region, I have considered it best to treat them separately. The junction of the volcanic series and the Manzanilla Beds is seen in the banks of the Rio Avangares behind the village of Las Juntas. The actual junction is extremely complex and difficult to make out in any detail, as the sediments are much broken up; and, owing to surface-weathering, it is not always easy to distinguish the lavas from the ashes. Along with the fracturing there is slight faulting; on the whole, the evidence points to the existence of a zone of much-fractured sediments, slightly baked, and more or less impregnated with strings and veins of igneous rock: these are, therefore, rather of the nature of shallow intrusions than actual surface lava-flows. At Las Juntas the strike of these beds is south 70° east, with a very gentle dip (5°) eastwards. They are all very pale, white or grey, and very well bedded, the bedding-planes in most cases being only a few inches apart. They vary considerably in texture, the finer bands having the appearance of a white marl, while in the coarser varieties they are somewhat like a medium-grained friable sandstone. In this district these stratified rocks consist almost entirely of volcanic débris, without any trace of organic remains. The coarser bands are formed principally of broken crystals of a very fresh labradorite, which shows the usual zonary banding. A few crystals of green hornblende and colourless augite are present, together with numerous dark-green fragments, apparently of hornblende altered to chlorite. In places are small pieces of the cherty material which occurs so plentifully in the ashes of Barranca, while pyrites and magnetite are plentiful. The ground-mass of the ash consists of minute fragments of the above minerals and glass; but sometimes a considerable quantity of calcium carbonate has come in, forming a more or less calcareous matrix. The lithological character of the finer bands is almost identical with that of the coarser varieties, but calcareous matter is entirely absent.

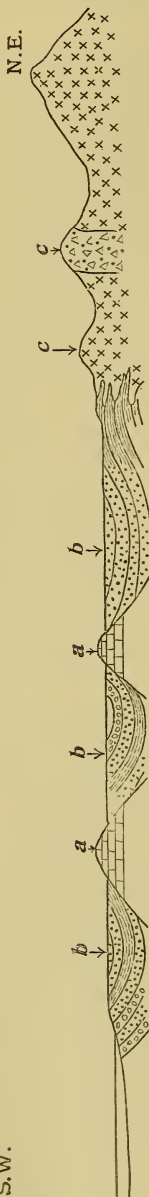


Fig. 5.—*Diagrammatic section from the Gulf of Nicoya to the Avangares Mines.*

[*a*=Older limestones; *b*=Manzanilla Series; *c*=Lavas, agglomerates, etc.]

Before proceeding to a consideration of the coastal belt, a brief description of the topography is necessary. The country immediately round the Avangares mines is typical Costa Rican mountain-scenery. The rivers flow in deep valleys with steep sides, from which rise high precipitous mountains, all clothed with rich vegetation; on these slopes landslides play a very important part in aiding denudation.

Standing on the higher ground above the mines, and looking south-westwards to the Gulf of Nicoya, the observer sees the lower slopes of the volcanic hills in the foreground; beyond is a broad level plain, the general surface of which is 150 to 200 feet above sea-level. A very striking feature of this landscape is the presence of several hills which rise sharply and suddenly out of the plain, exactly like islands dotted over the surface of a sea; these are of no great height, probably reaching some 400 or 500 feet above the general level. They at once suggest the peaks of an older landscape, buried by later deposits. Beyond the plain stretch the waters of the Gulf of Nicoya, with the high mountainous peninsula of Nicoya forming the background.

A traverse across this country from the mines to the coast reveals some points of interest, although the nature of the ground prevents detailed observation during a single journey. As might be expected, it is impossible to realize the existence of the plain when actually crossing it, for it is everywhere deeply cut into by rivers and streams, while the dense forest-growth shuts off any distant view. For the first half of the journey, the total distance of which is about 14 miles, the few exposures seen are certainly in the Manzanilla Beds, the deposits being very similar to those described at Las Juntas, though somewhat darker. Dips and strikes noted were, first, east 30° south, dip 15° northwards; and farther west the strike was east 50° south, and the dip 25° northwards. Approximately half-way to the coast strikingly different rocks are encountered. These consist of very fine, compact, cream-coloured limestones. So far as can be seen, they occur on the lower slopes of the hills which rise from the plain, and it is highly probable that these hills are formed entirely of limestone or at least of rocks belonging to the same series as the limestone. In these rocks are preserved numerous organic remains, especially foraminifera belonging to *Rotalia* and allied genera, together with some badly-preserved corals and calcareous algæ of the nature of Nullipores.

An interesting feature is the occurrence of some felspar and fragments of cryptocrystalline silica, giving evidence of contemporaneous volcanic action.

Somewhat farther west, beside some native huts, rises a low mound composed of a very dark, basic, igneous rock. This is a limburgite entirely free from felspar, and is a type which I believe has never before been recorded from Central America. In the hand-specimen the rock is dark green, owing to the serpentine; while grains of fresh olivine may be seen, and numerous bronzy crystals of rhombic pyroxene are visible. The rock has originally been composed of roughly equal quantities of olivine and enstatite, with a comparatively small amount of glassy ground-mass which is crowded with small crystals of augite, enstatite, and magnetite. The olivine, which forms large rounded crystals, has been largely serpentinized; and only in places are fresh grains of olivine seen scattered through the serpentine pseudomorphs (see Pl. IX, fig. 3).

Many rounded patches of colourless or pale-green serpentine are present, which seem to represent infilled vesicles. The rhombic pyroxene builds tabular or lath-shaped crystals which show well-developed prismatic cleavage, with extinction parallel to this. The colour is very pale pink, but no pleochroism can be seen. The ground-mass has undergone very considerable alteration and become completely devitrified. Dr. Bonney very kindly examined this rock, and has pointed out the strong resemblance which this ground-mass bears to the mineral pseudophite described by both Dr. Teall[1] and the late J. D. Dana[2] as forming a special alteration-product of felspar. The residual glass had, therefore, probably the composition of felspar or may even have largely consisted of minute felspar-crystals.

What the relations of this limburgite are to the Manzanilla Series it is impossible as yet to say, but I strongly suspect that it belongs to the older limestone series and has no connexion whatever with the andesitic lavas of Avangares.

Passing on now to the actual coast-line, the stratified rocks are extremely well exposed at Manzanilla, both on the foreshore and as low cliffs. They differ markedly from those at Las Juntas, as regards both texture and components. The beds crop out roughly parallel to the coast, strike east 20° south, and dip 65° northwards: they vary from coarse conglomerates to fine greenish ashes. The conglomerate contains a large and varied collection of boulders, generally subangular to rounded, and it is at once noticed, both in these and in the finer-grained types, that non-volcanic material plays a much more important part than in the ashes at Las Juntas.

In the conglomerates boulders of limestone are common, and this limestone is very similar indeed to that collected *in situ* farther inland. The main difference is that in the boulders the structure is slightly more crystalline, and the rock contains more numerous foraminifera and calcareous algæ, although these are unfortunately rather badly preserved. I am strongly of opinion, however, that the two limestones belong to the same series, and that during the deposition of the Manzanilla Beds hills of the limestone were undergoing denudation. Smaller pebbles of jaspers and cherts of various colours form a common constituent. A curious type is a dark compact rock, which has the appearance of a quartzite, but under the microscope strongly suggests a silicified limestone. Together with the typical augite-andesites there occurs a coarse ophitic hornblende-dolerite.

Turning now to the finer-grained deposits, these are found to vary from an extremely hard compact breccia (see Pl. IX, fig. 4) to a fine ashy mudstone. They are composed of subangular fragments of many different rocks, set in a matrix partly siliceous but consisting mainly of recrystallized calcite. Volcanic débris is not plentiful, some pieces of andesite and crystals of felspar and augite being all that can be seen. The commonest component is chert, and in many cases traces of radiolaria are distinctly visible in it. Quartz is but sparingly present. The rocks at Manzanilla contain an undoubted marine fauna: foraminiferal remains include *Globigerina* and a larger

[1] 'British Petrography' 1888, p. 107.
[2] 'System of Mineralogy' 6th ed. (1892) p. 652.

complex form allied to *Tinoporus*.[1] The other fossils are extremely badly preserved, being mainly much-crushed fragments of small gasteropods and lamellibranchs.

As regards the source of the material that forms the Manzanilla Series, it is difficult to base any definite conclusion on the rather scanty evidence at present available. Even the data collected give rise to contradictory evidence: on the one hand, the purely volcanic nature of the material and the angularity of the fragments in the deposits at Las Juntas suggest that here we are close to the volcanoes which gave rise to the deposits: in support of this must be taken into account the fossiliferous nature of the deposits at Manzanilla, the evidence which they give of considerable rounding by water-action, and the admixture of non-volcanic material. On the other hand, the apparent increase of coarseness of the material as we trace the beds westwards from Las Juntas seems to point to the source of the material having lain to the west. On the whole, I am of opinion that the material has not been derived from a simple source, but has been fed in from many different directions and that the conglomerates are a local facies dependent on the proximity of large, or at least torrential, streams.

The Manzanilla Series appears to correspond very closely with the Brito Series described by Mr. Hayes[2] from Nicaragua. According to this author, the material forming the Brito Series was derived from some volcanic range lying to the west of the present Pacific shore-line; such a range of mountains may well have supplied much of the material now forming the Manzanilla Series. Although, as yet, no direct palæontological evidence can be given as to the age of this series, the great similarity of many of the rock-types to those described at Barranca and their similar mode of occurrence make it more than likely that they will eventually prove to be contemporaneous.

The geology in this area seems to indicate three distinct periods of movement, and its history must have been more or less as follows:—

(1) Uplift of the older limestones.
(2) Denudation of these and formation of the Manzanilla Series.
(3) Uplift and folding of the Manzanilla Series.
(4) Base-levelling of the folded beds.
(5) Final uplift of a few hundred feet, initiating the raised coastal peneplain.

(*c*) Gulf of Nicoya.

The Gulf of Nicoya is a large stretch of very shallow water which extends from north-west to south-east, opening into the sea in the latter direction. On the north-east it is bounded by the mainland of Costa Rica, and on the south-west by the peninsula of Nicoya.

[1] Dr. R. L. Sherlock has very kindly examined some of the slides, and informs me that this foraminifer is most probably a species of *Orbitoides*.
[2] Bull. Geol. Soc. Amer. vol. x (1899) p. 309.

In length it is about 40 miles, and it has an average width of 10 miles. It may, I think, be taken as a very fair example of the type of topography characteristic of the Pacific coast of Central America. A glance at any map of this part of Central America shows a very striking difference between the coast-lines of the two oceans. The Atlantic shore-line is characterized by the long, smooth, sweeping curves so typical of a recently uplifted coast, and that this uplift has taken place is proved by the numerous raised coral-reefs which form a conspicuous feature round Limon. The Pacific coast, on the other hand, shows none of these characters; it is very much more irregular, with large peninsulas and bays, the most striking examples being the Gulf of Nicoya and the Golfo Dulce: these suggest at once that the main factor in the formation of the Pacific shore-line has been submergence instead of elevation. An examination of the coast-line in detail leads to the same conclusion.

There is no continuous belt of coastal swamp, such as is present on the Atlantic shores, but instead there is a succession of bold rocky headlands separated by curved sandy bays. These headlands are the seaward termination of the mountain-ranges of the interior. On the south-eastern coast of Nicoya these ridges may easily be traced for a considerable distance out into the gulf as a series of rocky islets.

That some considerable time has elapsed since this drowning took place is evident from the fact that the original form and size of the Gulf has been much modified by recent deposits. Two main types of these may be noted: in the first place, there are large deposits of beautifully clean quartzose sand; while Puntarenas itself, as the name implies, is built on a sand-spit. This latter is about 2 miles long, only a few hundred yards wide, and nowhere more than 15 to 20 feet above high-water mark. The recurved form of the point is very well marked, and the formation of this spit of sand is without doubt due to the strong tidal currents which prevail in the Gulf. Of much greater extent and importance, however, are the deposits formed by the fine alluvial mud which many of the rivers are continuously bringing down in great quantity, even in the dry season. In this way many large areas have been completely silted up, giving rise to flat alluvial land and mangrove swamps, the effect being to lessen to a great extent the irregularities in the coast-line due to the submergence.

Before the accumulation of this alluvium Nicoya can only have been connected to the mainland by a narrow isthmus, as the Rio Tempisqui is tidal for a very long way above its mouth and flows through mangrove swamps and alluvial flats. The whole of the lower part of this valley must, therefore, have originally been a long narrow area of the Gulf of Nicoya running approximately north-west and south-east. A very fine example of a completely silted bay is to be observed at Salinas (see Pl. VIII, fig. 2), a short distance south-west of Puntarenas. The old shore-lines can be very clearly seen in this case, rising abruptly from the wide expanse of alluvial flat which stretches a long distance inland. The coastal topography in this area corresponds, to a really remarkable extent, with the description given by Mr. Hayes[1] of the coastline farther north-west in Nicaragua. He describes the same phase of submergence followed by much 'alluviation,' which has considerably modified the original outlines.

VI. The 'Boulder Clays' of Costa Rica.

Of the surface-deposits existing in the country, the most interesting are certainly the so-called 'Boulder Clays,' which occur often to a very considerable depth, both on the Atlantic and on the Pacific slopes.

The occurrence of deposits similar to the Boulder Clays of Great Britain in Nicaragua was described in considerable detail by Thomas Belt.[2] He unhesitatingly ascribed to these a glacial origin. Similar deposits in Costa Rica are recorded by Mr. R. T. Hill,[3] who puts forward a theory that all these deposits have been formed by the rolling of material from the steep slopes of the volcanoes down into the valley. The large fragments of rock are supposed to become rounded in the process, while the finer material is weathered and forms the matrix. Having had a good opportunity of seeing these deposits both on the Atlantic and on the Pacific slopes, I find it impossible to agree with either of the theories mentioned above. As regards the first, nowhere did I see the least trace of glacial action, nor anything to suggest it, beyond the similarity of the deposits to Boulder Clay. The second theory, that of R. T. Hill, quite fails to explain the observed facts, as regards both the character of the matrix and boulders and the mode of occurrence of the deposits as a whole. His theory may partly explain the nature of the agents in certain local examples; in those cases, however, on which he lays great stress, not only have I been unable to find any evidence in favour of his theory, but there is direct and indisputable evidence against it.

So far as my experience goes, the formation of these Boulder Clays cannot be ascribed to one cause alone, but several processes must be taken into account. These may be classified under three headings, in order of their relative importance :—

(1) Torrential deposits;
(2) Landslides and scree-deposits;
(3) Spheroidal weathering and rearrangement by percolating water.

Taking the most important first, namely, torrential action, deposits thus formed are best seen on the Pacific side in the gorge of the Rio Grande at Cebadilla, and on the Atlantic side along the valley of the Rio Reventazon from Paraiso to the coastal plain. Those of the Rio Grande gorge have already been described in full

[1] Bull. Geol. Soc. Amer. vol. x (1899) pp. 289–93, 339–40.
[2] 'The Naturalist in Nicaragua' London, 1874, pp. 259–64.
[3] Bull. Mus. Comp. Zool. Harvard, vol. xxviii (1898) p. 223.

detail in the pages dealing with that area (see pp. 120–21). The most important points in this connexion are (i) the bedding, very clearly shown in the sands: in fact, in the finest deposits it is lamination rather than stratification, and this bedding is apparent even in the coarse conglomerates; (ii) the extremely rounded and waterworn condition of the boulders. There can be no doubt that these are normal river-deposits, laid down prior to the out-pouring of the lavas of the San José Valley.

Passing on now to the deposits of the Rio Reventazon, we find that in general character they are similar to those of the Rio Grande. They differ slightly, however, in being almost entirely conglomeratic, without the thick interbedded sands which are so conspicuous a feature in the section exposed at Cebadilla. The deposits of the Rio Reventazon, as a rule, consist of very well-rounded boulders up to several feet in diameter, embedded in a sandy matrix and showing little stratification.

At one place, however, in a railway-cutting about 2 miles above La Florida, occurs a band of well-bedded sand about 18 inches thick, intercalated with the conglomerate. This band strikes east and west, and dips at an angle of 15° northwards.

In places the rock-fragments are angular, and show no trace of water-action. This is probably due to local land-slides having added material to the river-deposits. The boulders are almost exclusively composed of volcanic rocks. The Rio Reventazon has cut deeply into these deposits, so that at La Florida a thickness of about 200 feet is exposed above the present river-level. This deposit forms a very well-marked, though fragmental, terrace throughout a large part of the valley of the Reventazon. That this terrace is formed of the 'Boulder Clay' is well shown at La Florida, although the actual deposits are obscured by vegetation. The rise from the river is very abrupt; but at a height of about 200 feet above the river a level bench is reached, with numerous large well-rounded boulders scattered over it. Beyond this the ground rises again, but no trace of waterworn stones is seen at any higher level, so that the 'Boulder Clay' obviously formed the terrace. At one time the 'Boulder Clay' must have completely filled up the valley to this level, but recent river-erosion has laid bare the old sides of the valley in many places.

In no case did I see any evidence for post-Boulder-Clay dykes, such as were described by Dr. Sapper.[1] In some cases, however, at first sight, igneous rocks seem to cut through the river-deposits; but closer investigation shows that these are simply buried spurs of old rock exposed by recent erosion, leaving the 'Boulder Clay' in place on either side, and there is never the least trace of any alteration of the 'Boulder Clay,' such as would have been occasioned by igneous intrusions.

The following appears to be the most probable sequence of

[1] Peterm. Mitth. Ergänzungsb. xxxii (1906) No. 151, p. 32.

events that will account for the great thickness and mode of occurrence of these river-deposits:—

(1) The uplift and folding of the Atlantic Tertiary strata;
(2) Outbreak of igneous action in the form of lava-flows overlying and intrusions cutting the folded Tertiary strata;
(3) Erosion of the old valley of the Rio Reventazon in the lavas and sediments; and
(4) Violent volcanic action, breaking through the pre-existing rocks and building up a high inland range of mountains with much coarse fragmental material derived from the pre-existing rocks.

Granting such a sequence of events, we should then have a river with a thalweg rising very steeply towards the interior, and much fragmental material on the high ground ready for transport. The rivers of this country are, moreover, liable to extraordinarily violent flood-action, and so the result would be that the river would come from the high ground charged with its fullest load of material. In the lower part of the valley where the slope of the thalweg was much less steep, most of this material would at once be dropped by the river, gradually filling up the pre-existing valley to a certain extent. After a time, when the upper slopes became less steep and supplies of loose material became exhausted, the river, not having its full load, would be able to start cutting down through the deposits which it had previously formed, thus arriving at its present state of having nearly re-excavated the old valley, leaving only a fragmental terrace of the torrential deposits. The dip of the deposits noted above is probably due to slight earth-movement since their deposition, as the angle is rather too high for the natural deposition of a well-bedded sand.

As noted above, in the deposits of the Rio Reventazon patches occur locally where the fragments are angular, instead of being rounded; and these may be attributed to admixture of scree-material which has undergone little or no river-transport. All over the country landslides take place on a very large scale during the wet season, and with great frequency. This action has no doubt contributed largely in certain parts to the formation of the 'Boulder Clays': for example, in the deposits which are well exposed in the railway-cuttings along the Pacific Railway between Atenas and Orotina. In these cases, however, some stratified intercalations due to water-action can generally be seen, associated with the angular landslide deposit.

Turning now to the third process, that of spheroïdal weathering, there can be little doubt that it plays an important part in the formation of the 'Boulder Clays,' both alone and in conjunction with landslides.

Spheroidal weathering is an extremely common feature in tropical climates, and has in many cases given rise to accumulations very similar in general appearance to the river-deposits. A good example of this may be seen in a roadside section between Cebadilla Station on the Pacific railway-line and the Cebadilla power-station. This deposit consists of rounded masses of andesitic lava in a brown earthy matrix. All the boulders show a very close resemblance in petrological character, and the deposit has been formed by the weathering-out in place of a lava-flow.

The action applies equally to sedimentary and to igneous rocks. The first stage consists of the formation of joints which divide the rocks into more or less rectangular masses. Soon the corners become weathered, and then shell after shell of completely weathered rock is formed, until the surface-layers are represented by isolated rounded boulders of fresh rock separated by a matrix of weathered material. Percolating water soon destroys any trace of original structure in the weathered portion, and in the final stage we have the rounded boulders in a yellow clayey matrix. In the case of the landslide deposits the same action is liable to take place, and the irregular angular fragments are soon reduced to rounded boulders, the weathered portion mingling with the original earthy matrix.

It is perhaps worthy of note that the river-deposits of the Reventazon Valley show in places an extraordinary resemblance, both in general appearance and in mode of occurrence, to some of the Old-Red-Sandstone conglomerates in this country. For example, Lauderdale, in the Southern Uplands, a pre-Old-Red-Sandstone valley, is partly filled up by conglomerate which is being re-excavated by the present River Leader, in precisely the same manner as the early deposits of the Rio Reventazon are being cut into by the present river. To push the analogy still farther, both these deposits were formed immediately after periods of violent earth-movement and upheaval which would naturally give rise to rapid and extensive denudation.

VII. Summary and Conclusions.

In a paper such as this I should not feel justified in allowing myself to wander off into theoretical considerations. When the material at my disposal has been more fully worked out, then perhaps some more definite conclusions may be arrived at, but in the meantime a summary of the more important facts will be given.

In the first place, as regards stratigraphy, there is no evidence of the occurrence of any pre-Tertiary rocks in the area described. With the exception of the San Miguel Limestone and the limestone of the Avangares district, practically all the deposits appear to be marine volcanic ashes. The topography and structure of the Avangares district point to three distinct periods of earth-movement, and here the fossiliferous coastal deposits appear to rest with a marked unconformity upon an older calcareous formation. However, considering the rapidity of earth-movement and denudation in this region, it is quite possible that this break, though well marked, does not represent any very great stratigraphical gap. It is probable, both from the fossils occurring in some of these beds and from the fact that marine Tertiary deposits cross the Atlantic-Pacific watershed between San José and Cartago, that there was free interoceanic connexion during their deposition.

There is no evidence on the Pacific side of any later marine deposits to correspond with the Pliocene deposits of Limon, and therefore a widespread submergence in late Tertiary time does not seem probable. In this connexion, it is important to remember that the Pliocene of the Atlantic coast apparently extends only to a very trifling height above sea-level.

As regards petrology, the most interesting fact is the evidence of the occurrence of true monzonites in the Cerro Candelaria, and it is possible that analyses of some of the associated lavas may place them with the trachyandesites rather than with the true andesites, since, in some, alkali-felspar is developed to a small extent. The occurrence of a limburgite in the Avangares region is interesting, as being a type not previously recorded from Costa Rica, and I believe that it must be much older than the main mass of the volcanic rocks of that region. The volcanic rocks other than this fall into two clear groups:—(1) an older series of andesites and ashes closely connected with the marine deposits described; (2) the range of recent volcanoes largely composed of ashes in the area under consideration, but containing lavas in the lower parts, which also appear to be pyroxene-andesites.

As regards topography, the most interesting feature is the great San José Valley, and its prolongation westwards as the 'San Mateo peneplain' of Hill.

The covering of lava, which occurs at least in the eastern part, represents, I believe, the outbreak of the second great period of igneous activity, and on the top of these lavas are piled the great ash-cones which form the northern boundary of the valley. The so-called 'lake-terraces' near Alajuela are regarded as fault-scarps. As to the southern boundary of the valley, I can say but little. The lavas clearly terminate against the Cerro Candelaria, but whether the relation between the mountains and the valley, on this side, is of the nature of a fold or a fault, is not at present clear, though what evidence there is points rather to the former.

The 'Boulder Clays' are attributed to three causes, torrential river-action, landslides, and spheroidal weathering.

In conclusion, I wish to express my sincere gratitude to many friends who have helped me. In the first place, to Mr. W. J. Le Lacheur, for his advice and help in undertaking the work; to the President and Government of Costa Rica and to Mr. F. Nutter Cox, British Consul in San José, for their unfailing kindness in assisting me while in the country; and to the many friends in Costa Rica, whose kindness and hospitality made this investigation

possible. Finally, I take this opportunity of thanking Dr. J. E. Marr, F.R.S., and Mr. R. H. Rastall for their kind help and interest during the working-out of my material.

EXPLANATION OF PLATES VIII & IX.

Plate VIII.

Fig. 1. Concentric jointing in lava, El Brazil. (See p. 117.)
2. Alluvium, Salinas Bay, near Puntarenas, showing the old sea-cliff in the background. (See p. 132.)

Plate IX.

(All figures are enlarged × 20 diameters.)

Fig. 1. San Miguel Limestone, showing section of *Balanus*. (See p. 108.)
2. Monzonite from the Cerro Candelaria. (See p. 111.)
3. Limburgite, near Manzanilla, showing olivine in process of replacement by serpentine; the numerous small granules are augite. (See p. 129.)
4. Breccia with foraminifera, Manzanilla. (See p. 130.)

Discussion.

Dr. J. E. Marr commented on the great difficulties with which the Author had been confronted, owing to climate, growth of vegetation, and other causes. He knew of these difficulties from letters received when the Author was carrying on his work. Prof. Suess had especially cited Costa Rica as a country where further work was required, and the speaker believed that the Author's extensive collection of new facts would be of great value in adding to our knowledge of a little-known country. He knew that the Author had done more work than was incorporated in the paper, as, for instance, in the peninsula of Nicoya, but that he wished to return to the area before publishing his account of that work. The speaker hoped that this further work would be prosecuted, and felt that the results of the journey which were that night brought before the Society augured well for such future work.

Prof. T. McK. Hughes pointed out that the Author had not had time to make a survey of the district, and that the map he exhibited had very well served the purpose of indicating the position of the places mentioned in their relation to one another and to the sea on either side. The Author had met with other unexpected difficulties. besides those arising from the country which he was sent to explore. He had very clearly laid before them the character of the rocks exposed and the fossils and mineral constituents, so far as he had in the limited time at his disposal been able to gather sufficient for the discrimination and identification of those rocks. He had explained the apparent and inferred sequence, and had suggested a geological history of the district. One of the most interesting inferences arising out of this was that geographical changes had taken place in comparatively recent ages, which involved a submergence of the isthmus and alternate separation and union of the

Fig. I.
CONCENTRIC STRUCTURE IN LAVA AT EL BRAZIL (COSTA RICA).

J. Romanes, Photo.

Fig. 2.
ALLUVIUM, SALINAS BAY, SHOWING THE OLD SEA-CLIFF IN THE BACKGROUND.

J. Romanes, Photo.

Bemrose Ltd. Collo., Derby.

Fig. 1.
San Miguel Limestone. x 20.

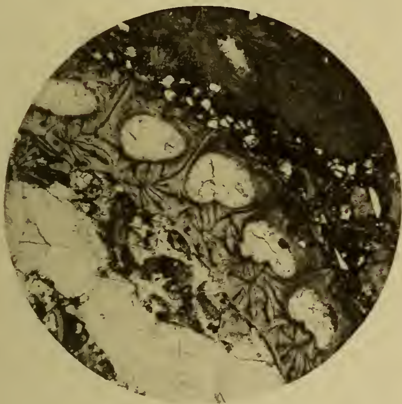


Fig. 2.
Monzonite. x 20.

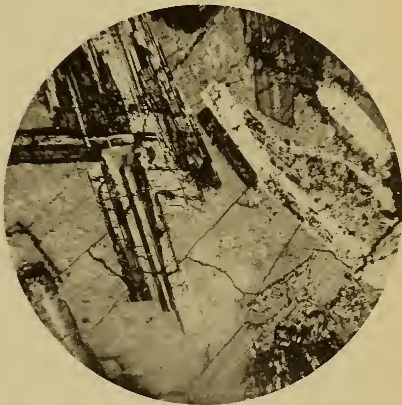


Fig. 3.
Limburgite. x 20.

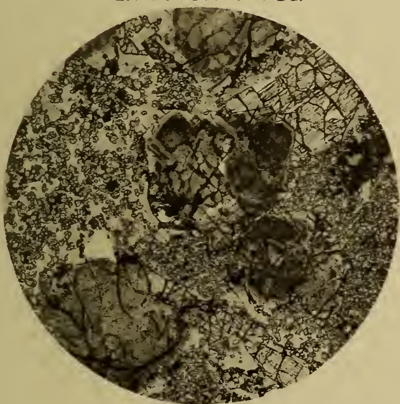


Fig. 4.
Manzanilla Breccia. x 20.

J. Romanes, Photomicro.

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ROCKS FROM COSTA RICA.

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Session 1912–1913.

1912.

Wednesday, November .... 6*—20
„ December .... 4—18*

1913.

Wednesday, January .... 8*—22*
„ February (*Anniversary*, Friday, Feb. 21st) ...... 5*—26*
„ March .... 5—19*
„ April .... 9—23*
„ May .... 7—28*
„ June .... 11—25*

[*Business will commence at Eight o'Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

continents of North and South America. His observations on the extension of land, not only westwards but also eastwards in the direction of the Antillean Continent, raised the question of the permanence of continental and oceanic areas, and it was very interesting in this connexion to learn that the strike of some of the rocks described was across the isthmus and transverse to the general trend of the great mountain-ranges.

Dr. J. W. Evans said the evidence that the Author had brought forward, showing a connexion between the Gulf of Mexico and the Pacific by way of Costa Rica, was of considerable interest, for it was recognized that South America was separated from the northern continent after early Tertiary times. Late in the Miocene, South-American types appeared in North America, but it was not until nearly the close of the Pliocene that transmigration in the opposite direction took place. This had been explained by supposing that a portion of Central America was connected with South America while separated from the land to the northward, and that subsequently it was detached from the former and united to the latter; but that a considerable time elapsed before the bridge between the two continents was complete. He suggested that the marine tract described by the Author constituted the northern boundary of that portion of Central America which was connected alternately with the two continents.

He was much interested in the torrential deposits mentioned by the Author. He had himself published a short paper in the 'Geological Magazine' on similar deposits north-east of the Bolivian Andes. Phenomena of this nature had been recently described by Dr. Hauthal from the borders of the Argentine and Bolivia, where the torrents of water and rock-fragments that from time to time poured out from the mountain-gorges were termed 'volcanoes' by the inhabitants.

The Author, in reply, stated that he fully appreciated the kind way in which the Fellows had received his paper. With regard to the intercontinental land-connexion discussed by Dr. Evans, he pointed out that certain evidence existed of a former land-mass to the west of Central America, which might have accounted for some of the phenomena of migration.

8. *The* Gopeng Beds *of* Kinta (Federated Malay States).

By John Brooke Scrivenor, M.A., F.G.S., Geologist to the F.M.S. Government. (Read November 8th, 1911.)

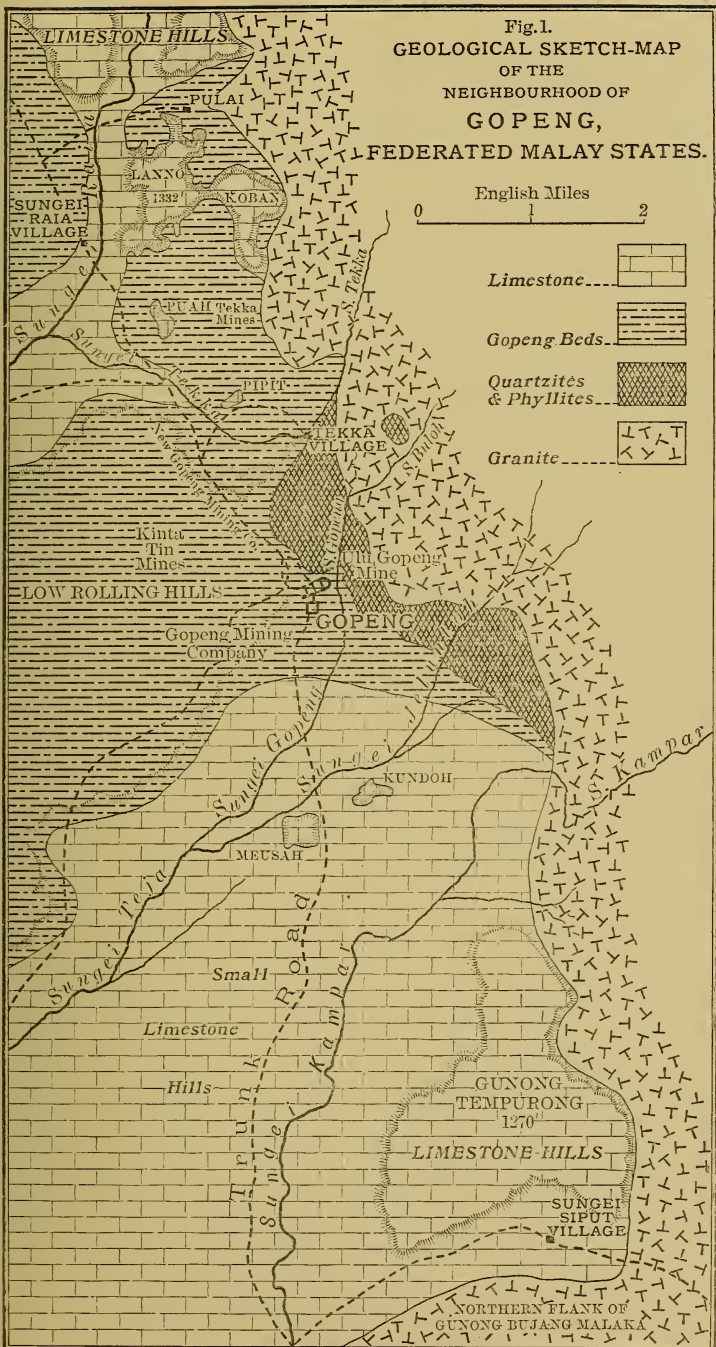
In a former paper [1] describing the remarkable tourmaline-corundum rocks found on the western side of the Kinta Valley in Perak, I mentioned the fact that on the eastern side of the same valley, near Gopeng, sandy schists occurred, but no tourmaline-corundum rocks—although tourmaline alone was found, as also pieces of pure corundum (at Pulai). Since that paper was written, I have been chiefly engaged in detailed work in the neighbourhood of Gopeng, and have also carried out some prospecting work in the same locality by means of bores: with the result that, while the western side of the valley had afforded an interesting study in petrology, it was found that on the eastern side the geology was such as to throw into the shade all the information previously gained in the Federated Malay States, as regards both economic importance and scientific interest.

It is my object in the present paper to show that, in the neighbourhood of Gopeng, there are remains of an ancient Gondwanaland tin-field, older than the granite of the main range of the Peninsula, altered by it, and further enriched in tin-ore by it near the contact and in the vicinity of certain veins; that the beds composing this Gondwanaland tin-field were deposited under conditions that were connected with the action of glaciers or of masses of floating ice; and that these Gopeng Beds are probably on the same horizon as the Talchir Beds of Orissa, and therefore the probable equivalents of the Bacchus-Marsh and Murree marine beds of Australia and the Ecca Group of South Africa.

Gopeng is a tin-mining centre of long standing and great prosperity, lying close under the granite hills of the main range, and situated on the trunk-road from Penang to Kuala Lumpur. To a miner the Gopeng tin-field is worthy of attention on account of the variety of methods that are employed to win the ore, ranging from the most primitive Chinese work to large hydraulic plants and a suction-gas dredge; to one, however, who finds an interest not only in the mining methods but also in the geology of the ground worked, it is a striking fact that with the exception of a few mines only, these various methods and installations of machinery are all employed in the same beds, which, as regards problems of treatment, do not vary to any great extent.

The physical geography of Gopeng and its neighbourhood is simple, but, as will be seen later, of great significance when considered in connexion with the geology. The accompanying sketch-map (fig. 1, p. 141) shows on the east the flank of the great main

[1] Q. J. G. S. vol. lxvi (1910) p. 438.



[Altitudes are indicated in feet.]

M 2

range of the Peninsula, composed of granite, while in the south-eastern corner a part of Bujang Malaka, a huge mass of granite that juts out from the main range into the Kinta Valley, is seen also. A little beyond the centre of the map is a broad transverse tract of low rolling hills, which become steeper as they approach the granite of the main range. North of this belt and south of it is a tract of low-lying ground drained on the north by the rivers Tekka and Raia, on the south by the rivers Gopeng, Jeluntoh, and Kampar. Beyond these tracts of low ground on each side are magnificent limestone hills, among which Lanno (1332 feet) on the north, and Tempurong (1270 feet) on the south, are prominent. If, therefore, we were able to pass over the country shown on the map at an altitude of 2000 feet, starting from Sungei Siput village and ending at Pulai, we should first see below us the mass of Gunong Tempurong, having Bujang Malaka behind us and the main range on our right. Then, from the northern end of Gunong Tempurong as far as Gopeng, we should pass over low-lying land diversified by two limestone hills of considerable size, Meusah and Kundoh. Continuing over Gopeng we should see below and stretching far away to the left the range of low rolling hills, and would steer for the gap between Lanno and Koban as we passed over the lowland on the north, with the limestone hills Puah and Pipit rising from it. Once over the white cliffs of Lanno and Koban, Pulai would become visible, lying in a hollow shut in by high limestone bluffs and granite hills, probably the hottest settlement in the Malay States, and northwards the limestone hills would be seen to continue as a well-marked range for many miles.

Two points would impress one particularly after this journey:—(1) that there is a kind of symmetry in the features of the country about the low Gopeng hills; and (2) it would also be evident that this transverse range marks a sudden break in the limestone hills, which are continued southwards in Gunong Tempurong. This break can be seen well by anyone standing on some of the land belonging to the Tekka Mines, owing to the fact that the transverse hills are much lower than the limestone bluffs: so that, when the observer is looking southwards, the tops of the Tempurong mass are visible over them, while immediately behind are the cliffs of Koban and Lanno. The length of this gap in the limestone range is approximately $6\frac{1}{2}$ miles.

Briefly, the structure of the features enumerated above is as follows:—The granite is part of the granite believed to be of late Mesozoic age,[1] and will be referred to in this paper as the Mesozoic granite. The limestone, which is all crystalline, is part of the large calcareous series that forms the oldest-known rocks *in situ* in the Peninsula, and is probably Carboniferous. The higher portion of the transverse hills is composed of phyllites, with thin beds of quartzite and schistose quartzite. The lower

[1] See 'The Rocks of Pulau Ubin & Pulau Nanas' Q. J. G. S. vol. lxvi (1910) pp. 420–34.

portion is composed of clayey beds that I propose to call provisionally the Gopeng Beds, and they cannot, I think, be better described in a few words than by saying that they strongly resemble drift, composed of till and boulder-clays. The lowland on the north, and the floor of the Pulai hollow, are an extension of part of the Gopeng Beds, the remainder, together with the phyllites and quartzites, having been denuded away by the River Tekka. Underneath this extension, and at no great depth, is a limestone floor. On the north-west the cap of Gopeng Beds is broken by the Sungei Raia, which has cut down to the limestone; and on the south the same conditions obtain in the lowland as on the north, but the extension of the Gopeng Beds is not so marked.

The development of alluvium in this area is small, and, so far as concerns this paper, unimportant.

The following is the sequence of the rocks of the Gopeng neighbourhood in point of age:—

Youngest: The Mesozoic granite and its modification, and the associated veins.
The phyllites and quartzites.
The Gopeng Beds.
Oldest: The crystalline limestone.

(1) The Crystalline Limestone.

The crystalline limestone is part of the great limestone formation of Kinta that forms the floor of the valley, and there can be little doubt that it is of the same age as the limestone on the other side of the main range in Pahang, where fossil remains point to a Carboniferous or Permo-Carboniferous age. The crystalline structure is due to regional metamorphism, and the bedding, where visible, generally is highly inclined or vertical. In colour the limestone is white or grey, and the grains of calcite may reach a considerable size.

Where the limestone forms hills, the sides are always steep, and generally take the shape of precipitous cliffs, the most notable of which is on the east side of Gunong Tempurong, where there is a sheer precipice about 800 feet high (see fig. 2, p. 144). The surface of the limestone under the Gopeng Beds is always irregular, and consists of numerous sharp pinnacles and troughs that are often capped by iron and manganese oxides. There is no reason to suppose that this irregularity represents an old land-surface: for the presence of the cap of iron oxides supports the view that the pinnacles and troughs are due to solution of the limestone by ground water operating underneath the covering of Gopeng Beds, and carrying iron in a soluble form.

No trace of organisms has been found in the limestone in the Gopeng area, so far as I am aware. The junction with the intrusive granite is sharply marked.

The general strike of the limestone is parallel to the trend of the main granite range.

Unfortunately, the vertical or highly inclined bedding has given rise to a belief that the limestone originally formed an anticlinal arch over the transverse range of Gopeng Beds and phyllites and quartzites, and is therefore younger than the latter. This view is evidently adopted in a recently published report, entitled 'Étude du District stannifère de Tekkah' by M. Joseph Roux-Brahis (Bordeaux: Gounouilhou, 1910); but, as will be seen later, it has

Fig. 2.—*Fault-face of limestone forming a cliff on the eastern face of Gunong Tempurong, near Gopeng.*

been conclusively proved that this is a mistake, and that the limestone continues under the Gopeng Beds. I referred to the subject briefly in my paper on the tourmaline-corundum rocks (Q. J G. S. vol. lxvi, 1910, p. 436). It is a case of 'Barrow's Paradox.'

(2) The Phyllites and Quartzites.

These form the higher portion of the transverse range, which is that nearest the granite, and are very well exposed on the Ulu Gopeng Tin-Mining Company's land. The beds are vertical or nearly so, and strike north and south. The phyllites are all somewhat weathered, and in consequence show a brilliant display of colour. There are numerous small quartz-veins parallel to the bedding, and thin stringers trending east and west, carrying tin-ore. It is important to note that, so far as is known, all the tin-ore won in this mine comes from the quartz-veins and stringers, and was derived from the Mesozoic granite, which is also exposed in the Ulu Gopeng mine.

No organisms have been found in these rocks.

(3) The Mesozoic Granite.

The border of the Mesozoic granite is generally marked by soft granitic rocks rich in kaolin and tourmaline, and carrying tin-ore. The typical granite is coarsely crystalline, with large porphyritic crystals of orthoclase. The fact that it is intrusive into the limestone, the Gopeng Beds, and the phyllites and quartzites, is proved by numerous sections.

Modifications of the Mesozoic granite, such as are commonly found in tin-bearing areas, are found in the vicinity of Gopeng also, but need not be described here.

(4) The Gopeng Beds.

These beds, as already stated, resemble glacial clays, or till, and boulder-clay. They have been examined, not only in the excellent sections afforded by the hydraulic operations on the land leased to the Gopeng Mining Company, the New Gopeng Mining Company, and the Kinta Tin-Mines Ltd., but also by means of bores which were put down to prove if possible, among other points, that the limestone lay beneath them.

The clays are generally pale in colour, a light grey or even white being the usual hue; but, near the surface, they are frequently stained red by the deposition of iron hydroxide, which also produces a curious mottled appearance, the reason for which has not been determined. Also in the vicinity of certain intrusive veins from the Mesozoic granite, and along the junction with the main granite mass, the clays are stained deep red, but not invariably.

The boulder-clays are of the same colour as the clays, and undergo the same staining.

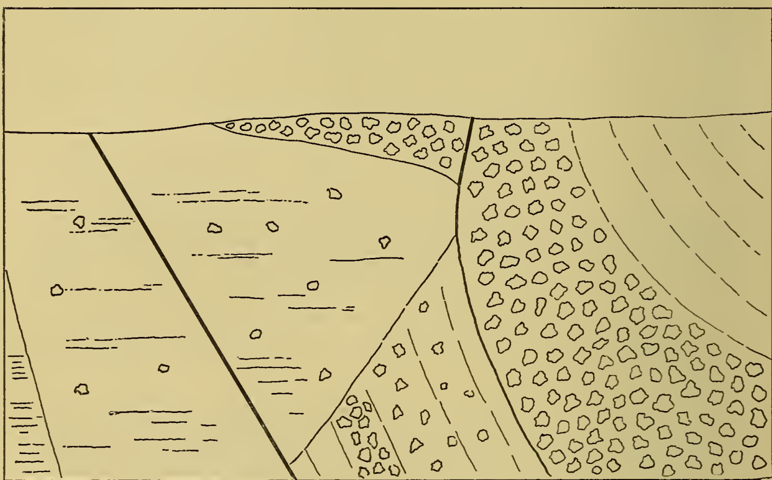
For the most part a fairly distinct bedding of the clays and boulder-clays can be observed, and in some sections the separation of individual beds is clear; but, on the other hand, it may be difficult in some places to find any trace of bedding at all. It is in the best sections showing stratification that one sees to how great an extent the beds have been faulted, and how irregular is the degree of dip. In some cases sections have been exposed, showing finely-stratified thin beds which suggest stratified drift.

The clays and boulder-clays sometimes show concentric dark and light-red bands cutting across the bedding-planes. These are probably due to recent deposition of iron hydroxides.

The clays and the matrix of the boulder-clays are very rich in alumina. This is chiefly present as the hydrous silicate, kaolin; but alumina in an easily soluble form (an hydroxide) has been found to the amount of 10·72 per cent. and 3·65 per cent. respectively as the result of two analyses. This free alumina is doubtless due to tropical weathering, acting on aluminous minerals in the beds.

Seeing that the earth-movements, which allowed the Mesozoic granite to rise to its present position relative to the Gopeng Beds, rendered the underlying limestone crystalline, and converted the beds above into phyllites and quartzites, one might reasonably expect to find some well-marked characteristic due to regional metamorphism in the beds lying between the altered rocks. No such characteristic, however, is observable, and its absence is probably due to the great plasticity of the material acted upon, which enabled the beds to adjust themselves to the strains in the earth's crust without great development of heat. In two sections I have seen what might possibly be described as 'the shadow of a schistose structure' in a much-weathered rock, but I have observed nothing conclusive in this direction. Therefore, if any marked characteristic

Fig. 3.—*Diagrammatic section in Kinta Tin-Mines, showing disturbance of 'glacial clays' and 'boulder-clays.'*



was ever imposed on the Gopeng Beds by regional metamorphism, it must be assumed that the characteristic has been destroyed by the weathering action of ground water. This is not very probable, because immediately one passes up to the overlying phyllites and quartzites, a schistose structure in the former is at once obvious, while it is sometimes present in the latter.

It is also remarkable that no quartz-veins have been observed in the Gopeng Beds away from the granitic intrusions mentioned above and the granite margin.

The only result of the earth-movements which affected the limestone and the other rocks that can be observed in the Gopeng Beds is the faulting; but, at the same time, it must be remembered that some slight derangement of the beds would be caused by the recent solution of the limestone below by underground water and the consequent settling-down of the clays and boulder-clays.

This also might render small pre-existing quartz-veins unrecognizable.

Many geologists have doubtless noticed cases of selective metamorphism by igneous rocks: the limestone, the Gopeng Beds, and the phyllites and quartzites here show an interesting difference in the effects of regional metamorphism.

The Petrology of the Gopeng Beds.

Leaving one item, namely the presence of cassiterite, for consideration later, the petrology of the clays and boulder-clays may here be briefly described.

A detailed knowledge of the mineral constitution of the clays was obtained by washing, and examining under the microscope and by other methods, numerous samples from the bores. The clays always contain some sand, which may vary from a quantity so small as to be difficult to estimate to 30 per cent. or more. The clayey material, as already indicated, is largely composed of hydrated silicate of alumina, and free aluminium hydroxide. The sand is mostly composed of quartz, but tourmaline, topaz, ilmenite, and magnetite frequently occur, the first two constantly, in my experience, wherever tin-ore is abundant. In addition to the minerals just enumerated, zircon and manganese dioxide are found: also corundum and monazite as occasional grains (in the neighbourhood of Gopeng); at Pulai, corundum in small grains is very abundant in association with the roughly washed tin-ore.

The matrix of the boulder-clays has the same mineral constitution as the clays. The following is, I believe, a complete list of the boulders found so far:—

Quartz: abundant.
Sandstone.
Sandy schists with white mica: abundant near Gopeng.
Phyllite: rare.
Hornstone: rare.
Hornblende-schist: rare.
Tourmaline-rock: abundant.
Quartz-muscovite rock: abundant.
Quartz-tourmaline-muscovite rock: abundant.
Quartz-kaolin rock: common.
Small masses of kaolin: not very common.
Tourmaline-schist: abundant, and often veined with quartz and white mica. The tourmaline is brown.
Granite: not common at Gopeng, but common at Pulai.
Tourmaline-granite: Do. do.
Corundum: rare at Gopeng, abundant in one part of the Tekka Ltd. property, and abundant at Pulai.
Cassiterite: rare as boulders.
White mica. Probably formed a veinstone originally.

The boulders differ considerably in size and abundance in the clay. They vary from small pebbles to masses weighing over 50 lbs. Exceptionally large boulders are occasionally found, the biggest that I have seen being exposed at the New Gopeng Mine. It is composed of quartz and tourmaline, and, judging by the measurements, should weigh about 3·6 tons.

Some of the boulder-beds are crowded with boulders to such an extent that the matrix of clay only occupies interstices between individual boulders. On the other hand, boulders may be few and far between in one bed, as at Pulai. The big boulder, just mentioned as having been found at the New Gopeng Mine, was in a bed with very few large boulders. There were one or two tourmaline-rock boulders weighing about 10 lbs. each near by, but the clay did not contain many others of any sort.

The outline of the boulders varies considerably, although for the most part they show rounded edges. Generally speaking, the angularity increases with size. All, with the exception of those of corundum, show signs of recent weathering on the surface.

The granite-boulders are remarkable—in that they are nearly always bounded by two flat surfaces, and have a roughly oval or circular outline. The best example of this is a boulder found recently on the Tekka property, washed out of dark red clay. It is nearly circular, and has a maximum diameter of 7 inches. Its thickness is roughly $1\frac{1}{4}$ inches, and the two surfaces are quite flat, although roughened by weathering. The condition of boulders such as these, when seen *in situ*, shows that they are not 'cores' representing the remains of larger weathered blocks, but that when they became embedded in the clay they already had their present form. The flat surfaces are suggestive of the boulders having been ground down by ice-action.

The sand in the clays is angular, and distinct from sand that has been worn down in a river-bed, but the edges of the grains are generally rounded off.

The form of the corundum boulders is noteworthy. Those occurring on the Tekka property, where they have been found in one bed only so far and in a restricted portion of that bed, although in great numbers, are angular and in some cases exceed 80 lbs. in weight. At Pulai also, where the tin-workings are littered with them, the bigger boulders are angular; but, both at Tekka and at Pulai, the smaller pieces separated from the tin-ore during the final dressing are often beautifully rounded.

The corundum at Pulai sometimes occurs also in the form of flat tabular masses, suggesting that it was originally a veinstone. Occasionally, the tourmaline-rock boulders are similar in form.

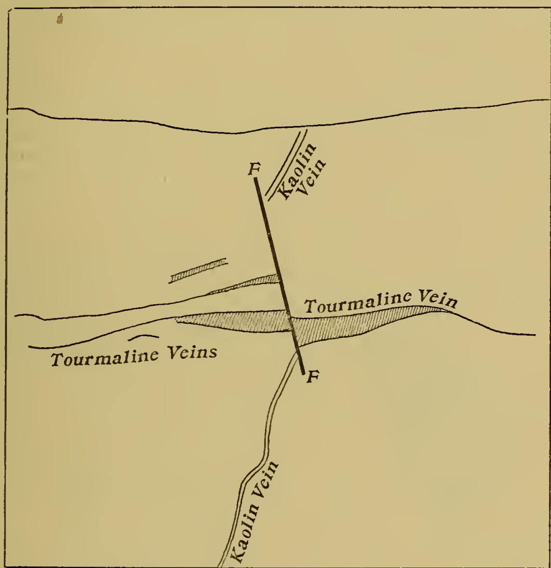
(5) The Intrusive Veins and the Junction with the Mesozoic Granite.

In several localities on the Gopeng mines large veins of white kaolin and of kaolin and quartz can be seen cutting the Gopeng Beds. A very good section has been exposed for a long time on the Kinta Tin-Mines land, showing a sharp junction with deeply stained boulder-clay on either side, and the termination of the vein in a thin stringer above. On the Gopeng Mining Company's land, I have seen an excellent section of a vein with a breccia of kaolin and deep red clay at the margin. A deep red staining of the clays and boulder-clays is usual, but not universal, at the margin of these veins.

In some cases the clayey vein-material is stained yellow or red. This is the rule with small veins on the Kinta Tin-Mines land.

At Tekka a big kaolin-vein has been exposed cutting deep red clays, while close by this vein I noted a vein of tourmaline and a vein of kaolin intersecting one another.

Fig. 4.—*Section at the Tekka Mine, showing faulted tourmaline and kaolin veins.*



[Approximate scale: 1 inch = 6 feet.]

The junction of the Gopeng Beds with the granite is clearly exposed at the Tekka Ltd. Mine and at a big Chinese mine farther south. The clays are stained deep red for a long distance, and are traversed by veins of tourmaline, the continuity of which has generally been broken by slight movements in the mass of the clays after their formation. Veins of kaolin also occur.

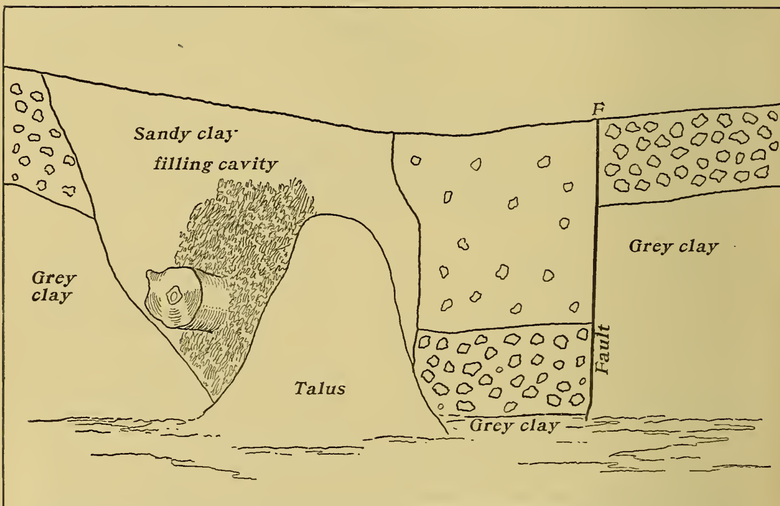
At Pulai the junction with the granite can be seen, but there the staining is not so strong and is, indeed, in some places entirely absent.

(6) Proof that the Gopeng Beds are of Earlier Age than the Mesozoic Granite.

Until a short time ago the Gopeng Beds were looked upon by miners as recent alluvial deposits, the evidence of the kaolin veins being unappreciated. They contain tin-ore throughout, but individual beds are found to be generally richer (with the possible exception of Pulai) at the granite junction; while, in the neighbourhood of the kaolin veins, an increase in the richness of ore is sometimes met with. This, combined with the sections of the junction and of the veins, is conclusive proof that the Gopeng Beds are older than the Mesozoic granite, but there is a curious point to be mentioned that might be taken at first sight as direct evidence to the contrary.

On several occasions tree-trunks have been found deep down in the clay with all the appearance of being *in situ*, and with their woody tissue generally in a good state of preservation, although portions are carbonized. Seeds were found with one tree, for the

Fig. 5.—*Old tree-trunk lying at the bottom of a cavity filled in with sandy clays, New Gopeng Mine.*



[Note the fault in the Gopeng Beds: it appears as though there must have been another fault originally in the position of the cavity.]

identification of which, as belonging to *Mezzetia leptopoda*, I am indebted to Mr. H. N. Ridley, F.R.S., of the Botanical Gardens, Singapore. I am also indebted to Mr. Clement Reid, F.R.S., for information concerning the state of preservation of fossil wood in special cases.

The tree-trunks seemed to contradict the other evidence, but I had noticed around some of the trunks what looked like a sandy casing; and later on two fortunate sections solved the riddle. A monitor cutting the beds at the New Gopeng Mine exposed a big section, showing a pipe of sandy clay with boulder-clays on each side. The junction between the pipe and the latter was distinct, and at the bottom of the pipe lay a big tree-trunk with twigs and leaves, while on the trunk were marks that the manager of the mine and myself agreed were cuts made by an axe or some such instrument (see fig. 5, p. 150). Again, at Tekka a tree-trunk and mass of leaves, in very fair preservation, were found actually embedded in soft granitic rock *in situ*, but with a casing as at New Gopeng. These could not possibly have reached their present position until the granite had solidified and cooled, and it is difficult to see how they could have done so afterwards by purely natural agencies; therefore I have no doubt now that these trunks reached their present position by falling down old, long-forgotten excavations, and that the latter were filled in by detritus from the surface.

(7) The Cassiterite in the Gopeng Beds.

Owing to the great irregularity of the limestone surface, it is impossible to give a definite figure for the thickness of the Gopeng Beds: 200 feet from top to bottom would probably be near the mark; but the feature to be emphasized here is that, from top to bottom and over the whole area comprised in the map, no sample has been properly examined that has not been found to contain tin-ore. This is the experience of every English-speaking miner in the district, and I believe of every other miner who has sampled his ground carefully.

The bores that I put down in 1910 bring out this point excellently. In clay from one bore the amount of tin-ore was so small as not to be worth estimating. In the others it ranged from ·1 of a kati (1 kati = 1·33 lb.) to over 8 katis per cubic yard. Most of the bores reached the limestone or the ironstone capping it, and not one sample (taken every 2 feet) failed to afford tin-ore.

The condition of the cassiterite is like that of the rest of the sand. The grains are angular with the edges smoothed off, but very rarely masses of cassiterite are found which must be regarded as boulders in the boulder-clays.

A few were found on the Kinta Tin-Mines land last year, and proved to be a remarkable form of cassiterite containing so much iron as to be lifted by an electro-magnet. Another was presented to me long ago by M. Legros, of the Société des Étains de Kinta. Unfortunately I did not know at the time from which beds it came, and the boulder was broken up; but I remember it very well as it was originally, on account of its great weight, which was well over 100 lbs.

My experience of the Gopeng Beds convinces me that the bulk of the tin-ore—to be precise, all, except part of that found at the granite junction and near the kaolin veins,—is an original constituent of the beds and therefore older than the Mesozoic granite; but, as others may find some difficulty in accepting this conclusion from what has been said above, I give briefly the reasons that have led me to it.

If this cassiterite is not an original constituent, then it, with the tourmaline and topaz, must have been formed by impregnation from the Mesozoic granite. But a glance at the map, and the recollection that the ore is present everywhere in these beds and that the highest values of the beds *as a whole* are not confined to a zone bounding the granite, will show that this view is untenable. Moreover, could we expect impregnation to form cassiterite as grains of sand?

Again, if it is a case of impregnation on a great scale, what is the significance of the boulders of tourmaline-rock, tourmaline-schists, and tourmaline-granite? It is impossible to assume that these were brought into being by the Mesozoic granite; while, on the other hand, such an assemblage of rocks in a detrital deposit would justify a search for tin-ore.

In 1910, on the Kinta Tin-Mines land, a very rich patch of ore was found close to the big kaolin vein mentioned above. A quantity of the ore occurred as masses of sharply defined crystals. This was clearly a case of impregnation from the Mesozoic granite, the medium that bore the tin having risen through the limestone. If the bulk of the tin-ore in the Gopeng Beds is of similar origin, why does it not generally exhibit the same habit?

On the Ulu Gopeng Mine all the tin-ore, so far as is known, comes from veins and stringers in the phyllites and quartzites, and it is all sharply angular, often showing good crystal faces. This ore was derived from the younger Mesozoic granite, but is quite unlike the bulk of the ore in the Gopeng Beds.

Finally, if the cassiterite boulders are accepted as an original constituent of the boulder-beds, what difficulty is there in regarding the bulk of the tin-ore in the beds as an original constituent also?

The mineral constitution of the Gopeng clays and boulder-clays clearly points to the material having been derived from some mass of tin-bearing granite and rocks altered by it, distinct from, and older than, the Mesozoic granite; but the Mesozoic granite has certainly further enriched the beds by impregnating them locally with a second supply of tin-ore.

(8) The Faulting of the Rocks in the Neighbourhood of Gopeng, and its Connexion with the present Physical Features

One of the problems that has often presented itself to those who live in Perak, and has called forth some opinions of a rather original nature, is the origin of the limestone hills. It is unnecessary to notice the views that have been put forward in detail, and it will suffice to say that denudation, coupled with the solubility of the rock, has been overlooked.

In the case of Pahang, where limestone hills also occur, I have failed to find any direct evidence that they are due to anything but denudation modified by the solubility of the limestone; but in 1904, during a visit to Sarawak, I found conclusive evidence that there inland cliffs of limestone were fault-faces, the shales that had been faulted down against them having been removed by denudation.

As I had been anxious to obtain similar evidence of the origin of the limestone hills in the Malay Peninsula, it was gratifying to find that in the neighbourhood of Gopeng conclusive testimony exists of their precipitous sides being in truth fault-faces.

To take the evidence in detail, if one goes to Sungei Siput (in the south-eastern corner of the map, fig. 1, p. 141), and takes the path that skirts the eastern cliffs of the Gunong Tempurong limestone mass, it will be noticed that lying against the base of the cliffs in several places, and between the limestone and the granite, are small patches of phyllites like those at Gopeng. They are not interbedded with the limestone, and the obvious significance of their present position is that the junction between the limestone and the granite is a fault-junction and that the faulted side (that is, the eastern side) sank bodily into the granite except for these small patches of phyllites that were scraped off against the fault-face and held there by the granitic magma as it welled upwards.

Equally good evidence of the granite-limestone junction being a fault-junction is found in the neighbourhood of Pulai, and it may therefore be concluded that the whole of the granite margin in this map is bounded by a big fault, some idea of the magnitude of which may be gained by standing underneath the Gunong Tempurong cliff mentioned above, where the precipitous limestone fault-face is seen towering up to something not far short of 800 feet (see fig. 2, p. 144).

Now, let us examine the outcrops of Gopeng Beds north of the Sungei Tekka, namely, that bordering Lanno and Koban and surrounding Puah and Pipit, and that in the Pulai hollow. It will be found that beneath the Gopeng Beds is always crystalline limestone, and that the Gopeng Beds lie up against perpendicular cliffs of limestone. Since it is clear, from the evidence gained by boring on the Gopeng mines, that the natural position of the Gopeng Beds is above the limestone, we may safely conclude that when the Gopeng Beds abut on the limestone cliffs, their position is due to faulting, and that the limestone cliffs are fault-faces.

The evidence of the faulting on the west of the Tempurong mass, and round the limestone hills known as Meusah and Kundoh, is not so good, because that part of the country is largely agricultural; but remnants of the Gopeng Beds are found on the limestone floor over which flow the Sungei Gopeng and the Sungei Jeluntoh, and in the absence of evidence pointing to a different conclusion we may assume that the cliffs of Meusah and Kundoh are fault-faces also, like those of the limestone hills north of Gopeng.

West and south of the Tempurong limestone-mass no direct evidence of faulting has been obtained so far; but, seeing how the granite juts out to the west to form the mountain Bujang Malaka, and how clear the evidence of faulting is on the east of the Gunong Tempurong, it is not too much to assume that the northern boundary of the Bujang-Malaka mass is a fault and that the southern and western cliffs of Gunong Tempurong are faults also.

Information lately obtained shows that, if the western cliffs of the limestone hills north of Lanno are followed up beyond the limits of the map (which can be easily done, because the trunk-road skirts the cliffs for about 4 miles before reaching Ipoh, the chief town of Kinta), it will be found that the Gopeng Beds persist, faulted down on the west against the limestone, and that there are more limestone hills towards the centre of the Kinta Valley. It appears, then, that this is an area of complicated fracture; but, in order to understand fully what has taken place, we must cross the main range of the Peninsula and enter Pahang, where we shall find information concerning the arrangement of the beds immediately prior to the intrusion of the granite.

On descending from the granite hills on the Pahang side of the main range, hornblende-schists, limestone, and calcareous shales are encountered. Continuing, a belt of shale, sandstone, and conglomerate is crossed, and then one enters a broad tract of limestone, calcareous shales, and associated volcanic rocks in a much less disturbed condition than the limestone in Kinta, and capped by outcrops of sandstone, shale, and conglomerate agreeing in petrological characteristics with the belt just referred to. Now fossils have been found both in the shallow-water and in the calcareous rocks, such as to show that the latter are Carboniferous or Permo-Carboniferous, and that the shallow-water deposits are distinctly younger. So far no trace of an extension of the Gopeng Beds has been seen in Pahang, and it is of course possible that they never extended so far. But, taking into consideration the fact that the main range forms the backbone of the Peninsula, the similarity of the limestone on either side of it, and the smallness of the country considered as a geological area, it is permissible to conclude that the limestone beds on either side of the granite axis are of the same age and were once continuous; that the same conclusion applies to the Gopeng quartzites and phyllites and some part of the Pahang shallow-water deposits; and that we are dealing in the Gopeng area with part of a shattered anticlinorium.

To take this proposition in detail: before the granite rose to its present position relative to the other rocks, the quartzites and phyllites, the Gopeng Beds, and the limestone, while deep down in the earth's crust, were folded by lateral forces into a broad anticlinorium. Further stress brought about fracture of this anticlinorium, and masses fell away into the granite magma beneath. Thus we may take the present granite junction in the Gopeng area as the line of the main fracture. East of this line the whole mass of limestone, clays, quartzites, and phyllites fell bodily, and sank into the magma: with the exception of the patches of phyllites, mentioned before as lying against the limestone, and the island of quartzites and phyllites on the Sungei Buloh. West of the main fracture the crust was broken up by irregularly outlined faults that determined then what would be the shape of the limestone hills to-day. We do not know to what extent the limestone blocks that now form the hills were affected by the faulting, but it would appear that all the rocks forming the rest of the country dropped relatively to them in the crust.

The physical features of the Gopeng neighbourhood are, then, the result of denudation acting on part of a shattered anticlinorium. North of Gopeng, and (we may believe) south also, the limestone hills represent blocks of the limestone beds that did not fall, or fell but slightly, when the fracturing took place. The Pulai hollow and the gap in the range of the limestone hills mark areas where blocks of the anticlinorium fell to such an extent that the soft Gopeng clays and the higher phyllites and quartzites were brought up against a considerable thickness of crystalline limestone, with the result that when denudation reached these blocks the softer beds were largely worn away and the limestone fault-faces left as cliffs.

(9) The Age and Origin of the Gopeng Beds.

It has been stated above (p. 143) that fossils found in Pahang have shown that the calcareous rocks there are Carboniferous or Permo-Carboniferous. For the identification of these fossils I am indebted to Mr. G. C. Crick and to Mr. R. B. Newton. The former identified the following forms in the limestone from Goa Sar (or Sah):—*Orthoceras*, *Cyrtoceras*, *Gyroceras*, and *Solenocheilus*. Mr. Crick also examined a fossil found in calcareous shales on the Pahang river, and ascertained that it closely resembled Waagen's *Xenodiscus*; while Mr. Newton described a form closely allied to *Dentalium herculeum* of De Koninck, from the same beds, and remarked that *Xenodiscus* and *Dentalium herculeum* are found in the Upper *Productus* Limestone of India.

Now, it is to India that we must look first for possible equivalents of the shallow-water sandstone, shale, and conglomerate of Pahang, and extensions of these rocks outside that State. Parts of them have already been determined as Rhætic in Pahang,[1] as probably Middle Jurassic in Singapore,[2] and as Triassic in Perak[3]; but, as all three determinations were based on small collections of fossils, that in Perak being based on one form only, we may expect that larger collections, if they are ever made, will show that the rocks, which I have described elsewhere as the Tembeling Series, do not cover so great a range in time as is indicated at present.

When describing the Singapore fossils, Mr. R. B. Newton remarked (Geol. Mag. 1906, p. 488) on the possibility of the beds in which they were found representing an outlier of the Upper Gondwana rocks of India. Even without this suggestion, it would not be unnatural to look for an extension of the Gondwana Series over the limestone in the Federated Malay States; and, although it is not claimed that what I have termed the Tembeling Series was

[1] R. B. Newton, Proc. Malacol. Soc. vol. iv (1900) pp. 130–35.
[2] *Id.* Geol. Mag. dec. 5, vol. iii (1906) pp. 487–96.
[3] *Id.* & T. R. Jones, *ibid.* vol. ii (1905) pp. 49–52.

laid down under precisely the same conditions as the Gondwana rocks, the palæontological evidence, such as it is, points to its having been deposited during part of the Gondwana Period on a shallow coast-line, which may without a great stretch of imagination figure as an extension of the Gondwanaland coast-line, whether that debated land covered the whole Indian Ocean or not.

It is unnecessary now to occupy space by giving references to show that the general opinion is that, at the close of the Carboniferous Period or thereabouts, there was a large extent of land under glacial conditions, covering in part what are now India, Africa, and Australia. It is, I believe, generally acknowledged that such was the case, and therefore it would not be altogether surprising to find, overlying the limestone of Kinta, beds that show signs of glacial action. I believe that the only satisfactory explanation of the peculiarities of the Gopeng Beds is that they are in some way due to glacial action; and, although correlation by other than palæontological evidence is as a rule unsatisfactory, these characteristics of the Gopeng Beds, if admitted to be due to glacial action, give as valuable a point from which to commence a comparison of the geology of the Federated Malay States with that of other countries, as do the collections of fossils that have hitherto been obtained.

The peculiarities to which I refer have been described above, and need not be enlarged on here; but it will certainly be objected that no mention has been made of marks on the boulders or of glacial pavements. The reason is that neither have ever been found, and apart from the corundum boulders, are not likely to be found: for, in a country where weathering can, by the removal of silica, reduce a mass of hard conglomerate to the consistency of cheese without any disturbance of the position of the pebbles, as I have lately seen in a railway-cutting, it is not to be expected that a glaciated limestone pavement will retain its glaciated surface long under a bed of moisture-sodden clay, or that boulders in that clay will long preserve delicate surface-markings. The corundum, of course, does not weather so easily; but corundum is not easily scratched. Nevertheless, as it is quite possible that during the progress of a glacier corundum may have been ground against corundum, and since some of the smaller pebbles are beautifully rounded, search has been made among the boulders at Pulai and Tekka for such evidence of glacial action. The result has been, however, that while fine markings are frequently met with, these must be interpreted as hollows between minute veins showing up on the surface of the boulders (the veins being of corundum also), and that nothing has been found that can be described as a scratch due to ice-action.

If we remember, then, how unfavourable are the conditions for the preservation of striæ or grooves on the surface of the boulders or on the limestone floor, and the probability of glacial deposits occurring above the Kinta limestone, we must admit that the resemblance which the Gopeng Beds bear to drift, stratified and unstratified, is genuine, and that they are in fact glacial clays and boulder-clays which we may compare with the Talchir Beds of Orissa, and with their correlatives in Africa and Australia; and we can, moreover, regard the Gopeng Beds as the base of an extension of the Gondwana System in the Malay Peninsula.

(10) Economic Aspect of the Recognition of the Nature of the Gopeng Beds.

Interesting as the Gopeng Beds are to a student of the earth's history, there is no doubt that in the Federated Malay States their economic possibilities claim the greatest attention. The field and petrological evidence show that the material of which they are composed was derived from a tin-bearing granite mass and the altered rocks on its margin. This granite mass was probably situated somewhere to the west of the position of the Gopeng Beds, and was part of Gondwanaland. Although much older than the Mesozoic granite that forms the granite hills of to-day, it may be still within reach as undiscovered outcrops, or under younger rocks; and the extent of the tin-bearing glacial detritus under younger rocks, or in unprospected parts of the country, calls for immediate investigation.

A digression may perhaps be made here, to notice a point raised in my paper on the rocks of Pulai Ubin and Pulau Nanas (Q. J. G. S. vol. lxvi, 1910, p. 430), where it was shown that there was at least a strong probability of the fragments of granite in the tuff of Pulau Nanas belonging to the same period of irruption as the granite of Amboyna, which Dr. Verbeek stated could not be younger than the Permian. It may prove, then, in the course of further work in the Peninsula and the Archipelago, that the parent granite of the original tin-ore in the Gopeng Beds, the granite of Amboyna, and the granite fragments in the tuff of Pulau Nanas, all belong to the same period of irruption. It is interesting also to recall the mention of the small pebbles of schorl-rock in the Tembeling conglomerate, and especially the following sentence:—

'These pebbles may have come from the pre-Carboniferous granite; but, as tourmaline in a granite mass always suggests the possibility of finding tin-ore also, I must add that hitherto I have found no detrital tin-ore in rocks older than the tin-bearing [Mesozoic] granite.' (*Op. cit.* p. 428.)

This admission is no longer necessary.

(11) Relation of the Corundum Boulders to the Tourmaline-Corundum Rocks of Kinta.

Three striking points about the geology of the Kinta Valley, so far as it is known at present, are that on the east side boulders of pure corundum are found, on the west boulders of the tourmaline-corundum rocks, and that the two have never been found together:

that is, no boulders of tourmaline-corundum rocks have been found on the east, and no pure corundum boulders have been found on the west side of the valley.

The manner in which the corundum boulders are massed together in a small area (at the Tekka mines and at Pulai) suggests that they were dropped from melting ice, and occupy at present the same position in the clays as that which they occupied when so dropped. Supposing, then, that there should prove to be an extension of the Gopeng Beds across the valley to the west side, it would be possible to account for the absence of corundum boulders on the west by supposing them to have been carried over that area by ice without any being dropped; and a further possibility would suggest itself of the tourmaline-corundum rocks having been in part brought from a distant source by ice. Whether this is so I am not prepared to say yet, but it must be mentioned here that Mr. W. M. Currie, the General Manager of the Pusing group of Mines, to whom I am indebted for much information, expressed an opinion some time ago that the soft clayey masses over the limestone, which I described as much-weathered schists (Q. J. G. S. vol. lxvi, 1910, p. 438), strongly resemble glacial clays. If Mr. Currie is correct in thinking that they are of glacial origin, then the angular masses of tourmaline-corundum rock found in such clayey ground may be regarded as erratic boulders, instead of remnants of a once-continuous bed (*op. cit.* p. 439). Sections lately exposed by miners show that I may have been mistaken in considering any of these rocks to be *in situ*.

(12) Conclusion.

The main points of this paper may be summarized by sketching briefly the probable course of events in the earth's crust in this particular region, as indicated by the available evidence in the neighbourhood of Gopeng.

In Carboniferous times a large tract of land, Gondwanaland, existed some way to the west of a sea occupying the site of the present Malay Peninsula, and in this sea calcareous beds were deposited.

The coast-line of Gondwanaland advanced eastwards, and glaciers coming down from the highlands, after traversing rocks carrying tin-ore, deposited above the limestone a mass of detritus, partly stratified, in which tin-ore, tourmaline-granite, tourmaline-schists, etc., are common.

Conditions changed, and above the glacial detritus shallow-water beds of clay and sandstone were deposited, and also further thicknesses of rocks, now denuded away, which had the effect then of making the relative position of the limestone, the glacial beds, and the shallow-water clays and sands very deep in the earth's crust.

Lateral pressure and heat caused the three members of the series of rocks with which we are concerned to be bent, folded, and altered, so as to form part of the western limb of an anticlinorium, the rocks being now crystalline limestone, glacial detritus, and phyllites and quartzites.

At the same time a granitic magma was being urged upwards from below the limestone by entangled gases, and the upward pressure led to the break-up of the anticlinorium, one huge block falling bodily into the magma ('magmatic stoping'), and allowing the granite to rise up and to form the material from which the main range of the Peninsula was carved later. West of this main fracture there were subsidiary fractures that had the effect of faulting down the glacial detritus against blocks of crystalline limestone. At the same time the glacial beds, already tin-bearing, were further enriched in tin-ore where they were invaded by the granite magma.

The granite magma cooled and solidified, cementing together the remains of the anticlinorium. Denudation gradually worked down to the shattered arch and the granite, and carved out the present physical features: the main mass of granite standing out in relief as the main range of the Peninsula, and the preference of the streams for the phyllites and quartzites and glacial beds leaving the limestone blocks as hills bounded by fault-faces. Thus an old Gondwanaland tin-field, after having been buried in the earth's crust during more than the whole of the Mesozoic Era, is once more on the surface and is yielding up its mineral wealth to commerce; whereas, when these deposits were first formed, the ore lay unheeded in a glacial waste pre-dating by many centuries the birth of primitive man.

Although interesting side issues suggest themselves for discussion in connexion with the Gopeng Beds, such, for instance, as their precise mode of deposition, and the abundance of alumina in a pre-Carboniferous magma, indicated by the quantity of pure corundum, and perhaps by the tourmaline-corundum rocks also, I have left such questions for the future, in order to make this paper as short as possible while emphasizing the more important points. There is, however, one matter that I might mention here. If, as I believe to have been the case, huge masses of limestone fell away into the granite magma during a process of magmatic stoping, would not one expect to find support for the hypothesis in the mineral and chemical composition of the granite? Unfortunately, no series of systematic analyses of the granite has been made as yet. But it is significant that, considering the mass as a whole, hornblende is one of the mineral constituents; that in some places, as for instance on the Pahang road near Kuala Kubu, hornblende is abundant; and that a plagioclase felspar is nearly always found in thin sections.

Appendix.

[Owing to the fact that this paper on the Gopeng Beds reached England too late for reading at the final meeting of the Session 1910–1911, it will not be read until November. At the time of writing (September 1911), a year has elapsed since the greater part of the information contained in the paper was collected, and since the paper was despatched a considerable amount of supplementary information has been obtained, strengthening my conclusions. I embody this in the following short appendix.]

(*a*) Absence of Schistosity in the Mass of the Gopeng Beds.

There is now a very clear section exposed at the Tekka Ltd. Mine, showing the junction of the Gopeng Beds and the granite. For a distance of about 10 feet from the granite along part of the junction the Gopeng Beds are distinctly schistose, and there are quartz-veins parallel to the planes of schistosity. The passage from schists to red clay is gradual; and it would appear that the hot granite so far hardened the clays and robbed them of their plasticity at the junction, as to render them capable of taking on a schistose structure. This is not the case, however, in the big Chinese mine on the south. There the clays show nothing that can be called schistosity, and the veins, which are abundant, do not appear to follow any physical feature in the clay. One vein of tourmaline-rock can be traced for 40 feet.

While the phyllites and quartzites are clearly distinct from the Gopeng Beds, it is possible that some pale-grey rocks, resembling phyllites, but much weathered, exposed on the road at the top of a hill not far from Tekkah Sungei Raia, are really grey Gopeng clay retaining a structure imposed by the earth-movements at the time of the granite irruption. I cannot regard this as proved, however, until boulder-clay showing the same structure has been found.

(*b*) Clayey Fault-Breccia.

A very remarkable rock is seen at the Tekka Mine, close to the granite junction. This is a dark-red clay full of angular fragments of tourmaline-rocks, siliceous rocks, and ironstone. These may have formed veins originally, but there can be little doubt that the rock is a fault-breccia in the Gopeng Beds. A photograph was obtained, showing a sharp junction between this breccia and ordinary red clay with small boulders. A smooth face with a surface like that of a slickenside has been seen in this breccia.

(*c*) The Intrusive Veins.

There are now very clear sections on the Kinta Tin-Mines property and on the Gopeng Mining Company's property, showing the kaolin veins cutting the Gopeng Beds. The big vein described on the Kinta Tin-Mines property has been cut down to a lower level, and is now clearly exposed in a ditch: its width is about 60 feet, and it contains a considerable quantity of quartz. In part the kaolin in this vein is compact, and has to be broken with a hammer to disintegrate it.

On the Gopeng Mining Company's land the vein containing lepidolite has been cut away to a lower level also, and shows some good sections of the junction with the Gopeng Beds. The lepidolite is abundant, and so is quartz. Tourmaline occurs sparingly.

I have lately seen another kaolin vein in the Tekka Valley, with stringers of tourmaline running through it. It is intrusive into grey boulder-clay of the Gopeng Beds.

(*d*) Buried Trees.

Two more buried trees have been found, and both have a sandy casing. There can be no doubt that these trees fell down into their present position at a comparatively recent date, and that the holes into which they fell were filled up from above.

(*e*) Extensions of the Gopeng Beds.

Field-work during 1911 has shown that there is a northward extension of the Gopeng Beds. They have been traced for 12 miles from Gopeng township, and throughout the extension they are faulted down against the crystalline limestone by a north-and-south fault. A few of the peculiar flat boulders of granite have been found, and corundum boulders occur in the beds near Ampang.[1] There is further evidence of intrusive veins from the granite.

On the west side of the Kinta Valley evidence is accumulating that points to the clay there being glacial also, and to the tourmaline-corundum rocks being included boulders. Mr. W. M. Currie has given me a flat boulder of granite from the Siputeh Ltd. Mine analogous to those found about Gopeng and Pulai; and in the same mine it appears that big boulders of tourmalinized sandstone, veined with quartz carrying tin-ore in the form of large cassiterite crystals, and having similar ore in the body of the rock, may be boulders of glacial origin also. They occur in stiff clay with angular tin-ore disseminated through it, as at Gopeng.

(*f*) Final Conclusions.

On reviewing all the evidence obtained since July 1910, it is impossible to doubt that the Gopeng Beds are older than the Mesozoic granite. This is clearly proved by the numerous sections of the veins of kaolin, and the sections of the actual junction with the granite. The field evidence is overwhelming: there can be no doubt, moreover, that the bulk of the tin-ore in the beds was not derived from the Mesozoic granite, but from a much older granite, known to us at present only by the boulders in the clays; and that, on the other hand, a second supply of ore, resulting in local enrichment at the junction with the granite and near the veins,

[1] A village beyond the limits of the map (fig. 1, p. 141).

has been brought by the younger granite mass. The older ore may be readily distinguished from the younger ore by the fact that the latter occurs as unworn crystals of cassiterite.

The more I see of the Gopeng Beds in the splendid sections afforded by the hydraulic and other mines, the more secure do I feel in my opinion that these beds are of glacial origin. I cannot expect others, however, who cannot possibly visit the locality, to feel the same confidence, more especially since clear photographs are difficult to obtain on account of the uniform, and generally pale-grey, colouring of the sections, and on account of the fact that (except in a few cases) the smaller boulders are so weathered as to fracture as though they were part of the clay when a bank falls in the course of mining, with the result that it is uncommon to find them standing out in relief. That I am not entirely unsupported, however, will be seen from a letter to the 'Mining Journal' of July 1st, 1911, in which Mr. F. E. Mair says that my arguments in favour of a glacial origin are convincing. Another mining engineer, who was once assistant Manager on the Kinta Tin-Mines, has remarked to me on the resemblance of some sections to the drift sections on the Norfolk coast.

The absence of any striations on the boulders will appear remarkable to those who do not appreciate the extraordinary power of weathering in a humid, tropical climate; but no one who has seen how the hardest siliceous rocks can be reduced to a friable state, simply by the removal of silica in solution, could expect to find the surface of the boulders fresh enough to retain such markings.

In Chamberlin & Salisbury's 'Geology: Earth History' vol. iii (1906) there are some illustrations of drift to which sections that I have seen at the Gopeng mines bear a striking resemblance. Thus on p. 338 is a photograph of stratified drift that might have been taken on the Gopeng Mining Company's land. On p. 378, again, is shown a section of stratified and unstratified drift that might serve for parts of the Gopeng Beds, if the boulders did not stand out so prominently.

The climatic evidence afforded by the Gopeng Beds is very valuable, in that it gives so sure a basis of correlation. In the words of the authors of the 'Manual of the Geology of India' (2nd ed. 1893, p. 206),

> 'it is consequently justifiable to use these glacial deposits for the purpose of correlation, and to conclude that the boulder-beds of the three continents were formed contemporaneously.'

So far as can be judged by the scanty palæontological evidence, the Gopeng Beds are where we might expect to find glacial beds in the succession; but they naturally differ very considerably from the other boulder-beds in petrological composition, because the ice that was instrumental in their formation passed over stanniferous rocks rich in the minerals that constitute the usual satellites of cassiterite: namely, tourmaline, topaz, and kaolin.

Postscript.

[As this paper goes to press, I am able to add that Mr. W. R. Jones, F.G.S., lately appointed Assistant Geologist to the Federated Malay States Government, has been over most of the ground described in this paper with me and by himself, and that to him also a glacial origin seems the only possible explanation of the peculiarities of the Gopeng Beds. I took particular care to ask Mr. Jones to consider the possibility of their being 'torrential deposits.' This possibility I have, of course, considered myself, and rejected.—*J. B. S., April 22nd, 1912.*]

9. *The* Glen Orchy Anticline (Argyllshire). By Edward Battersby Bailey, B.A., F.G.S., and Murray Macgregor, M.A., B.Sc. (Read February 28th, 1912.)

[Plate X—Map.]

Contents.

I. Introduction.

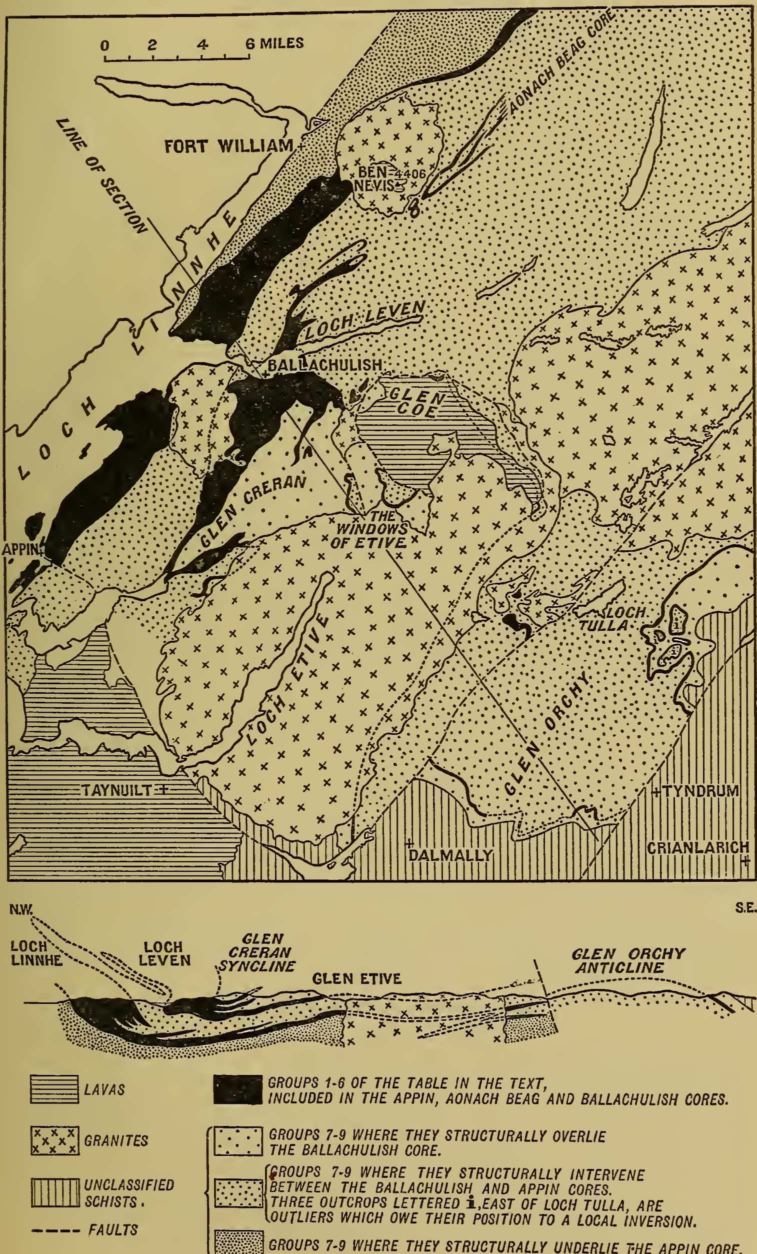
In a previous paper [1, p. 586][2] an explanation has been offered of the tectonics of the schists occupying a district of the West Highlands between Loch Tulla and Appin, in the south, and the River Spean, beyond Ben Nevis, in the north (fig. 1). In the present paper the south-eastern continuation of this district is dealt with, from the head of Loch Awe to Beinn Achallader, one of the summits of the Beinn Doirean range (Pl. X). In the district originally described lying to the west and north of Loch Tulla the following stratigraphical sequence was established; but, whether it should be read upwards or downwards, is still unascertained:—

9. Eilde Flags.
8. Glen Coe Quartzite (fine-grained).
7. Leven Schists (grey phyllites, with 'Banded Series' next the Glen Coe Quartzite).
6. Ballachulish Limestone (dark grey, with a thick cream-coloured margin next the Leven Schists).
5. Ballachulish Slates (black).
4. Appin Quartzite (pebbly).
3. Appin Limestone (cream, pink, or very pale blue).
2. Appin Phyllites (with a large proportion of flaggy quartzite).
1. Cuil Bay Slates (black).

These rock-groups, as previously shown, are disposed in two major recumbent folds, known as the Ballachulish and Appin Folds respectively, to which may be added the subordinate Aonach Beag Fold, recognized as yet in the neighbourhood of Ben Nevis only. For convenience of description, the cores of these three folds have been arbitrarily defined as those portions which are made up of

[1] Pronounced approximately Ben Oodly.
[2] References in square brackets are to the Bibliography, § V, p. 178.

Fig. 1.—*Sketch-map and section illustrating the effect of the Glen Creran Syncline and Glen Orchy Anticline upon the recumbent folds of Ballachulish and Appin. (Scale of map=1 : 506,880.)*



rocks included in Groups 1–6 of the foregoing stratigraphical table. Fig. 1 (p. 165), which shows the new district in relation to the old, has been constructed on this basis, and illustrates very clearly how the Ballachulish Core has been bent into a widely-extended secondary syncline in Glen Creran and into a corresponding anticline in Glen Orchy. The presentation of the evidence which has enabled us, as we believe, to trace the outcrop of the Ballachulish Core round the rim of the denuded Glen Orchy Anticline is the main feature of the following account. Incidentally, however, a description is given of a particularly convincing example of a recumbent fold in Beinn Udlaidh, and of an important inversion of the Ballachulish Core in Beinn Doirean.

II. History of Research.

A comparison between our map (Pl. X) and the adjacent northern corners of Sheets 45 & 46 of the Geological Survey Map of Scotland shows many new features of importance. The subdivision of the schists did not attract special attention when the original mapping of this particular district was carried out. Before publishing Sheet 45, however, a joint traverse of a few days' duration was undertaken in 1907 by Dr. Horne, Mr. Clough, and Mr. J. B. Hill, to revise the boundary-line of the Eilde Flags, or, as they were called at that time, the 'Moine Series.' For one day Mr. Kynaston was also present, as he happened to be in Scotland on furlough from the Transvaal. The party kept to the east of the fault which runs up Glen Strae, and for this part of the district the line engraved on the published map to represent the boundary of the 'Moines' has been of great service to us. During the same visit the quartzite and mica-schist of Beinn Udlaidh were differentiated from the 'Moine Series' along the bottom of Glen Orchy, where this valley enters Sheet 45. The quartzite of the Beinn Udlaidh outcrop was considered to be quite distinct from that which occurs south-west of the 'Moine Series' farther down the glen. In the following pages we suggest, however, that these two quartzites are on one and the same horizon; but this is a matter wherein there is still room for differences in regard to interpretation. The results of the joint traverse were incorporated [2, p. 38] in a short account published in the Memoir dealing with Sheet 45.

In 1908 one of the present writers accompanied Mr. Clough [3, p. 63] on a second brief visit to the district; it was hoped, and the hope was justified, that light would be thrown upon the stratigraphical succession of the schists in the complicated country north-west of the Etive Granite. Much was learnt during the traverse, mainly as a result of Mr. Clough's experience in mapping Highland schists. The Beinn Udlaidh quartzite and mica-schist were carried eastwards into Sheet 46, where the latter had already been in part separated from the 'Moines' by the late Mr. Grant Wilson. The folded nature of the Beinn Udlaidh rocks was suspected, but not proved. It was found, too (as was, in fact, already known at the time), that a band of rock mapped as epidiorite by Grant Wilson around the flanks of the Beinn Doirean range (Sheet 46) was in reality a tremolite-schist representing an impure limestone, frequently accompanied, it is true, by definite sills of epidiorite. The Allt Coire an Easain section was mapped, and a metamorphic limestone was found in it. This and the Beinn Doirean limestone were both taken to be on the same horizon as another better-known limestone already mapped by Messrs. Kynaston, Maufe, and Clough in the region of the Windows of Etive. During the same traverse the Loch Dochard limestone was visited and its true nature recognized by Mr. Clough, who, in Mr. Kynaston's absence, modified the account given of it in the Memoir descriptive of Sheet 45, then passing through the press. Another conclusion arrived at as a result of this traverse was the correlation of the mica-schist mapped by Grant Wilson in Beinn Doirean with that occurring in the Beinn Udlaidh, Loch Dochard, Allt Coire an Easain, and Etive sections. This correlation has subsequently been maintained, although in 1910 it was pointed out that the Loch Dochard mica-schist is probably on a much lower structural level than that of Allt Coire an Easain and of the region around the Windows of Etive [1, p. 616].

The results outlined above were all obtained by members of the Geological Survey Staff employed in their official capacity. Our field-work last year was carried on in holiday-time. As will be seen presently, it has confirmed the suggestion just mentioned in regard to the relative structural positions of the mica-schists of Loch Dochard and Allt Coire an Easain, and has shown, what was totally unexpected even in 1910, that the mica-schist of Beinn Udlaidh is similarly situated on a much lower structural level than that of Beinn Doirean. Another unforeseen discovery is the finding of outliers on the summits of the Beinn Doirean range in which the Beinn Doirean limestone and its associated strata occur in inverted sequence, as compared, that is, with the succession prevalent throughout the rest of the district now considered.

This last result was obtained by Mr. Macgregor, who has remapped the Beinn Doirean range. Beinn Udlaidh and the country to the south has been revised by Mr. Bailey. The Loch Dochard Fold, and the sections of Allt Coire an Easain and of the Windows of Etive, have not been re-examined since the publication of the earlier paper already referred to [1].

III. Tectonics.

In describing the geology of the Glen Orchy district there can be no question as to where we should begin. Beinn Udlaidh affords a firm foundation whereon to build.

(A) The Beinn Udlaidh Fold.

Three rock-groups enter into the composition of the Beinn Udlaidh Fold—a flag group, a quartzite group, and a mica-schist group.

Fig. 2.—*Geological map of Beinn Udlaidh, on the scale of 1 : 80,000.*

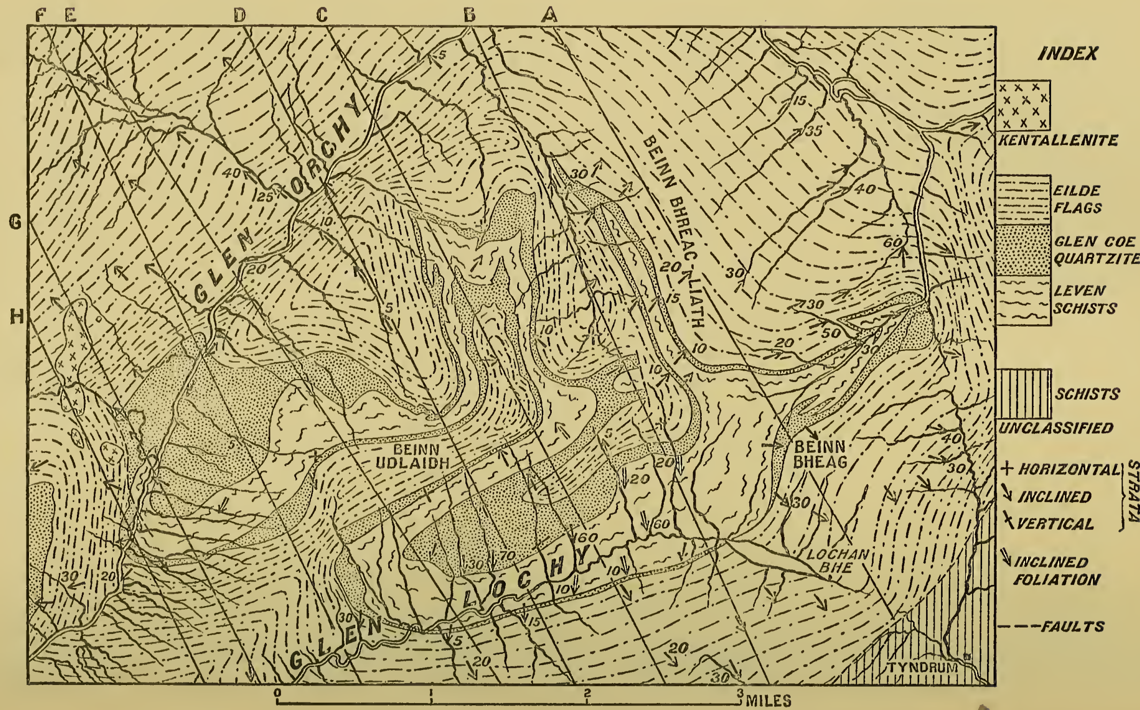
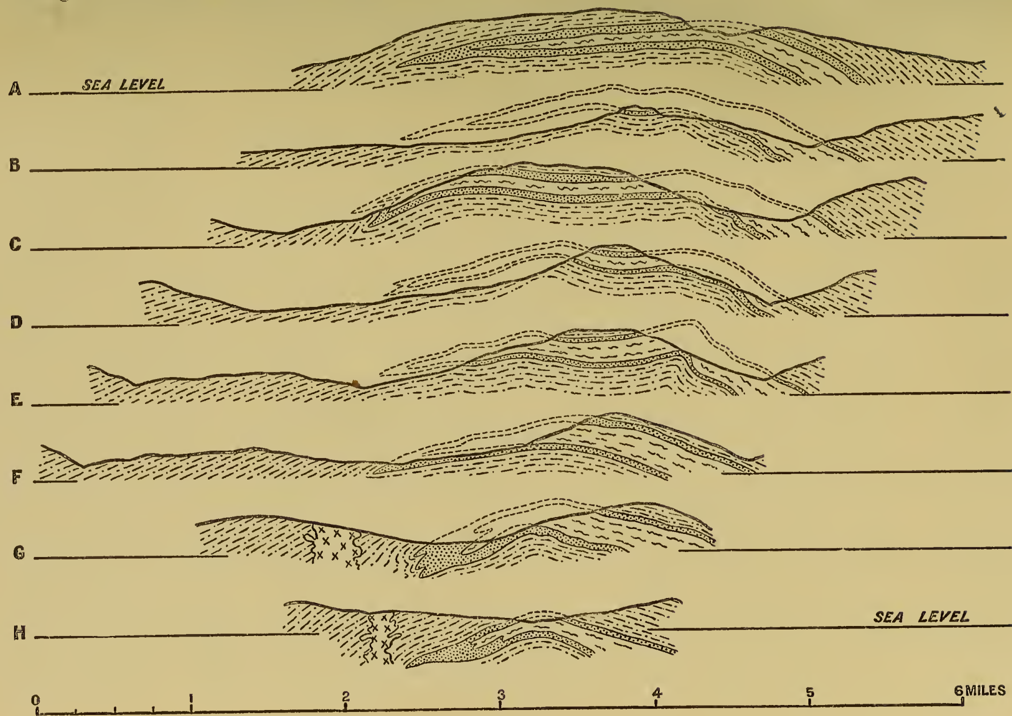


Fig. 3.—*Serial sections across Beinn Udlaidh. (Horizontal and vertical scale=1 : 80,000.)*



The flag group consists of well-bedded quartzo-felspathic gneisses, in which there is a constant alternation of more and less micaceous layers. In places small pebbles of quartz or felspar have been recognized, but it is fairly certain that the original impure sandy sediments, from which the gneissose flags have been derived, were essentially fine-grained. The flags occurring in Beinn Udlaidh resemble exactly the Eilde Flags of the Loch Eilde district east of Loch Leven, and we have accordingly placed them in this group. Rocks of like character occur, almost uninterruptedly, between Beinn Udlaidh and Loch Eilde; although, since they are crossed by the Glen Strae Fault and also by the Glen Coe Fault with its accompanying Fault-Intrusion [4, p. 611], their outcrop cannot properly be described as continuous. Over 500 feet of flags are exposed in the slopes of Beinn Udlaidh, and the group is certainly very thick indeed.

The succeeding division consists of fine-grained, white, highly siliceous, thinly-bedded quartzite. In Beinn Udlaidh it varies in thickness from about 50 to 100 feet; but it is much thinner south of Glen Lochy, where it averages about 15 feet—and for a short distance north of Lochan Bhe (pronounced Vay) it is entirely absent. Apart from its small thickness and its thinly-bedded character, this quartzite agrees very closely with the Glen Coe Quartzite of the type-locality. Since, moreover, the sediments associated with it on either side are precisely such as accompany the Glen Coe Quartzite, we feel great confidence in referring it to this well-known horizon.

In certain outcrops previously described in connexion with the Glen Coe district, among them that situated near Loch Dochard, which is included in the map (Pl. X) accompanying the present paper, the Glen Coe Quartzite is very thin, and in some cases altogether absent. Such occurrences, up to the present, have all been explained as a result of sliding[1]; but we hesitate, without local evidence, to extend this interpretation to account for the thinness of the Glen Coe Quartzite in Beinn Udlaidh. It seems equally probable here that the feature may be an original sedimentary character.

A banded passage-zone links together the quartzite and mica-schist groups of Beinn Udlaidh. It is very well exposed in the northern spur of the mountain crossed by Section C (figs. 2 & 3, pp. 168 & 169), and also at the side of the road which runs along Glen Orchy (Section H). In the latter locality the Banded Series, as we may call it, consists of intercalated quartzite and grey mica-schist, with thin black seams of pelitic material. An exactly similar banded series links the Glen Coe Quartzite of the Loch Leven and Glen Nevis district with the Leven Schists.

The main mass of the mica-schist group of Beinn Udlaidh consists of well-crystallized, homogeneous, grey, pelitic mica-schist, often studded with conspicuous garnets. Garnets are well

[1] Slide is used throughout this paper as a synonym of fold-fault [1, p. 593].

known in the Leven Schists of the type district, but are not often really conspicuous, except in the outcrop which passes immediately west of the Kinlochleven Reservoir. Apart from this difference, depending upon metamorphism, the mica-schists of Beinn Udlaidh resemble the Leven Schists of Loch Leven and Glen Nevis very closely; and, as the rest of the sequence is so clearly comparable, we have no hesitation in regard to their correlation with this group.

The tectonics of Beinn Udlaidh are extremely simple and diagrammatic. The Leven Schists and Glen Coe Quartzite have been folded into the heart of the Eilde Flags in the form of a recumbent anticline[1] closing towards the north-west. The minimum magnitude of this Beinn Udlaidh fold is 2 miles. Owing to a variety of favourable circumstances—including the nature of the topography, the abundance of exposures, the marked lithological contrasts, the absence of slides, and also of any serious complication due to later movements,—the Beinn Udlaidh fold is clearer and more readily understood than any yet described in the Scottish Highlands; in fact, it can take its place alongside of the best examples of small-scale recumbent folds afforded by the Alps.

Localities showing the close of the fold are, of course, of critical importance. They are two in number: one of them is the steep western slope of Beinn Bhreac Liath[2] lying between Sections A & B (figs. 2 & 3, pp. 168 & 169). Exposures are not continuous in the most important part, but they are fully sufficient, for at short intervals the hill is washed bare by lateral streams; at the south-eastern end of the slope the escarpments of the various bands give rise to conspicuous crags. Half-way up the hill-face a thick mass of gently-inclined mica-schist forms a very definite belt, with quartzite and flags both above and below; in a north-westerly direction this belt of mica-schist thins out, allowing the upper and lower bands of quartzite to come together: finally, the quartzite disappears, and the flags are left continuous.

The other locality for showing the close of the fold is situated at the bottom of Glen Orchy (Sections F, G, & H, p. 169). Nothing could be much clearer, once the mapping has been completed, than the manner in which the band of Glen Coe Quartzite, underlying the Leven Schists, sweeps across the River Orchy to meet the band which overlies the same. A little west of the crucial point the overlying band is displaced by a small normal fault; but, fortunately, this accident does not in the least affect the matter at issue. Exposures, although not continuous, are quite adequate, and can be reached at once from the road and from a bridge which crosses the River Orchy in the most convenient position imaginable.

As appears from the map and sections (figs. 2 & 3, pp. 168 & 169),

[1] *Anticline* is here used in the sense of *anticline of observation* [1, p. 600]; there is no implication that the Leven Schists and Glen Coe Quartzite are older than the Eilde Flags.

[2] Pronounced approximately *Ben Vrec Leea*.

the Beinn Udlaidh Fold has been bent into a gentle secondary anticline, which in the vicinity of Beinn Udlaidh is very clearly dome-shaped. This dome is a part of the extensive anticlinal structure already spoken of as the Glen Orchy Anticline. Readers familiar with Scottish geology will not fail to realize the essential resemblance between the Beinn Udlaidh Fold bent into the Glen Orchy Anticline and the Carrick Castle Fold bent into the Cowal Anticline, as described several years ago by Mr. Clough [5, fig. 47, p. 204, & pl. x].

(B) The Loch Dochard Fold.

At Loch Dochard the Eilde Flags enclose a mass of garnetiferous mica-schist, with a central core of tremolite-schist representing limestone. Thin quartzite locally occurs at the junction of the flags and the mica-schist. Upon indirect evidence the mica-schist and the limestone have been correlated with the Leven Schists and the Ballachulish Limestone respectively, and it has been suggested that they occupy an anticlinal fold rising up from beneath the Eilde Flags [1, p. 616]. Analogy with the Beinn Udlaidh Fold greatly strengthens this interpretation. At the same time, the relation of the two folds cannot be very simple, for the Leven Schists of Loch Dochard are exposed far to the north-west of the line along which the Glen Coe Quartzite and Eilde Flags close round the termination of the Leven Schists of Beinn Udlaidh.

(C) Rocks overlying those of the Beinn Udlaidh and Loch Dochard Folds.

A glance at the map (Pl. X) shows that a well-defined succession of rocks follows the Eilde Flags that overlie the other groups included in the Beinn Udlaidh and Loch Dochard Folds. This succession, stated in downward structural sequence, is as follows:—

(*e*) Unclassified schists, consisting, in their lower part, of pebbly quartzite and black pelitic schist.
(*d*) Thick grey pelitic schists.
(*c*) Thin limestone.
(*b*) Banded pelitic schists and quartzite.
(*a*) Quartzite, locally very thick.

(*a*) On the east side of the Glen Orchy Anticline the quartzite overlying the flags first puts in an appearance in Beinn Doirean. When followed southwards it swells out enormously, and where it crosses Glen Orchy it is fully 1000 feet thick. In most of its course the whole of the deposit is somewhat impure, and of a grey or pinkish tint. In Glen Orchy, however, especially in the south-western slopes, there is a thick mass of pure white siliceous quartzite at the top of the group. On both sides of Glen Strae, pebbles can be readily detected, and in Allt a' Ghiubhais[1] they are very large and abundant; but elsewhere the quartzite is thoroughly fine-grained.

[1] Pronounced approximately Alt a Gyuse. It is the tributary, shown in Pl. X, entering Glen Strae almost at right angles from the east.

The north-western side of the Glen Orchy Anticline is in large measure obliterated by the Etive Granite; but in Allt Coire an Easain, within the boundary-fault of the cauldron subsidence of Glen Coe, thin quartzite follows the Eilde Flags in a perfectly regular manner. It will be noticed that in the diminished thickness of its quartzite Allt Coire an Easain agrees very closely with Beinn Doirean, which it directly faces across the anticline of Glen Orchy. The thinning in Allt Coire an Easain is but local, moreover, and 2 or 3 miles to the north-west the quartzite emerges in great force from beneath an unconformable covering of Glen Coe lavas. It is also exposed in the Windows of Etive half a dozen miles west of Allt Coire an Easain, and here again it is of considerable thickness. In all these north-western exposures the quartzite is fine-grained, white, and highly siliceous, and it has been proved beyond reasonable doubt to belong to the horizon of the Glen Coe Quartzite [1, pp. 607 & 609]. Accepting this correlation, it is fair to draw the following important conclusion. The Eilde Flags, although underlain by Glen Coe Quartzite in Beinn Udlaidh, are overlain by the same group all round the rim of the denuded Glen Orchy Anticline from Allt Coire an Easain to Beinn Doirean. This involves, of course, the existence of a large-scale recumbent fold.

It may be pointed out that the rather impure character of the Glen Coe Quartzite, in the upper limb of the fold just mentioned, can be paralleled in the type region in many outcrops north of Loch Leven. In these, however, the somewhat impure variety is as a rule closely associated with the more conspicuous white rock, which is justly regarded as typical of the Glen Coe horizon.

The thinning of the Glen Coe Quartzite in Allt Coire an Easain and Beinn Doirean deserves closer investigation than we have been able to afford, for the time at our disposal was strictly limited.

(*b*) The Glen Coe Quartzite, everywhere in its course around the Glen Orchy Anticline, except perhaps in Allt Coire an Easain, is overlain by a Banded Series of grey mica-schist with quartzite ribs. Where it is exposed in the Windows of Etive, this Banded Series has been shown to be that part of the Leven Schists which normally comes next to the Glen Coe Quartzite.

(*c*) In the Beinn Doirean range the Banded Series is overlain immediately by a somewhat calcareous tremolite-schist which varies from about 5 to 30 feet in thickness. This impure highly-metamorphic limestone is more persistent in a northerly direction than the underlying Banded Series and Glen Coe Quartzite, so that for some few miles it rests directly upon the Eilde Flags.

It is found again, with about the same thickness, along the southern rim of the Glen Orchy anticline, where it has been traced for considerable distances. It is not so highly metamorphic here as in Beinn Doirean. On the summit south of Glen Lochy, for example, where reference to Mr. Kynaston's field-maps shows that he was the first to note its presence, it contains very little tremolite indeed, and is most fitly described as a grey, highly calcareous mica-schist, with occasional seams of cream-coloured limestone. The next good exposures of the limestone are met with in Glen Orchy, near a sheepfold close to the road and in several streams draining the ridge on the north-west side of the valley; in fact, Mr. J. B. Hill shows it on the published 1-inch map, Sheet 45, near the summit of this ridge, and has also noted its presence in his field-maps—along a tributary stream flowing in the opposite direction into Glen Strae. In these exposures it is sometimes about 40 feet thick, and is a cream-coloured limestone, sandy and micaceous, and, so far as has been observed, free from tremolite. On the west of Glen Strae it has been traced in clear exposures for half a mile from the margin of the Etive Granite towards Loch Awe; it is here 20 or 30 feet thick, and is in the condition of calc-silicate-hornfels owing to the proximity of the Etive Granite. It is similarly affected by the granite where it reappears in Allt Coire an Easain and in the Windows of Etive.

In these two last-mentioned exposures it has been proved that the limestone belongs to the Ballachulish Limestone Group; and that it is underlain by a fold-fault, known as the Ballachulish Slide, which cuts out the thick pelitic portion of the Leven Schists that one might expect to find between this limestone and the Banded Series below [1, pp. 607 & 609]. As the condition of affairs characteristic of these north-eastern sections continues throughout the region now under consideration, it seems necessary to suppose that here also the Ballachulish Limestone rests upon the Ballachulish Slide; and incidentally we are led to postulate a displacement of 24 miles, or more, along this slide-plane. It is possible that the marked transgression of the limestone, which brings it to rest directly on Eilde Flags north of Beinn Doirean, is due to the Ballachulish Slide; but this is a point which has not been closely investigated in the field.

(*d*) The grey pelitic mica-schist which follows above the limestone is a most useful group, from the map-maker's point of view, on account of its being very thick and therefore conspicuous. At the northern extremity of the Beinn Doirean range it contains a considerable proportion of quartzose material; but in Beinn Achallader, Beinn Doirean, and Beinn a' Chaisteil it is very free from such intercalations, and is a massive garnetiferous mica-schist of the type that occurs in the heart of the Beinn Udlaidh Fold. In some sections this massive mica-schist starts immediately on the top of the limestone; in others it contains a band or so of quartzite interbedded near its base. South of Glen Lochy the mica-schist is again garnetiferous, and contains quartzite bands—some of which lie a little above the limestone. In the Glen Orchy exposures and in the outcrop near Loch Awe, west of the Glen Strae Fault, bands of quartzite are found in the mica-schist near the limestone; and above this comes massive grey pelitic schist, very seldom garnetiferous. In Allt Coire an Easain and in the Etive sections the limestone is succeeded by a great thickness of grey pelitic mica-schists, free from quartzite and locally garnetiferous; in these north-eastern sections it is quite certain that we are dealing with the pelitic portion of the Leven Schists.

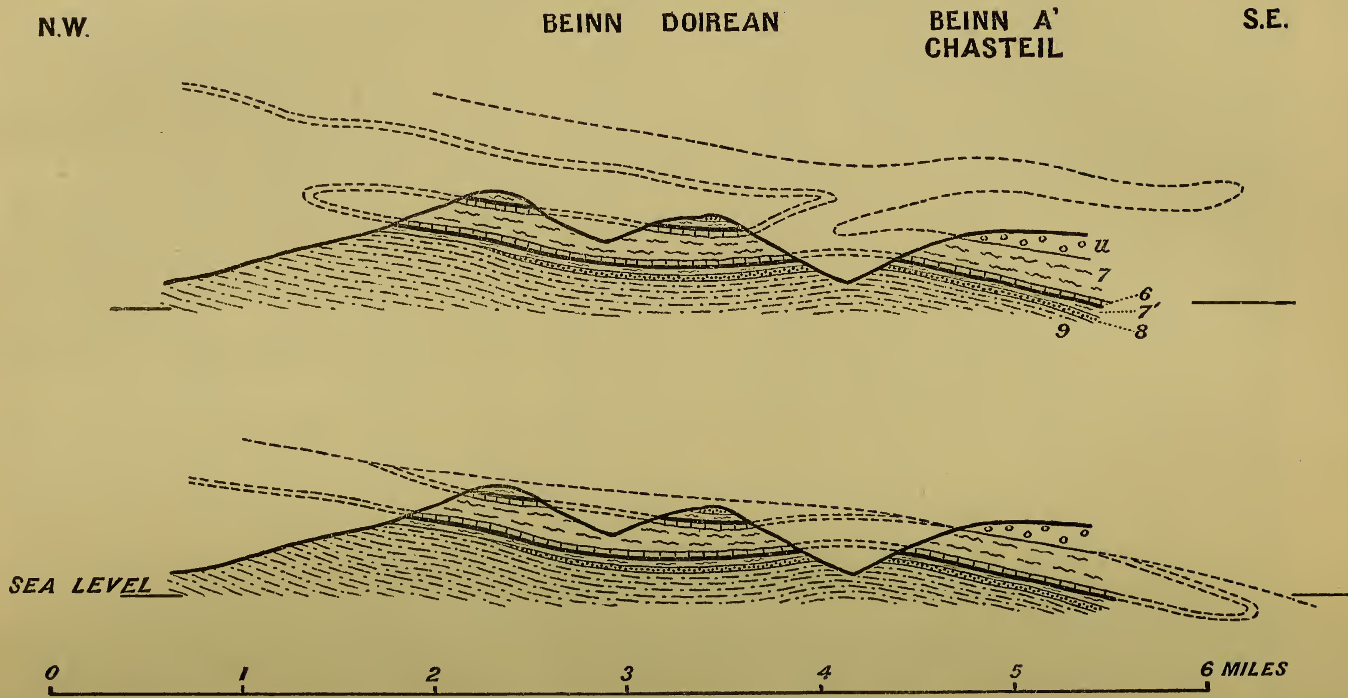
In one feature, the presence of thin quartzite bands between the limestone and the main mass of the pelitic schists, the sections round the southern rim of the Glen Orchy Anticline differ from many of the Beinn Doirean exposures and also from those afforded by the whole of the type-region of Ballachulish, including Allt Coire an Easain and Glen Etive. In the type area the Ballachulish Limestone is, it is true, sometimes extremely siliceous near its junction with the Leven Schists; but, at the same time, actual bands of quartzite are not known to occur in the mica-schist close to the limestone. We emphasize this difference because the natural way to read the southern sections, if we pay no regard to the Ballachulish and Glen Coe evidence, is to interpret the limestone as merely marking an episode in the accumulation of the Banded Series. On account of the Ballachulish and Glen Coe evidence, however, we regard the local appearances as deceptive in this matter, and we believe that the quartzite bands overlying the limestone are quite distinct from those of the Banded Series underneath.

The assumption that a few thin beds of quartzite have locally come into the Leven Schist Group near its junction with the Ballachulish Limestone is, in itself, by no means startling. It is much easier to accept this than to dispute the correlation of the Beinn Doirean, Glen Orchy, Allt Coire an Easain, Glen Etive, Glen Coe, and Ballachulish Limestones.

(*e*) The Leven Schists overlying the Ballachulish Limestone east and south of the Glen Orchy Anticline are succeeded by a thick group of pebbly quartzites and black pelitic schists. In Beinn a' Chaisteil and near the head of Loch Awe there is a strong development of pebbly quartzite at the base of the group. In the intervening Glen Orchy district, however, this quartzite is not very recognizable. The line inserted on our map for the base of this pebbly quartzite and black schist group, indexed as 'unclassified schists,' is strictly provisional: we have as yet merely raised the question of the relation of these schists to the Leven Schists below, without having had time to carry through an investigation of the subject. The evidence so far obtained is conflicting: on the one hand, there are suggestions in some localities, especially in Glen Orchy, of a transitional zone linking the Leven Schists with the pebbly quartzites and black schists above; on the other hand, one cannot help suspecting that this appearance is deceptive, since in the Glen Etive district the pelitic portion of the Leven Schists is capped by outliers of perfectly normal Banded Series and Glen Coe Quartzite.

The Beinn Doirean range will probably supply the answer to our

Fig. 4.—*Alternative interpretations of the Beinn Doirean inversion. (Line of section shown on the map, Pl. X. Horizontal and vertical scale=1 : 63,360.)*



[6=Ballachulish Limestone; 7=Leven Schists; 7′=Banded Series of Leven Schists; 8=Glen Coe Quartzite; 9=Eilde Flags; *u*=Pebbly quartzite of the 'unclassified schists.' The heavy black band indicates the course of the Ballachulish Slide.]

riddle when it comes to be more fully investigated, especially in its northern continuation. Meanwhile, we take this opportunity of drawing attention to a feature in the tectonics of the range which may in the future prove to be of decisive importance in solving the problem.

(D) The Beinn Doirean Inversion.

The massive garnetiferous mica-schist of the Beinn Doirean range is capped by three important outliers, in which the structural sequence, given in descending order, is as follows :—

Fine-grained quartzite.
Banded mica-schist and quartzite.
Thin calcareous tremolite-schist.

After careful examination, it seems practically certain that we are dealing here with exactly the same sequence as that which underlies the garnetiferous mica-schist, only in inverted order. It is a very small point of difference that quartzite is found farther north in the outliers than in the basal outcrop. The broad exposures of the Banded Series in the outliers are due, not to any excessive thickness of the group, but merely to the form of the ground.

The question immediately arises : what is the relation between these inverted outcrops and the pebbly quartzite of the 'unclassified schists' on the east? Two alternative explanations suggest themselves (fig. 4, 176), and we have, as yet, not been able to decide between them. Even a preliminary examination makes it clear, however, that the pebbly quartzite rests either directly, or almost directly, upon the great garnetiferous mica-schist. Accordingly, we followed the approximate junction of the two, in a hurried traverse, in order to see whether we could identify the thin zones of the outliers in this position. In a cliff-exposure in Beinn a' Chaisteil we found what might stand for representatives of this sequence, including a thin tremolite-schist; but we prefer for the present not to lay much stress on this coincidence, as our search at other points remained unrewarded.

IV. Difficulties.

Our main conclusions and suggestions are sufficiently summarized in the maps and sections which accompany this paper. In the following paragraphs a few important difficulties will be dealt with in succession.

(*a*) No definite zone of mylonite marks the outcrop of the Ballachulish Slide in this, any more than in the type region. In explanation it is suggested that sliding, when it occurs under conditions such as lead to regional metamorphism, does not necessarily result in the production of mylonite.[1]

[1] Mr. Clough draws our attention to the fact that the pre-Torridonian thrusts of the North-West Highlands are not invariably accompanied by mylonites.

(*b*) The persistence of a thin remnant of the Ballachulish Limestone for many miles immediately above the Ballachulish Slide is not what one would expect *à priori*. In fact, all the phenomena revealed in the district here described can quite well be accounted for, without invoking a slide at the base of the limestone at all. The need for caution in interpreting the type sections in the neighbourhood of Ballachulish, north and south of Loch Leven, and in Glen Creran [1, pp. 605 & 609] is correspondingly increased; but the evidence in these localities is so definite that we have not felt ourselves at liberty to abandon it.

(*c*) In the great spread of southern schists, which we treat as 'unclassified' for the purposes of the present paper, there are many sheets of foliated basic igneous rocks. Some of these Dr. Peach [6, chap. vii] has clearly shown to represent ancient lavas, contemporaneous with the sedimentary schists among which they occur. Many, on the other hand, have been proved to be intrusive, but until recently it has been assumed that even these intrusions are of earlier date than the folding of the schists. Since the recognition of great horizontal movements in the schists, this interpretation has been questioned. In the lower part of Glen Creran (fig. 1, p. 165), for instance, many small, foliated, basic intrusions of restricted distribution occur in equal abundance on the two sides of the Ballachulish Slide, as if they are of later date than all, or almost all, the movement which has taken place along the slide [7, p. 188]. In like manner, in the district here described, sheets of epidiorite occur fairly often for some distance below the base of the 'unclassified schists,' and are especially common in this position in association with the limestone of the Beinn Doirean range. If a great slide is eventually demonstrated at the base of the 'unclassified schists,' it will probably be necessary to assign these epidiorite intrusions also to a late date in the tectonic history of the district.

V. Bibliography.

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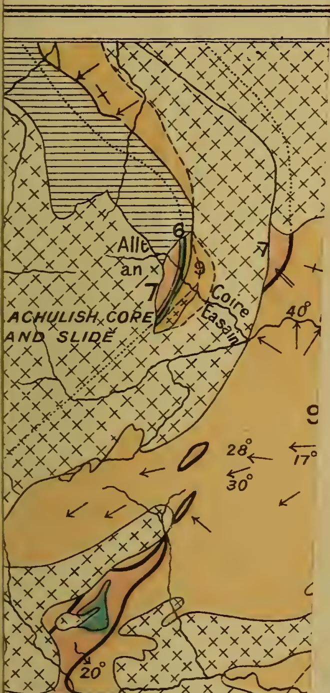
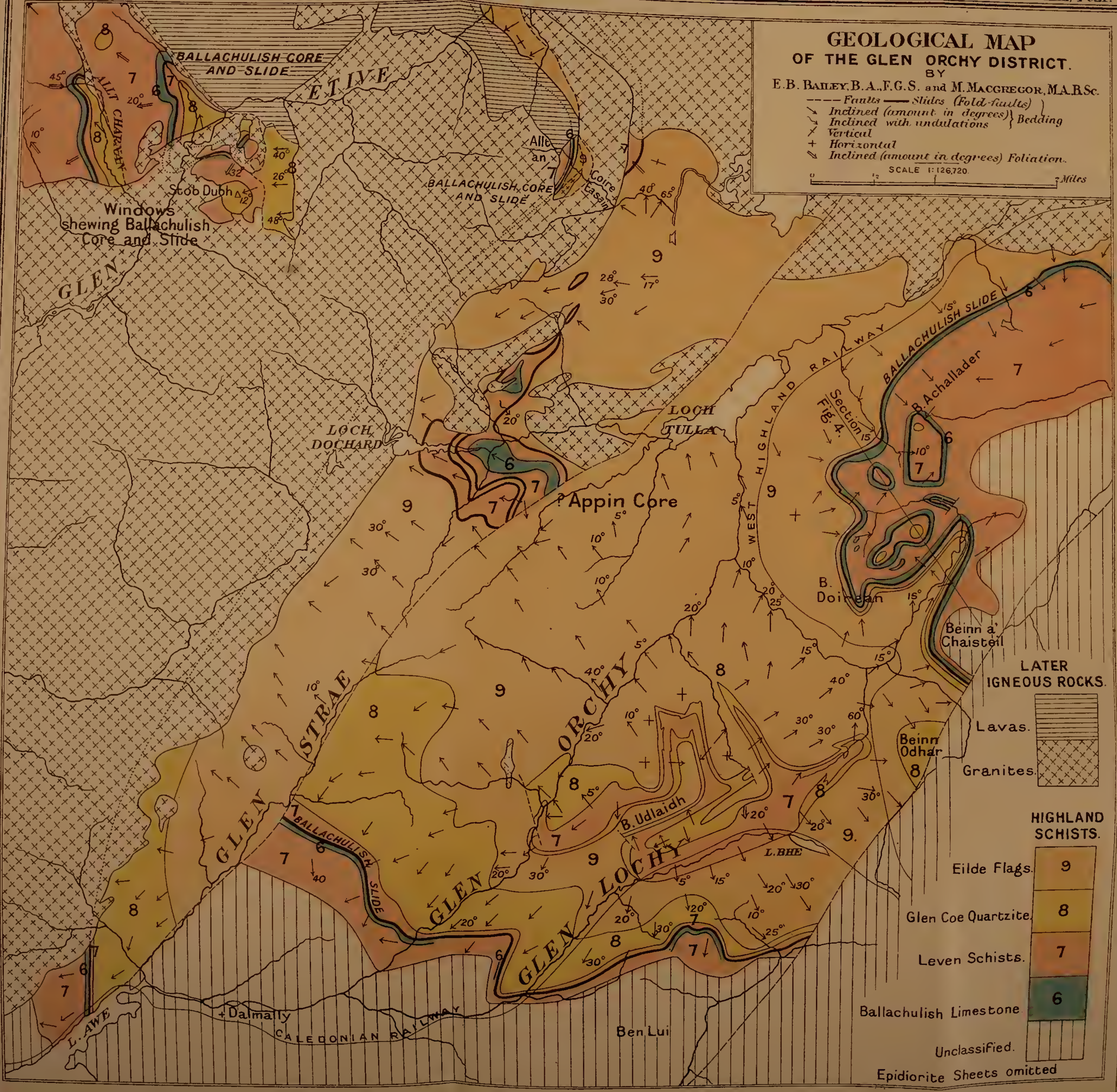
6. B. N. Peach, in 'The Geology of Knapdale, Jura, & North Kintyre' Mem. Geol. Surv. Scotl. 1911.
7. E. B. Bailey, 'The Geology of the Neighbourhood of Fort William' Proc. Geol. Assoc. vol. xxii (1911) pp. 179-203.

EXPLANATION OF PLATE X.

Geological map of the neighbourhood of Glen Orchy, on the scale of 2 miles to the inch, or 1 : 126,720. (By a draughtsman's error, the inch-scale has been wrongly lettered on the map.)



Allt
an
ACHULISH CORE
AND SLIDE
Coire
Easain
48°
28°
17°
30°
20°


GEOLOGICAL MAP
OF THE GLEN ORCHY DISTRICT.
BY
E. B. Bailey, B.A., F.G.S. and M. Macgregor, M.A., B.Sc.
Faults
Slides (Fold-faults)
Inclined (amount in degrees)
Inclined with undulations
Bedding
Vertical
Horizontal
Inclined (amount in degrees) Foliation.
SCALE 1:126,720.
Miles
LATER IGNEOUS ROCKS.
Lavas.
Granites.
HIGHLAND SCHISTS.
Eilde Flags.
9
Glen Coe Quartzite.
8
Leven Schists.
7
Ballachulish Limestone
6
Unclassified.
Epidiorite Sheets omitted
BALLACHULISH CORE AND SLIDE
ETIVE
ALLT CHARNAN
Stob Dubh
Windows shewing Ballachulish Core and Slide
GLEN
Allt an
Coire Lasain
LOCH DOCHARD
LOCH TULLA
? Appin Core
WEST HIGHLAND RAILWAY
BALLACHULISH SLIDE
B. Achallader
Section Fig. 4.
B. Doirean
Beinn a' Chaisteil
GLEN STRAE
ORCHY
Beinn Odhar
B. Udlaidh
GLEN LOCHY
L. BHE
BALLACHULISH SLIDE
L. AWE
Dalmally
CALEDONIAN RAILWAY
Ben Lui

Discussion.

Mr. G. Barrow remarked that too much importance seemed to be attached to small variations in the succession. The Geological Survey had published numerous sections of colliery shafts; in these the coal-seams were seen to continue for great distances, but the succession between the seams was never alike in any two of them. Similarly, along the North-East Yorkshire coast the marine beds of the Lower Oolite were singularly persistent; but it was impossible to find a similar succession in the intervening beds, even at such small distances as 500 yards apart.

With regard to the sudden thickening of the quartzite, the speaker had never seen such a phenomenon; the increase or decrease in thickness of this rock was very slow, and always in definite directions. The apparent increase was due to 'pitch' or inclination of the axis of folding, which cut the 'surface-section' obliquely. From experience in other districts, the speaker was inclined to adopt a different interpretation of the outcrops shown on the map, which formed a very small portion of the lines shown in the diagram.

Mr. E. H. Cunningham-Craig asked what relations the structures described by the Authors bore to the main folding of the country, and whether the anticline was earlier or later than the main folding. He could not entirely accept their reading of the succession, and felt a doubt as to the conclusions that the Authors had put so clearly before the Society.

Mr. E. B. Bailey, replying for the Authors, stated that the Glen Orchy Anticline was regarded as, in all probability, a later structure superinduced upon the recumbent folds of the neighbourhood. The fan-structure of Ben Lawers (Perthshire) may also eventually prove to be a comparatively late development. Mr. Barrow's suggestion that the limestone which had been traced along the front of the Beinn Doirean range did not continue regularly underground for any considerable distance was negatived by the very evident relation between the outcrop of the limestone and the surface-irregularities of this region. In fact, although it might be admitted that certain of the more speculative conclusions arrived at were still *sub judice*, it was confidently claimed that the local geometrical relations of the various rock-masses were correctly represented in the maps and sections accompanying the paper.

10. Late Glacial *and* Post-Glacial Changes *in the* Lower Dee Valley. By Leonard Johnston Wills, M.A., F.G.S., Fellow of King's College Cambridge. (Read February 28th, 1912.)

[Plate XI—Map.]

Contents.

I. Introduction.

This paper is the result of observations made in the Lower Dee Valley by myself and other members of H.M. Geological Survey, in the course of mapping in the Denbighshire Coalfield and neighbouring areas. My thanks are especially due to Mr. G. W. Lamplugh, F.R.S., for the help that his knowledge of Glacial geology has afforded me and for the generous way in which it has been offered; and also to Mr. D. A. Macalister and Mr. C. B. Wedd for observations relating to part of the Dee Valley.

Dr. Strahan's[1] memoir on the Geology of Flint, Mold, and Ruthin, chapt. xii, appears to be the only work that has dealt directly with the post-Glacial history of the Dee. His observations relate to that part of its course which lies in the neighbourhood of Chester, and will be referred to in the sequel.

In § II of the present paper a general account of the Drift deposits of the critical area around Llangollen and Chirk is given; while § III deals with post-Glacial changes in the topography and in the drainage of the Dee from near the former place to its mouth.

[1] A. Strahan, 'The Geology of the Neighbourhoods of Flint, Mold, & Ruthin' Mem. Geol. Surv. 1890, chapt. xii, p. 149.

II. The Composition of the Glacial Drifts.

The region in which the River Dee leaves its deep valley in the Welsh hills and enters the comparatively flat country formed by the Coal-Measures has been found to be a critical area in connexion with the post-Glacial history of the remainder of its course. In this district the Glacial Drifts are a thick and important deposit forming the greater part of the surface. They have been derived, roughly speaking, from the Irish Sea Ice-Sheet and from the Welsh Ice-Sheet, as may be seen from their distinctive compositions.

(*a*) The Irish Sea Drift.

Except in the Llangollen Valley and in the upper part of the Ceiriog Valley, the Irish Sea Boulder Clay forms the base of the drift-deposits. It is a stony till, usually red, though sometimes blue, and contains a number of Lake District erratics. The most abundant and easily recognized are Eskdale granite, Ennerdale granophyre, and various dyke-rocks and lavas which are not as a rule specifically identifiable. At the same time Coal-Measure sandstone and Carboniferous-Limestone boulders are usually present, while Welsh erratics are rare. The following species of marine shells, occurring as derivatives, have been kindly identified by Mr. Clement Reid:—

Turritella communis.	*Cardium edule.*
Psammobia.	*Trophon.*
Mya (?).	*Tellina balthica.*

East of the mouth of the Ceiriog this basal Boulder Clay is often overlain by Glacial sands; while these in turn are succeeded by an upper, almost stoneless, clay. This is sometimes laminated, and may be a re-sorted boulder-clay which has been accumulated on the land side of the retreating ice-sheet in much the same way as that in which, according to Mr. Wedd, a similar clay originated in North Staffordshire.[1] Lake District boulders and shell-crumbs are found also in this clay.

West of the mouth of the Ceiriog and south of the Dee the basal Red Drift (Irish Sea Drift) occurs below the Welsh Drift, and has been recognized in the Ceiriog Valley as far up as Castle Mills. In the Brookside tributary also, it has been traced up to 1000 feet above sea-level. Judging from the abundance of northern pebbles in the gravels throughout the district, one might well consider that the Red Drift formerly extended over all the ground east of the Millstone Grit escarpment. At the same time, it must be borne in mind that if the Irish Sea and Welsh ice had mingled, Welsh Boulder Clay and northern erratics might be deposited at the same time. The occurrence of northern boulders in the Welsh gravels might thus be accounted for; but the former explanation seems to be more reasonable, and is supported by a section of sand

[1] W. Gibson & C. B. Wedd, 'Geology of the Country around Stoke-upon-Trent—Explanation of Sheet 123' Mem. Geol. Surv. 2nd ed. (1905) p. 63.

and gravel high up on the Millstone Grit outcrop near Fron by Craignant, where rolled pellets of red boulder-clay with scratched boulders in it occur as pebbles.

(*b*) The Welsh Drift.

The Welsh Drift, both Boulder Clay and gravel, is essentially made up of Silurian and Ordovician rocks. The clay is a very stony, grey till, often containing 80 or 90 per cent. of stones, the majority being flat fragments of Silurian shale. The gravels are practically the same material, slightly washed and rearranged; and the two deposits are not readily distinguished, even in good exposures.

As regards the distribution, it may be said that, wherever in the neighbourhood of Chirk the Irish Sea and Welsh Drifts are associated, the Welsh is the later formation.

North of the Dee Valley, Welsh Drift of a typical composition is not well developed east of the Millstone Grit Escarpment; but it is the only Glacial deposit seen at low levels in the Dee Valley above Fron Cysyllte,[1] and has been found near that locality under the recent alluvium.

The ground between the Dee and the Ceiriog, and west of the Black Park—Chirk Green ridge, is chiefly occupied by Welsh Drift, and it is seen overlying red drift up to Castle Mills in the Ceiriog valley. In the upper part of this valley it is the only Glacial deposit found.

South of the River Ceiriog the dip-slopes of the Millstone Grit are covered by a series of rude terraces composed of the same Welsh Drift, although there is evidence at one or two places here that it overlies red Irish Sea Boulder Clay.

The Welsh gravels—best described as 'slaty gravel'—are chiefly found in the Dee Valley as rough, high-level terraces. Similar deposits spread out as flats at Chirk and Brynkinalt, and in the Rhyn Park. In these cases it is clear that they are flood-gravels, belonging to the early post-Glacial Ceiriog drainage.

Near Chirk Bank the gravels form esker-like ridges and mounds, and are less monotonously Silurian in origin.

The difficulty of distinguishing Welsh Boulder Clay from the 'slaty gravel' is increased in the Ceiriog valley, by the fact that some of the Boulder Clay assumes a terrace-like form.

III. Post-Glacial Changes in the Topography of the District.

It may be well to preface this discussion by a definition of post-Glacial changes as those which have been effected since the time of the maximum glaciation. They were probably initiated at a late stage in the Glacial Period.

In pre-Glacial times there existed in the district the same two chief drainage-lines—the Dee and the Ceiriog—as at the present

[1] Misspelt 'Cysysllte' on the map, Pl. XI.

day, but their courses have been seriously altered by the presence of ice and by the deposition of Glacial Drift.

This paper only deals with the Dee Valley below Glyn-Dyfrdwy. From thereabouts to the Great Western Railway Viaduct near Cefn, Glacial Drifts can be traced low down in the valley, and, in two cases at least, Boulder Clay has been found below the present alluvium, showing that the Dee has not yet reached its former level.

This stretch of the valley is therefore plainly pre-Glacial in the main. But, when more closely examined, it is found that in several places the river has abandoned its old course. Some of these diversions are 'short cuts,' others the reverse.

That stupendous physiographic changes could take place in a deep, narrow valley, such as the Dee occupies near Llangollen, was only rendered possible by the serpentine nature of its whole course. This must be a very ancient feature, for it was evidently initiated at a level many hundred feet higher than the present river-bed. The winding gorge of the Dee is, in fact, reminiscent of 'incised meanders'; but, if the loops were ever meanders, they must have belonged to a stream of far larger volume than the present Dee. The flat tops of the neighbouring hills may well be relics of a peneplain, but inequalities on its surface and not meanders may have initiated the bends.

The form of the valley led to strange happenings when it was filled to overflowing by the ice-sheet, and later when a valley-glacier and its accompanying waters held sway within it. At present one can judge of the power of the ice, as it forced its way down the narrow winding valley, by the marked truncation of the spurs and the uniformly steep slopes which it has left behind. (Similar phenomena are even better displayed in the Ceiriog Valley.)

(1) The Llantisilio Diversion.

The first post-Glacial diversion to be noticed is the 'short cut' through the gorge at Berwyn (see fig. 1, p. 184).

A drift-plugged hollow leaving the present valley at Llantisilio Church can be traced northwards for about a mile, where it bends round to the east into the Valle Crucis Valley. At the bend there is a col rising to about 430 feet O.D. The Valle Crucis Valley joins the Dee at Pentre-felin near the lower end of the above-mentioned Berwyn Gorge; and, viewed from near Llangollen, it is clearly a continuation of that of the Dee. Its pre-Glacial age is evidenced by a considerable thickness of Drift in its lower part. The deserted valley near Llantisilio is also filled with Drift, on the irregular surface of which were kettle-holes that are now marked by stretches of alluvium. A small stream drains through it to the Dee, near the church.

The broad, drift-filled pre-Glacial valley stands out in strong contrast to the narrow rocky gorge of the present Dee at Berwyn. We have here a clear case of diversion, and one which is specially interesting, as it appears possible to account for the existence of a low col at Berwyn, which could be seized upon by the river on the retreat of the ice. For, at the present day, the Plas-yn-Vivod stream enters the Dee at Berwyn Bridge, but in pre-Glacial times it joined the latter farther east at Pentre-felin. The erosion of this tributary valley would necessitate a low col near Llantisilio between

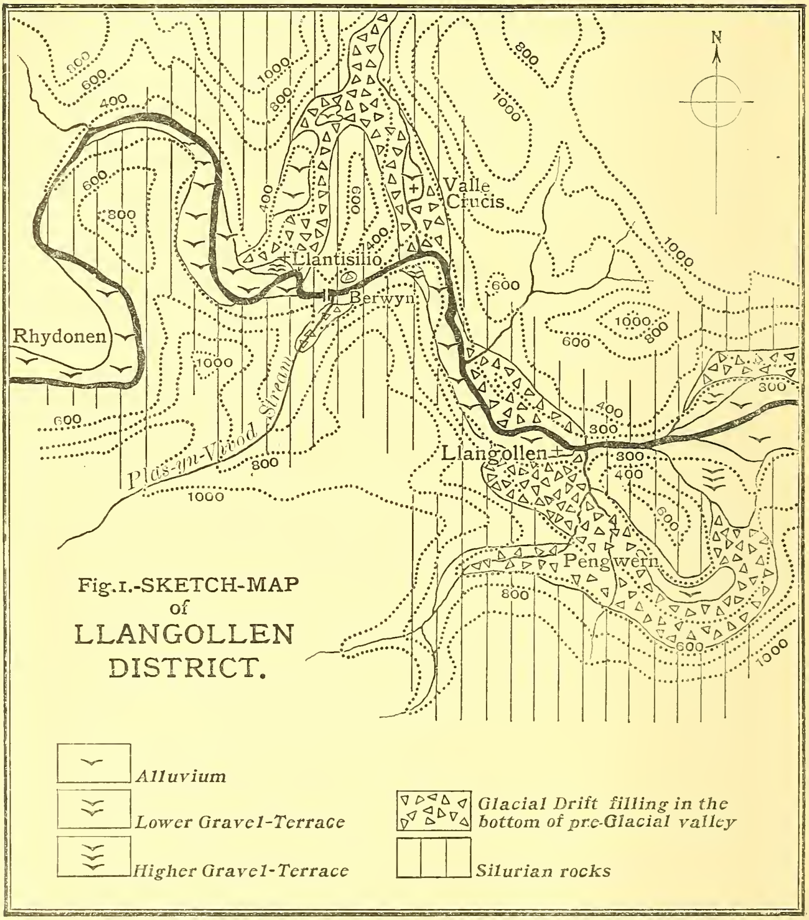


Fig. 1.—SKETCH-MAP of LLANGOLLEN DISTRICT.

it and the Dee, and it was by the flooding of this col by the post-Glacial waters that the Berwyn gorge was initiated.

It can be pointed out, in support of this hypothesis, that on the north side of the gorge near the bridge there occurs a small patch of boulder-clay about 100 yards in diameter, which once formed part of the Drift that filled the Plas-yn-Vivod Valley. This boulder-clay rests at about the same level as that which still occupies the tributary valley on the south side of the gorge, and lies about 30 or 40 feet above the river, which here flows in a rocky ravine.

The Berwyn Gorge can, I think, be regarded as a marginal overflow channel, initiated when the Dee Glacier had shrunk considerably and now only occupied the bottom of the valley, while the drainage ran between it and the higher slopes of the hills. At the same time, it must be noted that the drift dam in the loop rises to about 130 feet above the present river, and 90 to 100 feet above the base of the drift in the gorge, and may have determined the direction of flow after all the ice had disappeared.

(2) Holyhead Road Overflow Channel.

The pass which the Holyhead Road takes about a mile west of Berwyn cuts across the neck of land round which winds the loop of the Dee between Rhydonen and Llantisilio. On the north, a knoll occupying the centre of the loop slopes steeply towards this pass; while on the south rise high hills forming the upper slopes of the whole valley-side.

The explanation of this curious physiographical feature appears to be that during the Glacial Period the gap formed an overflow channel. One is led to the conclusion that, in order to avoid moving round the long loop which the valley takes here, part of the ice flowed over this col, tearing away the sides and grinding out a fairly flat bottom. At the same time, it is probable that such action was supplemented or was replaced, when the ice was dwindling, by that of water flowing between the edge of the Dee Glacier and the high ground on the south. If this latter hypothesis holds, the minimum thickness of stagnant ice in the valley at that time must have been 230 feet, the height of the pass above the river.

Had this channel become permanent on the disappearance of the ice there would have been here a gorge similar to, though far deeper than, the one at Berwyn.

(3) The Pengwern Diversion.

The Dee follows its pre-Glacial course from Pentre-felin to Llangollen, where it has again been diverted from its original direction, and now flows through the Llangollen Gorge. The history of this diversion is similar to that of the Llantisilio diversion.

A broad valley leads south-eastwards from Llangollen to Pengwern Hall, where it bends round to rejoin the present Dee Valley near the Llangollen Golf Links. The Drift forming its wide bottom is of considerable thickness, and is well exposed in the banks of the Cyflymen Brook.

This broad through-valley I have called the Pengwern Valley, and it is a conspicuous case of 'misfit.' At present there is no through-drainage in it, but a small stream enters it from the south. Part of the stream joins the Cyflymen Brook, while part is led through a drained peaty flat[1] past Tyndwr to the Dee near the Golf Links. Such a drainage-system could not have cut out this valley, the breadth of which corresponds to that of the Dee.

At present the river flows through a narrow gorge at Llangollen some 250 feet deep, in which there is no Drift, and which is clearly post-Glacial. As further proof of this, we find spreading out from its mouth a series of gravel-terraces that are cut in the Drift of the pre-Glacial valley below, and mark the various stages in the erosion of the gorge.

The similarity of the Llantisilio and Llangollen diversions suggests that they were both formed in the same way; that is, probably by the obstruction of the drainage by inert ice in the valley-bottom, aided to some extent by a dam of drift.

(4) The Argoed Diversion.

The next diversion is not a 'short cut,' but the reverse. Near the large house at Fron-Cysyllte known as Argoed, the river swings northwards to near the Trevor Aqueduct, and then bends south-eastwards again at a sharp angle (see Map, Pl. XI). This loop is clearly post-Glacial, for the Drift comes nearly, if not quite, down to the level of the Dee beneath Argoed, and also near the railway viaduct; while between these points the river flows through a fairly deep gorge eroded in the solid rock near Trevor. Thus, whereas the Dee formerly ran nearly straight, the present course is, as it were, along the other two sides of the triangle.

The explanation of this, as of the following diversions, must be sought for in the post-Glacial surface-configuration of the Drift, which determined the direction of the flow of the water when the retreat of the ice occurred. At this particular point all that can be said is that, even now, the surface of the Drift rises to about 100 feet above its old course at Argoed, and presumably it always sloped towards the north and thus deflected the waters in that direction.

(5) The Chirk Diversion.

The diversion next to be dealt with is a phenomenon of much greater magnitude, and involves the river's desertion of its former valley for many miles; in fact, its present course from the railway viaduct near Cefn to below Overton Bridge has been excavated in post-Glacial times (see Map, Pl. XI). Although above the viaduct we can see Boulder Clay beneath the present alluvium, nowhere along this stretch except near Erbistock does the surface of the solid rock reach as low as the Dee. The river has dissected the coating of Drift, and in most cases has cut through 100 feet or more of the solid rock below. This is enough to demonstrate the post-Glacial nature of the gorge, unless the Vale of Llangollen has been overdeepened by Glacial erosion.

[1] This represents an old kettle-hole lake, and was a morass as late as 1850.

By means of this dissection the heights above sea-level at which Glacial deposits rest upon solid rock can be determined, and the approximate contouring of the pre-Glacial surface can be deduced as in the accompanying map (Pl. XI), which shows that before the Glacial Period the river could not have occupied its present valley.

I now propose to examine some few details of this post-Glacial gorge.

The lowest point west of the railway viaduct at Cefn at which Boulder Clay is seen resting upon solid rock is about 175 or 180 feet above O.D. As mentioned above, it is not found so low as this until one approaches Erbistock. At most points near Cefn and Black Park it lies at about 250 to 300 feet above sea-level, or even higher; but at one place in Halton Woods it is as low as about 215 feet O.D. Now this occurrence is remarkable, in that solid rock surrounds it at higher levels on every side except where the river flows. One is led to the conclusion, therefore, that this Boulder Clay lies in what was originally a small tributary valley of the Dee that joined it from the east somewhere near Pentre. If this be the true explanation, it suggests a likely reason why, on the retreat of the ice, the Dee took its present course. For here, possibly, would be a low col through which the river could escape to the east; while, even at the present day, its old course towards Chirk is blocked with drift up to 350 feet above sea-level.

The only other explanation of this peculiarly low patch of Boulder Clay inside the gorge postulates an Interglacial Period, during which the river cut through the Drift and through the solid rock to within 50 feet of its present level. Then followed a Glacial Period, of which this single patch of Boulder Clay and possibly a few isolated occurrences of high-level gravels lying well within the gorge are the only relics so far discovered. The above-mentioned gravels are certainly puzzling: for, although they resemble Glacial gravels in their moundy mode of occurrence, yet they lie apparently inside the gorge, and often at much lower levels than the rest of the Drift in their neighbourhood. They may possibly be explained as late Fluvioglacial flood-gravels, the terrace-like form of which has been strongly modified by subsequent denudation.

The early history of the gorge is recorded in the rough terraces at Sodyllt and Gron-wen, and possibly that at Halton, which must be classified as Fluvioglacial gravels of the Dee. Their height above the river is approximately 120 feet. These are comparable to others at Chirk, Brynkinalt, and the Rhyn Park, which were deposited by the post-Glacial Ceiriog.

These Fluvioglacial flood-gravels mark the first stage in the erosion of the gorge, when the waters were flowing almost entirely on Drift. At lower levels on the sides of the gorge alluvial and gravel terraces repeatedly recur at approximately 60, 40, and 20 feet above the river, although its meanderings preclude the possibility of tracing any one continuously for far. But, from the end by

Overton Bridge, the 60-foot terrace can be mapped, lying on the Boulder Clay, for 3½ miles to the north-east, and represents the gravel-fan thrown out by the river during the earlier part of its erosion of the gorge. Similarly, it is in this neighbourhood that the 40-foot terrace has its chief development. The 20-foot terrace approaches nearly, and may in some cases coincide with the recent alluvium. It may be that these terraces indicate successive uplifts, but the absence of any signs of the 60-foot and 40-foot terraces between Bangor and the sea is against this view. More probably, therefore, they denote stages in the development of the gorge, and depended for their formation rather on changes of climate than of sea-level.

The re-excavation of the drift-filled Vale of Llangollen and higher reaches of the Ceiriog Valley almost to their former depth can be matched in many glaciated regions, but the cutting of such a gorge as this Cefn-Overton Valley, 10 miles long and 120 to 200 feet deep, affords a striking testimony to the power of erosion and to the great duration of post-Glacial time. For, not only has the thick covering of Drift been removed, but in some parts of the gorge 100 feet or more of solid rock has been scooped out.

At the suggestion of Mr. Lamplugh, a rough estimate has been made of the amount of rock removed from the post-Glacial valley between the Cefn Viaduct and Eyton, near Overton, neglecting the Ceiriog and larger tributary valleys. The estimate does not profess to be at all precise, but it shows in round numbers the removal of some 477 million cubic yards, or ·087 of a cubic mile of material, which, if spread out as a uniform sheet 1 foot thick, would cover 462 square miles.

As the area from which this amount has been denuded is only about 7 or 8 square miles, the average degradation of its surface is some 57 feet. An idea is thus gained of the colossal length of time required to effect this, even if we admit that the rate of erosion was much faster at the close of the Glacial Period than now.

It is interesting to note that, if one assumes that the 60-foot terrace near Bangor, Eyton, and Overton is, on the average, only 6 feet thick, one can claim that it contains 4 per cent. of the total material removed from the gorge.

Before leaving the description of the gorge, we may notice the change which the narrow valley undergoes as soon as it reaches the Drift plain. It expands at once, the valley from near Overton Bridge to Holt being several miles wide and excavated entirely in Glacial deposits, until it enters a narrow gorge in the Triassic rocks at the latter place.

Let us now turn to the question of the direction which the pre-Glacial Dee took from near Cefn.

If we may trust the contour-map (Pl. XI), the only possible course lay along the outcrop of the soft Lower Coal-Measures towards Chirk, and thence south-eastwards towards Gledrid.

Although this valley is now obliterated by Drift, the upper slopes of its sides are seen between Pentre and Chirk. On the west the Millstone Grit hills slope gently towards it; while on the east the Black Park–Chirk Green ridge shuts it in, and is most evidently unconnected with the present drainage-system.

Between these two limits lies a fairly flat spread of Drift, the great thickness of which is shown, not only by the deep-cut valley of the Pen-y-Park stream, but by the evidence from two trial bore-holes, which, in my opinion, prove this diversion conclusively.

The first bore-hole showed 130 to 140 feet of Drift, and did not even then reach the solid rock. It was situated immediately north-west of Black Park Lodge (No. 1 on the map, Pl. XI), and the pre-Glacial floor is here at most 170 feet above sea-level, or 5 to 10 feet lower than it is near the Viaduct. No. 2 boring was at Black Park Wharf, and not far west of the solid outcrop of the Chirk Green ridge. It proved 142 feet of Drift, and passed into Coal-Measures at about 200 feet above O.D. Incidentally this shows that the pre-Glacial valley-side here is steep, for it drops 200 feet in less than a quarter of a mile.

Further evidence as to the position of the buried hollow is found in the valley of the Ceiriog near Chirk. This stream has not yet cut through the infilling of Drift at the point where one would expect that the pre-Glacial Dee was joined by the pre-Glacial Ceiriog. There are no data as to the thickness of the Drift below the present valley-bottom; but it must descend below 200 feet O.D., for the river passes from Drift on to solid rock at this level near Ladybridge.

Since the Morlas Brook runs in a similar way on to solid rock at about the same level near the village of Glyn Morlas, these two points help us to locate a north-eastern side to the former Dee Valley: for, as one goes north and east from here, the surface of the solid rock rises.

The only other direct evidence of the course of the former valley is obtained from an isolated occurrence of solid rock which projects from a wilderness of Glacial Drift near St. Martin's Moor. This must, I think, have formed part of the same north-eastern valley-side, since the Drift-covered escarpment of the Coed-yr-allt Rock offers an apparently unbroken barrier towards the east from Glyn Morlas to Esgob Mill.

So great are the changes which have been brought about in the physiography of this district by the Drift, that it is very doubtful whether early post-Glacial lines of drainage form any indication at all of the pre-Glacial lines. But, if the possibility be allowed, we may perhaps see some support for our theory of the position of the pre-Glacial Dee in a remarkable valley, now almost dry, along which the Shropshire Union Canal runs from near Esgob Mill, past St. Martin's Moor, to Hindford. Its direction almost coincides with the supposed course of the pre-Glacial Dee.

This valley deserves more than passing notice, for it is clearly a continuation of the Morlas Brook valley beyond Esgob Mill (see fig. 2). But at this point the Morlas Brook has been captured in post-Glacial times by a tributary of the Ceiriog, as is well shown in the accompanying map. It will be seen that the width of

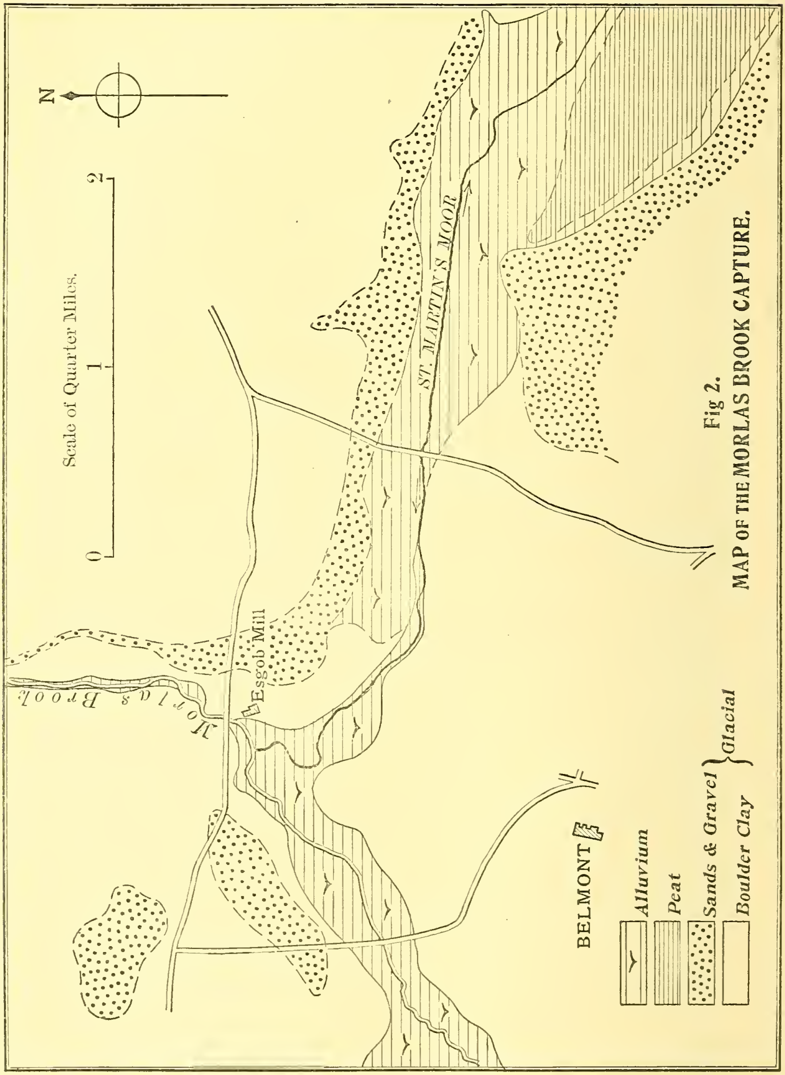


Fig 2.
MAP OF THE MORLAS BROOK CAPTURE.

alluvium in the Morlas Valley above Esgob Mill corresponds with that in the deserted valley near St. Martin's Moor, while the present lower part of the Morlas Brook flows in a gorge. Further, a small obsequent stream, rising in an artificial ditch at St. Martin's Moor, flows to Esgob Mill and so into the Dee drainage, whereas the other end of the same ditch sends water into the Severn.

This opens up the possibility of the pre-Glacial Dee having joined the Severn, but a discussion of this point will be reserved until later.

One might expect to find in the nature of the Drift that fills the buried valley between Pentre and Chirk a conspicuous cause for the diversion. That it was here that the obstruction took place is proved by the presence of the Ceiriog Valley: for, had the barrier lain more to the south, the Ceiriog would still join the Dee at Chirk. Instead of this both rivers now cross the pre-Glacial valley, and pursue an independent course roughly at right angles to it until they meet farther east.

Beyond the fact, however, that the Drifts rise to 350 feet above sea-level (about 180 feet above the former surface) nothing very remarkable can be said of them. At the same time, they occur at a very sharp bend in the pre-Glacial valley that appears near Cefn to have been deflected southwards, along the outcrop of the soft Lower Coal-Measures, by the escarpment of the Middle Coal-Measures and Coed-yr-allt Series. It is easy to imagine that, on the recession of the ice, the drainage might be induced by a comparatively small obstacle to avoid so acute a change of direction. We have already seen that in doing so it probably availed itself of a pre-Glacial tributary valley trending eastwards. The peculiar loop of the Dee near Pentre appears almost to coincide with the direction of this tributary valley (see Pl. XI).

(6) The Story of the River Ceiriog.

At this point, it may be profitable to turn for a moment to a consideration of the River Ceiriog. This stream has re-excavated its present course through the Drift that filled up the bottom of a pre-Glacial valley, the straightness and narrowness, depth and steep-sidedness of which have precluded the possibility of diversions such as the Dee has undertaken.

From the village of Glyn [1] downwards, patches of Drift may be seen clinging to the old valley-sides and filling up the tributary stream-courses. But below Chirk, at the point where one would expect that the Ceiriog joined the Dee in pre-Glacial times, the whole gorge is excavated in Drift, and the river flows on Boulder Clay.

The only post-Glacial change, therefore, in the Ceiriog drainage is its extension to join the Dee near Pont-y-Blew; and this is effected by a deep valley cut through the Ruabon Marls.

A series of gravels that accompany the lower part of the present course of the Ceiriog, spread out on the Boulder Clay as high-level flats near Chirk, Brynkinalt, and the Rhyn Park [2] at heights

[1] Llansantffraid-Glyn-Ceiriog.

[2] The similar terrace at Halton may belong either to the Dee, or to the Ceiriog, or to both.

approximating from 120 to 150 feet above the present river. These are early flood-gravels, and are connected with the first stages in the formation of the valley. They indicate that the earliest post-Glacial drainage took the course now occupied by the Ceiriog Valley, and that this stream was never captured by the Dee after the manner of the Morlas Brook diversion. Their early date and their intimate connexion with the Glacial deposits are shown by the continuity of some of them with moundy Glacial gravels near Chirk Bank.

Later stages in the erosion of the valley are recorded by several large river-terraces at much lower levels than the above-mentioned gravel-flats. Their heights above the Ceiriog show them to be capable of a rough comparison with the 60- and 40-foot terraces of the Dee.

Thus the post-Glacial origin of the lower part of the Ceiriog valley is as clearly demonstrated as that of the Dee between Cefn and Overton.

(7) The Pre-Glacial Valley near Holt and Chester. (See fig. 3, p. 193.)

The occurrence of a pre-Glacial valley in the Chester district was dealt with by Dr. Strahan [1] in 1890 and 1898. He records a number of borings under the estuary of the Dee in which the base of the Drift lies far below sea-level, the greatest reliable depth being 195 feet near Sandycroft. This means that the surface of the solid rock is here 184 feet below Ordnance Datum, whereas the present river is, of course, at sea-level.

The course of this buried valley was roughly indicated by the following depths below sea-level at which either solid rock was reached or at which wells or borings ended in the Drift (see fig. 3):—

	Feet.
Near Queensferry	−146 and possibly −177
,, Sandycroft	−184 and −132
,, Saltney	−134
,, Dodleston	− 90
,, Pulford	− 20[2]
,, Eaton Hall	− 40[2]

It has now been traced some 7 miles farther south by means of the following observations of depths:—

	Feet.
Near Horsley Hall	−25[2]
,, Ridley Wood	−30[2]
At Dutton Diffeth.......... ..	−10[2]
At Rodens Hall	−30

[1] A. Strahan, 'The Geology of the Neighbourhoods of Flint, Mold, & Ruthin' Mem. Geol. Surv. 1890, and Supplement, 1898. Dr. Strahan informs me that, in view of more recent borings at Sandycroft, the record of 300 feet of Drift must be disregarded.

[2] This indicates that the solid rock was not reached, and that the depth below sea-level may be greater.

Rodens Hall is about 2½ miles north-north-east of Bangor, and some 4 miles, as the crow flies, from the end of the Overton gorge. Between Rodens Hall and the sea, the former course of the river

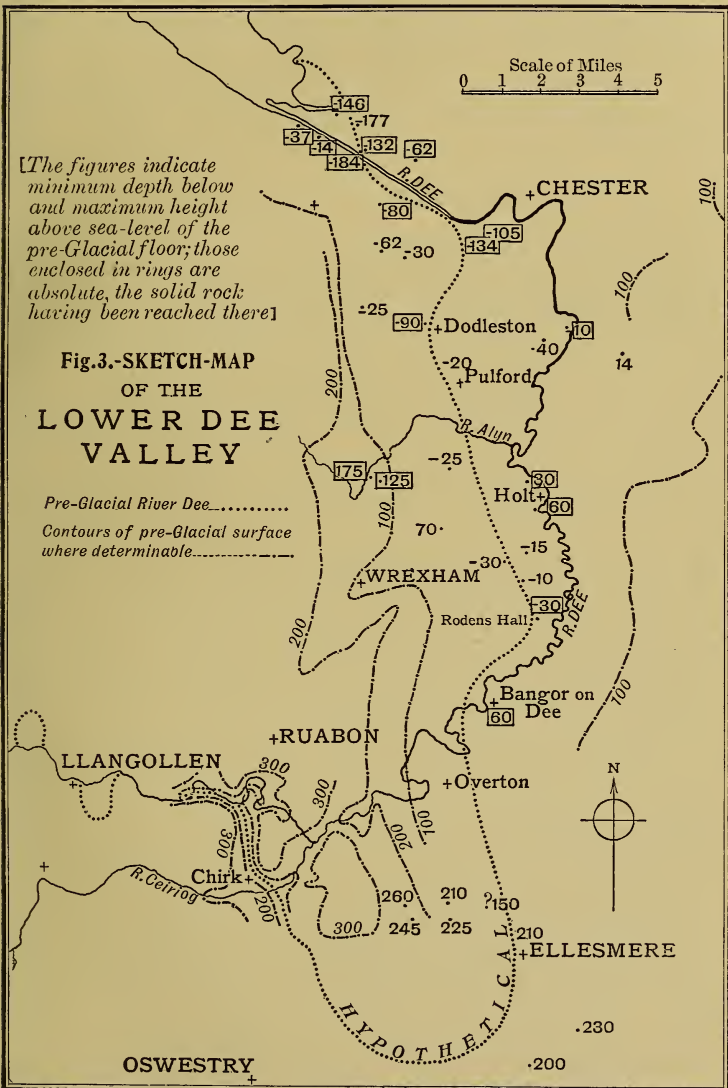


Fig. 3.—SKETCH-MAP OF THE LOWER DEE VALLEY

appears to lie to the west of the present one (see map, fig. 3). Further, although the Dee flows for the most part on Drift over this reach, yet at Holt and again at Chester it has cut through it and now runs in a gorge in Triassic rocks at both places. Thus it affords another typical instance of a superimposed drainage-system: for the present course is determined by its relation, not to the rocks through which it flows, but to the deposit of Drift superimposed upon them and since eroded away. The valleys of the Clywedog and Alyn in the neighbourhood of Wrexham show that even the courses of the tributaries fall under the same system.

It is interesting to notice that, by the diversion at Chester, the Dee to within a few miles of its mouth maintains its reputation for escaping from its pre-Glacial course.

(8) The Relationship of the Two Buried Valleys.

With regard to the relationship between the buried valley near Chester and Bangor and that which has been traced through Chirk, if we assume that 30 feet below sea-level at Rodens Hall is the greatest depth of the pre-Glacial valley thereabouts, it is clear that the river at that period dropped about 150 feet between there and Queensferry,[1] whereas at the present day the fall is only about 20 or 25 feet. This would seem to indicate that the valley was a young one and not yet graded down to the extent that the present Dee is.

Further, it appears that, since the river is now flowing near Cefn at approximately the pre-Glacial level, the result of the Chirk diversion is a lessening of the fall between there and Rodens Hall of about 50 feet. This may represent the short-circuiting of a long bend of the river, such as may well have existed when the Dee flowed south through Chirk and St. Martin's Moor. At the same time one cannot be sure that this is the case, because the pre-Glacial 'thalweg' below the Cheshire plains is so much more abrupt than the present one, that the fall from Cefn to Rodens Hall may have been correspondingly steep. It is worth noticing in this connexion that, if an uplift took place, it is in the softer rocks of the Cheshire plains near the mouth of the Dee that the speedy excavation would occur, whereas in the harder Silurian and Lower Carboniferous rocks of the upper valley little effect might be evident. This hypothesis agrees with the foregoing observations if it be assumed that the river which cut out the Vale of Llangollen reached the sea near Chester.

The balance of probabilities is in favour of this having been the case, yet absolute proof is not at present forthcoming. We have traced the pre-Glacial valley southwards through Chirk into what is now the drainage-area of the Severn, and from the sea to Rodens Hall. Between these two points the country is deep in Glacial Drift, and we have to rely on wells and borings for our evidence as to its thickness. I know of no well in the Ellesmere district that touches solid rock. Only a poor approximation, therefore, to the

[1] The following arguments assume that the pre-Glacial valley was the product of river-erosion. They will not hold if Glacial overdeepening has played a prominent part in forming the buried valley.

pre-Glacial configuration is to be derived from this source. The lowest wells of which I have records are shown in fig. 3 (p. 193):—

		Feet above O.D.
Near the Trench (a mile and a half N. by W. of Ellesmere)	ends at about	150 or less.[1]
Haughton (half a mile N.E. of Ellesmere).	,,	210 or less.
Gadlas	,,	210 or less.
Colmere Wood ($2\frac{1}{2}$ miles S.S.E. of Ellesmere)	,,	230 or less.[1]
Petton (6 miles S.S.E. of Ellesmere)	,,	180 or less.[1]

These tell us but little: for, although they represent depths up to 150 feet, yet the Drift might easily be twice that thickness in this district.

If we attack the question in a different way, and try to trace the pre-Glacial watershed of the Dee Valley, we are met with difficulties which are again due to the covering of Drift. Certain parts of the watershed, however, can be seen and may be summarized thus:

1. On the west the Welsh Hills form a definite barrier.
2. On the south, round Knockin, West Felton, and Ruyton, the solid rock lies at about 300 O.D.
3. On the south-east the Grinshill Ridge runs from Middle to Weston and may, on the east, join up with the Prees outlier of Lias.
4. On the east are the Peckforton Hills and their continuation south to the east of Overton.

Thus we cannot produce evidence that the Severn and Dee did not join. There is, however, definite proof that the Severn did not, in pre-Glacial times, flow through either the gorge at Shrewsbury or that at Ironbridge. For at Dunn's Heath near Leaton, north of Shrewsbury, the base of the Drift descends 50 feet below the rock-lip of both these gorges.[2] We have confirmation here of the view, advanced independently by Prof. C. Lapworth[3] and Mr. Harmer,[4] that the Ironbridge Gorge is post-Glacial in origin.

The northerly trend of the pre-Glacial Severn drainage thus indicated is a strong point in favour of the view that the two buried valleys under discussion are really continuous, and further suggests the possibility of the Severn having helped to excavate the deep valley hidden below the Cheshire plains. At present I can offer no convincing evidence in favour of or against this latter hypothesis.

It will be noticed on the map (fig. 3, p. 193) that a course for the pre-Glacial Dee has been suggested just east of Whittington,

[1] *Fide* Geological Survey Map, O. S. Sheets 73 N.W. & 73 S.W.

[2] Charlotte Eyton, 'On the Pleistocene Deposits of North Shropshire' Geol. Mag. vol. vii (1870) p. 106.

[3] C. Lapworth, Proc. Geol. Assoc. vol. xv (1898) p. 425; C. Lapworth & W. W. Watts, in 'Geology in the Field' Jubilee vol. Geol. Assoc. (1909–10) pp. 768–69.

[4] F. W. Harmer, 'On the Origin of certain Cañon-like Valleys associated with Lake-like Areas of Depression' Q. J. G. S. vol. lxiii (1907) pp. 477–81.

past Hordley and Ellesmere to Overton, and so along a line west of Bangor-on-Dee, where a small patch of Trias emerges from the Boulder Clay, to Rodens Hall. This course is hypothetical, and has yet to be proved by borings.

(9) Points of Theoretical Interest.

There are one or two points of theoretical interest which are suggested by the foregoing observations.

I have assumed throughout the discussion that the work of Messrs. Lamplugh, Tiddeman, Wright,[1] and Maufe on the pre-Glacial beaches round our coasts is sufficient to prove that the pre-Glacial sea-level, south of the Tyne, was approximately the same as the present one. This removes the possibility of differential earth-movement having occurred within the area under discussion.

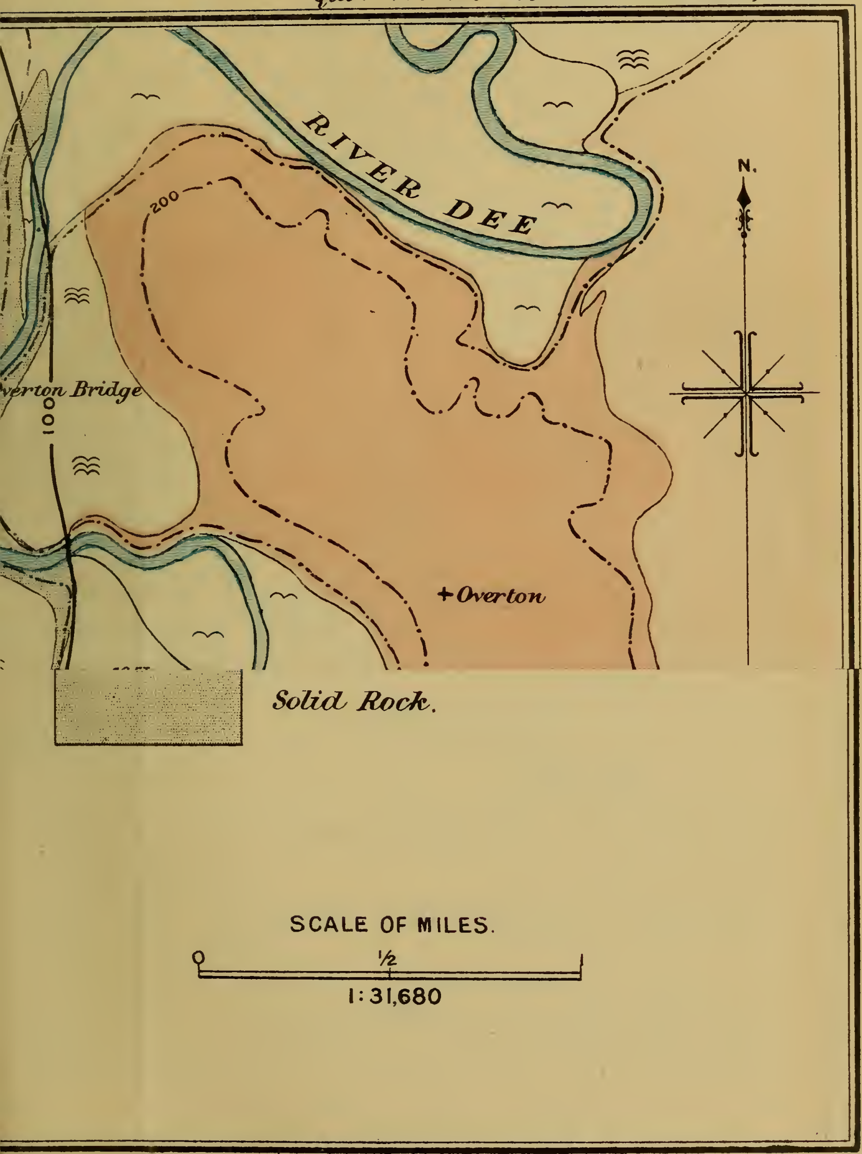
Dr. Strahan's observations have indicated an uplift of at least 184 feet at the mouth of the Dee. The varying depths at which the pre-Glacial surface lies beneath the Drift near the mouths of most of our northern rivers suggest either Glacial deepening, or that the uplift was considerably greater than 184 feet. In the latter case, the discrepancies could be explained by the fact that these areas were not then situated near enough to the sea for the valleys to be graded to the base-level of the sea at these points.

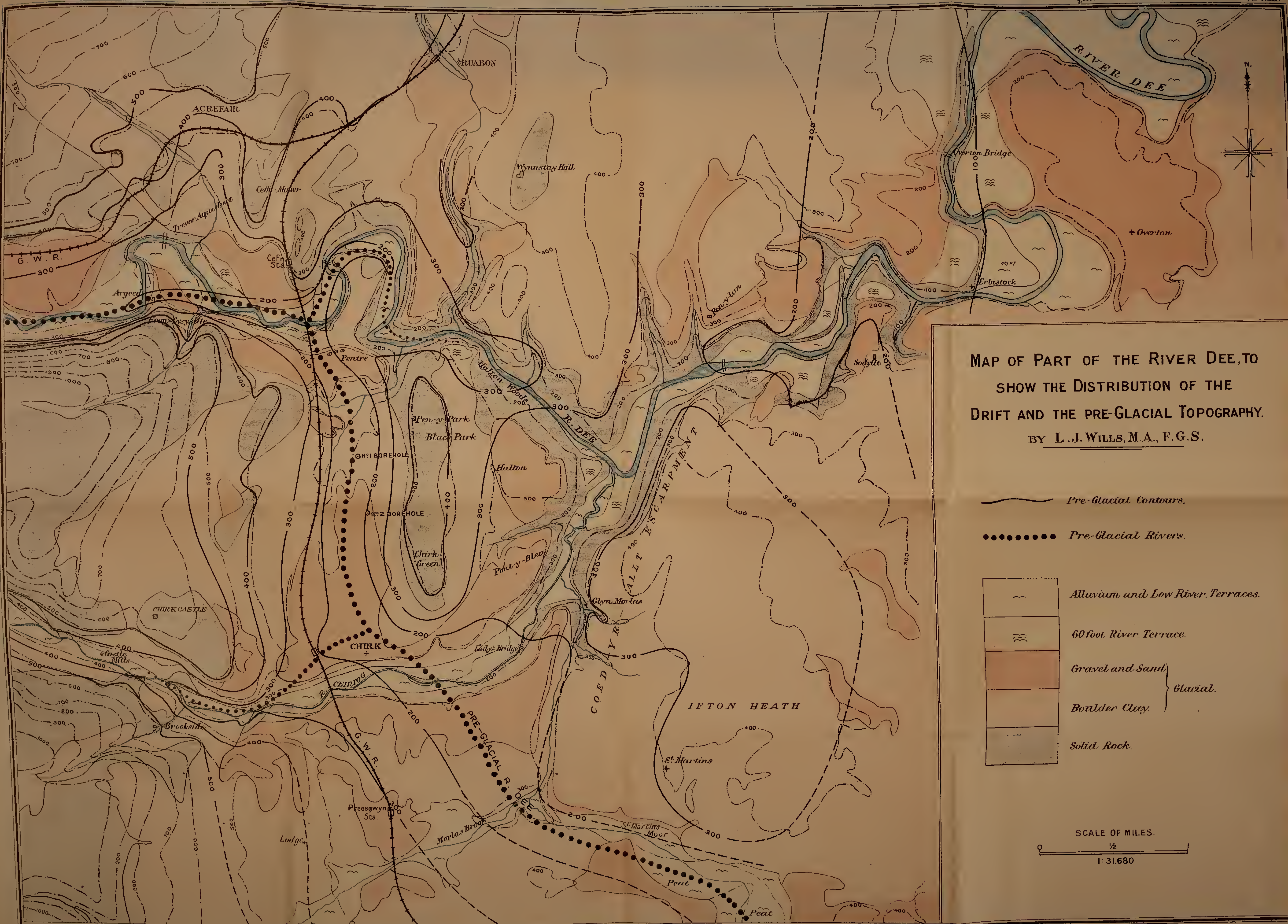
The youthfulness of the Dee Valley in the hill country is among its most striking features, and accords well with a hypothesis of recent uplift. My observations on the slope of the 'thalweg' of the pre-Glacial Dee also indicate that the valley was a 'young' one, and suggest that the uplift was sudden and not of long duration. Too much reliance cannot be placed upon this evidence, on account of the possibility of the sub-Glacial surface being the result of glacial erosion, to which the soft Triassic rocks would be very susceptible.

If we accept the hypothesis of an uplift, did it take place before or after the formation of the pre-Glacial beaches? If it was before, it follows that a re-subsidence had occurred to the present level before glaciation, and in this case the Drift filling in the Dee Valley as far as Rodens Hall, and probably much farther south, must have been deposited in an arm of the sea. There is no satisfactory evidence of this, however, in the composition of the Drift.

If, on the other hand, both elevation and re-subsidence occurred after the formation of the beaches, they are episodes in the comparatively short Glacial and post-Glacial Periods. The steepness of the thalweg and the strength of the eroding forces would fit in satisfactorily with this view.

[1] For references, see W. B. Wright, 'On a Pre-Glacial Shore-Line in the Western Isles of Scotland' Geol. Mag. dec. 5, vol. viii (1911) pp. 97–109.


RIVER DEE
200
Overton Bridge
100
+ Overton
N.
Solid Rock.
SCALE OF MILES.
0
½
1:31,680


MAP OF PART OF THE RIVER DEE, TO SHOW THE DISTRIBUTION OF THE DRIFT AND THE PRE-GLACIAL TOPOGRAPHY.
BY L. J. WILLS, M.A., F.G.S.
Pre-Glacial Contours.
Pre-Glacial Rivers.
Alluvium and Low River Terraces.
60 foot River Terrace.
Gravel and Sand
Boulder Clay
Glacial.
Solid Rock.
SCALE OF MILES.
0
½
1
1:31,680
N.
RIVER DEE
RUABON
ACREFAIR
Wynnstay Hall
Cefn-Mawr
Trevor Aqueduct
G. W. R.
Cefn Sta.
Argoed
Pentre
Overton Bridge
Overton
Erbistock
Sodylt
Holton Woods
R. DEE
Pen-y-Park
Black Park
No. 1 BOREHOLE
No. 2 BOREHOLE
Halton
Chirk Green
Pont-y-Blew
Glyn Morlas
ALLT Y ESCARPMENT
COED Y R
IFTON HEATH
St. Martins
CHIRK CASTLE
Castle Mills
CHIRK
Lady's Bridge
R. CEIRIOG
Brookside
PRE-GLACIAL R. DEE
Preesgwyn Sta.
Lodge
Morlas Brook
St. Martins Moor
Peat

IV. Conclusion.

Owing to obstruction of the peculiarly serpentine course of the whole valley of the Dee near Llangollen by ice and Glacial deposits, overflow channels across the necks of several loops were initiated. Two of these have become permanent on the retreat of the ice and are now river-gorges, while the loops are left as dry valleys.

Near Cefn the river enters a long post-Glacial gorge, which extends to beyond Overton Bridge. The pre-Glacial valley of the Dee is traceable beyond Chirk in a south-easterly direction to near St. Martin's Moor.

The Drift-filled valley, shown by Dr. Strahan to exist below the estuary of the Dee and as far south as Pulford, extends to Rodens Hall near Bangor-on-Dee, where it is still 30 feet below sea-level. This indicates a much steeper pre-Glacial 'thalweg' than the present one.

An attempt is made to prove that these two valleys are continuous, although the intermediate portion is obliterated by Drift.

The question is raised, whether the uplift during which the erosion of this deep buried valley took place was pre-Glacial, or whether it occurred during the Glacial Period. The evidence is far from conclusive, but appears to point to the latter view.

EXPLANATION OF PLATE XI.

Map of part of the River Dee, to show the distribution of the Drift and the pre-Glacial topography, on the scale of 2 inches to the mile, or 1 : 31,680.

Discussion.

Mr. G. W. Lamplugh said that, having seen the field-evidence with the Author, he could fully support the data given in the paper. The gap between the buried valley near Chirk and that under the estuary of the Dee might be bridged by deep borings in the future; but there was always the possibility of surprises in the hidden channels, as the drainage-system of the whole of the lowland country had been profoundly modified by the Glacial episode. All over the glaciated parts of the British Islands it was common to find that the rivers, on leaving their pre-Glacial valleys of the hilly country, had gone widely astray, and the Author had now brought the Dee into this class.

Dr. A. Wade referred to a recent paper, read before the Liverpool Geological Society, in which he had produced evidence to show that the Welsh Border valleys immediately to the south of the Dee Valley had been occupied by Glacial lakes. He asked the Author whether he had considered an explanation of this kind for some of the phenomena which he had described.

Dr. H. Lapworth called the Author's attention to the buried pre-Glacial river-course below Boulder Clay in the valley of the

River Alwen, a tributary of the Dee, about 15 or 20 miles north-west of Llangollen. Borings at the site of the new Birkenhead reservoir proved the old valley below the Boulder Clay and some distance away from the existing river, which has cut well into the solid rock. A similar phenomenon was observed in the excavations for the Rivington Reservoirs on the old Liverpool Waterworks, where the floor of the pre-Glacial gorge was seen to be about 100 feet lower than the present river-bed.

The PRESIDENT (Dr. STRAHAN) remarked that this paper formed an interesting continuation of the account of the physical history of the Dee given by Ramsay in 1876. With regard to the depression in the rock-surface, proved by borings near Chester, it was to be remembered that it coincided with the outcrop of the Lower Mottled Sandstone, an extremely friable rock which was likely to have suffered severely under glaciation. The observations on pre-Glacial valleys made by the Author and Dr. H. Lapworth recalled to mind those of the late Mr. Mellard Reade on the buried valley of the Mersey near Runcorn.

The AUTHOR, in reply, stated that in his opinion there was proof of the correctness of Prof. Charles Lapworth's view that the Severn did not in pre-Glacial times go southwards from Shrewsbury through the Ironbridge Gorge. This would eliminate the possibility suggested by Mr. Lamplugh, that the pre-Glacial Dee may have joined the Severn and gone south. No proof, however, has yet been found that the two rivers joined and flowed northwards.

There were no indications in the district of lakes such as had been mentioned by Dr. Wade.

Dr. H. Lapworth had illustrated a phenomenon that was exceedingly common in this area. As another example, the Author instanced the River Alyn near Wrexham, flowing in solid rock the sub-Glacial surface of which slopes away from the present valley.

The Author considered that it was highly probable that Glacial overdeepening of the Dee Valley had occurred near Chester. He agreed with the President that the soft Triassic rocks of Cheshire would be singularly susceptible to such erosion.

11. *On the* GLACIAL ORIGIN *of the* CLAY-WITH-FLINTS *of* BUCKINGHAMSHIRE *and on a* FORMER COURSE *of the* THAMES.

By ROBERT LIONEL SHERLOCK, D.Sc., A.R.C.S., F.G.S., and ARTHUR HENRY NOBLE, B.A., F.G.S. (Read March 13th, 1912.)

[PLATES XII–XIV.]

I. INTRODUCTION.

DURING the years 1910 and 1911 we have surveyed on the 6-inch scale some 260 square miles in the counties of Buckinghamshire, Berkshire, Hertfordshire, and Middlesex, and have obtained some results which we believe to be new. Perhaps we can now explain the mode of formation of the Clay-with-Flints and superficial gravels, so long a puzzle to geologists.

This paper falls naturally into two parts—first, the origin of the Clay-with-Flints and associated gravels of our area; and, secondly, the origin of the gravels which have sometimes been called Plateau Gravels,[1] and are high above the ordinary river-gravels, though at lower levels than those associated with the Clay-with-Flints. These Plateau Gravels we believe to be of Fluvioglacial origin, and their formation is inseparably connected with the former course of the Thames, at a time when the ice had not yet reached its southern limit of extension.

Our classification of the superficial deposits is somewhat different from that of the Old Series Survey Map. The brick-earth accompanying the clay with flints is usually a clay-gravel, and differs only from the deposits coloured as Gravel in that it is worked for brickmaking. We have, therefore, in these cases mapped it as a gravel. Also, the Pebble Gravel which caps certain hills does not differ in some cases from the Glacial Gravel. On the other hand, the Glacial Gravel of the old map has been divided into two divisions—one of Gravelly Drift, and the other of Fluvioglacial Gravels.

II. THE CLAY-WITH-FLINTS AND THE ACCOMPANYING GRAVELS.

(*a*) The Clay-with-Flints.

The irregular accumulation of clay, loam, and brick-earth with abundant flints, which covers large areas of the Chalk, received its name of Clay-with-Flints in 1861 from Mr. Whitaker,[2] who considered it to be derived in great part from the slow decomposition

[1] As, for instance, H. J. O. White, Proc. Geol. Assoc. vol. xv (1897–99) p. 159.

[2] 'Geology of Parts of Oxfordshire & Berkshire' Mem. Geol. Surv. 1861, p. 54.

of the Chalk under atmospheric action. To the insoluble residue left by solution acting during thousands of years would be added clayey and loamy wash from the Tertiary lands, and remains of Tertiary deposits left as pipes and hollows in the Chalk.[1]

This view was opposed by Mr. Clement Reid,[2] who pointed out that the amount of Chalk-with-Flints which would need to be dissolved to produce enough insoluble residue was excessive; that the proportions of clay to flints which would be produced by solution are not those present in the deposit; and that the bulk of the material was derived from Tertiary rocks.

Mr. Jukes-Browne[3] in 1906 published a paper in which he maintained the essentially Eocene derivation of the deposit, and gave the result of analyses of Chalk residues showing that the bulk of the flints is disproportionately great as compared with that of the clay. He also estimated that it would require the destruction of 100 feet of the *Micraster-coranguinum* Chalk to produce a residue 1·2 feet thick, together with a layer of flints 7 feet thick, so that the product would be a bed of flint with about enough clay to fill up the interstices.

In South Buckinghamshire the thickness of the Clay-with-Flints is known to be in places as much as 50 feet; and, although this is exceptional, and as a rule the thickness is unknown, it is probably from 10 to 20 feet on the average. As the Reading Beds rest upon the *Micraster-coranguinum* Chalk everywhere in South Buckinghamshire except at Taplow, there is a maximum thickness of 280[4] feet of Upper Chalk available for solution.

At Walter's Ash, near High Wycombe, there is about 70 feet of Upper Chalk below the Clay-with-Flints, and so the most that we could allow for denudation would be 210 feet, supposing that the whole of the *Micraster-coranguinum* Chalk had been present: this would yield 2½ feet only of insoluble residue, different in composition from that of the actual deposit. Probably the amount of Upper Chalk dissolved is much less than 210 feet: for the overlap of the Reading Beds is such that in the Colne Valley there is 150 feet, and in the Chess Valley only 130 feet, of Upper Chalk underlying the Eocene. Allowing for this overlap, there would be not more than 60 feet of Chalk-with-Flints dissolved away at Walter's Ash: that is, sufficient for about 4 feet of flints and 9 inches of residue to fill up more or less the interstices between them.

The brickyard at Walter's Ash, 3½ miles north-west of High Wycombe, shows sections of a very remarkable character, which have been previously described by the Rev. E. C. Spicer.[5] At this

[1] 'Geology of London' Mem. Geol. Surv. vol. i (1889) p. 282.

[2] 'Geology of the Country around Dorchester' Mem. Geol. Surv. 1899, p. 37; 'Geology of the Country around Ringwood' *Ibid.* 1902, p. 33 (and later memoirs).

[3] Q. J. G. S. vol. lxii (1906) pp. 132–62.

[4] A. J. Jukes-Browne, 'The Cretaceous Rocks of Britain' Mem. Geol. Surv. vol. iii (1904) p. 207.

[5] 'Sarsen-Stones in a Claypit' Q. J. G. S. vol. lxi (1905) pp. 39–41.

brickyard there are a number of small deep pits, usually from 20 to 30 feet deep. The bulk of the deposit is a mass of reddish-brown clay, containing abundant angular flints of various sizes. Irregular masses of bright red clay, frequently containing well-rounded flint pebbles, are found incorporated in the clay and flints, and in these pockets are found sarsen-stones of all sizes up to about 600 cubic feet, which would weigh about 40 tons. Mr. Spicer [1] mentions one which was reported to have weighed over 200 tons. The clay and flints extends under the pockets of red clay with sarsens, and as it is the stones that are of most economic importance, the pits do not reach to the Chalk beneath. The workmen say that the deposit is at least 50 feet thick here.

In the midst of a ring of sections of the kind just described, one pit showed material of a totally different character. Here was 4 feet of grey and brown clay overlying about 20 feet of laminated sandy brick-earth. The laminæ show little V-shaped loops, probably due to 'creep,' and the brick-earth breaks away in vertical sheets. Minute flint flakes are present, but very few flints; and these, of moderate size, are arranged along one small band near the bottom. The deposit bears a close resemblance to 'kettle drift' (Pl. XII).

The sarsens consist of a hard white sandstone, with occasional cavities containing loose white sand. In some cases one end of the stone is a flint conglomerate, and there is little doubt that the sandstone and the Hertfordshire Puddingstone are parts of the same deposit. The red clay in which they are embedded is clearly derived from the Reading Beds, and the sarsens and well-rounded flint pebbles that are found in it have the same derivation.[2]

The deposit, therefore, is composed of insoluble matter from the Chalk and Reading-Bed material variously mixed together.

Mr. Spicer's [3] theory is that the sarsens and red clay have sunk down into swallow-holes in the Chalk-with-Flints. By underground solution the Chalk was dissolved, and left Clay-with-Flints surrounding the foundered mass of Reading Beds. He states that the sarsens slope on all sides towards the centre of each pit, and at the bottom are horizontal. This is essentially the 'Chalk residue' theory of Mr. Whitaker, who admits the addition of Eocene material in cases such as this.

That there has been a certain amount of sinking is probable, but this is insufficient to account for the facts. We have seen that, on the 'Chalk residue' theory, the Clay-with-Flints is formed practically *in situ*; it has merely sunk vertically, as also on the swallow-hole theory—in fact, the unworn character of the flints is regarded

[1] Q. J. G. S. vol. lxi (1905) p. 40.

[2] The origin of the sarsens in the Reading Beds was suspected by Prestwich (Q. J. G. S. vol. x, 1854, p. 127); and Mr. Whitaker ('Geology of Middlesex, &c.' Mem. Geol. Surv. 1864, p. 66) and others have agreed that this is the true source of the sarsens.

[3] Q. J. G. S. vol. lxi (1905) pp. 40–41.

as evidence of this. In passing, we may note with Mr. Herries [1] the improbability of a convenient swallow-hole being always ready to receive a sarsen.

If the Reading Beds originally extended over the country, and their waste added the necessary clay, sand, and stones to the Chalk residue, there are still difficulties, for the unworn flints could only come from the Chalk, and we have seen that they are far too numerous to be accounted for by the solution of the small amount of Chalk-with-Flints which has been dissolved. The swallow-hole theory also does not explain the masses of laminated brick-earth (see Pl. XII) which occur in the midst of the deposit.

If, however, we regard the deposit as of Glacial origin, these difficulties disappear. In the first place, the deposits as seen at Walter's Ash have the appearance of Glacial Drift (see Pl. XII). At the beginning of Glacial times the Chalk outcrop would be covered with detritus derived from it and Eocene outliers by weathering, just as an unglaciated area such as Devon is covered by 'head' representing the waste of ages. An ice-sheet coming from the north or north-west would sweep up these materials, and produce the confused mass known as Clay-with-Flints. The absence of Midland rocks is accounted for by the fact that the ice would have to override the Chiltern Hills and the dirty bottom-ice would be stopped by the escarpment, only clean top-ice surmounting the barrier. It is noteworthy that in some cases, as at Aston Clinton, the Clay-with-Flints does not extend to the verge of the escarpment, although away from the escarpment it always caps the high ground.

We have spoken of the Chiltern Hills as existing in Glacial times, as there are good reasons for supposing that the Chalk escarpment and dip-slope had much the same development then as now. The Dry Valley Gravel is generally accepted as having been formed at a time when the soil was frozen, that is, during some part of the Pleistocene Epoch.[2]

The gravels widen out as they approach the Chilterns, as if they had never extended much farther than they do at present. The Wendover Gap is a good illustration. Although there is now a gap through the escarpment, the Valley Gravel ends a mile south of Wendover in a wide spread, and there is little doubt that it never extended much farther than it does at present. Moreover, the Clay-with-Flints forms a dissected plateau, the surface of which slopes parallel to the dip-slope of the Chalk; and the Chalk Rock crops out along each valley for miles, parallel at once to the bottom of the valley and to the base of the Clay-with-Flints above. This indicates the existence of the dip-slope before the Clay-with-Flints was formed, and the dip-slope implies the existence of an escarpment. But, on any theory, the Clay-with-Flints dates back

[1] R. S. Herries, in 'Excursions to the Chilterns' Proc. Geol. Assoc. vol. xix (1905–1906) p. 148.

[2] C. Reid, 'On the Origin of Dry Chalk Valleys & of Coombe Rock' Q. J. G. S. vol. xliii (1887) pp. 364–71.

at least in part, to a very ancient period.[1] We seem justified, therefore, in assuming the presence of the Chiltern escarpment in pre-Glacial times.

In addition to Walter's Ash, there are sections in other places showing similar structure. At Denner Hill, near Speen, are pits in Clay-with-Flints which do not reach the Chalk, although they are situated considerably below the top of the plateau; and one at least is 30 feet deep. Here the sarsens occur in association with ordinary Clay-with-Flints.

At Lee Gate, 3 miles south-east of Wendover, a group of sarsens has recently been discovered on the Clay-with-Flint flat. Some of them are as much as 15 feet long, and the group is embedded in Reading Clay surrounded on every side by Clay-with-Flints. One of the large sarsens is broken, and the fragment, about 4 feet long, lies about 4 feet from the main mass with Reading Clay between (Pl. XIII). It is clear that the fracture, which is along a plane of weakness, dates back to the time when the group of sarsens was deposited in its present place, for the whole mass (as we have stated) forms one huge boulder. The only cause of fracture, other than that of transport by ice, which we can think of is solifluction, and there is at present no dominating high ground whence the sarsens could have been moved; nor is there any trace of a Reading-Bed outlier nearer than Cowcroft, 6 miles to the south-east down the dip-slope.

Some of the sarsens, notably at Walter's Ash, showed a highly glazed surface, and in one case remarkably parallel scratches were seen. These features characterize a dry climate, such as is found in deserts; but they are also found under tundra-conditions, and might therefore be produced in Glacial times.

It should be noted that our objection to the 'Chalk residue' theory of the origin of the Clay-with-Flints of Buckinghamshire applies to the deposit as it now exists. The flints in the detritus which was swept up by the ice-sheet may very well have been derived from solution of Chalk; but we consider that these flints were mixed with detritus from the Eocene and moved into their present position by the ice.

(*b*) The Gravels associated with the Clay-with-Flints.

The Clay-with-Flint area is fringed towards the south-east by a belt of country about 2 miles wide, parallel to the strike of the Chalk, in which the high ground is covered by gravel. In addition, the gravel is frequently seen cropping out in the lateral valleys along the margin of the Clay-with-Flints and evidently underlying it, but as a rule there is not enough to map. There are, however, a few places, as at Prestwood, where the gravel replaces the Clay-

[1] W. Whitaker, 'Geology of London' Mem. Geol. Surv. vol. i (1889) pp. 281–83.

with-Flints. The relation of the two deposits seems fairly clear; when both occur together the gravel, except in the case of pockets, is below the Clay-with-Flints and towards the south-east replaces it.

The gravel is essentially composed of well-rounded flint pebbles derived from the Reading Beds and set in Reading-Bed detritus, either clay or sand. Frequently there are in addition subangular flints, especially towards the southern border. Sandstone and quartzite pebbles are found near the junction with the Fluvioglacial deposits into which the gravels pass.

The gravel can best be seen in some small pits in the wood south-east of Hazlemere Church, near High Wycombe. In one pit there is some bedded loam like that of Walter's Ash, and this is obliquely cut off by gravelly clay. There are a few green-coated flints. In one place the Chalk projects upward to within 4 feet of the surface of the ground, but elsewhere it was not touched at a depth of 10 feet. The general aspect of the deposit is that of Glacial Drift, and it differs from the so-called Clay-with-Flints as seen at Walter's Ash, in containing more sand and flint pebbles and fewer unworn flints—that is, more Eocene and less Cretaceous material.

Other sections may be seen in the small outlier a little south of Rayner's Park, Penn; in two pits 700 yards east of the outlier; at Tyler's Green; Egham's Farm, Knotty Green; Hill Farm, Chalfont St. Giles; and other places.

III. The Fluvioglacial Gravels.

Following on to the south of the Glacial Gravels, and in some cases separable with difficulty from them, are large spreads of gravel with associated masses of sand and loam, which slope very gently, from a height of 400 feet down to less than 200 feet above Ordnance datum, towards the south. Near Marlow they attain an elevation of about 300 feet above the present Thames. The spread of gravel has no relation to the present valleys, but is dissected by them. It agrees with the Glacial Gravels in its components being, like them, chiefly derived from the Reading Beds and Chalk, but these components are present in different proportions.

The gravels which we are now describing differ from the Glacial Gravels in the following characters:—

(1) They contain scarcely any clay, but brick-earth is found in them.
(2) The flints are generally subangular, unworn ones being uncommon.
(3) They contain a proportion, up to 5 per cent. or more, of pebbles derived from a distant source.
(4) They lie more nearly horizontally.

In composition they vary among themselves mainly in the relative proportion of flint pebbles to subangular flints, sometimes one and sometimes the other predominating. The proportion of far-travelled pebbles, such as sandstones and Bunter quartzites, is also variable, and their distribution is shown on the map (Pl. XIV). The far-travelled pebbles occur abundantly in a belt from

3 to 4 miles wide running parallel with, and including, the present valley of the Thames from Hurley to Bourne End, and continued in the same east-north-easterly direction through Beaconsfield and Chalfont to the Colne Valley. South of this belt, between Cookham and Uxbridge, the sandstone and quartzite pebbles are much less abundant.

Exceptionally, Bunter pebbles other than quartzites and sandstones are met with. Among the most remarkable rocks found are a tourmaline (schorl)-breccia, an arkose, quartz-schist, and several igneous rocks which appear to be rhyolites.

At the southern margin there is some difficulty in separating this gravel from the newer gravels—the terraces of the present Thames and Colne. In some places, the boundary is a purely arbitrary one; but, as a rule, there is a distinct feature between them.

In tracing the gravel we are dependent, to a great extent, on small sections a foot or two in depth and on ploughed fields. Of more important sections we may mention one at The Hockett, near Bisham, already described by Mr. H. W. Monckton,[1] which yields pebbles of white quartz, quartzite, sandstones of various colours, quartz-grit, and pebbles of igneous rock, in addition to the usual flints.

In the angle between the Thames and the Wye, near Wooburn Green, there is a platform in which is a brick-pit showing the following section :—

	Thickness in feet.
Gravelly wash	1
Brick-earth, with bands of small angular flints	10
Gravel, consisting of subangular flints and pebbles	6

Although very careful search was made, no sandstone, quartzite, or other far-travelled pebbles could be found in any part of the section, except in the gravelly wash at the top. Behind the platform, however, there is a steep rise, and in this a small gravel-pit yielded many sandstone and quartzite pebbles and also a schorl-breccia pebble. Between the two gravels is a narrow band of yellow clay with a few flints (Clay-with-Flints), exposed in a pond-section.

About a mile due south of Chalfont St. Giles is a brickyard showing 25 feet of yellow brick-earth, streaked with greyish bands and current-bedded throughout. About 6 feet from the surface occurs a thin, but fairly persistent, band of gravel composed of flint-pebbles and subangular flints. At the bottom of the pit is found a bed of whitish sand containing much clay. A small pit near by, in gravel with the far-travelled pebbles, seems to be piped into the brick-earth. The latter may be correlated with the bedded material at Walter's Ash.

The last two sections are important, because they show that the gravels with far-travelled pebbles are younger than the Clay-with-Flints and associated Gravels.

[1] 'On the Occurrence of Boulders & Pebbles from the Glacial Drift in Gravels south of the Thames' Q. J. G. S. vol. xlix (1893) pp. 312–13.

Distribution of the Far-travelled Pebbles.

The sandstones, quartzites, and other pebbles foreign to the district have been traced by Mr. H. J. O. White [1] down the Cherwell, Evenlode, and Windrush into the Thames at Stanlake, and then down the river to beyond the Colne; and he has shown on a map accompanying his paper that they occur in the angle between the Thames and Colne as far north as a line drawn from Bourne End to Rickmansworth, and then continue in a band up the Colne towards Hatfield.

We have found that there is a definite belt of gravel in which the Triassic pebbles are very abundant. Between Hurley and Bourne End the belt follows the north side of the Thames Valley with an occasional patch also on the south side; but at Bourne End, where the Thames bends sharply southwards, the band with abundant Triassic pebbles continues in its north-easterly direction through Beaconsfield, Chalfont, and Rickmansworth to Watford, where it passes beyond the area that we have mapped. The belt of gravel is about 3 miles wide, but widens to 4 miles between Hedsor and Hedgerley. South of this belt there is a marked falling-off in the number of Triassic pebbles, although a few can be found everywhere.

The fact, that the Triassic pebbles are plentiful in the gravels which border the Thames as far down as Bourne End, is strong evidence that the river introduced them into the belt of gravels between Bourne End and Watford. The Clay-with-Flints and associated Gravels do not contain Triassic pebbles (except occasionally near the junction with the Fluvioglacial Gravels), so that they were not derived from these deposits, and the only sources from which the pebbles can have come are down the Thames or down the Colne from above Watford. The fact that the level of the gravels falls from the Thames towards Watford, and that the number of the pebbles also falls off in this direction, leaves us in no doubt between these hypotheses—they came down the Thames.

IV. Former Course of the Thames.

We consider, therefore, that the Thames flowed at one time along the foot of the Eocene escarpment from Bourne End to Rickmansworth, and that the Colne between Rickmansworth and Watford is a part of the old channel. From this channel the river was diverted southwards by an ice-sheet coming from the north and north-west.

At the present time the boundary of the Eocene is buried under the Fluvioglacial Gravels between the Thames and the Colne. There is, however, a well-marked escarpment west of Bourne End, while south of that place is a gorge where the Thames turns southwards. Between the Thames and the Colne, we think that

[1] 'On the Origin of the High-level Gravel with Triassic Débris adjoining the Valley of the Upper Thames' Proc. Geol. Assoc. vol. xv (1897–99) pp. 157–74.

the original escarpment was considerably denuded at the time of formation of the gravel which now passes over it. East of the Colne the escarpment forms a prominent feature.

The sequence of events we believe to have been somewhat as follows. In Pleistocene times, when the cold was approaching its maximum, a lobe of the ice-sheet surmounted the Chiltern Hills and the clean top-ice tore up the 'head' of Chalk and Eocene waste which had been accumulating for ages, producing from the materials the Clay-with-Flints. The Eocene material would be relatively more and the Chalk material less abundant towards the south-east, and this accounts for the Clay-with-Flints passing into gravel, made up of Reading-Bed materials, in this direction.

The Thames offered an obstacle to the advance of the ice-sheet, and above Bourne End proved an effective barrier, for the Glacial Gravels do not cross here. Similarly, between Rickmansworth and Watford the ice seems to have been stopped by the old Thames; but between Bourne End and Rickmansworth the pressure of the ice was so great that it forced its way across the river, filling the old channel and eroding the old Eocene escarpment which had been the southern boundary of the river-valley.

The result of plugging the old Thames valley would be to force the river to rise, until it found a col over which to escape. This seems to have been found at Bourne End, and the water rapidly cut the valley between Bourne End and Maidenhead.

The Boulder Clay of Finchley appears to be a detached part of a mass of Drift which would cross the line of the old Thames at some point, perhaps near Hatfield, and block its channel. There would then be a section of the river, between Rickmansworth and the Eastern Drift, without an outlet, until the water rose high enough to find a col. A way of escape was along the eastern margin of the ice-plug, and the Colne was formed—running southwards from Rickmansworth, and so reversing the direction of drainage of the old river.

The ice-sheet, by the time that it had reached the Thames, had nearly approached its southern limit: for Bourne End is in the latitude of Highgate, and there would be floods of water from the melting ice, which spread out the Fluvioglacial Gravels. The materials of these gravels would be mainly derived from the ice-sheet; but a certain amount, and notably the Triassic pebbles, would be introduced by the Thames in flood-time. Such river-floods might be expected early in the year when the river was swollen by melting ice; and at such times the stream could return to its old course, for its new valley would not have been cut so deeply as at present. In this manner we account for the belt of Triassic pebbles across the Fluvioglacial Gravels. The belt, as we have seen, widens east of the present Thames, as might be expected on this hypothesis. The occasional Triassic pebbles met with south of this belt are regarded as derived from it.

On the retreat of the ice a new system of drainage would be instituted on the gravel-flat. We find a number of the small streams flowing over it regardless of the 'solid' geology. Thus the Misbourne below Chalfont St. Peter leaves the Chalk for the Reading Beds, and farther on returns to the Chalk. If the drainage is post-Fluvioglacial, this is readily accounted for.

Certain other peculiarities in the drainage receive an easy explanation on our hypothesis. We have already explained the sharp bends of the Thames at Bourne End and the Colne at Rickmansworth. If we reconstruct the old channel of the Thames through Beaconsfield and Chalfont to Rickmansworth, we find that north of this line its tributaries, the Wye and the Misbourne, entered the river normally. After the old channel was filled by Drift and the ice had retreated, the drainage of the Wye, seeking the nearest way of escape across the gravel-flat, turned sharply westwards in the remarkable curve at Wooburn. Similarly, the Misbourne turned eastwards into the Colne.

The great floods of water from the melting ice account for another peculiarity of the Thames drainage—that is, the sudden expansion of the valley below Taplow and Bray. The valley widens rapidly from about a mile and a half at Maidenhead to about 4 miles at Windsor, and, after passing the Chalk ridge of Windsor, which probably offered an obstacle to denudation, there is a further increase to 8 miles at Iver. The position of this great flat is exactly opposite to the termination of the glacier, where the floods from the melting ice, aided by the Thames and the Colne, have worn away the soft Tertiary clays.

It is possible that the southern end of the Fluvioglacial Gravels is buried under the later Thames gravels. J. Allen Brown [1] noticed, at Durley and elsewhere, gravels with quartzite and other far-travelled pebbles under gravels which but very rarely contain them.

In conclusion, we wish to express our indebtedness to Mr. Clement Reid, F.R.S., for help and encouragement in the preparation of this paper.

V. Summary.

(1) The Clay-with-Flints was formed by an ice-sheet from the north or north-west.

(2) The Glacial Gravels of the Old Series Geological Survey Map have been separated into two divisions, Gravelly Drift and Fluvioglacial Gravels.

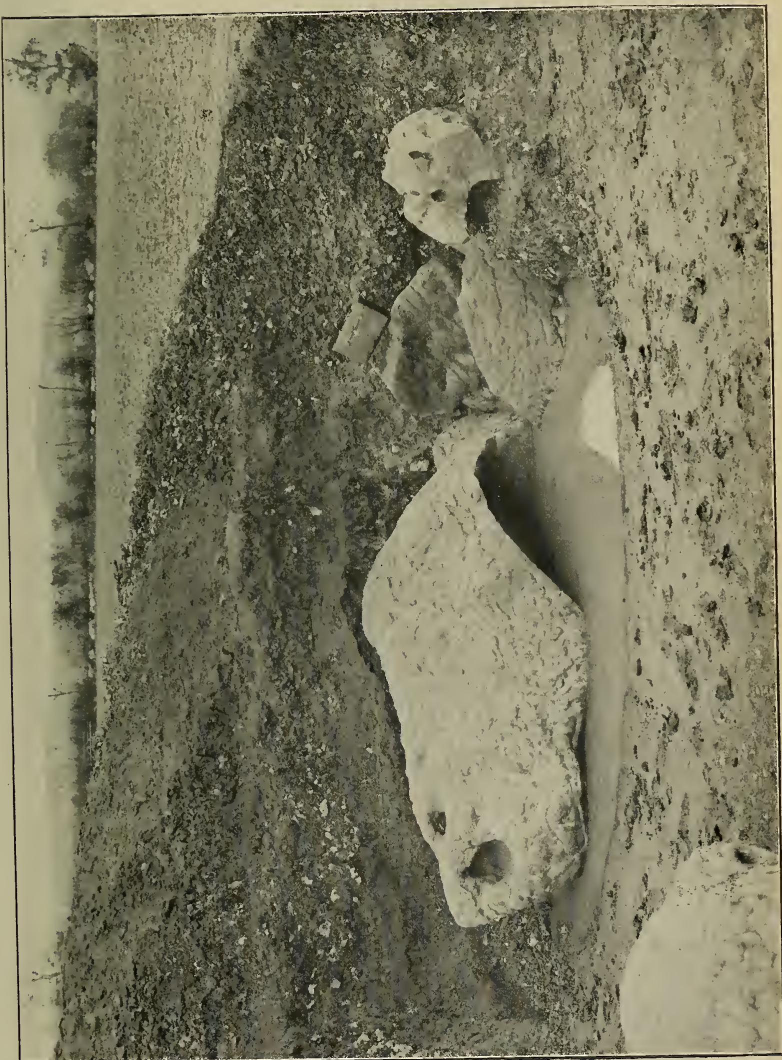
(3) The Thames in early Pleistocene times flowed from Bourne End to Watford along the foot of the Eocene escarpment. It was deflected into its present course by the ice-sheet which produced the Clay-with-Flints.

(4) The Colne, south of Rickmansworth, is a new river draining

[1] 'Notes on the High-Level River Drift between Hanwell & Iver' Proc. Geol. Assoc. vol. xiv (1895-96) p. 159.

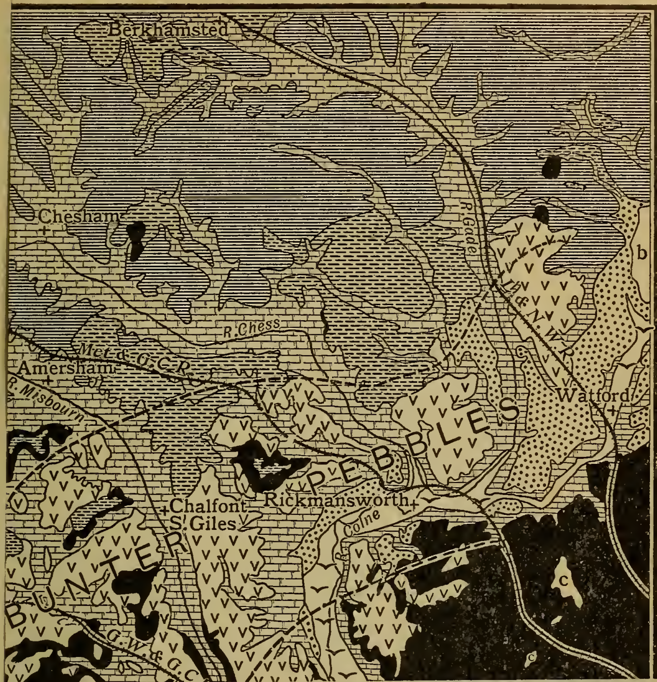
Geol. Surv. photo.

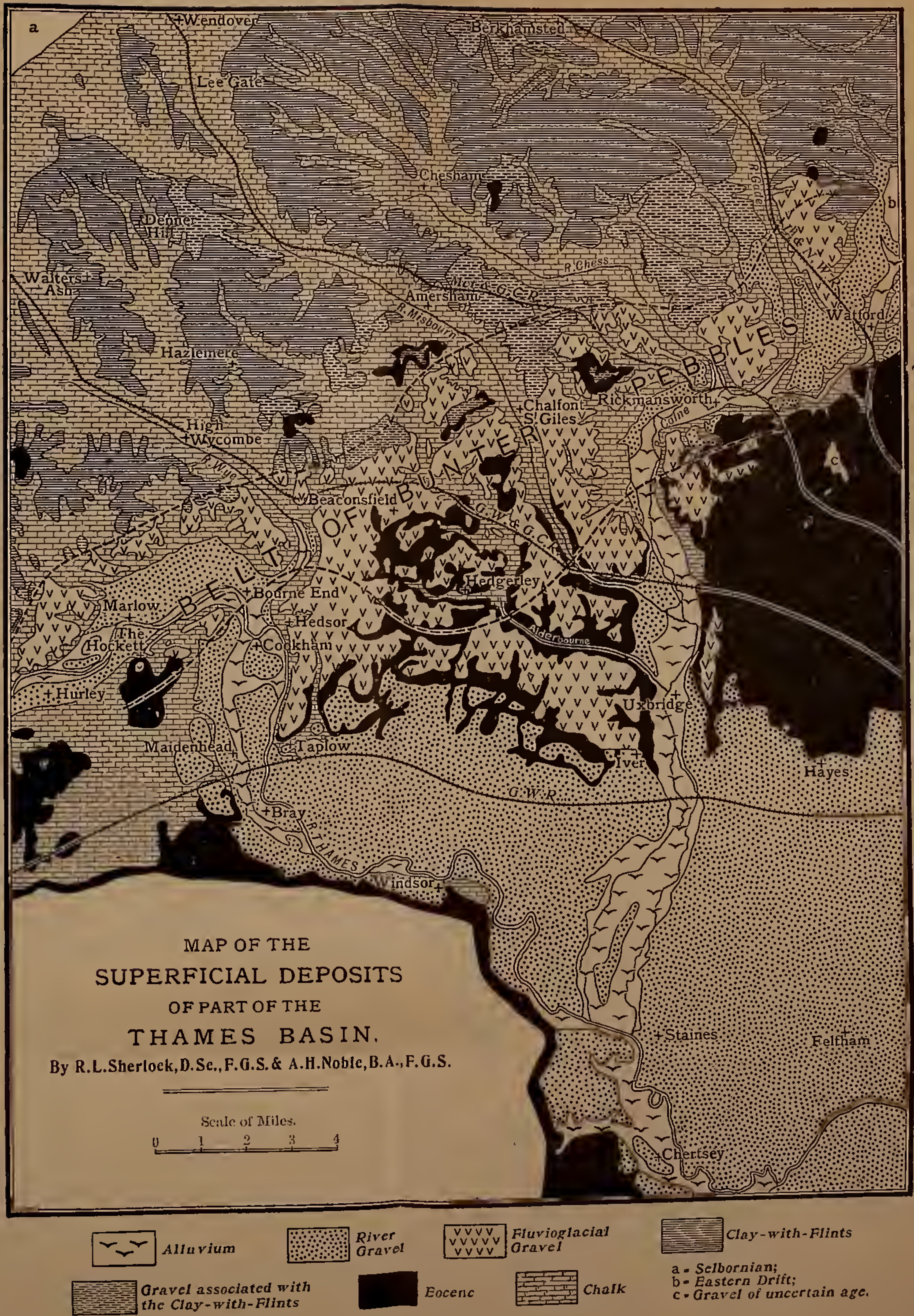
Bedded sandy brick-earth, containing small flints; Walter's Ash, near High Wycombe (Buckinghamshire).



Geol. Surv. photo.

Sarsen with a vermicular surface; Lee Gate, near Wendover (Buckinghamshire).


Berkhamsted
Chesham
R. Gade
b
R. Chess
Met. & G.C.R.
Amersham
R. Misbourn
Watford
PEBBLES
BUNTER
Rickmansworth
Chalfont
St. Giles
Colne
c
G.W. & G.C.


a
Wendover
Berkhamsted
Lee Gate
Chesham
Denner Hill
Walters Ash
Amersham
R. Chess
R. Misbourne
Hazlemere
Watford
Chalfont S. Giles
Rickmansworth
High Wycombe
R. Wye
Beaconsfield
BELT OF BUNTER PEBBLES
Hedgerley
Bourne End
Marlow
Hedsor
The Hockett
Cookham
Alderbourne
Hurley
Uxbridge
Maidenhead
Taplow
Iver
Hayes
G.W.R.
Bray
R. THAMES
Windsor
Staines
Feltham
Chertsey
b
c
MAP OF THE
SUPERFICIAL DEPOSITS
OF PART OF THE
THAMES BASIN.
By R.L.Sherlock, D.Sc., F.G.S. & A.H.Noble, B.A., F.G.S.
Scale of Miles.
0 1 2 3 4
Alluvium
River Gravel
Fluvioglacial Gravel
Clay-with-Flints
Gravel associated with the Clay-with-Flints
Eocene
Chalk
a = Selbornian;
b = Eastern Drift;
c = Gravel of uncertain age.

the portion of the old Thames valley that is cut off between Rickmansworth and the Eastern Drift near Hatfield.

(5) The flood-waters due to the melting of the ice, aided by the Thames and the Colne, produced the great flat now covered by Thames gravel to the east of Maidenhead.

(6) A new system of drainage developed on the Fluvioglacial plain, shown in the lower courses of the Wye and the Misbourne.

EXPLANATION OF PLATES XII–XIV.

Plate XII.

Sandy brick-earth, bedded. The stones are small flints. Walter's Ash, near High Wycombe, Buckinghamshire. (Geological Survey photograph.)

Plate XIII.

Sarsen with a vermicular surface. The stone was found broken, as shown, with the fragment about 4 feet from the larger piece and separated by red clay. Lee Gate, near Wendover, Buckinghamshire. (Geological Survey photograph.)

Plate XIV.

Map of the superficial deposits of part of the Thames Basin, on the scale of 3·3 miles to the inch, or 1 : 209,088.

Discussion.

Mr. G. Barrow remarked that some of the ideas put forward by the Authors were not likely to be accepted by everyone; the suggested change in the course of the Thames did not appeal to the speaker. At the same time, it was advisable to have all the Authors' views in print, so that there might be an organized production of evidence for or against them.

Mr. C. E. N. Bromehead thought that the Authors did not intend to suggest a Glacial origin for all Clay-with-Flints, but would welcome a more exact description of the distinction, between the deposit described in the paper, and Clay-with-Flints in the ordinary sense of the term.

He thought that they had done valuable work in tracing the distribution of Triassic pebbles, but pointed out some difficulties. If these pebbles were used to trace a pre-Glacial course of the river, their introduction into the Thames system could not be attributed to Glacial action. Again, he considered that mention should have been made of the gravel of Ashley Hill: this gravel was full of Triassic pebbles; but, on the Authors' theory, it was anomalous, both in its position south of the Thames, and in its great height above Ordnance datum.

If we accept the former course of the Thames past Beaconsfield, an explanation other than that adopted by the Authors is possible. He drew attention to an interesting parallel in Oxfordshire, where the Wilcote Valley is an old course of the Windrush, by which that river formerly joined the present course of the Evenlode. In each case the river had been diverted southwards, leaving the awkward bends at Crawley and Bourne End at the point of diversion. This fact suggested capture by a small stream to the south of the old river-course, cutting back its head-waters. In each case the abandoned course was over clays, whereas the new one was in limestone; the cutting back of the head-waters of the capturing stream might, therefore, be accomplished by solution along joint-planes.

Mr. A. L. Leach remarked that, on the North Downs in the vicinity of the Darent and the Medway, the superficial deposits, which appeared to resemble those described by the Authors, included Clay-with-Flints and brick-earths associated with scattered sarsens and drift-gravels. The resemblance between the two sets of deposits certainly suggests similarity of origin; but the Clay-with-Flints of the North Downs cannot be ascribed to any ice-sheet advancing from the north-west. He had been desirous of learning what were the special characters which the Authors regarded as criteria of the Glacial origin of the Clay-with-Flints in the area described, and this part of the subject had not been fully brought out. It certainly appeared significant that no ice-scraped flints had been found; yet, if ice had actually passed over this mass of clay and flints with which hard siliceous sandstones (sarsens) were abundantly associated, the conditions would not have been unfavourable to the production of striations.

The Rev. E. C. Spicer commented upon the Walter's Ash deposits, and pointed out that the clay containing the large sarsen-blocks contained no flints, but rested in Chalk hollows 50 or 60 feet deep, lined by a thickness of a few feet of Clay-with-Flints. These crater-like pits, filled with laminated clays, were also covered over by a thin 'drift' deposit of mixed materials; but, since the plateau containing these pits was here 640 feet high, it was difficult to imagine a mass of ice of that thickness advancing over the Chilterns without blocking the Goring Gap, and thus preventing the Thames from flowing to Bourne End. There was undoubted Boulder Clay near Wolverton. He considered that the Brick Hills standing in front of the Chiltern escarpment, but lower, should show strong evidence of Glacial deposits, which the speaker had not found upon the sandy surface. If the theory of the paper were accepted, it would be necessary to reconsider the topography of the whole Oxford region. The mapping of the observed deposits, however, was a very valuable contribution.

Dr. A. E. Salter stated that he could not agree with the last speaker concerning the evidence of 'Glacial' deposits in front of the Chiltern escarpment. Drift and boulders occurred on the highest points of the Lower Greensand area (above 500 feet O.D.), near the Brick Hills. At Great Brickhill, near the Wesleyan Chapel, is a section in chalky drift, about 20 feet deep, and Boulder Clay can also be seen in a pit on the right-hand side of the road leading from Heath to the 'Fox & Hounds' and Sheeps Lane, at a height of 420 feet above O.D.

Mr. G. W. Lamplugh asked whither the Authors proposed to send their Thames after it reached Watford. If again north-eastwards, it would cross country with which he had some acquaintance. But his impression had been that the quartzite-gravels of this part probably belonged to a Glacial outwash-plain formed by waters which flowed south-westwards from Hatfield to Watford—a direction diametrically opposite to that of the supposititious Thames. He considered that the Authors were hardly justified in abandoning their river, without indicating whither it was to go.

Mr. G. W. Young agreed that when one attempted to apply the theory of the Glacial origin of the Clay-with-Flints to other areas, one was confronted with very grave difficulties. For instance, in Surrey the Clay-with-Flints occupied a large part of the high ground close up to the Chalk escarpment, and it was difficult to imagine whence the ice-sheet that formed it in such a position could have come. If, as the Authors asserted, the northern sheet was arrested by the Tertiary escarpment at Rickmansworth, one was driven to suppose that the Weald must have had a separate ice-sheet, which was difficult to believe. The great variability in thickness and 'pocketty' nature of the Clay-with-Flints led the speaker to think that solution *in situ* and the letting-down and commingling of Eocene material was a more satisfactory explanation of its origin in Surrey.

Mr. H. W. Monckton said that the course of the discussion had made him suspect that the Authors had included under the name 'Clay-with-Flints' some deposits which differed from those usually included under the term.

With reference to the suggested blocking of valleys by ice, he wished to repeat the remark which he had often made, that with regard to the stratified gravels of the district he felt convinced that they were in all cases older than the valleys which adjoined them and were at a lower level. He did not believe that these stratified gravels had been deposited on the tops of hills.

Dr. R. L. Sherlock, in reply, thought that much of the criticism was due to a misunderstanding. The Glacial origin was claimed for the Clay-with-Flints over a limited area only, and it might be that the Clay-with-Flints of other districts was a different deposit formed in a different way. Mr. Whitaker's objection, that the Chiltern Hills were too low to stop a great ice-sheet, loses its force when we remember that the ice was not far from its southern limit. The amount of Upper Chalk denuded can be estimated from the known thickness of the zones, and the horizon on which the Eocene rests. The boundary between the Gravelly Drift and the Fluvio-glacial Gravel is fairly well marked, and only occasionally offers difficulties. The Authors had not thought it desirable to make any statement about the country, which they had not mapped, east of Watford, and so the delineation of the course of the Thames beyond that place was left for future workers. The gravel on Ashley Hill, which contains Bunter pebbles, is anomalous, and has not been coloured on the map. It is at a much higher level than the Fluvioglacial deposits and probably much older. The deposit at Walter's Ash is not supposed to be of the uniform thickness of 50 feet; but the numerous pits which are scattered about the district, 30 feet or more in depth, show that the deposit is thick. With regard to Mr. Lamplugh's idea that the Bunter pebbles came from the east instead of the west, it was not unlikely that, after the Colne had been formed and the drainage reversed, Bunter pebbles were introduced at a late stage from the Eastern Drift, and deposited above those derived from the old Thames. The general fall in the level of the gravels from Bourne End to Watford, and the diminution in the size of the pebbles from west to east, would indicate that the Bunter Pebbles came from the west.

12. *On a* LATE GLACIAL STAGE *in the* VALLEY *of the* RIVER LEA, *subsequent to the* EPOCH *of* RIVER-DRIFT MAN.

By S. HAZZLEDINE WARREN, F.G.S. *With Reports on the Organic Remains and on the Mineral Composition of the Arctic Bed, by various Authors.* (Read January 10th, 1912.)

[PLATES XV–XVII.]

CONTENTS.

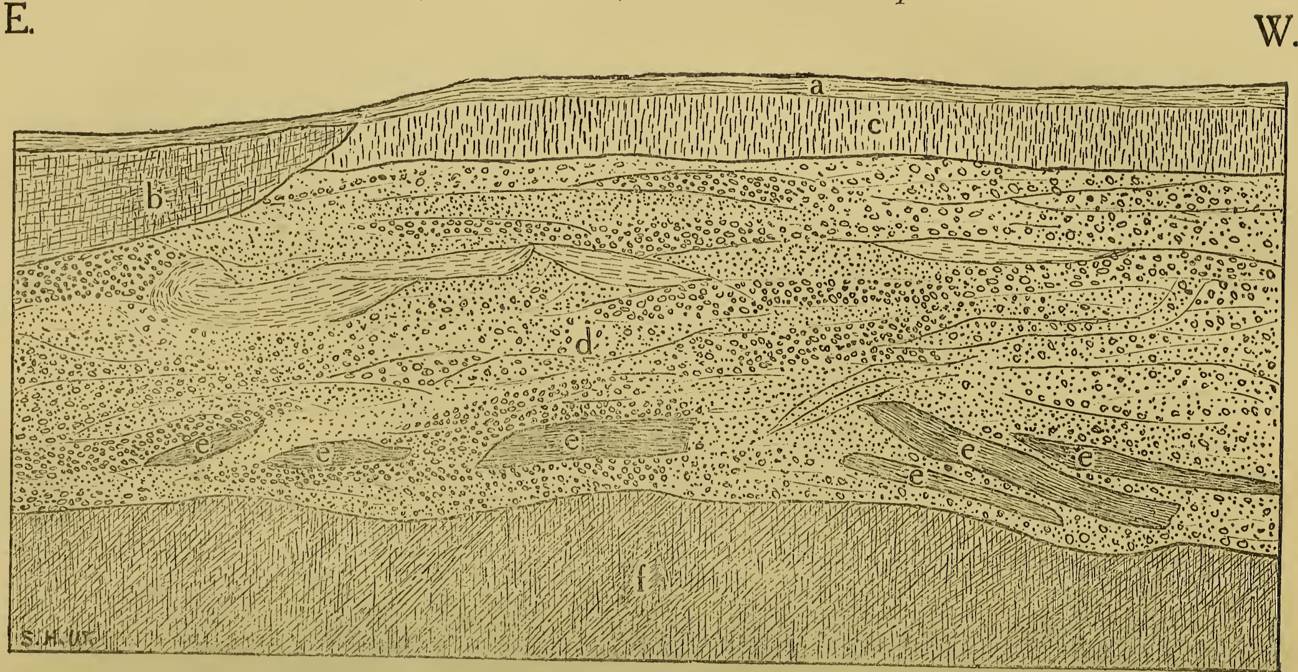
I. THE DISCOVERY OF THE ARCTIC BED.

FOR some few years past the Great Eastern Railway Company have been obtaining remains of the Mammoth from a large ballast-pit, known as the Pickett's Lock pit, at Ponder's End (Middlesex). Many of these remains, through the instrumentality of Mr. A. Atkins, of the Engineers' Department of the Company, have been carefully preserved, and are placed in the Board Room at Liverpool Street Station, the London terminus of the Great Eastern Railway.

The Pickett's Lock pit at Ponder's End is an extensive one, and it is situated in the Low-Level River-Drift of the Lea Valley. The surface of the ground lies at about 43 feet above Ordnance datum, and is but slightly raised (to an amount of 2 or 3 feet) above the present alluvial flood-plane of the river. The pit exhibits a very fine section, chiefly composed of gravel and sand, showing the effects of strong current-action. There is a subordinate capping of brickearth, which does not exceed 4 feet in thickness, and is usually less. The greatest total thickness of the Drift amounts, I believe, to 22 feet; but towards the western side of the pit the underlying floor of London Clay gradually rises, and the thickness of the Drift is much less.

When I first visited the pit, Mr. Guy Leonard, the engineer in charge of the works, pointed out to me a dark bed, from 1 to 2

Diagrammatic section of the Pickett's Lock ballast-pit.



a=Surface-soil. *b*=Alluvium, with *Bos longifrons* and prehistoric pottery and flint-flakes at the base. *c*=Brickearth. *d*=Gravel and sand, showing current-action; a clayey bed is frequently seen in the upper third of this gravel and sand, both here and in the Angel Road section, but no organic remains have been found in it. *e*=Disturbed masses of the Arctic Bed, associated with remains of *Elephas primigenius*, etc. *f*=London Clay, with an irregularly eroded surface. The total thickness of the drift deposits is 18 to 22 feet.

feet thick, intercalated in the lower part of the section. Some of the mammalian remains are found within this dark bed, others beneath or above it.

Upon examination, the dark bed was found to contain much vegetable matter. It was seen to vary considerably in lithological character in different places, being sometimes clayey, sometimes sandy; occasionally the vegetable matter was in very small proportion, sometimes it formed the bulk of the deposit. The bed was also observed to contain numerous shells of land and freshwater mollusca, the elytra of beetles, and other remains.

In certain spots it assumed a deep blue-black colour, was greasy to the touch, and emitted a fetid odour when freshly dug. I think this must be due to the impregnation of adipocere, from the carcases of the animals whose bones are also found associated with the deposit. I imagine that the larger patches showing this condition may be places where the carcases of big animals have lain. The same peculiar condition is found in the material that is in immediate contact with the bones.

Upon washing out a sample of this deposit, I found that seeds and leaves of plants were abundant and in good condition. I submitted these to Dr. F. J. Lewis, with whom I was corresponding upon another matter, and he kindly undertook their examination. He reported at once that the flora was Arctic, and that it was well worth fuller examination. I accordingly set to work on a more extensive scale, washing out the material, and sorting the determinable remains into their various classes.

II. The Stratigraphy of the Arctic Bed.

This Arctic Bed has been found over the whole of the extensive excavations of the Ponder's End pit. At the same time, it is very discontinuous, being much broken up and disturbed. Owing to its disturbed condition, the actual depth beneath the surface at which it is found varies considerably, but is commonly about 15 to 17 feet.

The Arctic Bed is occasionally seen in continuous section for 20 or 30 yards, but usually the individual masses are much smaller than this. Not infrequently these detached masses are inclined at a considerable angle, masses of gravel (probably frozen) having apparently been thrust beneath one end. Occasionally masses or tablets of this bed, several yards across, have been thrust over each other, with strata of gravel or sand intervening between them: thus duplicating the bed. At one place, which is named the 'Special Site' in the lists of species tabulated in the reports appended to this paper, a still more complicated section was exposed early in 1911. Here three large masses of Arctic Bed were seen in vertical succession, separated one from the other by strata of gravel and sand.

I collected separate samples from these beds, which have been separately examined throughout, in order to see whether there was any evidence to suggest that they represented a succession in time, with a change in climatic conditions. No such evidence was obtained, and I think it probable that the three beds seen in vertical succession were parts of the same deposit which had been floated, or thrust, one over the other by subsequent disturbance.

It is true that some slight differences in the flora were observed in the three collections, but these are not more conspicuous than are noticed in other samples of the Arctic Bed, which varies greatly within short distances, both in lithological character and in its organic remains.

When Dr. F. J. Lewis visited Ponder's End pit with me, he was impressed by the similarity of the physical features of the Arctic Bed to those which are referred to 'ice-raft action' in the Scottish deposits. It may be that the agency of ice is too frequently called in as an explanation of any difficulty. It seems to me, however, in the case of the Arctic Bed of Ponder's End, that its physical features, taken in conjunction with its boreal fauna and flora, must render such an explanation not only probable but inevitable.

Shortly after I had discovered the Arctic Bed at Ponder's End, some mammoth and rhinoceros-remains were brought to me by a workman, who stated that they were found in a temporary excavation on the Tottenham Marshes, at a spot near the oil-cloth factory. The material adherent to the remains was, so far as one could judge, identical with the Arctic Bed at Ponder's End. It also yielded seeds and mosses in the same manner as that bed: although, as the material had dried, the remains were unfortunately not in a satisfactory state for determination. Dr. F. J. Lewis could only say that the genera present, such as *Potamogeton*, were also common at Ponder's End.

One of these mammalian remains consisted of a well-preserved tusk of *Elephas primigenius*, measuring 3 feet 6 inches along the curve. The dark staining and condition of this tusk is the same as that of the mammalian bones found within the Arctic Bed at Ponder's End; it differs greatly from the condition of bones found in gravel, sand, or brickearth.

At the same time, I can give no personal verification of the locality, although a discovery that I have since made renders it probable that this may be correct.

Another large excavation, which belongs to the North London Ballast Company, is situated close to Angel Road Station, at a distance of about a mile and a half lower down the valley than the Ponder's End pit. This pit is in the same stretch of Low-Level gravel, and it shows an admirable section of the Arctic Bed. Here the features which it presents are similar to those that have already been described. In one part of this pit, some thin laminæ of peat were seen intercalated with sand: this material proved to be particularly rich in seeds.

Thus, if we accepted the indirect evidence of the mammoth-remains from the Tottenham Marshes, this would give three points at which the Arctic Bed is present. These three points form a triangle with sides measuring approximately 2 miles, a mile and a half, and three-quarters of a mile. In any case there are two points, a mile and a half apart, at both of which extensive exposures of the Arctic Bed may be seen.[1]

Much of the Arctic deposit is laminated and distinctly water-laid. At the same time, an examination of its fauna and flora shows that it is not a truly lacustrine deposit formed in a permanent lake. I think that the greater part of the deposit represents the silting of drifted material in water ponded up by some temporary barrier—this barrier being not improbably formed by the accumulation of ice-floes.

A little below the site of these discoveries, a hill, named Higham Hill, stands up almost in the fair-way of the valley. In addition to this, the features presented by the 50-foot contours appear to me somewhat suggestive. These contours close in across the valley at a point a little below Enfield Lock. If one follows them in the down-stream direction from this point, one finds that they gradually widen out until they are a mile and three-quarters apart at Angel Road. From this point they widen out rapidly to a space of nearly 2¾ miles immediately above Higham Hill: the space between the 50-foot contours opposite to that hill closing in again to a mile and a quarter.

Thus a time of flood would give a wide expanse of comparatively quiet water immediately above Higham Hill. This would, it seems to me, tend to favour the accumulation of ice-packs at the foot of the obstruction; these ice-packs might spread across the river, and eventually form a temporary barrier across the narrower channel below. This is, of course, only to be understood in the light of a suggestion. But the breaking-down of such a supposititious barrier, with the accompanying breaking-up of the river-ice, would supply an adequate cause for the disturbances which the Arctic Bed is seen to have undergone.

I have not succeeded in finding any evidence of glaciation among the stones; the conditions were probably not sufficiently rigorous to produce this. At the same time, the bones are not infrequently scratched with straight scorings 4 or 5 inches long. These surface-scratchings are particularly well seen on the mammoth-tusk from the Tottenham Marshes, to which reference has already been made. Such scratches would doubtless be formed under the conditions which have been suggested.

Certain portions of the deposit, instead of being laminated, are composed of unstratified stony clay; the stones are subangular flints, stained black. In one of the isolated masses presenting this

[1] [Mr. Arthur Wrigley and myself are now investigating some further plant-bearing beds, lower down the Lea Valley, in the neighbourhood of Temple Mills and Hackney Wick. These, although belonging to the Low-Level Drift, show differences in their plant associations from the beds described in this paper, but I am unable to speak more definitely at present.—*S. H. W.*, *June 12th, 1912.*]

character, I found, early in January 1912 (the week before the reading of this paper), a very remarkable bed of moss. This bed extended for 6 yards along the section, and the moss was found through a vertical thickness of 7 inches.

A sample of this material was examined by Mr. H. N. Dixon, who reported that it was almost homogeneous, the mass of it being composed of *Hypnum exannulatum* var. *orthophyllum* (Milde), with only a small admixture of *H. giganteum*. Mr. Dixon further said that he had only once seen a fossil moss in better preservation, and that was in a much more recent deposit from the Fens.

This is the only instance so far obtained of any plant actually growing upon the site. There can be no doubt that the moss grew up through the silt as this accumulated. Thus the rate of accumulation of the unstratified silt must have been sufficiently slow to allow the growth of the moss to keep pace with it for a certain length of time. This shows that the deposit was not all formed in the same manner, as, indeed, one would expect from its extremely variable character.

III. The Climatic Evidence furnished by the Arctic Bed.

Mr. T. I. Pocock[1] has observed that the contorted 'Trail' passes imperceptibly into the gravel of Low-Level River Drift (the 'fourth terrace' of Messrs. Hinton & Kennard[2]). Now the Trail has been frequently referred, and I think correctly referred, to some form of glacial action. In the Ponder's End bed there is positive evidence of an Arctic climate during the deposition of this same stage of the River Drift.

The climatic evidence of this bed is not essentially new. It has previously been foreshadowed by the plant-bed at the Admiralty Buildings, Westminster,[3] and also by the work of Mr. M. A. C. Hinton, on the smaller mammalia.[4] At the same time, the evidence from Ponder's End is more complete than any that has been previously forthcoming. It is, moreover, seen in two open sections, both of wide extent, and can be visited and revisited and large collections made; while the organic remains which it contains are abundant, varied, and in good condition for determination.

By collating the evidence detailed in the reports which are appended to this paper, we shall note that the climatic conditions

[1] 'Summary of Progress of the Geological Survey of the U.K. for 1902–1903' p. 205; see also A. L. Leach, Proc. Geol. Assoc. vol. xix (1905–1906) p. 140.

[2] Proc. Geol. Assoc. vol. xix (1905–1906) p. 84.

[3] W. J. L. Abbott, Proc. Geol. Assoc. vol. xii (1892) p. 346; and C. Reid, 'The Origin of the British Flora' 1899, p. 54.

[4] Proc. Geol. Assoc. vol. xxi (1910) p. 489. Mr. Hinton deserves great credit for having reached the conclusion that the Low-Level River Drift was deposited under cold climatic conditions, although I cannot associate myself with the correlation of this stage with the major glaciation of the country.

indicated are such as are only found to-day within the Arctic Circle, although, it must be understood, not very far within it; certainly less rigorous than the present state of Spitsbergen. Broadly speaking, the evidence brings the present climate of Lapland down to the site of London. This is a very important difference in climate, and one which deserves the name of Arctic or Glacial. There can be little doubt that, under these conditions, all the upper reaches of the mountain-valleys of this country would be occupied by ice. How far the ice might or might not spread over the plains, I will make no attempt to define. It is not contended that the conditions would compare with those under which the Chalky Boulder Clay or Cromer Till were formed.

As may be seen from Dr. Lewis's report on the flowering plants (pp. 229–30), some portions of the Arctic Bed at Ponder's End consist of little else than the matted débris of the Arctic willow, the Arctic birch being present in less amount. Although, during the past eighteen months, enormous quantities of the Arctic Bed have been carefully searched as the very extensive excavations have proceeded, no trace of the wood or leaves of any bigger tree has yet been found. One would not like to assert that no bigger tree existed in the Lea Valley at this time, but it is quite certain that if any such did exist, they were comparatively scarce.

Other parts of this country, particularly south of the Thames, may have been under forest; this one cannot say. But unless we imagine the Lea Valley to have been exceptional, extensive areas of the southern part of England must have greatly resembled the tundra of Northern Europe, although less flat and marshy. That is to say, a bleak, almost treeless region, largely covered by moss when not under snow, and with little more considerable in the way of vegetation than the stunted bushes of the Arctic willow and the Arctic birch, even these being half hidden in the growth of moss.

If it be desired, for convenience of reference, to give a name to this stage of the Pleistocene, I would suggest that the term 'Ponder's End Stage' would be an excellent one.

IV. The Correlation of Pleistocene Deposits.

We may now consider the important question of correlation.

There are, in my opinion, only two lines of evidence upon which to depend in defining the minuter subdivisions of age in the Pleistocene Period. These are, firstly, the stratigraphical succession, and, secondly, the human industries based upon that succession.

Upon the continent of Europe *Elephas antiquus* is taken as indicative of the Chellean stage. But, to cite only one instance, the Clacton bed, which is a purely *Elephas-antiquus* deposit, can be proved by the stratigraphical succession of the local river-drifts, and of the human industries which they contain, to be post-Chellean; indeed, in all probability, post-Mousterian. The Mammalia can show us the greater differences between Pliocene, Pleistocene, and Holocene; but they fail, at least when applied upon the rough and ready basis of two species of elephant, in respect of the difference between pre-Glacial and inter-Glacial.

Upon the average, *Elephas antiquus* may be earlier than *E. primigenius*, but this rule is not of universal application. Occasionally the two species occur together in contemporary association. It is more essentially relative climate than relative age that these two species represent.

Elephas antiquus may be taken as representative of the southern fauna, and *E. primigenius* of the northern fauna. As has been frequently emphasized by Dr. Boyd Dawkins, the boundary between these two zoological provinces fluctuated northwards and southwards according to secular, and even seasonal, climatic changes. Thus the same ground may be occupied by both northern and southern animals within the circle of a single year.

At the same time, it may be worth while to recall that Leith Adams has shown that at Ilford, where *Elephas antiquus* and *E. primigenius* occur in contemporary association, the latter species is not of the Arctic form.[1] The Ilford variety of *E. primigenius* is smaller than the Arctic form, and possesses certain peculiarities in the structure of its teeth. How far this might apply to other localities, I will make no attempt to discuss.

In any case, it must be conceded that the two species mentioned do not in this country represent a well-defined sequence in time. But, when we come to the human industries, I know of no authenticated instance in which these do not occur in the same invariable order of stratigraphical succession. It is true that all the stages that are found in France have not hitherto been recognized in this country, where the material at our command is so much less extensive. In spite of this, and although there may be, as one would expect, local differences, the general order of succession is the same in the two areas.

This conclusion will not pass without dispute, but my own experience leads me to the belief that it is justified. It would not be fitting to enter into a full discussion of these wide problems in the present paper. But, as the question of correlation is of so much importance, it may be desirable to give some brief outline of the Palæolithic succession of the Stoke Newington district, which has been so ably worked out by Mr. Worthington Smith,[2] especially as this is so nearly related to the lower part of the Lea Valley with which we are dealing. In the river drifts which lie between the surface-levels of 70 and 100 feet O.D., the earliest implements found consist chiefly of rude ovate forms, although a smaller number of pointed types also occur. These are typical of the series coming in to the 'sequence-dates' of 7.30 to 7.40,[3] although their

[1] A. Leith Adams, 'The British Fossil Elephants' pt. ii, p. 79 (Monogr. Palæont. Soc. for 1879).

[2] 'Man the Primeval Savage' 1894.

[3] The ages that these sequence-dates represent can be gathered from the table (p. 223). The use of this system possesses many practical advantages, although one cannot enter into these in the present paper. See 'On the Value

extreme range may be somewhat greater than this. This series is always remanié; the implements are greatly abraded, and derived from some earlier drifts. After these come another series in which the pointed forms predominate, although many other types also occur, and trimmed flakes are beginning to be more abundant than in the earliest series. The place of these in the scale is about s.d. 7.57 to 7.60, while on the line of a former surface overlying the gravels in which the last-named series occurs, the Palæolithic 'floor' is found. The true Mousterian terminal flakes form a large proportion of the implements found upon the 'floor.' The place of this series is probably about sequence-date 7.68 to 7.70.

From my own work in this district I can fully confirm Mr. Worthington Smith's conclusions. I have also found that in the next higher terrace to that which contains the 'floor,' there is another series of contemporary or but slightly abraded implements of somewhere about sequence-date 7.50.

It is true that certain deposits, such, for instance, as that of Warren Hill, Mildenhall, yield a series of remains of different ages that are commingled together. But these conditions of remaniement are not surprising when we remember the redistribution that many of these drifts have undergone. While I feel much sympathy with those who take the more sceptical view, yet at the same time the invariable order of succession of the human industries, where this succession is clearly shown, does seem to me to be supported by too great a weight of evidence, both in this country and on the Continent, to be discounted by the phenomena of remaniement, numerous as these may be.

V. The Correlation of the Arctic Bed.

In the part of the Lea Valley with which we are dealing, contemporary Palæolithic implements are found only in the terraces which are at, or above, the 100-foot contour. Upon comparing these with the standard series of our scale of industries, we find that they must be placed at 'sequence-date' 7.55 to 7.65 or 7.70. The succeeding gravels that are below the 100-foot contour must therefore belong to the period of s.d. 7.70 to 7.90. They cannot well occupy less time than this; they may occupy more. It would, therefore, appear that the Ponder's End bed, at the low level of 43 feet O.D., separated from the gravel terrace of s.d. 7.65 or 7.70 by some 70 feet of vertical valley-erosion on the one hand, and immediately succeeded as it is by the Alluvium on the other hand, should be placed somewhere in the indefinite sequence-date 8.xx, which is still so largely an unknown quantity.

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of Mineral Condition in Determining the Relative Age of Stone Implements' Geol. Mag. dec. 4, vol. ix (1902) p. 97; 'On the Correlation of the Prehistoric Floor at Hullbridge with similar Beds elsewhere' Essex Naturalist, vol. xvi (1911) p. 279; and 'On the Classification of the Prehistoric Remains of East Essex,' read before the Anthropological Institute on May 23rd, 1911.

Judged by the physical succession of the river-deposits, the Arctic Bed appears to be nearer to the Neolithic age than it is to the age of River-Drift man, although its fauna is purely Pleistocene.

In the accompanying table (p. 223) an attempt has been made to show the position of the Ponder's End stage in the general Pleistocene succession. In the first five columns are placed certain of our English plant-bearing deposits which can be approximately correlated with the succession of culture stages. Of these the Stoke Newington temperate flora is particularly well defined [1]; it is very near the line of s.d. 7.70, or it may be slightly earlier, say about s.d. 7.68. The Wolvercote deposit, described by Mr. A. M. Bell,[2] also temperate, is probably on about the same horizon, although its correlation is less clearly defined, and it may be a little earlier or a little later. The Hoxne deposits, again, which have been proved by the researches of Mr. Clement Reid, F.R.S.,[3] to contain an Arctic flora overlying a temperate one, are so far clearly defined as lying between the Chalky Boulder Clay below and the stage of s.d. 7.50 to 7.60 above: this higher stage being itself also temperate. The temperate flora of Hitchin [4] may probably be on the same horizon as the lower temperate bed of Hoxne. The Shacklewell deposit [5] may be of about the same age as, or somewhat later than, that of Stoke Newington. The deposit of the Admiralty Buildings, first described by Mr. W. J. Lewis Abbott (see footnote on p. 218), is on nearly the same horizon as the Ponder's End bed.[6] The evidence of the Twickenham [7] deposit seems a little conflicting; it may probably be somewhat later than Ponder's End. But, so far as the remains of *Bos longifrons* from Twickenham are concerned, it is well to remember that Dr. Leeson & Mr. Laffan are careful to point out that these bones were obtained among many others thrown into a sack by the workmen. There is, therefore, no definite information to show the horizon from which they came. This point appears to have been sometimes overlooked in quotations from the Twickenham paper.

It is not necessary to discuss the other English plant-bearing deposits that have been described, as these either yield no further information, or else the evidence for their correlation is too indefinite to enable us to use them.

To sum up the evidence of the Pleistocene plant-bearing beds, one may say that the temperate flora of Stoke Newington cannot be on the same horizon as the temperate flora of Hoxne—the Arctic

[1] Worthington G. Smith, 'Man the Primeval Savage' 1894.

[2] Q. J. G. S. vol. lx (1904) p. 120.

[3] Rep. Brit. Assoc. (Ipswich) 1896, p. 400.

[4] C. Reid, Proc. Roy. Soc. vol. lxi (1897) p. 40.

[5] J. Prestwich, Q. J. G. S. vol. xi (1855) p. 107; and C. Reid, *ibid.* vol. liii (1897) p. 463.

[6] The Arctic plant-bed of the Admiralty Buildings was overlain by a shell-bed containing *Unio littoralis*, etc. This is certainly remarkable; but, without further evidence, one could not suggest two separate Arctic stages so near together as that of the Admiralty Buildings and Ponder's End.

[7] J. R. Leeson & G. B. Laffan, Q. J. G. S. vol. l (1894) p. 458.

The Correlation of the Ponder's End Stage.

Periods.	Sequence dates.	Ponder's End.	Admiralty Buildings, Westminster.	Hoxne.	Stoke Newington.	Norfolk.	Boule.		Penck.	Sequence dates.
Prehistoric.	10.00									10.00
	9.30									9.30
Hiatus?	8.xx	Arctic.	Arctic.	(Trail.)	(Trail.)		Post-Glacial.			8.xx
Magdalenian.	7.90								Post-Glacial. Glacial (Wurmian).	7.90
Solutrean.	7.80								Interglacial.	7.80
Aurignacian.	7.73 to .77									
Mousterian.	7.70				Temperate.	(Palæolithic River Gravels.)	Glacial (Wurmian).		Glacial (Rissian).	7.70
Acheulian.	7.60			Temperate.						7.60
[Chellean] in part.	7.50						Interglacial.		Interglacial.	7.50
Early Palæolithic.	7.40			Arctic.					Glacial (Mindelian).	7.40
	7.30			Temperate.					Interglacial.	7.30
Chalky Boulder Clay.				Glacial.		Glacial.				
Contorted Drift, etc.							Glacial (Rissian).			
Cromer Till, etc.									Glacial (Günzian).	
Forest Bed.						(Arctic Fresh-water Bed.) Temperate.	Interglacial.		Pre-Glacial.	
							Glacial.			

horizon of the latter locality necessarily intervening between them, as is shown in the table of strata. And, further, it is impossible for the Arctic flora of Hoxne to be contemporary with that of Ponder's End.

Thus (including the evidence of the Chalky Boulder Clay) there are three clearly-proved Arctic stages, separated by intervening temperate epochs, between the Forest Bed and the prehistoric deposits. It is possible that there may be more than this, for the evidence at present available is not sufficient to warrant the suggestion of a completed scheme. The researches of Dr. F. J. Lewis in the peat-beds of the Highlands of Scotland and of the North of England [1] have also revealed a series of interbedded Arctic and temperate stages. These continue the alternating climatic changes down to more recent times.

In the last two columns of the table are placed, for comparison with our English deposits, the schemes adopted by Prof. Penck [2] and Prof. Boule respectively. These show considerable discordance with each other. If I may express an opinion upon so wide a question, I think that Prof. Boule is, in some respects, nearer the truth than Prof. Penck. Even this scheme, however, does not altogether accord with our English evidence, and there is certainly no place in it for the Ponder's End Stage. The primary difference between these two distinguished authors lies in the placing of the Rissian (the epoch of maximum glaciation). This Prof. Penck places in the Mousterian stage, a position which, in the opinion of Prof. Boule, is an impossible one.[3] In this opinion I most certainly concur.

In summing up the evidence for the correlation of the Ponder's End Stage, all that one can positively assert is that this is post-Mousterian and pre-Neolithic. In weighing the probabilities for a more precise correlation, one has to consider the length of the interval between the Mousterian and Ponder's End Stages, as measured by the valley-erosion which then took place. This amounts to a vertical height of 60 or 70 feet, and must surely represent many successive stages in the evolution of human culture. One must further consider the general relationship, over a wide area, of the Palæolithic drifts to the contorted trail that overlies them. One must also remember the evidence brought forward by Dr. Hicks in his exploration of the caves of North Wales [4]: although his evidence has not been generally accepted—and he was certainly mistaken at Endsleigh Street,—it does seem to point to the conclusion that the Cave men lived in North Wales before the latest glaciation of that area.

[1] Trans. Roy. Soc. Edin. vol. xli, pt. iii, no. 28; vol. xlv (1906) p. 335; vol. xlvi (1907) p. 33; vol. xlvii (1911) p. 793. See also Rep. Brit. Assoc. (York) 1906, p. 430; and *ibid.* (Leicester) 1907, p. 410.

[2] A. Penck & E. Brückner, 'Die Alpen im Eiszeitalter' 1901–1909.

[3] 'L'Anthropologie' vol. xix (1908) p. 1. Dr. R. R. Schmidt, again, places a continuous glacial phase from the Mousterian to the Lower Magdalenian.

[4] Q. J. G. S. vol. liv (1898) p. lxxxiv, where references to previous papers will be found.

On considering all these data, it appears to me that one is justified in provisionally placing the Ponder's End Stage opposite the line marked in the table (p. 223) as 8. xx, a period about which we at present know so little.

In the view of those who may not accept the minuter subdivisions of the Palæolithic Epoch, I think that the general succession of the correlations given in the table will still hold good, although the details will be more indefinite.

VI. The Relation of Palæolithic Man to the Glacial Period.

The evidence of the Ponder's End deposit supports in a remarkable manner the contention of those who have maintained that Palæolithic man in this country is interglacial. For although it is, of course, undeniable that Palæolithic man is later than the maximum glaciation of this country, there can yet be no doubt that after Palæolithic man had left these shores, even the southern part of this country passed through a spell of Arctic cold.

To my mind, the evidence of the Ponder's End Stage puts into our hands the key to many outstanding difficulties, particularly with regard to the conflicting nature of the evidence upon the relationship of early man to the Glacial Period. That Palæolithic man is later than the Chalky Boulder Clay has been proved over and over again, beyond any possibility of doubt. But at the same time there are frequently contorted drifts overlying the Palæolithic deposits which are at least strongly suggestive of Glacial action. These have been described by Sir Joseph Prestwich, Mr. Worthington Smith, Prof. Sollas, and many others. They are, indeed, familiar to every collector of flint-implements. I believe, with Mr. Worthington Smith, that these post-Palæolithic contorted drifts should be grouped with the 'Trail' of the Rev. Osmond Fisher. And therefore, if the officers of the Geological Survey be right in identifying the Trail with the Low-Level River Drift, these contorted drifts also become linked to the Ponder's End Stage.

One of the most striking exposures of the Trail that I have seen was in a brickyard at Hoddesdon, which was open in or about the year 1896, but has now been closed for some time. There the Trail had ploughed its way through a Palæolithic river-drift gravel about 4 or 5 feet thick, and had folded this gravel back upon itself through an angle of 180°. Part of its material was composed of redistributed Boulder Clay, and was practically indistinguishable from that deposit.

The Lea Valley is cut through the plain of Chalky Boulder Clay, and is therefore later than that formation. The Palæolithic river-drifts of this valley, of which the Hoddesdon deposit is one, can be further shown to be post-Chalky Boulder Clay by the erratic rocks that they contain, the Glacial deposits being the only source of local derivation for these erratics. Yet the Palæolithic gravels are cut into by contorted drifts, sometimes composed in part of redistributed Chalky Boulder Clay which must have been thrust into them in large frozen masses. I think that the Ponder's End evidence affords the explanation. During this stage snow must have continuously accumulated during, perhaps, six months, or more than six months, of the year. When the summer thaws set in, great slides of slush mixed with clay and stones, and frozen blocks of dislodged soil, would creep down the hillsides and along the valley-slopes, disturbing the superficial deposits in their course.

There is another archæological problem upon which the climatic conditions of the Ponder's End Stage may possibly throw some light. This is the poverty of all the lower terraces of the River Drifts in remains of early man. May not the inclemency of the climate have driven man from the open air to seek the protection of the caves and rock-shelters, and finally have caused him to leave these shores altogether to find his home in sunnier climes? It is significant in this respect that reindeer and other Arctic mammalia abound in the cave-deposits associated with the relics of the later Palæolithic men.

VII. The Holocene Alluvium of the River Lea.

Holocene Alluvium begins to come on at the south-eastern corner of the Ponder's End pit, but the section so far exposed is a small one and the Alluvium does not exceed 6 feet in thickness. The junction between the Recent and the Pleistocene beds is an eroded one, and there is evidence of much redistribution of the upper beds of the drift-gravel beneath the Alluvium. The brickearth which caps the gravel is also cut off, equally with the gravel itself, by the Alluvium, and is thus seen to belong to the Pleistocene series.

At the base of the Alluvium I have found some fragments of prehistoric pottery and a few flint-chips. These scanty remains do not furnish sufficient evidence to fix their date; but they are not necessarily Neolithic, and may belong to the Early Bronze Age. Associated with them were some mammalian and other bones, which Mr. E. T. Newton, F.R.S., has been kind enough to examine. They include a skull of *Bos longifrons*, with the horn-cores somewhat flattened and turned backwards instead of forwards. Among the limb-bones, some probably belong to the same species, while others represent a large variety of pig. There is also the femur of a swan.

In the neighbouring excavations for the Chingford Reservoir, a good many mammalian remains have been found in the extensive exposures of Alluvium which have been made during the progress of the work. These include, among many others, some antlers of *Cervus elaphus* and a fine skull of *Bos primigenius* that is now in the British Museum (Natural History). It has hardly seemed worth while to collect the bones of horse and ox, as their date is a matter of great uncertainty. There is no uniform stratigraphical succession over the area, which has been one of shifting river-channels, constantly becoming silted up and re-excavated in new directions. Archæological remains which I have found in place in the deposits prove that many parts of the Alluvium belong to the historic period, or even come down to our own day.

VIII. The Reports upon the Fauna and Flora of the Arctic Bed.

Appended to this paper are reports by various specialists upon the fauna and flora of the Arctic Bed, and upon the microscopic examination of the sand. My sincere thanks are due to these workers who have so generously supplied me with these valuable results. The labour which they have undertaken, in spite of all the preliminary assistance that I could give, has in many cases been very arduous. The conclusions at which they have arrived will speak for themselves. It is very gratifying to note that, although arrived at independently, they are in very close agreement with each other.

IX. The Mammalia of the Arctic Bed and Associated Gravels.

My search for any remains indicating the presence of man have not been rewarded with success. In fact, I have never yet discovered contemporary Palæolithic implements in the Low-Level gravels of the Lea Valley. All the implements at present found in these drifts are remanié forms derived from the higher and older terraces in which contemporary implements are abundant.

For the determination of the Mammalia I am chiefly indebted to the kindness of Mr. E. T. Newton, F.R.S.; Dr. C. W. Andrews, F.R.S., and Dr. A. Smith Woodward, F.R.S., of the British Museum (Natural History), have also given me assistance. The most abundant remains are those of *Elephas* and *Rhinoceros*. Tusks and teeth of the former have been found in some abundance, and these belong exclusively to *E. primigenius*. Some molar teeth of the latter genus that I have found belong to *Rh. antiquitatis*. Next in abundance to these come the remains of *Equus caballus*. Probably, indeed, *Equus* is quite as abundant as *Elephas*, only its remains being smaller, they are commonly overlooked by the workmen. Remains referable to *Bos* [or *Bison*] are extremely rare, and are only represented by a single fragment of a vertebra. No spot has yet been found where remains of the smaller mammalia are abundant,[1] but one shrew, which is believed to be a new species,

[1] [I have since discovered a bed yielding remains of lemming. See Pl. XV and Appendix VII, p. 249.—*S. H. W., June 12th, 1912.*]

has been described by Mr. M. A. C. Hinton under the name of *Sorex kennardi* (Geol. Mag. dec. 5, vol. viii, 1911, p. 533).

It ought perhaps to be stated that the bones from the Alluvium and those which are found within the Arctic Bed resemble each other so closely, that some care has to be exercised in separating the one from the other when these have not been found in place by a scientific observer.

The teeth of elephants and large bones are reported to have also been found in the Angel Road pit. I have only myself seen molar teeth of the horse, and a portion of an antler which I felt little hesitation in determining on my own responsibility as *Rangifer tarandus* (a determination since confirmed by Mr. E. T. Newton).

So far as present information goes, the comparative scarcity of the reindeer is somewhat surprising. This is especially the case in the light of the group of mammalia found in the brickearth of Cheshunt. A series of these remains is in my possession: they have not yet been described, but I have received much assistance in their determination from Mr. M. A. C. Hinton. This deposit is situated about 5 miles farther up the valley, and lies a little below the 100-foot contour. I believe it to be earlier than the Ponder's End Stage.

In the Cheshunt brickearth *Rangifer tarandus* and *Bison priscus* are peculiarly abundant; while associated with these are *Elephas primigenius* and *Rhinoceros antiquitatis*, *Equus caballus* being very rare. The group of mammalia thus differs from that found at Ponder's End.

In conclusion, it only remains for me to thank the officers of the Great Eastern Railway Company, and Mr. Berriman in charge of the Angel Road works, for their many kindnesses.

EXPLANATION OF PLATES XV & XVI.

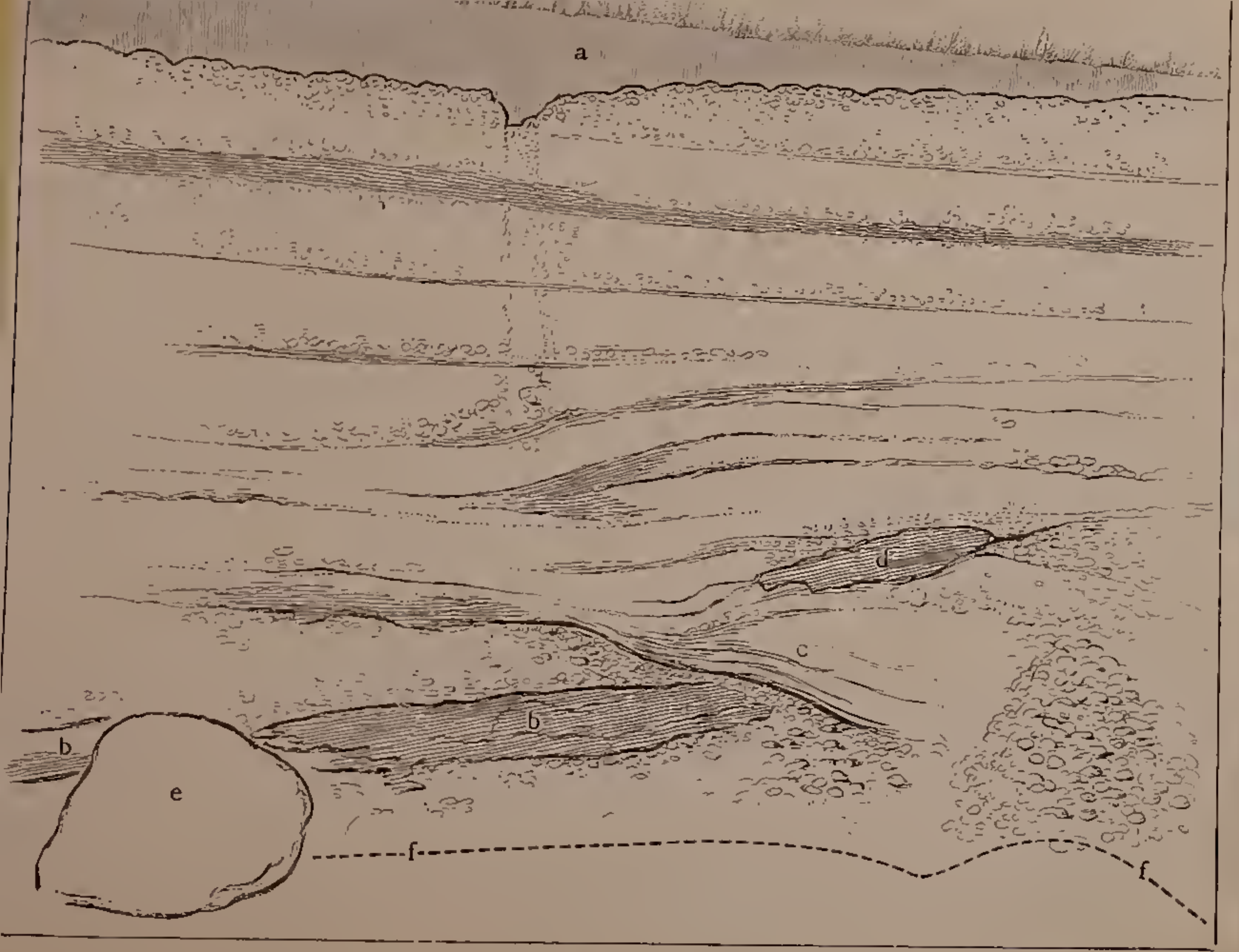
Plate XV, and Key to same.

Section in the Pickett's Lock Pit. *a*=Brickearth; the apparent thinning-off on the right is due to the fact that the face of the brickearth is cut farther back than that of the gravel and sand, and is thus partly hidden. *b*=Arctic Bed, cut off by an oblique stream of sand, *c*. *d*=The edge of a large mass of concreted gravel, cemented together by ferruginous material. *e*=A similar block, fallen down and partly hiding the Arctic Bed. *ff*=line of fallen material at the base of the section.

Plate XVI, and Key to same.

Section of the Arctic Bed seen in the Angel Road ballast-pit. This shows an unusual amount of the Arctic Bed which was left untouched in the middle of the excavation. *a*, *b*, *c*, *d*, *e*=Successive masses of the Arctic Bed overlapping each other, and mostly separated by thin layers of gravel and sand. *a'*, *b'*= Continuation of the same beds seen in the foreground. Between *a*, *b* and *a'*, *b'* there is a cutting made for the light railway used in the works. At the spot marked *f*, at the bottom of the Arctic Bed, were found the remains of the banded lemming, *Dicrostonyx henseli* Hinton.

t Ponder's End.



...y to Pl. XV: a=Brickearth; b=Arctic Bed, cut off by an oblique stream of sand, c; d=Edge of a large mass of iron-cemented gravel; e=A fallen block of the same. f=Line of fallen material at the base of the section.

S. H. W. photo.

Section in the Pickett's Lock Pit at Ponder's End.

Angel Road ballast-pit.

Key to Pl. XVI: *a*, *b*, *c*, *d*, *e* and *a'*, *b'* = Overlapping masses of the Arctic Bed.
Remains of *Dicrostonyx henseli* have been found at the spot marked *f*.

H. W. photo.

Section of the Arctic Bed seen in the Angel Road ballast-pit.

Appendix I.—List *of the* Flowering Plants. By Francis John Lewis, D.Sc., F.L.S.

Genera and Species. *=scarce; **=abundant; ***=very abundant.	Ponder's End.				Angel Road.
	General Collection.	Special Site.			
		Lowest Bed.	Middle Bed.	Upper Bed.	
Ranunculus hederaceus L.	...	*	...	...	*
Ranunculus acris ? (1) L.	...	*			
Silene maritima With.	*	*			
Silene sp. (2)	*				
Alchemilla vulgaris L.	*				
Potentilla comarum Nestl.	*	*	...	...	*
Potentilla tormentilla Scop.	*	*			
Potentilla sibbaldi Hall	*	...	...	*	
Hippuris vulgaris L.	**	***	***	***	***
Menyanthes trifoliata L. ? (3)	...	*			
Littorella lacustris L.	***	...	...	***	***
Atriplex sp.	...	*			
Betula nana L. (4)	*				
Salix herbacea L.	***	***	...	...	***
Potamogeton heterophyllus Schreb.	...	**	...	...	**
Potamogeton crispus L.	*	*	...	*	
Potamogeton sp.	*	...	*		
Carex spp. (5)	**	*	...	...	**
Isoetes lacustris ? (6)	*				

(1) Only one achene, much crushed. (2) One much-crushed specimen; species not determinable. (3) One much-worn seed; doubtful. (4) One catkin scale. (5) Nutlets only; species not determinable. (6) One leaf-base, with sporangium, much crushed and doubtful.

These plants occurred in a layer of peaty sand. Small stems and twigs were not uncommon, and all belonged to the genera *Betula* and *Salix*. In most cases these stems were decorticated, and bore evidence of drifting. Most of the seeds and fruits in the list were quite uninjured, but the character of the layer and the assemblage of plants indicate that they were drifted by water to the place where they are now found.

Several small pieces of charcoal 5 to 10 mm. square were also found in the general collection, but the carbonization may possibly be due to causes other than fire. A considerable portion of the material consisted of the leaves of *Salix herbacea*, felted together in lenticular masses.

In addition to the plants enumerated in the above list, the washings contained many small petal-like objects. These have not been identified, but they are certainly not the petals of *Dryas*, *Rubus chamœmorus*, or *Parnassia palustris*. Several small brownish flakes were present: these consisted of much-compressed fragments of epidermis and other plant-débris, felted together. The appearance of this material rather suggests the dung of some big mammal.

The presence of these plants at sea-level in the Lea Valley indicates a decided difference in climatic conditions from those of the present day.

At no place in the world do such plants as *Salix herbacea*, *Betula nana*, and *Potentilla sibbaldi* grow in quantity at sea-level along the annual isotherm of 10° C. or the July isotherm of 17° C. Such plants as *Salix herbacea* and *Betula nana* grow abundantly in Iceland near or at sea-level, with a mean annual temperature of 4·41° C. and a mean July temperature of 10° C.

Doubtless, at the time when these plants lived in the Lea Valley, the British flora was poorer in species than it is now, and the absence of competition may have allowed many of the Arctic and Alpine species to linger on in the lowlands. But, after allowing full weight to this possibility, I do not think it likely that such plants as the Arctic elements in the list occurred at sea-level under climatic conditions similar to the present.

The position of the plant-bearing stratum in the river-gravels indicates a late Glacial age for these remains, a period at any rate considerably later than the retreat of the general ice-sheet of the main glacial stages. This makes the find more interesting, and tends to confirm evidence pointing to widespread Arctic conditions from other sources in the north of Britain.

The material does not in any way suggest the washed-out fragments of a peat-bog, but rather resembles the drifted vegetation from a tundra surrounding the spot where the fossils are now found.

Appendix II.—Report *on the* Mosses *from the* Arctic Bed. By Hugh Neville Dixon, M.A., F.L.S.

The moss-remains sent to me from the Arctic Beds at Ponder's End represented four separate gatherings. The first was a general collection from the deposit, while the others were taken from three superimposed beds, and are referred to as the Upper, Middle, and Lowest Beds.

I have been able to determine with scarcely any doubt some forty or more species. A certain number at present unnamed may yet be determined, but these are so few that they cannot modify to any appreciable extent the conclusions to be drawn from those already determined. I give here a table showing the forms so far detected, with their distribution through the different beds.

The fragmentary or patchy nature of the three superimposed beds left some doubt as to how far they represented different periods of deposit, or how far one or other of the upper layers might be simply a redistribution of the subjacent layers; and also as to the relation of any of them to the deposit from which the first sample

LIST OF MOSSES.

Genera and Species. *=scarce; **=abundant; ***=very abundant.	Ponder's End.				Angel Road.
	General Collection.	Special Site.			
		Upper Bed.	Middle Bed.	Lowest Bed.	
Ditrichum flexicaule var. *densum* ...	*	...	**	**	
Distichium capillaceum ...	*	...	*	**	
Ceratodon purpureus (?) ...	...	...	*	*	
Barbula rubella ...	*	...	...	?	
Tortula aciphylla var. *mucronata* ...	*	...	**	**	?
Encalypta rhabdocarpa ...	**	...	...	**	
Orthotrichum diaphanum ...	*				
Philonotis fontana ...	*	...	*	*	
Timmia norvegica ...	...	...	*		
Bryum pallens ...	**	...	*	**	
Bryum capillare ...	*	...	*		
Bryum intermedium (?) ...	*				
Bryum pseudotriquetrum ...	?	...	...	*	
Bryum cirratum (?) ...	?	...	?	*	
Mnium rostratum ...	...	...	*		
Mnium punctatum (or *subglobosum*)	...	...	*		
Thuidium sp. ...	...	...	...	*	
Camptothecium nitens ...	*				
Brachythecium mildeanum ...	*	...	*		
Amblystegium fluviatile ...	*				
Amblystegium filicinum ...	**	*	...	*	
Amblystegium filicinum var. *vallisclausæ* ...	...	*			
Amblystegium serpens B. & S. ...	...	...	...	...	*
Hypnum polygamum Brid. ...	*	*	*	*	*
Hypnum stellatum ...	*	...	*	*	
Hypnum aduncum Hedw. ...	**	...	?	?	
Hypnum aduncum (Group *pseudo-fluitans*) ...	*	*			
Hypnum sendtneri ...	**	**			
Hypnum wilsoni ...	**	...	...	*	
Hypnum capillifolium ...	**	**	*	**	**
Hypnum fluitans ...	...	*	...	*	
Hypnum fluitans (Group *falcatum*) .	...	...	...	**	
Hypnum exannulatum ...	...	**	**	**	**
Hypnum exannulatum (Group *rotæ*)	*	...	**	*	
Hypnum exannulatum var. *orthophyllum* (Milde) ...	*				
Hypnum revolvens ...	**	*	...	*	
Hypnum fastigiatum ...	...	...	...	*	
Hypnum vaucheri ...	**	...	**	**	
Hypnum molle ...	*	...	*	*	
Hypnum scorpioides ...	*	...	...	**	**
Hypnum giganteum ...	**	**	**	**	**
Hypnum cuspidatum ...	**	**	*	**	
Hypnum sarmentosum (?) ...	...	...	...	*	
Hypnum stramineum ...	...	...	?		
Hypnum turgescens ...	...	...	...	*	
Hypnum callichroum Brid. ...	...	...	...	...	*

was collected. The foregoing Table gives, I think, some reply to these problems. Leaving the Upper Bed out of the question for the present, it will be seen that of the forty or so forms determined from the remaining three beds, fourteen at least occurred in all three. Of about 24 species determined from the Middle Bed, 16 at least are also in the Lowest, and 15 at least in the General Collection. Of about 32 determined from the General Collection, all but six occurred either in the Middle or Lowest Bed: of these six, five occurred very sparsely; in every case, I think, a single fragment only—the remaining plant, *Hypnum sendtneri*, being the only species which occurred with some frequency in one of the Beds without being found—or at any rate, without being frequent—in the others.

The conclusion I think is inevitable, that the floras from which the plants of the General Collection, the Middle, and the Lowest Beds were derived must have been practically identical. The General Collection probably represents actually the same level and the same deposit as the Lowest Bed, for out of its 32 determined species, about 20 (and probably more) occurred in the Lowest also, rather fewer being common to the General and the Middle. But I think that in all probability the Middle Bed also represents the same flora, either deposited at roughly the same time, or at a very slightly later period, when not only were the conditions similar, but a practically identical (not merely similar) flora existed in the neighbourhood. Otherwise, it is scarcely conceivable that out of so comparatively small a total of species noted so large a proportion could be common to the Middle Bed and to the others: especially when the fact is taken into consideration, referred to later, that in both cases there are two distinct associations combined—one which is probably more or less *in situ*, while the other must have been brought from at least some distance. The comparatively small amount of material obtained from the Middle Bed probably quite accounts for the absence of some species found in the other two.

The main characteristics of this flora represented in the General Collection, the Middle and Lowest Beds, are that, in the first place, it includes, as mentioned above, two distinct associations: (1) a paludal or aquatic one with Harpidioid Hypna dominant, in addition to other paludal species, *Hypnum scorpioides*, *H. giganteum*, and *H. cuspidatum*; (2) a terrestrial or more or less rupestral association, of which several of the *Brya*, *Tortula aciphylla*, *Encalypta rhabdocarpa*, *Distichium*, etc., are characteristic. Some of the last-named, especially, have no aquatic predilections, and in no way depend on proximity to water; while, on the other hand, they are much too commonly represented here for their presence to be merely fortuitous—the small fragments that from time to time might be carried into a bog or marsh from a surrounding general land flora by wind, or rain, or ice-action, could not account for the large representation which some of these species have among the paludal ones. I think that the explanation is certainly to be found in a river, or tolerably large stream, flowing in some of its upper reaches through a stony channel, with probably frequent stretches of sandy margins; then spreading out into a pool or series of pools or marshes, or at least flowing at a much gentler gradient. I do not mean to imply that the paludal species are actually *in situ*: they are much too fragmentary for this to be the case; but their dominance, on the whole, seems to imply that the present position is, at any rate, much nearer to their original station than to that of the rupestral and terrestrial species.

The second conclusion to be drawn from the material is as to the nature of the climatal conditions. The association is certainly an Arctic one. Quite a considerable number of species (namely, *Tortula aciphylla*, *Timmia norvegica*, *Hypnum fastigiatum*, *H. molle*, *H. turgescens*) are Alpine-Arctic mosses which are either entirely extinct in Britain at the present day, or are now confined to one or two summits of the higher Scottish mountains; while, with the possible exception of *Orthotrichum diaphanum* (the determination of which is perhaps open to question), all the remaining species are such as might occur under climatal conditions similar (though not identical topographically) to those which would be suitable to these others. I have gathered the great majority of the species within a limited area in Tornean Lapland (lat. 68° N.), at little above the sea-level; and the conditions necessary to produce these associations at Ponder's End might, I think, be very fairly compared with those of the Arctic mainland of Europe at the present day.

The Upper Bed exhibits some slightly different features, notably in the absence of all the terrestrial and rupestral forms. The association is entirely a paludal one, but I have found nothing which does not occur in one or other of the beds, with the single unimportant exception of *Amblystegium filicinum* var. *vallis-clausæ*, that is, the form with excurrent nerve. On the other hand, there are no species included which indicate a colder climate than that of the present day, unless *Hypnum capillifolium* be considered to do so; while the presence of *H. aduncum* (Group *pseudofluitans*) might, if anything, point the other way, but neither of these could adequately serve as a basis for any definite conclusion. With regard to the Upper Bed, therefore, so far as the moss-remains point, there is clearly a slight difference of origin as compared with the other beds; but there is no evidence to show whether there was any long interval of time separating it from the others, or any material difference in the climatic conditions obtaining at the epoch of its deposition.

Facts worthy of notice are the total absence of any trace of *Sphagnum*, or peat-moss, and the very sparse occurrence of *Camptothecium nitens*, a species which generally occurs with some frequency in prehistoric paludal moss-associations in this country. Whatever may be the cause, however, the point is one rather of botanical, than of geological, or of general interest.

Appendix III.—*The* Mollusca. By Alfred Santer Kennard, F.G.S., and Bernard Barham Woodward, F.L.S., F.G.S.

[Plate XVII.]

The material on which the following notes are based was derived from two sources—(1) a large series sent by Mr. S. Hazzledine Warren, and (2) a number of examples collected by Messrs. A. S. Kennard & F. N. Haward, the result of washing several hundredweight of the clay, the water in the pit being very convenient for that operation. Mr. Warren's collection consisted of four series marked 'Upper Bed,' 'Middle Bed,' 'Lower Bed,' and 'General.' We have considered it advisable to enumerate these separately, but we have incorporated our own series with the last.

List of Mollusca from the Arctic Bed.

Genera and Species. *=scarce; **=abundant; ***=very abundant.[1]	Ponder's End.				Angel Road.
	General Collection.	Special Site.			
		Upper Bed.	Middle Bed.	Lowest Bed.	
Arion sp.	*				
Limax arborum Bouch.-Chant.	**				
Agriolimax lævis (Müll.)	*				
Sphyradium columella (G. v. Mts.)	**	..	*	*	*
Vertigo parcedentata (A. Braun)	*	...	*	*	*
Jaminia muscorum (Linn.)	***	***	...	***	***
Limnæa pereger (Müll.)	*	...	...	...	*
Limnæa palustris (Müll.)	*	...	...	*	*
Limnæa truncatula (Müll.)	**	...	...	*	*
Limnæa stagnalis Linn.	...	*			
Limnæa sp.	...	*			
Planorbis crista (Linn.)	*				
Planorbis arcticus Beck	*	...	...	*	*
Planorbis spirorbis (Linn.)	*	...	...	*	*
Planorbis leucostoma Millet	*	...	...	*	*
Succinea oblonga Drap.	***	...	***	***	***
Succinea schumacheri And.	*	...	...	*	***
Succinea cf. *grœnlandica* Beck	*	...	...	*	*
Succinea elegans Risso	...	...	...	...	*
Valvata piscinalis (Müll.)	*	...	...	*	*
Sphærium corneum (Linn.)	*	*	...	...	*
Pisidium supinum A. Schm.	...	...	...	*	
Pisidium obtusale Pfr.	*	...	...	...	*
Pisidium nitidum Jenyns	*	...	...	*	*
Pisidium pusillum (Gmel.) Jenyns	*	...	...	*	
Pisidium henslowanum (Shepp.)	...	...	...	...	*
Pisidium subtruncatum Malm	...	...	...	...	*
Pisidium casertanum (Poli)	...	...	...	...	*

It will be noted that the general list contains all the species from the three beds, with the exception of *Limnæa stagnalis*.

[1] These details are of most value in the 'general collection' enumerated in the first column, as they are there based on more extensive material than in the case of some of the other beds.

Notes on the Species.

ARION sp.

There are several granules representing the internal shell of this genus, but it is quite impossible to ascribe them to a given species. The northern limit of *Arion* is the isotherm of 8° C., but on the Alps its vertical limit is the isotherm of 3° to 4° C. It may here be observed that the isotherms quoted in this note are those for July.

LIMAX ARBORUM Bouch.-Chant.

This species is common, but all the examples are dwarfed. Its northern limit is Iceland, lat. 66° 30′ N., with an isotherm of 8° C.; while in both Norway and Sweden its limit is the isotherm of 8° to 10° C. In the Alps its vertical range is the isotherm of 10° C.

AGRIOLIMAX LÆVIS (Müll.).

There are only four examples of the internal shell of this species. Its northern limit in Europe is the isotherm of 14° C.; but, if *A. hyperborea* West is only a variety of *lævis*, as has been suggested, it ranges in Asia as far as the isotherm of 10° to 12° C.

SPHYRADIUM COLUMELLA (G. v. Mts.). (Pl. XVII, figs. 5 *a* & 5 *b*.)

Abundant. This is an extremely interesting species, and one over which there has been considerable confusion.

It is the custom in this country to consider it as a variety of *Sph. edentulum* (Drap.), and as not uncommon in a living state; but the shells to which the name *columella* is applied by British authorities are very different from the true *columella*, and are in fact an elongated form of *edentulum*.

The species *columella* (*vera*) does not occur in a living state in these islands. It is a high Alpine and Arctic species inhabiting Norway, Sweden, Finland, and the Alps. Its northern limit is the isotherm of 8° to 10° C., while its vertical limit in the Alps is the isotherm of 6° to 8° C. In these islands it is only known from the Pleistocene of Barnwell (Cambridgeshire) and Copford (Essex). It is a common fossil in the German lœss.

It is interesting to note that a similar disposition occurs in the Nearctic region. There, as in Europe, *Sph. edentulum* (Drap.) is a widely distributed species, but an elongated form, *Sph. alticola* Ing., occurs living at a height of 8000 to 9000 feet in Colorado; and it also occurs as a fossil in the Mississippi 'lœss.' Whether the species *alticola* is identical with *columella* we cannot say, for we have been unable to see an authentic specimen of *Sph. alticola*.

VERTIGO PARCEDENTATA (A. Braun). (Pl. XVII, figs. 6 *a* & 6 *b*.)

Seven examples of this species were detected. They belong to the variety *genesii*, Gred., which is the edentulous form of *parcedentata*. This is a rare form in a living state, being only known from one locality in Tyrol, one in Sweden, and two in Germany, its northern limit being the isotherm of 12° C. In a fossil state the variety *genesii* is known from the Pleistocene of Mosbach, from several localities in the 'lœss' of Germany, from two Holocene deposits in Germany and one in Sweden. In these islands it is only known from the Holocene of Elie (Fifeshire) and from a deposit of uncertain age at Stamford (Lincolnshire). This last, where the species was common, is probably of late Pleistocene age.[1]

JAMINIA MUSCORUM (Linn.).

This is the most abundant form in the deposit and a Holarctic species, the limit of which in Iceland is the isotherm of 8° C.; in Norway, Sweden, and Finland the isotherm of 8° to 10° C.; and in Siberia the isotherm of 12° C.; while in the Alps its vertical limit is the isotherm of 6° to 7° C. There is great variation in the examples of this species, but a certain number may well be referred to the var. *lundstrœmi* West, now living in Iceland and Sweden. This variety also occurs in the Pleistocene of Crayford, Swalecliff, and Ightham (Kent); Fordingbridge and Fisherton (Wiltshire); West Wittering (Sussex); Barnwell (Cambridgeshire); and Stamford (Lincolnshire). It is also a common form in the lœss of Germany.

LIMNÆA PEREGER (Müll.).

A single dwarfed example is referred to this polymorphic species. Identical shells are in our collection from the Pleistocene of Crayford (Kent), the Holocene of Hale Moss (Westmorland), Silverdale (Lancashire), and Perranporth (Cornwall). In Iceland its limit is the isotherm of 8° C.; in Norway, Sweden, and Finland 8° to 10° C.; and in Siberia 10° to 12° C.; while in the Alps its vertical limit is 4° to 5° C.

LIMNÆA PALUSTRIS (Müll.). (Pl. XVII, figs. 3 *a* & 3 *b*.)

This species is represented by three dwarfed examples. It is a Holarctic form, the limit of which in Norway is the isotherm of 14° C.; in Sweden 10° to 12° C.; in Finland 8° to 10°; while in the Alps its vertical limit is 13° to 14° C.

These shells may be looked upon as a dwarf form of the variety *turricula* Held., and identical shells are in our collection from the Pleistocene of Chelmsford (Essex), St. James's Square, Westminster (Middlesex), and Barnwell (Cambridgeshire), Benkendorf, Regensburg, Stuttgart, and Osterrode in Germany, all of which are late Pleistocene in age.

LIMNÆA TRUNCATULA (Müll.). (Pl. XVII, figs. 4 *a* & 4 *b*.)

Not uncommon, about twenty examples having been obtained; all of them are small.

[1] See Proc. Malac. Soc. vol. vii (1906) pp. 119–20.

This is a Holarctic species, the limit of which in Iceland is the isotherm of 8° C.; in Norway, Sweden, and Finland 8° to 10° C.; in Siberia 10° to 12° C.; while in the Alps its vertical limit is 5° C. Judging from the description, these shells belong to the variety *lapponica* West, now living in Lapland.

Identical shells are in our collection from the Pleistocene of Chelmsford (Essex), Swalecliff (Kent), and Stuttgart (Germany); while examples from the Pleistocene of Barnwell (Cambridgeshire) and Crayford (Kent) come near to them.

LIMNÆA STAGNALIS (Linn.).

This is only represented by an apical fragment. It is a Holarctic species, the northern limit of which in Norway, Sweden, and Finland is the isotherm of 8° to 10° C., and in Siberia 10° to 12° C.; while its vertical Alpine limit is 13° C.

PLANORBIS CRISTA (Linn.).

A single dwarfed example only of this species was found.

This is a European form, the northern limit of which in Europe is the isotherm of 12° C.; while its vertical Alpine limit is that of 14° C.

PLANORBIS ARCTICUS Beck. (Pl. XVII, figs. 8 *a* & 8 *b*.)

Rather rare, only six examples being detected.

It is a Holarctic species with a decidedly northern range. In Iceland and Greenland its limit is that of the isotherm of 4° to 5° C., and in Norway 12° C. The examples are quite indistinguishable from specimens in our collection which were brought from West Greenland. *P. arcticus* is not uncommon in the Pleistocene of Crayford (Kent), and it also occurs in lacustrine deposits near Edinburgh, the age of which is still a matter of doubt.

PLANORBIS SPIRORBIS (Linn.).

Rather rare, about eight examples having been found.

This European species has a range in Iceland to the isotherm of 10° C.; in Norway, Sweden, and Finland to 14° C.; and in Siberia to 12° to 14° C.; while in the Alps it does not occur above the isotherm of 10° to 11° C.

All the examples from Ponder's End are decidedly dwarfed, and resemble those from the Pleistocene of Chelmsford (Essex).

PLANORBIS LEUCOSTOMA Millet.

Rare, being represented only by three dwarfed examples.

This is a European species, the northern limit of which is the isotherm of 12° C. It is often considered as only a variety of *spirorbis* Linn., yet it is noteworthy that both species occur together in this deposit without any intermediate forms being seen.

Succinea oblonga Drap.

Next to *Jaminia muscorum* (Linn.) this is the most abundant species in the deposit. It is a European form, the range of which in Norway and Sweden is the isotherm of 15° to 16° C., and in Siberia 10° to 12° C. The vertical Alpine limit is the isotherm of 9° to 10° C.

This is a characteristic species of the German lœss; while it is represented in our collection from the Pleistocene of Swalecliff and Ightham (Kent), Fisherton (Wiltshire), Portland (Dorset), Barrington (Cambridgeshire), and St. James's Square, Westminster (Middlesex).

Succinea schumacheri And. (Pl. XVII, figs. 2 *a* & 2 *b*.)

Rare; two examples only found.

This is a species of which it is quite impossible to give the present range. If it is identical with *S. altaica* von Mts. var. *norvegica* West, as, judging from the description, it appears to be, then it occurs in Iceland with an isotherm of 10° C. It is a characteristic fossil of the German lœss, and is represented in our collection from Bischheim (near Strassburg), Regensburg (Bavaria), and Osterrode (Thuringia).

In these islands it is known in a fossil state from the Pleistocene of Barrington (Cambridgeshire), Crayford (Kent), Chelmsford (Essex), and St. James's Square, Westminster (Middlesex). In our opinion it is indistinguishable from recent shells from Hale Moss (Westmorland), Grange (Lancashire), Stoke Inner Pool (Hereford), Old Colwyn (Denbighshire), and the Orkneys. With regard to the shells from Hale Moss, we had the confirmatory support of the late Dr. O. Bœttger.

Succinea cf. grœnlandica Beck. (Pl. XVII, figs. 1 *a* & 1 *b*.)

There are seven examples of *Succinea* which we are unable definitely to name. The nearest living form is *S. grœnlandica* Beck, but these examples are rather smaller than that species.

S. grœnlandica ranges as far north as the isotherm of 4° to 6° C.

We have seen no British fossil examples that will compare with them. Even if the Ponder's End shells are only an extreme form of *S. putris* (Linn.), it is noteworthy that this last species ranges to the isotherm of 8° to 10° C., with a vertical range in the Alps to 13° C.

Valvata piscinalis (Müll.). (Pl. XVII, fig. 7.)

This species is represented by eight dwarfed examples.

Judging from the literature, these may be the variety *cyclomphala* West; but, since we have seen no authentic specimens, we are unable to speak definitely on the point. The range of *V. piscinalis* is to the isotherm of 8° to 10° C. in Europe, and 10° to 12° C. in Siberia. The highest vertical range that we can trace is in the Jura, 15° C.

Sphærium corneum (Linn.).

This common European species is represented only by fragments;

but they are apparently true *corneum* and not *Sph. mœnanum* Kobelt, while they are certainly not *Sph. solidum* Norm. The species ranges in Europe to the isotherm of 8° to 10° C. and in Siberia to that of 10° to 12° C.

Pisidium supinum A. Schmidt. Young specimen. (Pl. XVII, figs. 9 *a* & 9 *b*.)

Pisidium obtusale (Lamk., ? Pfr.) Jenyns.

Pisidium nitidum Jenyns. (Pl. XVII, figs. 10 *a* & 10 *b*.)

and

Pisidium pusillum (Gmel.) Jenyns. (Pl. XVII, figs. 11 *a* & 11 *b*.)

These species are represented by a few stunted valves, obviously denoting unfavourable conditions. There has been so much confusion among the *Pisidia* that it is difficult, if not impossible, to state anything as to their range; but it would appear that these three species range in Europe as far north as the isotherm of 8° to 10° C.

Conclusion.

The whole assemblage indicates the fauna of a marsh or swamp. There is practically no other British deposit that is actually analogous. The Pleistocene beds at Swalecliff, near Herne Bay, and the Brickearths, near Chelmsford, are probably of the same age; but in both these instances the number of species is very small as compared with that of Ponder's End.

After careful consideration of the matter, we venture to think that the deposit denotes a July isotherm of 8° to 10° C.—that is to say, the temperature of Southern Iceland or Lapland.

The mollusca from Ponder's End can be divided into two groups: one containing *Sphyradium columella*, *Vertigo parcedentata*, *Planorbis arcticus*, and *Jaminia muscorum* var. *lundstrœmi*, which are all boreal species; while those of the other all have a wide distribution. Practically, all of this latter group are dwarfed, and clearly indicate the existence of unfavourable conditions, which may well be supposed to have been due to the prevalence of a low temperature.

It is noteworthy, too, that a number of species which we might reasonably expect to be present are absent, such as *Planorbis corneus* (Linn.), *P. carinatus* (Müll.), *P. umbilicatus* (Müll.), *P. vortex* (Linn.), *Physa fontinalis* (Linn.), *Ancylus fluviatilis* Müll., *Bithynia leachii* (Shepp.), *B. tentaculata* (Linn.), and *Valvata cristata* Müll. These all range as far north as the isotherms of 13° C. or 14° C., and it is not unreasonable to assume that their absence may be accounted for by the fact that the July temperature was probably below 13° C. Taking into consideration the range of the boreal species, a July isotherm of 8° to 10° C. seems most likely to be the correct one for the period.

At the eastern end of the section the overlying Holocene beds can be seen, although the line of demarcation between the two deposits is not well marked. We were able to obtain a number of mollusca from these upper beds, namely:—

Vitrea radiatula (Alder).	*Planorbis albus* Müll.
Hygromia hispida (Linn.).	*Planorbis umbilicatus* Müll.
Hygromia liberta,[1] West.	*Planorbis carinatus* Müll.
Helicigona arbustorum (Linn.).	*Valvata piscinalis* (Müll.).
Succinea elegans Risso.	*Bithynia tentaculata* (Linn.).
Limnæa auricularia (Linn.).	*Bithynia leachii* (Shepp.).
Planorbis contortus (Linn.).	*Neritina fluviatilis* (Linn.).
Planorbis crista (Linn.).	*Unio tumidus* Retz.
Planorbis leucostoma Millet.	*Pisidium amnicum* (Müll.).

These are all normal shells, and exhibit none of the dwarfing so noteworthy in the Pleistocene examples. The contrast between the two faunas is very marked, although a number of species are common to both.

In conclusion, we have to thank Mr. E. A. Smith, I.S.O., for his very kind assistance in the determination of some of the examples.

Supplementary Note on a Collection of Mollusca from the Arctic Bed in the Angel Road Ballast-Pit.

Mr. Warren also sent us another series of molluscan remains obtained at Angel Road, and twenty species were represented. These are enumerated in the last column of the table (p. 234).

It will at once be noticed that this fauna is practically the same as that from Ponder's End: for, excluding the *Pisidia*, there is only one species, *Succinea elegans* Riss., that did not occur at the latter locality. This species has a decidedly northern range. Its limit in Sweden is the isotherm 10° to 12° C., and in Finland 8° to 10° C., thus confirming the views which we have already expressed.

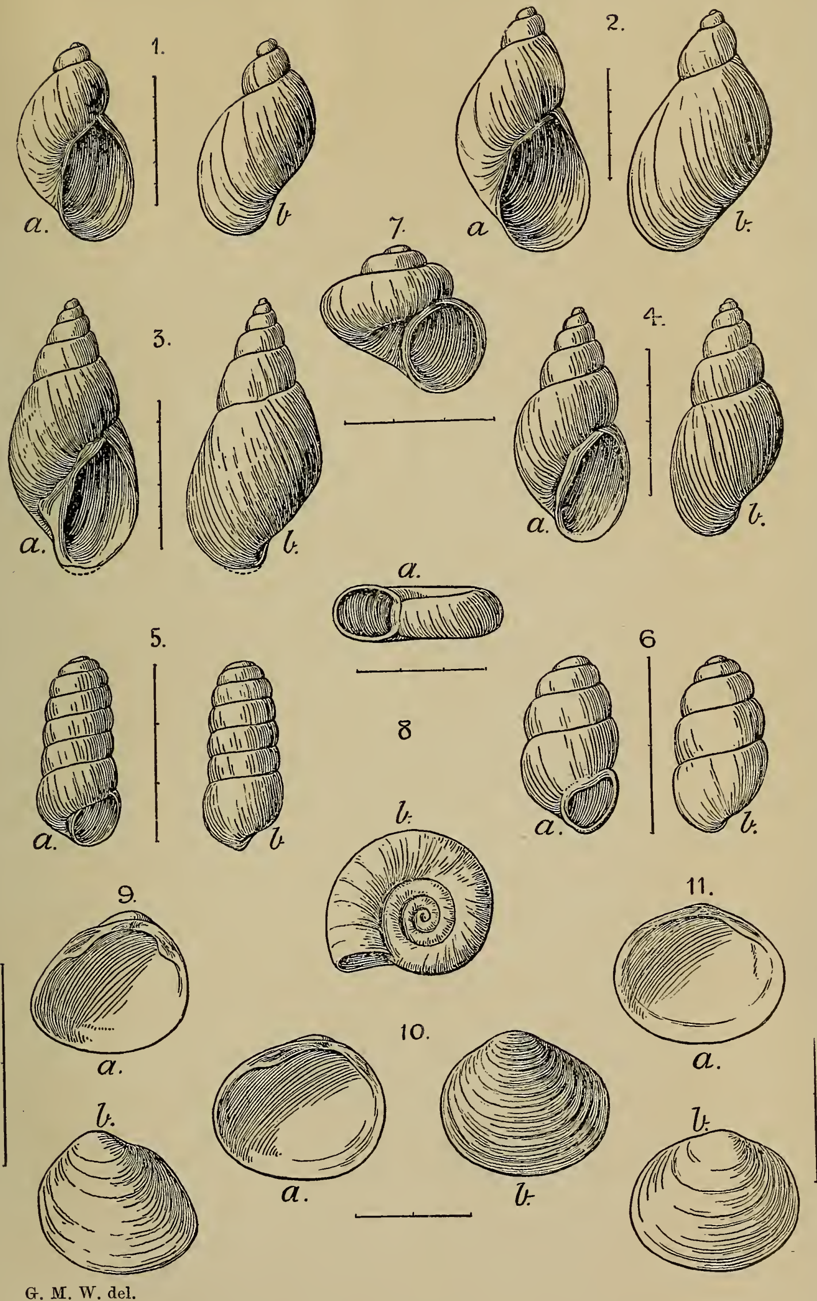
All the *Pisidia* are dwarfed, and the conditions were evidently not favourable. There is the same dwarfing of certain species and the abundance of others as at Ponder's End, and there can be no doubt that they are of the same age and represent similar conditions.

EXPLANATION OF PLATE XVII.

[The dimensions are shown in millimetres.]

Fig. 1. *Succinea* (cf. *S. grœnlandica* Beck). (See p. 238.)
2. *Succinea schumacheri* Andreæ. (See p. 238.)
3. *Limnæa palustris* (Müll.) var. (See p. 236.)
4. *Limnæa truncatula* (Müll.) var. (See p. 236.)
5. *Sphyradium columella* G. v. Mts. (See p. 235.)
6. *Vertigo parcedentata* A. Braun. (See p. 235.)
7. *Valvata piscinalis* (Müll.). (See p. 238.)
8. *Planorbis arcticus* Beck. (See p. 237.)
9. *Pisidium supinum* A. Schmidt. Right valve of young specimen.
10. *P. nitidum* Jenyns. Right valve: dwarfed form. (See p. 239.)
11. *P. pusillum* (Gmel.) Jenyns. Left valve of young specimen.

[1] =*H. sericea*, Drap. of Continental authors, *non* Müller



MOLLUSCA FROM THE ARCTIC BED, PONDER'S END.

Appendix IV.—Report *on the* Insect-Remains.

By Charles O. Waterhouse, I.S.O., F.E.S.

I have examined the insect-remains from the Arctic Bed at Ponder's End, and find that the following groups are represented:—

Carabidæ.

Anchomenus ? (several species).
Cyrtonotus sp.
Pterostichus sp.
Carabus sp.
Elaphrus cupreus Dufts.

Dytiscidæ.

Agabus ?

Hydrophilidæ.

Hydrobius fuscipes L.

Aphodiidæ.

Aphodius.
Ægialia ?

Curculionidæ.

Otiorhynchus (several species).

Phytophaga.

Donacea.

The above are mostly ground-beetles and weevils, nearly all water or marsh-insects. The commonest forms of the Carabidæ appear to belong to the genus *Anchomenus*, but the species are not known to me. A thorax is almost certainly a *Cyrtonotus*, of about half the size of our British species.

The *Elaphrus cupreus*, which is represented by an elytron, lives on the mud at the side of lakes. *Hydrobius fuscipes* is a common pond species. The *Donacea* is very near to *D. sericea*, which is found in *Sphagnum*, but is more rugose. It may be a variety of that species.

The majority of the forms present I am unable to identify as extant British species, and the collection certainly suggests conditions that differed greatly from those of the present day. Unfortunately, I am quite unable to attempt the work of comparing these insect-remains with the species of Northern Europe.

Appendix V.—Report *on the* Entomostraca.

By David J. Scourfield, F.Z.S., F.R.M.S.

I have examined the sample of the Arctic Bed from Ponder's End submitted to me, and have also received picked-out remains of Ostracoda from the washings made by Messrs. Warren, Kennard, and Davies.

My own attention was directed mainly to the discovery of the remains of Cladocera, as I had previously found it possible to identify a number of species of this group in samples of the peaty deposit known as 'moorlog' dredged up from the Dogger Bank. After a considerable amount of search, I succeeded in finding three specimens representing two species, namely *Chydorus sphæricus* and *Acroperus harpæ (?)*. In each case only the shell-valves were obtained, the head-shield and all internal parts having disappeared. One of the two specimens of *Ch. sphæricus* was in the 'ephippial' condition, that is, it had undergone the peculiar modification adapting it to receive the resting-egg. The specific determination of the specimen of *Acroperus* is not quite certain, owing to its distorted condition, but the probability is that it is *A. harpæ*. It is very satisfactory to have found these traces of such delicate animals as Cladocera, especially as the recorded fossils of this group are, I believe, neither very numerous nor always reliable.

With regard to the Ostracods, the numerous specimens were found to belong to about twelve species, representing six genera. The exact specific determination is doubtful in some cases; but this is scarcely to be wondered at, when it is remembered that with fossils only single valves are available, and that these differ in the same species according to the age and sex and often on the right and left sides also. I wish to express my great indebtedness to Dr. T. Scott, of Aberdeen, for very kindly looking over the material and revising my preliminary determinations.

The following is the complete list of the Entomostraca so far seen from the Ponder's End Arctic Bed:—

Cladocera.

Chydorus sphæricus.
Acroperus harpæ ?

Ostracoda.

Cyclocypris serena.
Cypris affinis.
Cypris sp.
Herpetocypris reptans.
Herpetocypris strigata (?).
Ilyocypris bradyi.
Candona candida.
Candona neglecta.
Candona acuminata (?).
Candona lactea.
Candona rostrata.
Limnicythere inopinata (probably the form described as *L. incisa* by Dahl).

All the species are freshwater forms and, so far as determined, still living in this country. I do not think that any of them are characteristically Arctic in character, though probably all are to be found living under Arctic conditions at the present day.

I may add that I have also found the tests of a freshwater Rhizopod (*Arcella vulgaris ?*), some egg-cocoons of aquatic worms (leeches or Turbellarians?), and some foraminifera that are probably derived from the Tertiary beds.

Appendix VI.—*The* Mineral Composition *of the* Arctic Bed *at* Ponder's End. By George MacDonald Davies, F.G.S.

I. Introductory.

During the visit of the Geologists' Association, on March 11th, 1911, to the Great Eastern Railway Company's ballast-pit at Ponder's End,[1] I collected a sample of the late Pleistocene marsh-deposit known as the Arctic Bed, with a view to washing out the fossils. A casual examination of the sandy residue left after washing suggested that a more systematic study of the mineral composition of the deposit would be of some interest. The need of more material was met by Mr. S. H. Warren, who very kindly supplied six samples, weighing 16 pounds when received, selected from different parts of the bed. These six samples form the basis of the present note.

II. Method of Examination.

The method of examination employed was as follows:—The air-dried sample was broken into small pieces, and desiccated in a steam-oven until the weight became constant. It was then washed, the muddy water being poured through a 60-mesh wire sieve, which collected most of the vegetable matter. A final separation of the clayey particles from the sand was obtained by well boiling the material, after which the sandy residue was dried and weighed. For quantitative purposes, a 50-gramme sample of the sand was treated with bromoform of specific gravity 2·85, and the portion that sank was weighed. The rest of the sand was panned down, and the concentration completed by bromoform. As a precaution against contamination, no sieves were used until the heavy minerals had been separated from the sand. The portion heavier than bromoform included, besides detrital minerals, varying proportions of earthy pyrrhotite, pyrites, and iron-oxide. The first was separated by an ordinary horseshoe-magnet; the iron-oxide was removed by hot dilute hydrochloric acid, and the pyrites by weak nitric acid—a portion of the concentrate being first examined for other minerals soluble in these acids. The residue, after further treatment with bromoform, may be regarded as the total detrital heavy minerals present in the material, the sulphides and oxides of iron being of chemical origin. This residue was separated into three portions by the electro-magnet, and examined under the microscope in the usual way.

[1] Proc. Geol. Assoc. vol. xxii (1911) pp. 166–71.

III. Description of Samples.

Sample 1 was a dark-grey loam, well laminated and containing much vegetable débris. Ostracods and broken gastropod shells were fairly common. The sample contained 11·9 per cent. of fine sand, the largest grain having a diameter of 1·5 millimetre. Quartz was the dominant constituent; but 21 per cent. of the sand consisted of shell-fragments, foraminifera, and other calcareous remains. Flint-grains appeared to form 3 or 4 per cent. and quartzite was almost as common; felspar, glauconite, and white mica occurred in smaller amounts.

No less than 7·9 per cent. of the sand sank in bromoform. The bulk of this consisted of plant-remains coated with pyrites and, to a less extent, with pyrrhotite and iron-oxide. When freed from these, the heavy residue amounted to only 0·046 per cent. of the sand; it consisted of garnet, tourmaline, staurolite, kyanite, zircon, hornblende, epidote, rutile, ilmenite, pyroxene, and apatite.

Sample 2 was a brownish laminated loam containing a little vegetable matter, with ostracods and foraminifera, but few molluscan remains. The sandy residue amounted to 31·4 per cent. of the sample; it was a fine white sand, the average diameter of the grains being under 0·3 mm. and the maximum 2 mm. It contained 17·7 per cent. of calcareous matter, small amounts of flint, quartzite, felspar, and glauconite, and flakes of white mica.

The portion denser than bromoform amounted to 0·41 per cent. of the sand. Only a trace of pyrrhotite was present, but there was a good deal of limonite and some pyrites. The brown colour of the sample was no doubt due to the oxidation of the greater part of the iron-sulphides. The detrital heavy minerals formed 0·12 per cent. of the sand, and consisted of garnet, tourmaline, staurolite, zircon, kyanite, hornblende, epidote, rutile, ilmenite, apatite, and andalusite.

Sample 3 was a grey loam, laminated in part, containing a considerable amount of vegetable matter. A few shells of *Planorbis*, *Limnæa*, and *Pupa*, numerous ostracods, and one *Chara* were present. The sand, 11·2 per cent. of the material, was fairly fine-grained, but contained one piece of flint 3 mm. in length. Calcareous matter amounted to 25 per cent. Glauconite, quartzite, flint, and felspar were present in small amounts, together with a few flakes of white mica.

The total heavy residue was 4·87 per cent. of the sand. This included 0·71 per cent. of pyrrhotite, considerable amounts of pyrites and limonite, and only 0·065 per cent. of detrital heavy minerals. These consisted of garnet, zircon, ilmenite, tourmaline, staurolite, hornblende, epidote, kyanite, rutile, and andalusite.

Sample 4 was a grey sandy loam, containing little vegetable matter but fairly numerous calcareous sporangia of *Chara*. Ostracods, foraminifera, and small gastropods were also present. The sandy residue amounted to 49·1 per cent. of the sample. It was coarse in grain, and included 8·4 per cent. of stones measuring over 2 mm. in diameter; only two of these exceeded 1 cm. All the stones were flint, and most of them were subangular; many had a lustrous black-stained surface, while the interior was grey or whitish flint. The sand contained 4·3 per cent. of calcareous matter, rather numerous grains of quartzite, and small amounts of flint, felspar, and glauconite.

The heavy minerals amounted to 0·6 per cent. of the sand. The greater part of the concentrate consisted of dark-grey grains which appeared to be an intimate mixture of pyrrhotite and pyrites; they were lifted in a weak electro-magnetic field, and were only partly soluble in hydrochloric acid, but completely so in nitric. A little free pyrrhotite and pyrites also occurred, the former in dull earthy-looking grains, the latter in spherical and irregular aggregates. The remaining heavy minerals, 0·07 per cent. of the sand, consisted of garnet, ilmenite, zircon, tourmaline, staurolite, hornblende, epidote, kyanite, rutile, andalusite, pyroxene, and apatite.

Sample 5 was a grey sandy loam, containing a small amount of vegetable matter and a few ostracods, foraminifera, and broken gastropod-shells. Sand formed 50·1 per cent. of the sample. The largest grain was a splinter of flint 3 mm. long. Calcareous matter amounted to 11·5 per cent. of the sand; flint and quartzite were fairly common, but felspar and glauconite less so; one grain of brown biotite and a few flakes of white mica were noted. On treatment with bromoform, 0·55 per cent. of the sand sank. Of this, 0·26 was pyrrhotite, a considerable amount limonite, a smaller proportion pyrites, and 0·09 per cent. detrital heavy minerals. These last consisted of garnet, tourmaline, staurolite, epidote, zircon, hornblende, kyanite, ilmenite, rutile, and andalusite.

Sample 6 was a grey sandy loam, containing small amounts of vegetable matter, ostracoda, foraminifera, and gastropoda. The sandy residue amounted to 49·3 per cent., and contained 11·5 per cent. of calcareous matter. Flint and quartzite were present in some abundance, as also small amounts of felspar and glauconite. The biggest grain observed had a length of 4 mm.

The heavy minerals included 0·27 per cent. of pyrrhotite, some limonite, a little pyrites, and 0·09 per cent. of other minerals (namely, garnet, tourmaline, staurolite, epidote, zircon, hornblende, kyanite, ilmenite, rutile, and andalusite). It will be noticed that this sample is practically identical in composition with Sample 5.

The principal points in the foregoing descriptions are summarized in the following tables.

TABLE I.—COMPOSITION OF THE SAMPLES.

Sample Number	1.	2.	3.	4.	5.	6.
Weight of sample, dried, in grammes	784·5	1608·5	631	589	403	351
Percentage of sand in sample	11·9	31·4	11·2	49·1	50·1	49·3
Percentage of vegetable matter in sample [1]	15·0	1·7	8·3	1·4	about 1	0·9
Percentage of calcareous matter in sand	21	17	25	4·3	11·5	11·5
Percentage of total heavy residue in sand	7·9	0·41	4·87	0·6	0·55	0·53
Percentage of pyrrhotite in sand ...	0·52	trace	0·71	...	0·26	0·27
Percentage of detrital heavy minerals in sand	0·046	0·12	0·065	0·07	0·09	0·09
Percentage of detrital heavy minerals in original sample	0·005	0·038	0·007	0·034	0·045	0·044

[1] These figures represent the vegetable matter, with a small admixture of shell-fragments, etc., washed off and caught in the 60-mesh sieve. They are tabulated merely for purposes of comparison, and are not to be taken as the absolute amounts present in the samples.

TABLE II.—MINERALS PRESENT IN THE SANDY RESIDUES (IN ORDER OF RELATIVE ABUNDANCE).

Sample Number	1.	2.	3.	4.	5.	6.
Quartz	×	×	×	×	×	×
Quartzite	×	×	×	×	×	×
Flint	×	×	×	×	×	×
Felspar	×	×	×	×	×	×
Glauconite	×	×	×	×	×	×
Pyrrhotite	×	×	×	×	×	×
Pyrites	×	×	×	×	×	×
Limonite	×	×	×	×	×	×
Garnet	×	×	×	×	×	×
Tourmaline	×	×	×	×	×	×
Staurolite	×	×	×	×	×	×
Hornblende	×	×	×	×	×	×
Epidote..................	×	×	×	×	×	×
Zircon	×	×	×	×	×	×
Kyanite	×	×	×	×	×	×
Ilmenite	×	×	×	×	×	×
Rutile	×	×	×	×	×	/
Andalusite	...	×	×	×	×	×
Apatite	×	×	...	×		
Mica	×	×	×	...	×	
Pyroxene (monoclinic)	×	...	...	×		

Table I brings out the fact that a low proportion of sand (as in Samples 1 and 3) is associated with high proportions of vegetable and calcareous matter and of iron sulphides, and with a low proportion of detrital heavy minerals. This is what one might anticipate, seeing that both platy shell-fragments and plant-débris tend to be deposited chiefly with the finer sediment, and heavy detritus with the coarser, and that decaying vegetation seems to have been the cause of the precipitation of the sulphides.

IV. Description of Minerals.

Few of the minerals enumerated in Table II require special description. The grains described as quartzite are compound quartz-grains, showing a mosaic structure in varying degrees of minuteness; they were probably derived in the first case from schists, but some may be silicified sandstones of Mesozoic or Tertiary age. The felspars include orthoclase, microcline, and plagioclase. The tourmaline is usually brown, but blue grains also occur; perfectly rounded grains are common, reminding one of the well-rounded tourmalines of the Bagshot Sands. The hornblende is green and strongly pleochroic. Many of the andalusites are colourless or nearly so, but several grains show the characteristic pink tint for light vibrating parallel to the axis of elongation, which is also the negative or fast direction ($c = \mathfrak{a} =$ red).

The iron pyrites occurs as spherical, cylindrical, and irregular aggregates, showing crystal facets and sometimes encrusting plant-remains. The surface is often fresh and brassy, but sometimes oxidized. The crystalline form is not sufficiently developed to determine whether the mineral is pyrite or marcasite, and the grains are too minute for a satisfactory determination of their density. The magnetic sulphide of iron, pyrrhotite, commonly occurs in spherical aggregates intermixed with large amounts of clayey and organic matter and iron-oxide. The pyrrhotite itself appears to be in a very finely divided condition, and its presence is only indicated by the magnetic character of the aggregates and the evolution of hydrogen sulphide in hydrochloric acid.

V. Origin of the Sulphides.

It is well known that decaying organic matter, under anaërobic conditions, can precipitate the sulphides of iron from iron-bearing solutions. The black mud deposited in insufficiently aërated sewage-beds owes its colour to the formation of ferrous sulphide. Prof. N. Andrussov[1] has described a black mud from the bottom of the Black Sea in which the pigment consists of minute globules of ferrous sulphide (FeS). These globules have been observed in the interior of diatoms. In other parts a blue mud occurs which contains nail-shaped concretions of ferric disulphide (FeS_2). These

[1] 'La Mer Noire': in Guide des Excursions, VIIème Congrès Géol. Internat. (St. Petersburg) 1897, Fascicule xxix.

Black Sea sulphides are said to be due to the action of microbes, *Bacterium hydrosulphuricum ponticum* and others, which disengage hydrogen sulphide both from decaying organic matter and from alkaline sulphate solutions. Part of the hydrogen sulphide evolved combines with iron to form ferrous or ferric sulphide, the remainder effectually poisons the water against the higher forms of life up to within 100 fathoms of the surface. On the coast of Bornholm [1] a yellow film of ferric disulphide is formed on the pebbles on the sea-bottom through the action of decaying seaweed on iron-bearing spring water. In the 'Mineralmooren' (chalybeate bogs) of Franzensbad and Marienbad [2] beds of pyrite and marcasite occur, for the most part enveloping plant-stems. The great development of iron pyrites here is partly due to the numerous chalybeate springs which rise in the moors.

The Arctic Bed of the Lea Valley seems to have formed in a marsh, or in a series of pools of stagnant water, subject to periodical floods. In these pools remains of terrestrial plants and marsh vegetation by their decay, accompanied by bacterial action, abstracted the dissolved oxygen from the water and evolved hydrogen sulphide, which combined with iron salts to form ferrous sulphide or pyrrhotite. The ferric disulphide (pyrites) may have been formed under less perfect reducing conditions, or by the subsequent alteration of pyrrhotite. The ferric hydrate (limonite) resulted from further oxidation.

VI. Derivation of the Detrital Minerals.

With the exception of the sulphides and hydrate of iron, formed *in situ*, all the minerals observed may well have been derived from the Eocene beds over which the River Lea flows. The foraminifera, moreover, by their perfect preservation, appear not to have travelled far and come probably from the London Clay. Flint and glauconite, derived from Cretaceous rocks, are abundant in many Eocene deposits. The heavy minerals, too, are such as are constantly met with in examining the Eocene sediments of the London Basin.

The occurrence of andalusite perhaps deserves special attention. Mr. Herbert H. Thomas [3] has inferred, from the absence of records of detrital andalusite in sedimentary rocks of greater antiquity than the Pliocene, 'with the possible exception of the Chalk of Beer Head,' that andalusite cannot survive as such in a sand of pre-Pliocene age. If we accept that theory, we must look to the Boulder Clay or the Crags as the immediate source of the andalusite of the Arctic Bed. There seems, however, no reason to doubt Dr. W. F. Hume's diagnosis of the mineral in the Chalk of Beer Head,[4]

[1] G. Bischof, 'Lehrbuch der Chemischen & Physikalischen Geologie' 1st ed. vol. i (1847) p. 926.

[2] E. Palla, 'Rezente Bildung von Markasit im Moore von Marienbad' Neues Jahrb. (1887) vol. ii, p. 5.

[3] Min. Mag. vol. xv (1909) pp. 241–44.

[4] 'The Cretaceous Rocks of Britain' Mem. Geol. Surv. vol. ii (1903) p. 510.

for the writer has found perfectly fresh and pleochroic andalusite in the Bagshot Sands of Brentwood, the Woolwich and Reading Beds of Plumstead and Northwood, the Thanet Sand of Crayford, the Folkestone Sands (Lower Greensand) of Dunton Green, Limpsfield and Reigate, and the Wealden Ironsands of Shotover Hill. That andalusite has not previously been recorded from these beds is probably due to its scarcity and to the difficulty of detecting it when the grains do not show striking pleochroism, as also to the small number of workers on the petrology of sedimentary rocks.

Appendix VII.—Note *on* Lemming-Remains *from the* Arctic Bed *at* Angel Road. By Martin A. C. Hinton.

I am indebted to Mr. Warren for permission to study the small bones which he has so carefully collected from the Arctic Bed at Angel Road. The remains are exceptionally fragile, and they say much for Mr. Warren's skill and perseverance.

All the specimens are referable to the species of *Dicrostonyx* which occurs in the deposit of the Ightham Fissures, namely, *D. henseli*.[1] All the more important parts of the skeleton are more or less well represented; and, when fully worked out, the collection will form a valuable contribution to our knowledge of this form. It comprises the remains of from eight to ten individuals, and includes seven palatal specimens in six of which the maxillary teeth are present. These teeth agree in form with those of *D. henseli*; the anterior and middle molars (dm.$\frac{1}{}$ and m.$\frac{1}{}$) have the posterior walls of their 4th inner and 3rd inner prisms respectively reduced, and each tooth completely lacks all trace of the minute vestigial inner angle which occurs behind the prisms named in *D. torquatus* and *D. gulielmi*. The skulls, moreover, agree in size, in their narrow nasals, small and peculiarly shaped bullæ, palatal structure, etc., with *D. henseli*.

D. henseli is an extinct form known from the German Pleistocene, the Ightham Fissures, Langwith Cave, and Doneraile Cave (County Clare). Most of the living species of *Dicrostonyx* live in the Arctic tundra of the Old and New Worlds, and the form living in Grinnell Land reaches 83° or 84° lat. N. On the other hand, we must not forget, in drawing conclusions from the occurrence of two species of *Dicrostonyx* in the late Pleistocene of temperate Europe, that one living form still inhabits Unalaska (54° lat. N., *D. unalascensis*) and that our fossils represent extinct species.

[1] M. A. C. Hinton, Ann. & Mag. Nat. Hist. ser. 8, vol. vi (1910) p. 37; and Proc. Geol. Assoc. vol. xxi (1910–11) p. 496.

Discussion.

Mr. Clement Reid welcomed the paper as one of the most important contributions to Pleistocene geology that had been made of recent years. It was particularly valuable, as the Arctic deposit yielded so prolific a fauna and flora, which were being so carefully studied. In these Arctic deposits in Britain, it was noticeable that traces of man were extremely rare and local. The speaker advised caution, before accepting as a criterion of relative age the height of terraces. He pointed to Hoxne as an example of what may have happened. If the silted-up valley at Hoxne had been re-excavated, so as to leave only terraces of the various fluviatile deposits clinging to the sides of the valley, we should be told that the highest terrace was the oldest, while the most recent occupied the bottom of the valley. It was only the clear vertical superposition of the different deposits at Hoxne that enabled observers to avoid this mistake.

Mr. Reginald Smith said that he was gratified to notice in England a growing scientific interest in Palæolithic man, and congratulated the Author on making an important addition to the existing evidence for considerable changes of climate since the Boulder Clay. There should be a ruling as to what constituted the Ice Age, as some investigators regarded anything after the great glaciations as post-Glacial; and others, in agreement with Continental evidence, included several oscillations of the ice-sheet that occurred during the late Palæolithic or Cave Period. He ventured to doubt whether the stratigraphy in North-East London gave the chronological sequence of the implements, for those shown as the earliest, brown and rolled, with a cutting-edge all round and twisted sides (at least on one), were of St. Acheul type; while that exhibited as a later specimen was lustrous and unrolled, but of Chelles form. Mr. Worthington Smith had noticed brown implements in his 'contorted drift' of this area, which were evidently the sweepings of higher ground, and included some specimens earlier than those covered by the deposit. A recent paper on the Rhine lœss had put the earlier and later parts of that formation into their proper places in the Palæolithic scheme, and investigators in this country seemed to be on the road to a satisfactory equation of British and Continental Palæolithic deposits.

Mr. W. Whitaker, while admiring the ingenuity of Mr. Reid's explanation of how a small mass with the appearance of belonging to a higher terrace might really be newer than another small mass at a lower level, suggested that an explanation which might serve in regard to a brickyard-section some 50 feet deep, could hardly do so in the case of a valley four times as deep and several miles wide.

Mr. G. W. Lamplugh congratulated the Author upon the extreme interest of his subject and upon the thoroughness of his work. The speaker had been constantly impressed in the northern and western Midlands with the proofs of severe and prolonged erosion since the period of maximum glaciation, which was evidently a remote event in most parts of the interior of England. This erosion was active, however, long before the great ice-reservoirs of the

North Sea and Irish Sea were melted out. In Britain, as in Scandinavia, there appeared to have been some considerable variations of climate during the slow and oscillatory recession of the ice-sheets; but the speaker had as yet failed to find evidence that the changes were ever sufficient to initiate a new and independent system of ice-sheets or glaciers anywhere in England. It was a characteristic feature of the late-Glacial erosion that, while the high-graded upper parts of the valleys were sharply deepened, great sheets of flood-washed detritus were deposited simultaneously in the lower and broader parts of the valleys. Consequently, the gradient of the late-Glacial terraces was generally steeper than that of the present valley-bottom, and deposits on the floor of the open lower valley were often equivalent in age to high terraces of the upper reaches. This condition was observable in the upper part of the Lea Valley, and the speaker seconded Mr. Reid in asking the Author to consider the possibility of the 'Arctic Bed' in question being older than its position would seem to imply.

Mr. Whitaker explained that he had not compared terraces at distant parts of a valley, as Mr. Lamplugh had done, but terraces at one and the same part, which was a very different matter.

The Rev. E. C. Spicer, in the hope that the paper would throw light upon the gravel-mounds around Buckingham, drew attention to the occurrence of a lenticular patch of loose dark peat in a gravel-pit near Woodford and Hinton railway-station, which was unfortunately destroyed before it could be investigated. The patch of peat was intercalated among contorted gravels containing very large pebbles and big fragments of Jurassic rock, and must have been a frozen flake originally. One shell, which was possibly *Pupa muscorum*, was obtained from a small handful of the peat, but this too was accidentally destroyed.

The Author, in reply, thanked the Fellows for their reception of his paper. With regard to the point raised by Mr. Reid, he admitted that some valleys had been filled with drift and then re-excavated, so that the higher terraces were the newer; but this explanation could hardly apply to the River-Drifts of the Thames Basin. The fact that abraded implements derived from the higher terraces were found in the lower, was a confirmation of the reading of the drifts as given in the paper. He had also to thank Mr. Whitaker for answering this point. In reply to Mr. Reginald Smith, the photographs of implements shown on the screen were not copied from Mr. Worthington Smith's book, but were all of specimens in the speaker's own collection: they had been given in their correct sequence of relative age. He so far agreed with Mr. Lamplugh that the Arctic conditions claimed in the paper would not compare with those of the epoch of maximum glaciation. The evidence, so far as it went, suggested snow and river-ice for the lowlands, probably with glaciers in the more mountainous districts; but not a general ice-sheet of such magnitude as to displace the water of the sea-basins adjacent to our shores.

In reply to a question put by Mr. J. F. N. Green, the Author was certainly of opinion that the Ponder's-End deposit was a true Lea river-gravel.

13. *The* UPPER KEUPER (*or* ARDEN) SANDSTONE GROUP *and* ASSOCIATED ROCKS *of* WARWICKSHIRE.

By CHARLES ALFRED MATLEY, D.Sc., F.G.S. (Read January 24th, 1912.)

[PLATE XVIII—MAP.]

CONTENTS.

I. INTRODUCTION.

THE field-work on which this paper is based was mainly carried out between 1895 and 1901, at a time when I lived near Birmingham. It was then suspended, owing to my removal from the district, and until 1911 I was unable to revisit the ground and advance the mapping sufficiently for the presentation of this paper.[1] Even now I have been compelled to curtail considerably my original plan of work, which was to zone the Keuper Marls of Warwickshire from base to summit as far as possible, and, when that was accomplished, to investigate their lithology and fossils with the view of ascertaining their origin and mode of formation. The present paper deals mainly with the stratigraphy, tectonics, and geological relations of a well-marked horizon in the Marls which is usually known as the 'Upper Keuper Sandstone,' and further work on the Marls of this area must be left to other workers.

II. GENERAL DESCRIPTION OF THE DISTRICT.

The portion of Warwickshire to be described extends from the neighbourhood of Solihull, Knowle, and Barston on the north to Wilmcote and Snitterfield, near Stratford-on-Avon, on the south; and from Tanworth-in-Arden, the Alne Hills, and Wixford on the west to Hatton and Claverdon on the east, an area of about

[1] I desire gratefully to acknowledge two grants made about 1896 and 1897 from the Endowment of Research Fund of the Birmingham Natural History & Philosophical Society in aid of this work, and to express regret at the belated publication of the results.

108 square miles. The Keuper Marls occupy the whole of this district, except where they are overlain in the south by the Rhætic and Lower Lias, and in the north, near Knowle, by an outlier of the same formations. Geologically, the country forms part of the southern portion of the broad syncline of New Red Rocks that lies between the South Staffordshire and the Warwickshire Coalfields. Physically, it consists of a dissected plateau rising usually to altitudes between 400 and 500 feet above O.D. in the north and west, and sloping gently on the whole to the south-east and south, the River Arrow at Wixford being only 110 feet above O.D. The district is drained in the north by the Blythe and other tributaries of the Tame, which falls into the Trent; and in the south by the Alne and Arrow, which drain into the Warwickshire Avon and so into the Bristol Channel. The topography of the watershed between these two river-systems and the courses of the rivers are interesting, but will not be discussed here.

The district occupies the site of much of the ancient Forest of Arden, but is now mainly given over to agriculture and is dotted with old-world villages. The country is picturesque and well-wooded, and affords a distinctly bolder type of scenery than does the Keuper Marl country immediately to the north: a fact which is no doubt attributable in some measure to the thinner mantle of Drift, but is also partly due to the presence of a sandstone horizon in the Marls of the area here described which gives rise to a number of escarpments. Another set of ridges and low hills has been produced by a hard zone lying at a higher horizon in the Marls than the sandstone band; while a third, and bolder, escarpment has been formed at the junction of the Marls with the Rhætic deposits. The scarp-slopes, varying from 40 to 100 feet or more in height, are frequently covered by woods and copses. Owing, as will be seen later, to the low dips and undulations of the strata, they wind about the country and so impart to it a particularly pleasant and diversified aspect. The soil of the Marl country, except where the sandstone zone crops out, is usually, and especially when freshly ploughed, of a bright red colour, which adds warmth to the scenery, particularly noticeable when intensified by the ruddy glow of the setting sun.

The marked change in colour observable, from the brilliant red of the Marls to the pale-grey soil with sandstone fragments of the sandstone zone, has been of the greatest assistance in tracing the course of the sandstone horizon; and, with the aid of the old marl-pits with which the district is dotted, the stratigraphy of the area can be usually worked out with close accuracy, except in places where the drift deposits are thicker than usual.

This sandstone is usually known as the Upper Keuper Sandstone; but, as it is evident from the writings of Prof. Hull (69),[1] the late Mr. Fox-Strangways,[2] and others that two or more Upper Keuper

[1] The numerals in parentheses refer to the Bibliography, § XI, p. 276.

[2] 'The Geology of the Country between Atherstone & Charnwood Forest' (Expl. of Sheet 155) Mem. Geol. Surv. 1900, p. 36.

Sandstones occur in the Marls of the English Midlands, I adopt a suggestion made to me some years ago by Prof. Charles Lapworth, and call it the Arden Sandstone, in view of its important development in the area of the old Forest of Arden. As I include with the sandstone the associated grey shales and marls, and as the sandstone is often so feebly developed as to be almost absent, it will be more exact to use the term Sandstone Group in speaking of this sub-formation.

III. History of Previous Researches.

The presence of a 'peculiar Zone of Sandstone' intercalated in the Red or Saliferous Marls was first made known in 1837 by Murchison & Strickland (37), in a paper communicated to this Society. They traced the zone from the borders of Gloucestershire through Worcestershire into Warwickshire, described its lithological character faithfully, and found that it occupied the same stratigraphical position throughout—a position which, though acknowledged by them to be difficult to ascertain with precision, they estimated to be (p. 332) 'separated from the Lias by at least 200 feet of red and green marls.' As regards the area with which we are now concerned, they described the sections at Shrewley, Rowington, and Oversley Lodge near Alcester; and so carefully had they explored the district, that they record the presence of the zone at the great majority of the localities shown on the Geological Survey map some seventeen years later. They noted also the presence of organic remains in the zone at Shrewley Common and elsewhere, including fish-remains, batrachian footprints, and *Posidonomya* (now *Estheria*) *minuta*.

In 1854 the Geological Survey 1-inch map of this district (quarter-sheets 54, N.E. & S.E.) appeared, in which this sandstone band is traced with considerable accuracy and with as much completeness as was to be expected from a survey carried out on a 1-inch scale; but, owing to the omission of the zone from a number of places where it has now been found to occur, the value of the map as a guide to the geological structure of this portion of the country is much lessened. In 1859 Mr. H. H. Howell gave an explanation of the map in the Survey Memoir on the Warwickshire Coalfield. He found that the sandstones occurring in the Marls around that coalfield occupy more than one horizon: those, for instance, at Orton Hill in Leicestershire being found at a lower level in the Marls than those near Henley-in-Arden. He recognized that the sandstone outcrops at Shrewley, Lapworth Hill, Mows Hill, Pinley Hill, and near Henley-in-Arden, etc., are all on the same horizon; but, as he omits any reference to the important detached outcrops of the Alne Hills and the Alcester district in the south-west and to the Knowle mass in the north, which lie closer to the outcrops of the Lower Lias than does the Henley-in-Arden sandstone, it is probable that he was uncertain whether they might not lie on a higher horizon. The position of the Henley-in-Arden sandstones is stated (59, p. 42) to be

'about 250 feet below the lowest bed of the Lias, and they are separated from the Lower Keuper Sandstone by about 350 feet of red marl.'

Our knowledge of the stratigraphy and geological structure of this area has advanced little since Mr. Howell's map and memoir were published, as later workers have turned their attention almost exclusively to the collection and description of the fossil contents of the sandstone zone. Numerous papers, extending over a period of forty years, by the Rev. P. B. Brodie gave accounts of the zone, especially as developed at Rowington and Shrewley, and have recorded from time to time additions to its fauna and flora—the most important and interesting discovery being the recognition (93 & 94) of a green gritty band at the base of the sandstone, which contains abundant fish-spines and teeth, as also casts of marine molluscan shells. Mr. E. P. Richards (94), who was associated with Brodie in this discovery, found that this band could be traced in the sandstone at other localities, as at Knowle and Preston Bagot. The fossils of the zone have been described by Sir Philip Egerton (58), T. Rupert Jones (62), Murchison & Strickland (37), Mr. E. T. Newton (87), Mr. R. B. Newton (94), and Dr. A. Smith Woodward (89[1], 89[2], & 93); and studies of the footprints have more recently been made by Mr. H. C. Beasley, and recorded in the Reports of the British Association by the Committee appointed to investigate the Fauna & Flora of the Trias of the British Isles. These Reports also contain a full list of the fossils recorded from this zone and a bibliography of the fauna and flora by Mr. A. R. Horwood, which has been found of material assistance in the preparation of the Bibliography appended to the present paper.

Recently, Mr. W. Campbell Smith, F.G.S., commenced the mapping of the zone in this and neighbouring areas, in connexion with an investigation of the fauna and flora of the Upper Keuper which he and Mr. L. J. Wills are carrying out. Although he had made considerable progress before he became aware that my own map was practically completed, he has most generously left the description of this portion of the ground to me, and has also allowed me to see his maps. Without involving Mr. Smith in any responsibility for the lines on my map, or for the views expressed in this paper, I should like to state that our field-observations coincided closely; that Mr. Smith had independently discovered many of the additional outcrops now recorded for the first time; and that I am indebted to him for information about two or three exposures which I had not previously observed, thus enabling me to present a better map.

IV. Stratigraphy of the Arden Sandstone Group.

In view of the known irregularity of Triassic deposits, and as sandstones are known to occur at several levels in the Marls, it is important that the evidence for showing the Arden Sandstone

Group on my map and sections as a continuous deposit belonging to a single horizon should be stated. It becomes therefore necessary to describe the stratigraphy in some detail, especially as regards those localities where it has not hitherto been recognized.

In the following description the classification suggested by Brodie (70) will be adopted, the Keuper Marls which lie below the Arden Sandstone Group being designated the Lower Marls and those which lie above that Group the Upper Marls.

The type-locality for the Sandstone in Warwickshire is the section exposed at the canal at Shrewley Common and in the adjacent disused quarry. This section was first described by Murchison & Strickland in 1837, and subsequently by Brodie on several occasions. According to Brodie's last detailed account (93), 26 feet of the sandstone zone is here exposed, consisting of alternating sandstones and green marls, of which 12 feet only is sandstone, the green marls, measuring about 14 feet, mostly lying at the base of the zone. The top of the zone is not exposed in the section, but the base is seen to repose on the Lower Marls. Fossils are not uncommon. The *Acrodus* Bed and the band with casts of mollusca lie in the marls close to the base. In the sandstones at least one bed is ripple-marked, foot-tracks of labyrinthodonts occur, and sun-cracks, as also other evidences of shore-conditions, are to be found.

(*a*) Shrewley to Knowle.

The base of the zone at Shrewley is about 345 feet O.D., and the beds are horizontal. This horizontality is maintained for a considerable distance to the north and west of Shrewley, the top of the zone being usually about 10 or 15 feet below the 400-foot contour and only occasionally rising slightly above it. The sandstone can be traced from Shrewley on both sides of the valley formed by the Wroxall Brook, which has cut into the Lower Marls, leaving a low escarpment on each side of the valley capped by the Arden Sandstone. In places it forms flattish terraces, as at Mousley End, and especially at Rowington, where its outcrop forms a lobe extending south-westwards to Finwood and separating the Wroxall Brook valley from that of the Kingswood Brook. The canal cutting through this lobe at Rowington gives a good exposure of the sandstone resting upon the Lower Marls. The sandstones exposed on the north side of the cutting in old quarries are white, sometimes weathering brown, with partings and beds of greenish sandy shale and marl. The sandstones are somewhat false-bedded, with apparent dips to west-north-west varying from 5° to 13°; though, when viewed as a whole from the opposite side of the canal, they are seen to be almost flat. The beds are variable in their composition, as even at Rowington Hall, close by these quarries, the sandstones have become (so I was informed) very shaly.

To the west of Rowington is a 'through valley' drained southwards by the Kingswood Brook and northwards by a stream which flows into the Blythe. On both sides of this valley the Arden Sandstone can be traced, as shown on the Geological Survey map, the Lower Marls occupying the bottom of the valley and the Upper Marls coming in at about 375 to 390 feet O.D., the strata being practically horizontal. The sandstone in the zone becomes less conspicuous, especially when the beds are followed northwards and westwards, and replacement of sandstone by pale-grey and green shale and marl seems to be taking place.

The outcrops on either side of the valley do not descend the valley-slopes and unite on the north near Netherwood Heath, as shown (with dotted boundaries) on the Geological Survey map, for the zone is to be found maintaining its horizontality at Chadwick End on the east, and about Packwood and Dorridge on the west. Along the eastern branch the course of the zone is obscure, owing largely to the presence of drift sands and gravels and red marly boulder-clay; but from time to time grey marl, mudstone, and shale, with an occasional thin sandstone or skerry, are discoverable about 350 to 370 feet O.D., indicating that the zone is present and that it remains almost flat. The best exposures about here are to the east of Temple Balsall and to the north of Fen End, and it is highly probable that the zone follows the contours of the country approximately as indicated on the map (Pl. XVIII).

The western branch can be joined up with the Knowle Sandstone outcrop. At Chessetts Wood drift sands with overlying boulder-clay are banked up against the zone; but the band is easily recognizable at and west of Packwood Church, where it occupies the floor of the shallow valleys. The exposures are not good, and seem to consist entirely of grey or greenish shale and marl. The top of the zone about here is, as usual, close to the 400-foot contour-line; but one of the outcrops running up a valley to the south-west crosses that contour, and reaches 445 feet O.D. at Sand's Farm, near Hockley Heath. Thick drift obscures most of the ground between Packwood and Knowle. There is, however, an exposure of the characteristic shaly sandstone in the stream and in the roots of an overturned tree, east of Packwood Gullet, which enables the outcrop to be indicated as far as the road at Knowle Grove, north of which, about Ardendale and Jacknet, are several exposures of sandstone and shale which enable the zone to be linked up confidently with the outcrop mapped by the Geological Survey at Knowle.

At Knowle some 9 feet of the sandstone zone, resting upon the Lower Marls, is well exposed on the west side of the canal. It consists mainly of pale-grey laminated shales and mudstones, with an occasional thin, flaggy, quartzose and felspathic sandstone band. Near the base is a thin bed of dark-grey clay or shale, and about a foot above the base is a zone full of tiny pebbles, as at Shrewley, in which Mr. Richards (94) found fish-remains and close to which I obtained an ichthyodorulite. About 6 feet higher in the deposit *Estheriæ* are not uncommon. The beds here are well and evenly stratified, and dip gently towards the Rhætic and Lower Liassic outlier of Copt Heath, about two-thirds of a mile away to the north.

Fig. 1.—*Section from Illshaw Heath through Packwood to Wroxall.*

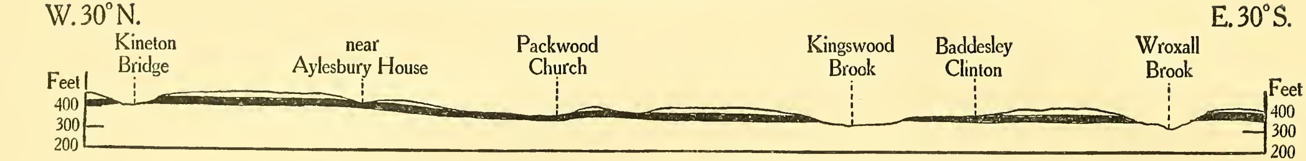


Fig. 2.—*Section from Mockley Wood to Rowington and Mousley End.*

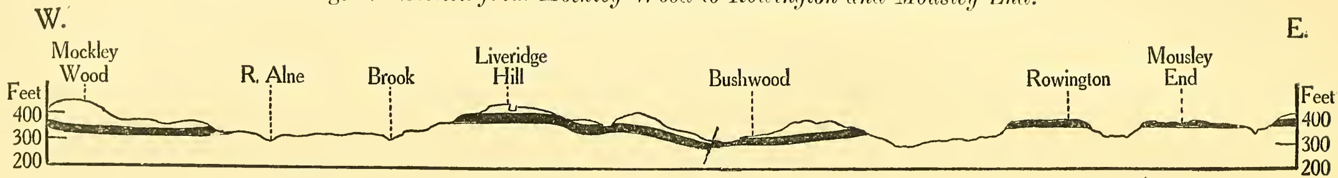


Fig. 3.—*Section from Oldberrow to Shrewley.*

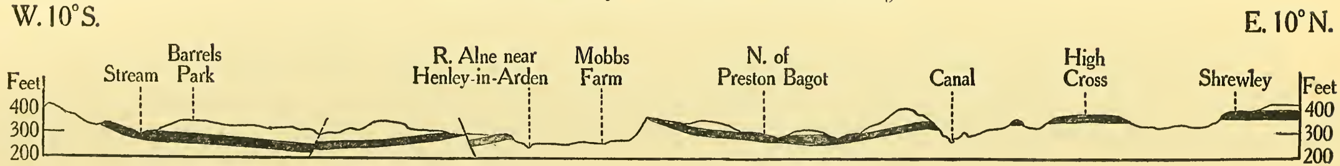


Fig. 4.—*Section from near Spernall Park to Wolverton.*

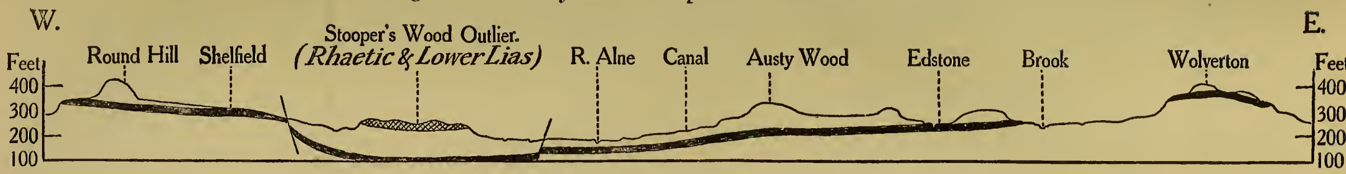
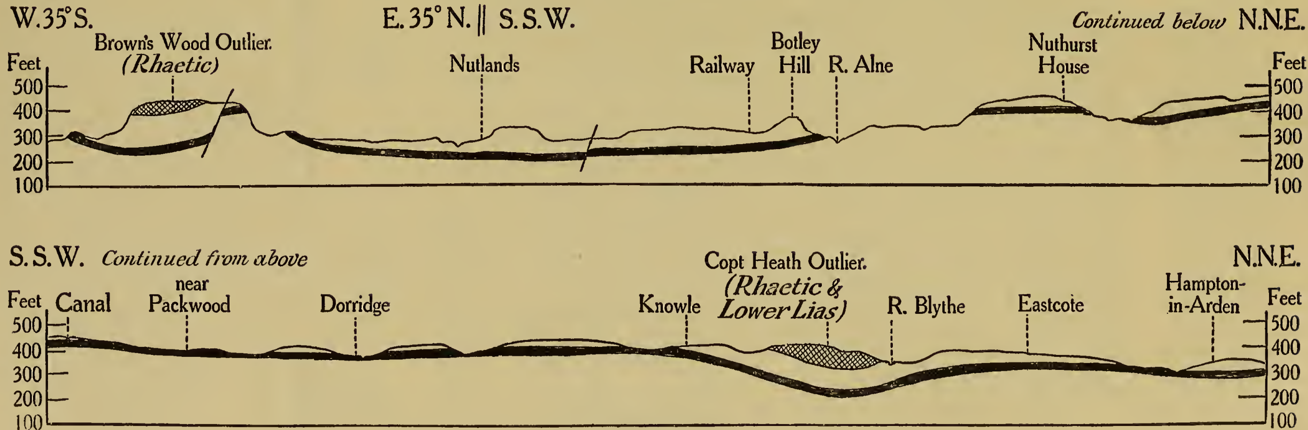


Fig. 5.—*Section from Morton Bagot to Hampton-in-Arden.*



[Horizontal scale of all the above sections: 1 inch = 1 mile.]

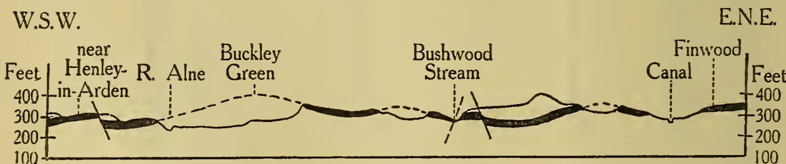
The sandstone is visible on the east, near the Blythe, and it is again exposed behind Barston Park Farm, where some 6 feet of sandstone and grey marl may be seen lying horizontally. It also occurs in the ditch by the side of the lane leading from the farm down to the River Blythe, and must be dipping westward towards the Rhætic outlier.

North of Barston the ground has not been completely mapped by me; but I have observed a grey marl-band with some sandstone occupying the little valley south of Hampton-in-Arden and passing thence towards Barston. Further, on the west side of the Copt Heath outlier, at Sandals Bridge Brickworks, near Solihull, 4 feet of grey-green marl and shale, with a hard sandstone band, occurs, overlying some 20 feet of red and green (but mostly red) marls, and covered by pebbly drift. This grey zone, in which I found comminuted fish-scales, etc., probably represents the base of the Arden Sandstone Group. Hence, despite the superficial deposits, it is not unlikely that, when the ground about Copt Heath is fully mapped, it will be possible to plot out the course of the Arden Sandstone Group as an outcrop completely encircling the outlier.

(*b*) Shrewley to Preston Bagot and Henley-in-Arden.

Let us now return to the type-locality at Shrewley, and trace the sandstone to the south and west. The upper boundary of the zone, though obscured in places by drift-gravel, etc., can be followed without much difficulty to High Cross (near which a small outlier occurs), Holywell (once famous for a spring which issues from the sandstone), Kington Grange, and Preston Green. In the country about Preston Bagot, from Pettiford Lane to Lapworth Street, a distance of about 4 miles, the sandstone forms extensive outcrops,

Fig. 6.—*Section along or near the Lapworth and Henley-in-Arden branch of the Great Western Railway, showing the folding of the Arden Sandstone.*



[Horizontal scale: 1 inch=1 mile.]

with inliers of Lower, and outliers of Upper Marls, consequent on the gentle undulations into which the strata about here have been thrown. These undulations are not only revealed by the mapping, but are (or, at least, were some sixteen years ago when I visited the ground) well exposed along the line of railway between Lapworth Station and Henley-in-Arden (see fig. 6, above). The Geological Survey map shows a doubtful fault in this ground following the course of the pretty little Bushwood valley, which lies in a synclinal trough. In view of the unusual straightness of this valley, and remembering that a fault is actually to be seen in the railway-cutting east of the supposed plane of dislocation, I have adopted the line on my map; but the fault, if it exists, must be of small throw, and soon dies out.

(*c*) Henley-in-Arden to Tanworth-in-Arden.

The River Alne, between Tanworth and Henley-in-Arden, has cut through a low anticline of the Arden Sandstone, which caps a good escarpment of the Lower Marls on the northern and eastern sides of the valley but makes only a slight feature on the southern and western slopes. My map of the ground bordering the escarpment agrees substantially with the Geological Survey map and will not therefore be discussed, but the other slope of the anticline has not hitherto been mapped. South of the Leasowes, near Tanworth, the Alne escarpment bends westward towards the river and sinks. The sandstone crosses the river at this point, and its base can be seen on the other side in an old marl-pit north of Robin Hood's Farm, where it contains *Estheriæ* and plant-remains. Between this locality and Henley-in-Arden it is exposed at various places. A fault was visible in 1907 during the construction of the new railway, a short distance south of Danzey Green station, throwing down the Upper Marls on the south-west against the Sandstone zone. Another fault with a small downthrow to the east brings in two small sandstone inliers near Impsley Farm. Another north-west and south-east fault breaks the end of the anticline at Blackford Hill, throwing down the sandstone on the south to river-level, but it dies out in a short distance to the south-east. A well-sinking at Blackford Corn Mill reached the top of the zone at a depth of $8\frac{1}{2}$ feet.

The sandstone reappears farther down the River Alne in the bed of the stream at Wootton Wawen, and crops out on the main road to Stratford-on-Avon and at other places in this locality. The outcrop should perhaps be extended farther eastwards than is shown on my map, but the rock is there buried beneath river-gravels.

(*d*) Wixford to the Alne Hills and Morton Bagot.

Near Stratford-on-Avon the Lower Liassic outcrop sends out a lobe north-westwards in the direction of Aston Cantlow, where it is further prolonged as two outliers with north-westerly axes. Around these outcrops there is a good development of the Arden Sandstone.

At Wixford, 2 miles south of Alcester, the sandstone is found at the level of the River Arrow (about 110 feet O.D.), and can be traced thence without difficulty, substantially as shown on the Geological Survey map, through Oversley and Haselor to Aston Cantlow. There is, however, an inlier not previously recorded, well exposed at the village of Exhall between this line of outcrop and the Rhætic escarpment. At least 8 feet is here exposed, consisting mainly of pale-grey arenaceous shales (with an occasional thin red marly parting) and thin flaggy sandstone, one band of which showed oblique lamination such as is also seen in the Alne Hills and elsewhere. Near Aston Grove there is a fault with a downthrow to the south-west.

Near Aston Cantlow the sandstone sinks beneath the Alne alluvium, and, reappearing west of that river, caps the escarpment of the Alne Hills, along which it can be followed with ease to Greenhill Farm and thence with more difficulty to Mars Hill and a quarter of a mile beyond, where it is cut off by a fault that has the usual north-westerly and south-easterly trend. The sandstone can be picked up again close to Morton Bagot Church, on the opposite side of the fault, dipping south-eastwards, whence it may be traced to Upper Wawensmoor. Here it forms the nose of an anticline, and bending back and dipping west-north-westwards at 10° to 15°, it runs through Oldberrow to the neighbourhood of Ullenhall, where it may be faulted out, as I have not been able to trace it farther. The beds flatten to the north-west, as is shown below the alluvium of the stream that runs through Barrells Park, where 4 feet of alternating sandstones and grey marls may be seen dipping at 0° to 5°.

In the neighbourhood of Shelfield, between the Alne Hills escarpment and the Rhætic outliers, are two inliers of sandstone, the southern of which occupies a shallow valley and the northern is thrown against the Upper Marls by a fault which soon dies out, as it is not seen to break through the escarpment. The sandstone is well exposed in some of the lanes here; but it is slightly undulating, and the boundaries of the zone are inserted on the map (Pl. XVIII) with some diffidence. The sandstone here contains a pebbly or conglomeratic zone, somewhat like, but coarser than, that exposed at Shrewley, Knowle, and near Tanworth.

(*e*) Area south of Shrewley.

Returning once more to the type-locality at Shrewley, we will now follow the zone from the eastern end of the canal tunnel, where the beds are unmistakably exposed. For a short distance the sandstone can be traced south-eastwards to an exposure, dipping at a low angle to the south-east or east, on the canal side near Hatton railway-station, east of which I have been unable to find it. South of the canal, however, it can be seen at several places on both sides of the valley occupied by the Hatton & Bearley branch of the Great Western Railway. It has been mapped with fair accuracy by the officers of the Geological Survey as far as Claverdon, but is exposed in the bed of a brook about three-quarters of a mile south of that village; and by sandstone fragments, etc. its course can be indicated as far as Edstone, where about 8 or 10 feet of flaggy sandstone is visible in an old stream-course south of Cutler's Farm. This is probably the spot where Brodie observed it many years ago, as mentioned in several of his papers (for instance, 96). The outcrop may be more extensive than that shown on the map, but I have not visited the grounds of Edstone Hall. The sandstone here crosses the Edstone stream and the railway, and its course can be followed along a winding escarpment about Songar Grange towards Snitterfield. East of Songar Grange, and also at an outlier to the north of it, 4 feet of white, flaggy, rippled sandstone, with *Estheria*, occurs. A mile farther to the south-east the zone seems to be still thinner, or may be split up by red marls, but I have not attempted to follow the band farther in this direction.

On the eastern side of the Hatton & Bearley Railway the zone is best developed and exposed at Wolverton, and I have found sufficient indications of the sandstone to enable me to link it up with that mapped by the officers of the Geological Survey at Cophill and Claverdon Lodge. The sandstone zone was also found to occur capping the Lower Marls along a line from Wolverton to Gannaway Gate (where it is fairly well exposed and dips westwards). It continues still farther northwards; but the exposures are poor, and the zone seems to be thin.

(*f*) Hockley Heath and Nuthurst.

The district about Hockley Heath is covered mainly by a thin zone of Upper Keuper Marls, from below which the Arden Sandstone comes to the surface as inliers at several places. The largest of the inliers occurs in the valley between Illshaw Heath and Box Trees, and two others are shown on the map (Pl. XVIII) near Bentley Manor. The sandstone zone was also proved in a well that was sunk to a depth of some 40 feet, about 200 yards north-east of the 'Nag's Head' at Hockley Heath, as a considerable quantity of grey shale and grey marl was thrown out. South of that village the top of the zone must lie quite close to the surface, which is, however, formed of a gravelly drift that obscures the Keuper rocks.

Between Hockley Heath, Nuthurst, and Lapworth Hill the mapping of the zone presents more difficulties, and yields less satisfactory results than in any other part of the area described. On the south side of the valley drained by a small stream (the Nuthurst Brook), which flows at the foot of Lapworth Hill, sandstone and grey marl are seen on the higher slopes to pass up into red marl at two places, one west and the other south-east of Nuthurst House; but red marl is to be seen below these outcrops, intercalated, apparently, between the sandstone mentioned above and a green marl that occurs lower down the valley-slope. The zone thus appears to be losing its individuality here, and I have been unable to follow its course to the north-west. Eastwards it can be traced across the Stratford road, keeping to the top of the slope, beyond which, however, it descends to the stream-level. The beds here have, therefore, a northerly or north-easterly dip, and this fact has been kept in view in inserting the conjectural boundaries shown on the map (Pl. XVIII).

As a result of the field-work described above, I have been forced to the conclusion that the Arden Sandstone Group, though varying in thickness and lithological composition from place to place, forms a persistent zone extending over all the area described.

Although the stratigraphy would lead one to expect an outcrop of the Arden Sandstone east of the Upper Marls of Fen End, Wroxall, and Shrewley, I have been unable to find it. There is abundant glacial drift about here, and it is possible that an old scarp-slope of the Sandstone Group may be buried beneath these superficial deposits. On the other hand, some miles to the north, at Maxstoke Priory, there is a strong fault, having a north-and-south direction, throwing down Keuper rocks on the west against 'Permian' rocks on the east; and it is not unlikely that its course is continued into the Keuper Marl country on the south, so as to cut out the Arden Sandstone by throwing the Upper Marls on the west against the Lower Marls on the east.

V. The Upper and Lower Keuper Marls and the Rhætic Beds.

The Upper Marls, though only some 100 to 160 feet in thickness, occupy a considerable area of the ground described in this paper. They consist mainly of red and chocolate-coloured marls, usually with green mottlings; but there are also occasionally bands of well-laminated, chocolate, micaceous, marly shale and thin beds of green shale and marl. In the rare instances in which there is an opportunity of following the bedding of the marls for some distance, as along the cuttings of the Birmingham & Stratford-on-Avon Railway in 1907, before they were grassed over, green bands only an inch or two thick can be seen to persist as far as the section extends. These Upper Marls also contain a hard band which forms a well-marked escarpment, or builds isolated hills in many places, for example, at Yarningale Common and near Claverdon, Preston Bagot, Bushwood, Tanworth-in-Arden, Wootton Wawen, and elsewhere. There is an exposure close to Morton Bagot Church of a hard, well-bedded, chocolate-coloured marl-rock, which is probably the bed in question. The base of these Upper Marls is seen in places, as at Henley-in-Arden railway-station, to consist of alternating bands of red and grey marl. The top of the Marls is rarely exposed, but the green marls (Tea-Green Marls) immediately underlying the Rhætic are occasionally visible along the margins of the Rhætic outliers.

Of the Lower Marls the upper portion only is exposed in this district. They consist of red, grey, green, and mottled marls similar in character to those occurring above the Arden Sandstone; but, on the whole, they seem to be somewhat softer than the Upper Marls. Gypsum occurs in them in the scarp-slope below the sandstone near Henley-in-Arden, as is shown in the cutting of the railway to Lapworth; and again in the corresponding slope at Spernall Park, where the mineral has been worked commercially.

Rock-salt occurs in these Lower Marls in Worcestershire, but has never been met with, so far as I am aware, in Warwickshire, although there is evidence of the crystallization of salt during the formation of these Lower Marls in the pseudomorphs of sodium-chloride that have been obtained at several localities east of Birmingham and at Maxstoke. Ripple-marked skerry-bands are also found in them at Bordesley and Yardley near Birmingham and elsewhere.

The Rhætic Beds of this district have been examined merely for the purpose of inserting on the map their boundary with the Keuper rocks. The Copt Heath outlier, between Solihull and Knowle, is obscured by drift-gravel in the direction of Solihull, and I have reduced the length of the outlier as shown on the Survey map by about half a mile in that direction, as I found no evidence of Rhætic or Lower Lias being present west of Longdon Hall. On the other hand, there is a possibility of the extension of these beds to the east of the boundary as mapped, as green marl (which appears to be the 'Tea-Green Marl' zone of the highest Keuper) was found in drain-excavations at Hob Lane, Barston; and fragments of Rhætic shales, and of Rhætic or Liassic limestone, occur lower down the lane and in the fields to the south and south-east of Barston Church.[1] The evidence at present is, however, by no means strong enough for asserting the occurrence of Rhætic deposits *in situ* here; and as I have left part of the area about Barston unmapped, I call attention to the point in the hope that it will be cleared up by local geologists. If present, the beds dip southwards, and a fault probably intervenes between them and the Arden Sandstone which occurs at Barston Park Farm near by.

The Morton Bagot and Stooper's Wood outliers have been mapped with their boundaries much as drawn by the officers of the Geological Survey. The same remark applies also to the boundary of the main outcrop of Rhætic and Lower Lias, except (*a*) that I show a faulted boundary at Aston Grove, and (*b*) that it seems to me that the plateau bounded by an Upper Keuper Marl escarpment between Lower Clopton and Lower Ingon, near Snitterfield, is perhaps covered by a thin layer of Rhætic. No definite exposures have been observed in this area where there is much drift; but the nature of the soil suggests this opinion, an opinion strengthened by the fact, of which I was unaware at the time of mapping, that Rhætic shales were actually discovered below the drift in making excavations for the Snitterfield reservoir, and were described by the Rev. P. B. Brodie (86 & 88).

[1] [Dr. F. L. Kitchin has been good enough to examine the fossils extracted from pieces of limestone obtained from this neighbourhood. *Ostrea liassica* Strickl., *Lima* (*Plagiostoma*) *gigantea* J. Sow., and *Cardinia* sp. are represented by several examples. *Modiola minima* J. Sow., *M. minima* auctt. *non* J. Sow., and radioles of *Cidaris* aff. *edwardsi* Wright, also occur. Dr. Kitchin regards them as of Lower Liassic age, probably from the *Ostrea* Beds or the *Planorbis* Beds, or perhaps from both. There is no evidence for Rhætic among them. With his views I quite agree.—*C. A. M., May 15th, 1912.*]

VI. Lithology and Fossils of the Arden Sandstone Group, and its Position in the Marls.

As will be inferred from the descriptions already given, the Arden Sandstone Group is a variable deposit, as regards both mineral composition and thickness. The zone never consists wholly of sandstone, but always contains a considerable admixture and often a great preponderance of grey shale and marl. Bands of red shale and marl are also occasionally present in it. The sandstone facies is best developed in the neighbourhood of a line passing in a north-easterly direction from Alcester through the Alne Hills, Henley-in-Arden, and Rowington. Occasionally, the sandstone is sufficiently thick-bedded and hard to be utilized locally for building-purposes and for gravestones, and it was formerly quarried for these purposes at Shrewley, Rowington, and Mows Hill. Several churches in Arden were built of it in mediæval times, and the town-cross at Henley-in-Arden seems to be made of it. But all the quarries are disused, and the only economic use that is made of the rock at present seems to be at the Alne Hills escarpment, where I found the friable rock being excavated for sand. The sandstone is also a minor source of water-supply for the district.

The sandstones of the zone are nearly always white or pale grey, or, when weathered, pale brown. They consist mainly of quartz-grains, often mingled with white kaolinized felspar, and sometimes contain mica-flakes. Small pebbles are locally abundant in one or more layers of the zone, and have been observed at Shrewley, Knowle, east of Tanworth, and Shelfield, and they will probably be found elsewhere if looked for. The sandstone bands not infrequently exhibit current-bedding and ripple-marks, and other signs of shallow-water conditions; while the presence of animal-tracks and sun-cracks testifies to the fact that the surfaces of deposition were left dry from time to time. The associated marls and shales are usually more evenly bedded than the sandstone bands. I have not observed pseudomorphs of salt-crystals in the group, although they occur in the Marls both above and below.

The fossils of the Upper Keuper in this area and in the adjacent districts are being systematically collected by Mr. L. J. Wills and Mr. W. Campbell Smith, and the former will, I understand, describe them at an early date. Such fossils as I have myself collected have been handed over to Mr. Wills. Only a brief reference to those occurring in Warwickshire will, therefore, be made here, and then solely with the view of considering the conditions under which the beds were deposited. The fossil list compiled by Mr. A. R. Horwood in the 'Sixth Report of the British Association Committee on the Fauna & Flora of the British Trias' shows that collections have hitherto been made almost exclusively from Rowington and Shrewley and their neighbourhood, but fossils are not rare at several other localities. *Estheria minuta* especially is widely distributed, and I have found it at many localities, including Shrewley, Rowington, Knowle, south and south-east of Tanworth-in-Arden, Morton Bagot, Shelfield, Blackford Hill (near Henley-in-Arden), Mows Hill, and near Wolverton. Plant-remains, nearly always badly preserved, are to be obtained not only at Shrewley and Rowington, but at Umberslade, Mows Hill, south of Tanworth, and Shelfield. Fish-teeth and other fish-remains are somewhat similarly distributed, but as a rule very sparingly. Mollusca, hitherto known only from Shrewley, have lately been discovered by Mr. Wills at Shelfield, 6½ miles to the south-west. Labyrinthodont and reptilian remains and footprints have been rarely found away from Rowington and Shrewley; but the above-mentioned facts go to show that the zone may be searched almost anywhere for fossils with a reasonable hope of success.

The zone is typically from 20 to 25 feet thick, but occasionally appears to reach 40 feet or even more. It thins rapidly eastwards and south-eastwards to about 4 or 5 feet, and probably also north-eastwards. In this easterly attenuation it follows the example of the lower members of the Warwickshire Trias, which, with the exception of the Lower Keuper Sandstone, disappear when followed eastwards from the neighbourhood of the South Staffordshire coalfield to that of the Warwickshire coalfield.

The zone lies some 120 to 160 feet below the base of the Rhætic, the overlying marls being probably of somewhat variable thickness. It is possible that in places it may be no more than 100 feet below the Rhætic deposits; but a precise estimate is difficult, on account of the slight undulations of the beds.

VII. Correlation with other Areas, and Conditions of Deposition.

From the continuity of the Arden Sandstone over the area described from Knowle and Barston to Alcester and Wixford, it seems highly probable that Murchison & Strickland were correct in asserting that the sandstone can be followed into Worcestershire and Gloucestershire as a zone occurring always at the same horizon. I am prepared to accept this view, although detailed mapping will be required before the point can be regarded as definitely proved. The same lithological characters and the same suite of fossils characterize the sandstone in those counties, as in Warwickshire. Around the Rhætic and Lower Liassic outlier of Berrow Hill, near Tewkesbury, Mr. Linsdall Richardson [1] finds that the Upper Keuper Sandstone is 215 feet below the base of the Rhætic, but its greater depth may be due to variation in the thickness of the Upper Marls.

The Upper Keuper Sandstone, near Leicester, a similar formation with a similar fauna and flora, was stated by Mr. James Plant, in 1856,[2] to be 80 to 120 feet below the Lias, and it is, therefore,

[1] Q. J. G. S. vol. lxi (1905) pp. 425–30.
[2] 'On the Upper Keuper Sandstone (included in the New Red Marls) & its Fossils at Leicester' Q. J. G. S. vol. xii (1856) p. 372.

probably also part of the same deposit as the Arden Sandstone. The mapping of this Leicester sandstone was revised about 1900 by C. Fox-Strangways, who stated [1] that it

'appears to occur in more or less lenticular masses, which thin out in all directions, and there is no evidence that this bed is so continuous and regular in its character as it has been supposed to be.' (*Op. cit.* p. 11.)

He also figured an instructive section showing the sandstone passing laterally into grey marly beds. In his map, however, partly for economic reasons, he differentiates only the 'principal mass of coarse sandstone' from the Keuper Marls; whereas, in the earlier edition, the sandstone was mapped as a group or zone including the associated grey marls, shales, and 'skerries.' Regarded as a group, the horizon is probably as persistent as that of Warwickshire, and Fox-Strangways admitted that these beds 'occupy a fairly definite horizon' (*op. cit.* p. 13).

The Arden Sandstone Group seems, therefore, to be part of a deposit which was laid down over an area extending at least 70 miles from north-east to south-west; it probably also thinned out south-eastwards. It was formed at a time when 'continental' conditions in Britain were nearly at their close, and it appears to me that the most satisfactory explanation of this sandstone zone is that it was probably formed, as an episode in the deposition of the Marls, when the open sea gained a temporary access to the Keuper-Marl area and brought with it the fishes and molluscs whose remains are now found in the zone. It represents, in fact, a phase corresponding to that of the Rhætic Bone-Bed and the Tea-Green Marls, but of somewhat earlier date.

The associated Keuper Marls have been dealt with, mainly in regard to their stratigraphical relations with the Arden Sandstone, and no special attention has been devoted to the vexed question of their origin. But my observations, so far as they go, tend to confirm the view of the older observers that the Marls are aqueous deposits, though possibly consisting largely of wind-borne material, deposited in a comparatively, and sometimes quite, shallow lake undergoing strong evaporation and subjected to occasional irruptions of the sea. They represent the closing phase of Triassic 'continental' conditions in the English Midlands, when the slow subsidence which was soon to bring in marine Rhætic and Liassic deposits was in progress, and produced that overlapping of the Keuper rocks on to the higher grounds of the Triassic land-surface which is observable in the neighbouring districts of the Lickey Hills, Nuneaton, and Charnwood Forest.

VIII. Tectonics of the Area.

One of the most interesting results of the mapping of the Arden Sandstone Group is the light that its stratigraphy throws on the geological structure of the area, which is now seen to be by no

[1] 'The Geology of the Country near Leicester' (Expl. of Sheet 156) Mem. Geol. Surv. 1903, pp. 11–13.

means of a simple character. From the sections made across the district (figs. 1–6, pp. 258–59, 260) it will be seen that the Marls are thrown into a number of shallow synclines and anticlines, and are broken in places by faults, usually of small throw. But the sandstone forms so many outcrops in this region that I have gone further, and have ventured to produce a contour-map (fig. 7, p. 270) showing, as nearly as I can determine it, the form of the top of the Arden Sandstone Group as it would appear if the overlying Marls were removed and the denuded portions of the Sandstone restored. Owing to the variation of thickness in the Sandstone Group, a contour-map for the base of the Sandstone would, of course, differ in detail; but in its main features it would correspond. The contours are taken at intervals of 25 feet, and they bring out the following points:—

(1) The beds have been subjected to folding of a slight character in several directions.
(2) The dominant strike is nearly parallel to the general trend of the main outcrop of the Lias of the Midlands, that is, it is north-east to south-west, or Caledonian in direction. The principal direction of the dip of this area, especially the western portion, is to the south-east.
(3) But there is considerable cross-folding at a right angle to the Caledonian direction of movement, producing axes having a north-west to south-east (or Charnian) direction. Most of the faults take this trend.
(4) Some folds have Pennine or Malvernian (north to south) axes, while at least one (near Henley-in-Arden) seems to have been produced by a combination of the Charnian and Pennine movements, being intermediate (north-north-west to south-south-east) in direction between the two.
(5) Owing to the south-easterly tilt, the contours do not often form closed curves.

A study of a geological map will show that all these three movements are represented in the adjoining areas. For instance, the Caledonian movement determines the main boundary of the Lias from Leicestershire to Warwickshire; the Charnian is revealed by several lobes of the Lias projecting from the main mass to the north-west, as at Feckenham and near Leamington; while the Pennine effect is well marked in the north-to-south faults at Warwick and the trend of the western edge of the Permian country of Warwickshire.

The folding of the Upper Keuper Sandstone in South Worcestershire (Pendock district) has been described by Mr. L. Richardson, who has given reasons [1] for the opinion that the folding of this band was initiated before the deposition of the Rhætic. This may well have been the case also in Warwickshire; but the pre-Rhætic movement must have been slight, as the greater part of the movement is certainly post-Liassic, the Lias of the neighbourhood being affected almost equally with the Keuper.

[1] Proc. Cottesw. Nat. F.-C. vol. xv (1904–1906) pp. 93–100; Q. J. G. S. vol. lx (1904) pp. 349–58; and *ibid.* vol. lxi (1905) pp. 425–27.

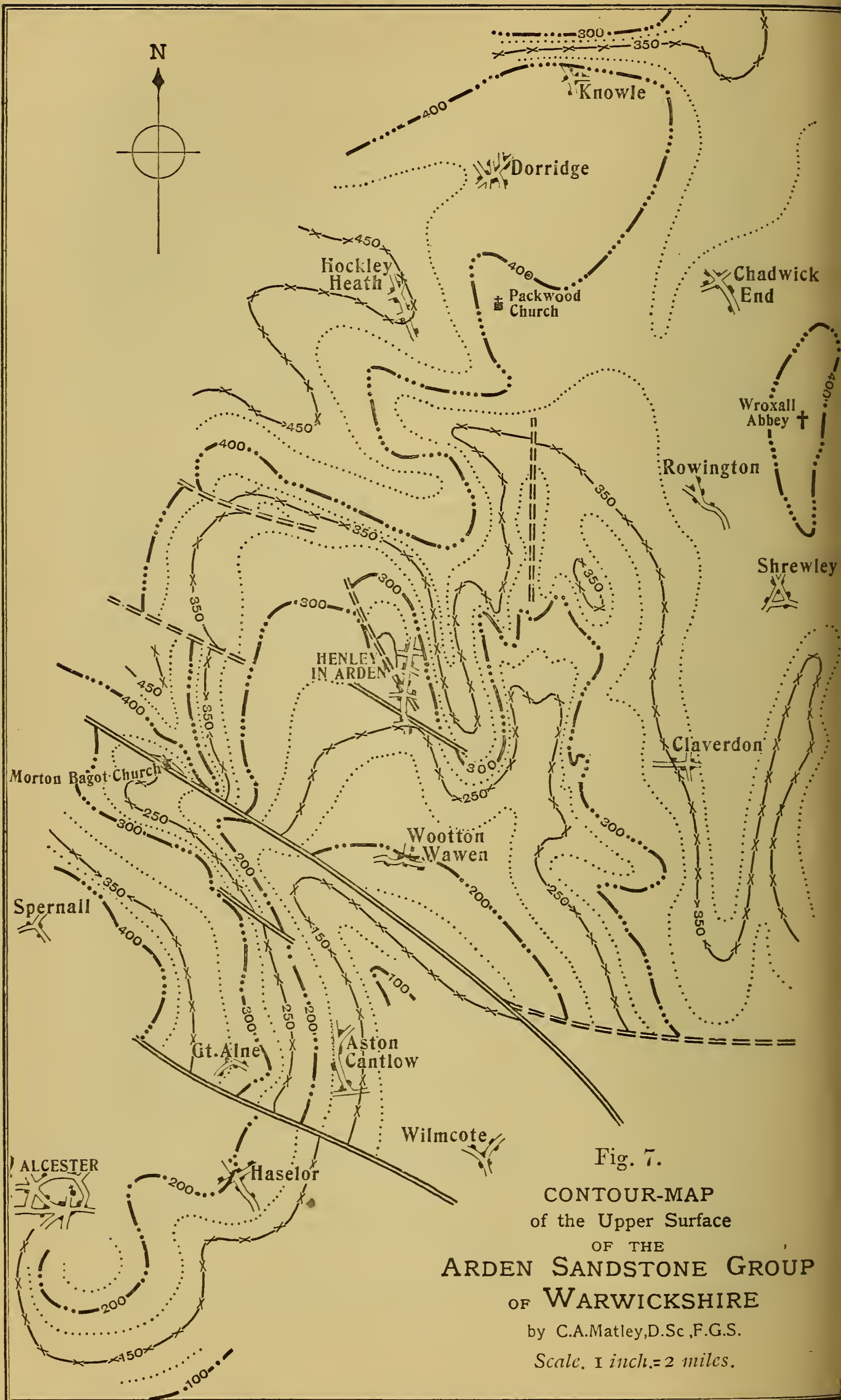


Fig. 7.

CONTOUR-MAP
of the Upper Surface
OF THE
ARDEN SANDSTONE GROUP
OF WARWICKSHIRE
by C.A.Matley, D.Sc., F.G.S.

Scale. 1 *inch* = 2 *miles*.

The point must not be ignored that the flexuring of the sandstone may, to some extent, have been caused by the removal of beds of rock-salt by solution from the underlying Marls. The contouring indicates that if such beds once existed, and if water gained access to them, there would be a flow of the brine to the south-east and south: as the basins are not 'locked up,' but are tilted in the directions mentioned. Beds of rock-salt of great thickness occur at Droitwich and Stoke Prior, a few miles to the west of the area here described, and it would be interesting to ascertain by means of the zoning of the marls how the salt basin is tectonically disposed. The fact that the water obtained in a deep boring through the Lias at Rugby into the Lower Keuper Sandstone was unfit for drinking purposes, owing to impregnation by salt and gypsum,[1] shows that salt-deposits must once have existed, and perhaps still exist, to the east of the district here described. That they once existed in Central and South Warwickshire also is, therefore, not unlikely.

From the foregoing remarks it may be inferred that an investigation of the folding of the Arden Sandstone Group in this and other areas may throw useful light on questions of theoretical and economic importance, especially on those relating to water-supply and the movement of underground water. Perhaps also, later on, such an investigation may throw light on the possibility of reaching coal at a workable depth, as the Lower Keuper in this district probably lies on rocks not younger than the Permian.

IX. Deep Borings through the Keuper Marls.

Deep borings have, from time to time, been made through the Warwickshire Marls into the underlying rocks, and a few of the sections have been published—for example, by W. Jerome Harrison, Dr. A. Strahan, and Dr. Horace T. Brown.[2] As it is important that fuller information should be accessible as to the sequence and thickness of the Marls and the nature of the underlying rocks, the three following additional borings are here recorded, although they are outside the limits of my map.

(i) Artesian Well at Alveston Hill.

This boring, which is situated about a mile and a half east of Stratford-on-Avon and a mile and a quarter from the nearest Rhætic and Liassic outcrop, was completed in 1898 to supply the villages of Alveston and Tiddington. The following details were supplied to me some years ago by the courtesy of the engineers, Messrs. Willcox & Raikes, of Temple Row, Birmingham, to whom I tender my best thanks. For 200 feet an 11-inch tube (10-inch internal diameter) was put down, then an $8\frac{3}{4}$-inch tube (8-inch

[1] Geol. Mag. dec. 3, vol. iii (1886) p. 454.

[2] W. J. Harrison, *ibid.* p. 453; A. Strahan, *ibid.* pp. 540–45; and H. T. Brown, *ibid.* dec. 4, vol. iii (1896) pp. 54–58.

internal diameter) to 592½ feet, then a 7⅝-inch borehole. There was a yield of over 60,000 gallons of water per day. At first a little trouble arose from oxidation of iron in the pipes, but that trouble soon ceased:—

Description of Beds.	*Thickness.*		*Depth.*	
	Feet.	*Inches.*	*Feet.*	*Inches.*
Soil	1	0	1	0
Small gravel	11	0	12	0
Red marl with small pebbles	128	0	140	0
Red gypseous marl	95	0	235	0
Grey gypseous marlstone	5	0	240	0
Sandy marl	1	0	241	0
Red marl	174	0	415	0
Grey marl	31	0	446	0
Red marl	54	0	500	0
Red sandy marl	17	0	517	0
Red marl and grey bands	17	0	534	0
Red marl	13	0	547	0
Greenish-grey marl	1	0	548	0
Red and grey marl	1	0	549	0
Coarse grey sandstone	30	6	579	6
Red marl	1	6	581	0
Grey sandstone with thin seams of grey marl	14	0	595	0
Red marl	2	6	597	6
Dark-grey sandstone	22	6	620	0
Coarse grey sandstone	15	0	635	0
Grey marl	1	0	636	0
Pale-grey sandstone	12	0	648	0
Dark-grey sandstone	28	0	676	0
Very fine grey sandstone	22	0	698	0
Fine red sandstone	6	0	704	0
Fine grey sandstone	3	0	707	0
Fine red sandstone	21	0	728	0
Dark purple marl	26	0	754	0
Total thickness of strata	754	0	754	0

The section may be summarized as follows:—

	Thickness in feet.
Soil and gravel	12
Keuper Marls (with probably a few feet of marly drift)	537
Lower Keuper Sandstone	205
Total	754

I have, unfortunately, not been able to visit the locality so as to ascertain the nature and thickness of the drift and the horizon in the Marls of the highest bed exposed here; but, although the section shows 128 feet of the uppermost red marls as 'with small pebbles,' it is quite unlikely that pebbles occur—except as drift-pebbles in glacially-reconstructed red marl for a few feet below the gravel.

The thickness of the marl forming the lowest bed reached in the boring suggests the possibility that the Lower Keuper Sandstone formation was completely passed through, and the marls and sandstones of the 'Permian' of the Warwickshire district reached.

This vertical section should be compared with that shown by the boring near Stratford-on-Avon described by Dr. H. T. Brown,[1] which is situated only a little over 2 miles north-west of the Alveston-Hill well. The Stratford-on-Avon boring passed through 604 feet of Keuper Marl into 200 feet of Lower Keuper Sandstone. The variation in the Lower Keuper is so great in this short distance, that it is practically impossible to correlate individual beds in the two sections; and equal difficulty is experienced when the Marls of the two sections are compared.

The most individualized beds met with in the Upper Keuper of the two borings were the following:—

	Thickness in feet.	*Distance in feet above base of Marls.*
Alveston Hill.		
Grey gypseous marlstone	5	309
Grey marl	31	103
Stratford-on-Avon.		
Grey marl and gypsum	5	539
Grey marl and gypsum	20	359
Red marlstone with beds of sandstone	29	290

It will be seen that there is no bed in the Stratford boring corresponding to the 31 feet of grey marl at Alveston Hill; also that the 29 feet of 'red marlstone with beds of sandstone' at Stratford does not occur at Alveston. This latter zone is the one which Dr. Brown correlates with the Arden Sandstone; but, if the latter is represented at all in the Stratford boring, its position is more likely to correspond with the 5 feet of 'grey marl and gypsum'[2] occurring at 539 feet above the Lower Keuper Sandstone. There is a possibility that the 20 feet of 'grey marl and gypsum' in the Stratford boring is the same band as the 5 feet of 'grey gypseous marlstone' at Alveston; but it is quite evident that there is great variation in the marls between the two localities.

(ii) Well and Boring at Small Heath, Birmingham.

Particulars of this and the next section were supplied to me about the year 1903 by the kindness of Mr. J. Cox, Superintendent-Engineer of the City of Birmingham Baths Department. The well and boring were made to supply the Corporation Baths at Small Heath, Birmingham, in 1896. The sinking commenced as a well 8 feet in diameter (lined cast-iron segmental cylinders to 113 feet, then concrete lining) to a depth of 170 feet, succeeded by steel tubes of 12-inch bore with couplers to 250½ feet, followed by a 12-inch borehole to 624 feet. There was a constant yield of about 7500 gallons of water per hour.

[1] Geol. Mag. dec. 4, vol. iii (1896) p. 54.
[2] The Alveston-Hill boring probably commences below this horizon.

Details of Strata.	*Thickness.*		*Depth.*	
	Feet.	*Inches.*	*Feet.*	*Inches.*
Soil, gravel, and clay mixed ...	8	0	8	0
Loose sand	8	0	16	0
Gravel	9	6	25	6
Loose marl	9	0	34	6
Red marl	16	0	50	6
Rock and slate	5	0	55	6
Red marl	8	0	63	6
Hard blue rock....................	2	0	65	6
Red marl	10	0	75	6
Hard rock............................	3	0	78	6
Hard red marl	21	0	99	6
Soft blue marl	2	0	101	6
Red marl	1	6	103	0
Soft blue rock	1	0	104	0
Hard red marl	1	0	105	0
Red marl	3	0	108	0
Blue rock	1	6	109	6
Red marl	3	6	113	0
Blue rock	2	6	115	6
Red marl	2	0	117	6
Hard blue rock....................	2	6	120	0
Red marl	79	0	199	0
Marlstone	1	6	200	6
Blue marl	3	6	204	0
Gypseous red marl	20	0	224	0
Blue marl	5	0	229	0
Gypseous red marl	10	0	239	0
Red marl	33	0	272	0
Marlstone	3	0	275	0
Red marl	20	0	295	0
Blue marl	7	0	302	0
Red marl	53	0	355	0
Blue marl	5	0	360	0
Red marl	53	0	413	0
Fine loamy sandstone	17	6	430	6
Very fine red sandstone	6	6	437	0
Red marl	3	0	440	0
Red sandstone	10	0	450	0
Red marl	8	0	458	0
Red sandstone	2	0	460	0
Fine red sandstone	39	0	499	0
Red marl	12	0	511	0
Red sandstone	3	0	514	0
Red marl	5	0	519	0
Red sandstone	18	0	537	0
Red marl	3	0	540	0
Red sandstone	18	0	558	0
Red marl	4	0	562	0
Fine red sandstone	1	0	563	0
Red marl	4	0	567	0
Red sandstone	17	6	584	6
Red marl	4	0	588	6
Red sandstone	14	6	603	0
Sandy red marl....................	6	0	609	0
Red sandstone	11	0	620	0
Coarse red sandstone	4	0	624	0
Total.........	624	0	624	0

The foregoing section may be summarized as follows :—

	Thickness in feet	*inches.*
Drift	34	6
Keuper Marls	378	6
Lower Keuper Sandstone	211	0
Total	624	0

The boring is situated about a mile away from the Birmingham fault, which throws down the Keuper Marls on the east of Birmingham against the Lower Keuper Sandstone on the west. The beds of red marl alternating with 'blue rock' and 'blue marl' evidently correspond to the red marls with intercalations of green and blue marl and bands of 'skerry' (or 'rotch,' as it is locally called by the brick-workers) to be seen in the brick-pits at Bordesley about a mile away.

(iii) Well and Boring at Moseley Road, Birmingham.

Dug well to 174 feet; 15-inch boring to 481½ feet; 11-inch boring to 550 feet; 10-inch to 570 feet. Subsequently bored to 727 feet. Water-level with the boring at 570 feet was 54 feet from the surface. Constant supply at 727 feet of about 8000 gallons per hour. The boring was made in 1902, to supply the Birmingham Corporation Baths at Moseley Road. It is situated about a mile from the Birmingham fault above mentioned.

Description of Beds.	*Thickness.*		*Depth.*	
	Feet.	*Inches.*	*Feet.*	*Inches.*
Dug well in red marl	174	0	174	0
Red marl	92	0	266	0
Red marl with gypsum	34	0	300	0
Red and grey Keuper marls	178	0	478	0
Grey marlstone	6	0	484	0
Fine red sandstone	12	0	496	0
Red and grey marls	16	0	512	0
Red sandy marls	2	0	514	0
Grey sandstone	17	0	531	0
Soft red plastic marl	26	0	557	0
Red sandstone	19	0	576	0
Soft plastic marl	8	0	584	0
Pale-red sandstone	14	0	598	0
Marl	3	0	601	0
Pale-red sandstone	10	0	611	0
Grey sandstone	12	0	623	0
Red marl	47	0	670	0
Red sandstone	10	0	680	0
Red marl	6	0	686	0
Red sandstone	1	0	687	0
Loose red sandstone	40	0	727	0
Total	727	0	727	0

Although the dug well is stated to be in 'red marl' for its whole depth, some drift is no doubt present in its upper part. The 'loose red sandstone' found in the lowest part of the boring may possibly belong to the Upper Bunter. The section may accordingly be summarized as under:—

	Thickness in feet	*inches.*
Keuper Marls (including some drift) ...	478	0
Lower Keuper Sandstone	209	0
Upper Bunter Sandstone (?)	40	0
Total	727	0

The intercalation of marls in the Lower Keuper Sandstone practically throughout its thickness is very striking. The great variation of the Keuper deposits in all the borings is quite evident.

X. Summary.

The results set forth in this paper may be summarized as under:—

(1) The Arden Sandstone Group of Warwickshire forms a band in the Keuper Marls about 120 to 160 feet below the Rhætic beds. It consists of sandstone, marl, and shales in varying proportions, is typically 20 to 25 feet thick, but often much thinner, especially in the south-east.

(2) It is thrown into numerous shallow folds having north-west to south-east and north-to-south axes, and is tilted as a whole south-eastwards.

(3) From its nature and fossils, and from a consideration of similar rocks in the Keuper Marls between Gloucestershire and Worcestershire, it appears probable that the Arden Sandstone Group was laid down over an area at least 70 miles in length, and was formed as an episode in the history of the Keuper Marls, by an irruption of the sea into the Keuper-Marl area.

(4) Particulars are given of three well-borings going down into the Lower Keuper Sandstone.

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EXPLANATION OF PLATE XVIII.

Map of the Upper Keuper (Marls and Arden-Sandstone Group) of part of Warwickshire, on the scale of 1 inch to the mile, or 1 : 63,360.

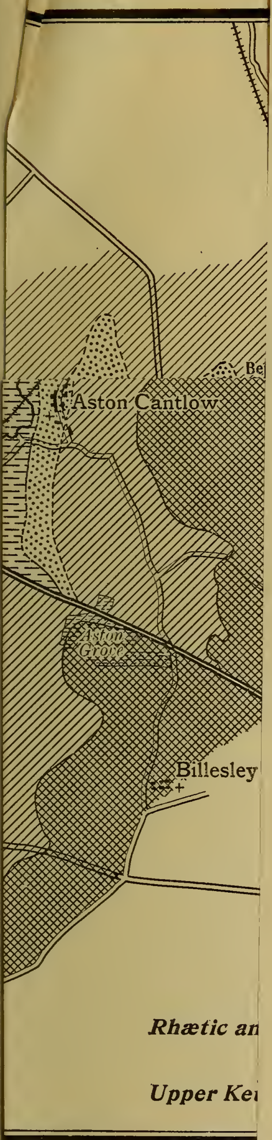
Discussion.

The President (Prof. W. W. Watts) remarked that, if ever there was an apparently hopeless district in which to embark upon geological work, it was that Forest of Arden which Shakespeare had immortalized. The paper just read showed how a genius for mapping enabled an observer to secure most valuable results under extremely unfavourable circumstances. The Author had shown that there were two types of marls—one above and one below the sandstones. He had also proved that the area had a definite geological structure; and, finally, he had demonstrated that what might appear to be, at first sight, merely an academic type of field-work, has a definite economic application.

Mr. L. J. Wills endorsed the President's remarks concerning the natural difficulties in the way of producing a map such as the Author had put before the Society, and congratulated Dr. Matley on his success. He had seen something of the ground, and would have liked to hear more evidence about the continuity of the belt or group, for the sandstones varied enormously in composition and thickness, and he believed that in many cases the connecting links were nothing but blue soil or bits of blue shale.

With regard to the fossils, the Author had handed over some specimens to him, and Mr. Campbell Smith and the speaker had found a number themselves, of which some were exhibited. Murchison & Strickland, in their original investigation of these sandstones, had found nearly all the forms since recorded.

The general resemblance of the plants to the Lower Keuper forms obtained at Bromsgrove, and in the case of *Voltzia* to *V. heterophylla* (also known from the German Bunter), was striking. The shell identified by Mr. R. Bullen Newton as *Nucula* had recently been found at Shelfield Square, 6 or 8 miles south-west of its type-locality at Shrewley.



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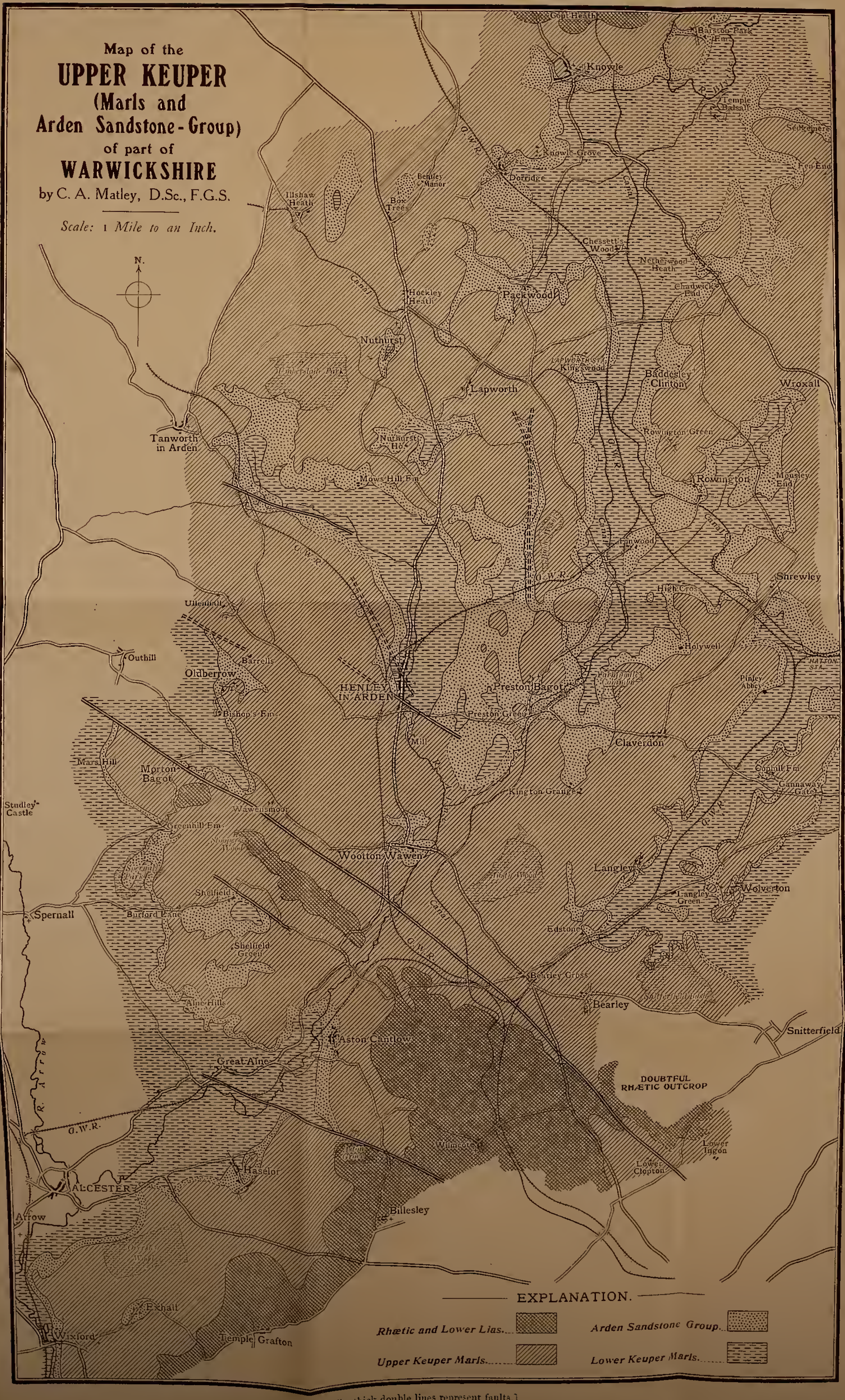


[The thick double lines represent faults.]

Mr. W. Campbell Smith thanked the Author for his acknowledgment of his observations in the area, but pointed out that these had added nothing to the completeness of the map. His own work, so far as it had gone, showed that the sandstones all over the area were included in a zone between 100 and 200 feet below the base of the Rhætic. The strong feature frequently seen above the sandstones was due to a hard band of marl, and not to sandstones. He had seen these Upper Keuper sandstones at Inkberrow and in the Pendock area, where they showed characters precisely similar to those now described. One very striking fact was the frequent appearance of a bed, relatively rich in teeth and bones of fishes, at about 2 feet above the base of the sandstone group. He thought that there was ample evidence for the existence of a north-west to south-east axis of folding, these folds being actually seen in the Henley-Rowington railway-cutting; but he suspected that some of the minor complications, shown on plotting the contours of the top of the sandstones, might be due to the rapid variations in thickness which were observable in very many parts of the district.

Mr. T. O. Bosworth could not agree with the Author that the sands were marine, but thought that they were the product of waters flowing down from surrounding hills and spreading out over the desert basin. *Estheria* occurred throughout on the included seams of grey clay-shale, while the garnets and other heavy grains showed the peculiar smoothing described by the speaker, and not yet observed in any proved sea-sand. The few molluscan remains, so far discovered, were in such bad preservation that no one could certify them to be marine.

The gentle folding shown on the Author's maps was not easily proved. The evidence depended on the assumption that all the sandstones observed might be mapped as on one horizon. On account of the false and lenticular bedding, no reliance could be placed on the dips, except in those few cases where they were observed in long continuous sections.

The term 'Charnian Axis' used by the Author suggested some interesting ideas. It must be observed, however, that the Keuper Marls, so well exposed overlying the old rocks in Charnwood Forest, showed no evidence of any post-Triassic movements.

There were various ways, besides ordinary folding along particular axes, by which strata might become inclined. Owing to lenticularity, the proportion of sandstone to marl in a complete vertical section of the Upper Keuper varied greatly from place to place; consequently, on drying and under compression by rocks above, there would be a differential contraction in the thickness of the formation which might cause gentle undulations such as those described.

Dr. A. Wade said that the presence of rounded sand-grains in this sandstone did not necessarily mean that it was not accumulated as a marine deposit. Recent personal observations in the Red-Sea area had convinced him that, under certain conditions, blown sand was deposited in the sea to a greater distance from land than was perhaps generally supposed.

Mr. G. W. Lamplugh, referring to the comments of the last speaker on rounded sand-grains in marine deposits, recalled attention to the well-known observations of Mr. A. R. Hunt on sands on the sea-floor in the English Channel, which seemed clearly to prove that the grains could be rounded by current-trituration as well as by wind-drift.

The Author, in reply, thanked the President and Fellows for the kind reception given to his paper, and looked forward to valuable results from Mr. Wills's investigation of the fauna and flora. The detailed evidence for the view that the Arden Sandstone Group formed a continuous though variable belt was given in the paper. As to the contour-map, the lines drawn were not inserted from dips but from outcrops, and were the outcome of an honest attempt to express the results of the mapping in contour form, without any preconceived idea as to the form which they would assume. The undulations were really very slight, and the extent to which the contours were attributable to true folding, and how far they were modified by other agencies such as contraction of the strata during consolidation (as suggested by Mr. Bosworth), solution of rock-salt and gypsum, or by an original slope in the surface of deposition, would be a useful subject for future enquiry.

He had hoped to utilize the results of his mapping as a basis for investigation into the lithology and origin of the Keuper Marls; but, as he had now left the district, he hoped that other workers would take up this line of research.

14. *The* Keuper Marls *around* Charnwood. By Thomas Owen Bosworth, B.A., B.Sc., F.G.S. (Read December 21st, 1910.)

[Plates XIX–XXVI.]

Investigation on the Keuper Marls during the past seven years has been the subject of various papers [1] by the author, read before the Leicester Literary & Philosophical Society, the British Association (1907), and finally before the Geological Society (1910).

As the complete work is being published in book form, only a brief abstract is given in these pages.

The area under consideration—about 300 square miles in extent—is situate on the eastern edge of the central plain of England, and the greater part of it is within from 150 to 350 feet of sea-level.

Rising sharply in this plain are the hills of Charnwood, formed of pre-Cambrian rocks, peeping up through the mantle of Keuper Marls, by which they were doubtless once completely covered.

The Marls are now found on the flanks of all these hills, and are seen in the quarries at Bardon Hill resting on the old rocks at 810 feet above O.D. and in joint-cracks up to within 32 feet of the summit [2] (912 feet above O.D.), which is the highest point in Charnwood. As has been shown by Prof. W. W. Watts,[3] denudation of the soft Marl cover is gradually revealing the pre-Triassic land-surface almost intact.

In this paper are described some of the details of the old rock-surface found beneath Keuper Marl in the quarries.

Generally, the quarries have been opened in the tops of the buried or almost buried hills; and as usually the extension of a quarry on each occasion is carried on in the direction where the overburden is at the time least, the outline of a quarry tends to be almost exactly a contour of the buried hill. Consequently, but a dwarfed impression of the irregularity of the rock-surface is presented in the sections, and the steepest slopes are away from the observer at right angles to the quarry-faces.

Nevertheless, considerable 'humps' and 'hollows' are visible wherever the margin fails to coincide exactly with the contour. (See Pl. XXI and Pl. XIX, fig. 1.) The 'hollows' are cross-sections of buried gullies leading down the old hillsides. The

[1] T. O. Bosworth, Trans. Leicester Lit. & Phil. Soc. vol. xii, pt. i (1908) pp. 28–34; Geol. Mag. dec. 5, vol. iv (1907) pp. 460–61, and *ibid.* vol. v (1908) pp. 353–57.

[2] W. Keay & M. Gimson, 'Relation of the Keuper Marls to the Charnian Rocks at Bardon Hill' Trans. Leicester Lit. & Phil. Soc. vol. xi, pt. i (1907) pp. 52–54.

[3] 'Charnwood Forest: a Buried Triassic Landscape' Geogr. Journn. vol. xxi (1903) p. 623.

'humps,' which commonly occur between hollows, are cross-sections of the spurs which separate the gullies.

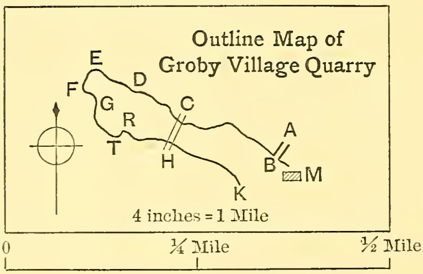
The shapes of the buried hills are various: some are sharp ridges, some roughly circular peaks, and some are more complicated. A number of them are shown by contoured maps in the more detailed paper which has been laid before the Leicester Literary & Philosophical Society, and is being published as mentioned above: of these, Pls. XXIII–XXVI are given here as examples. These maps have been prepared by making measurements, from time to time, around the quarries, of the levels wherever the Marl is exposed in contact with its rocky floor.

The rock-slopes found beneath the Marl are usually very steep and often precipitous. Sometimes slopes and cliffs are bared of Marl to depths of 20 or 30 feet at a time, preparatory to blasting operations (see Pl. XIX, fig. 2).

The character of the rock-surface beneath the Keuper depends partly on the nature of the rock.

The homogeneous granite and syenites usually present greatly worn surfaces. Thus at Mountsorrel occur the grooved and terraced surfaces described by Prof. Watts,[1] and surfaces somewhat similar are found on the Groby syenite; while the fine-grained homogeneous South Leicestershire syenites are fretted into more intricate shapes, and are pitted and somewhat polished. Quite a high polish was observed on the Narborough (misprinted 'Marlborough' on the map, Pl. XXII) syenite, which is mainly felsitic.

Fig. 1.



An interesting example was found at Croft Quarry beneath undisturbed Marl.[2] The rock is divided into great blocks by joint-cracks which have been widened out downwards. It is suggested that this widening, which is most marked on the south sides of the cracks, was caused by the action of dew. But, above a certain level, the surface of the rock is fretted and the joint-cracks widened upwards. This may have been caused by sand drift at a time when the rock was buried up to this conspicuous limit.

[1] Rep. Brit. Assoc. (Dover 1899) p. 747; Geol. Mag. dec. 4, vol. vi (1899) p. 508; 'The Geology of the Country near Leicester' (Expl. of Sheet 156) Mem. Geol. Surv. 1903, pl. i; Geogr. Journ. vol. xxi fig. 12, facing p. 632.

[2] See Trans. Leicester Lit. & Phil. Soc. vol. xii, pt. i (1908) fig. iii; or Geol. Mag. dec. 5, vol. v (1908) pl. xv, fig. 1.

The evidence of intense wearing must not be sought for inside a quarry, for the natural rock-slope is facing away from the observer; but it may be found outside the quarry, wherever the marl is being dug away from the rock preparatory to extension of the working.

In the cleaved rocks of Bardon and Shepshed, etc., and in the slates of the Brand Series the surfaces are more angular.

Cross-sections of gullies are common in most of the quarries. In the homogeneous granite and syenites they are often U-shaped, but in the cleaved rocks they are V-shaped or trough-shaped.

Many of the gullies have been determined by cleavage, fault-lines, or master-joints.[1]

Condition of the Buried Rocks.

Effect of Quaternary Climate.

The igneous rocks exposed to the present climate are intensely weathered. For instance, at Huncote, and also at Enderby, the South Leicestershire 'syenite' shows spheroidal weathering even to the bottom of the quarries; and the topmost 12 feet of rock has decayed *in situ* into loose grit, in which colonies of sand-martins make their nests. At Mountsorrel exposed granite was observed similarly decomposed (*op. supra cit.* fig. i).

Apparently, similar weathering occurred before or during the Glacial Period: for, in some cases, the lowest portion of the drift clays resting on the igneous rocks is composed largely of scraps of decayed rock.

Effect of Triassic Climate.

In marked contrast is the state of the same rocks beneath the Keuper Marl: for, right up to their very surface, these rocks are in sound condition. At Mountsorrel, Croft, Earl Shilton, and other localities, the best stone is that beneath the marl, and it appears equally good from the bottom of the quarry to the top.

For this reason many old surface-workings are abandoned, and the quarries are being extended and new ones opened to win the rock from beneath the Keuper Marl.

Similarly, the derived stones found in marl, whether worn or angular, are perfectly sound, and can be sent to the mills along with the best quarried stone.

Breccias, Stone Bands, etc.

In the immediate neighbourhood of the Charnian rocks, as seen in the quarries, the marls include a large quantity of stones, both small and great. It is remarkable that, in all cases, they are

[1] See Trans. Leicester Lit. & Phil. Soc. vol. xii, pt. i (1908) fig. v.

derived only from the rock immediately at hand. There is no commingling, such as occurs in gravels and beaches. On account of the number and distinctiveness of the different Charnian rocks, this statement is made with confidence.

The stones are utterly unlike beach or river-pebbles. Around the South Leicestershire syenites they are worn and fretted into irregular 'nugget' shapes, with surfaces pitted and smoothed (see Pl. XX, fig. 1). Even the very small chips are not sharp. At Mountsorrel the stones, though irregular, are less 'warty.'

At Groby, besides the worn stones, are some with very sharp points and edges, as though they had been splintered off by temperature changes (see Pl. XX, fig. 2). At Bardon, where the rocks are cleaved, the fragments are mainly angular. At Swithland and Woodhouse the chips of slate mostly have blunted edges. But common to all is their unweathered state.

The stones occur as :—

(1) Breccias and screes resting against the rock-slopes or in gullies.—The finest example of a scree was seen at Croft. It was from 10 to 12 feet thick, resting against a rock-face sloping at 35°, and exposed in section to a height of 35 feet, all beneath Keuper Marl.[1]

The scree consisted of fretted and subangular stones, and its upper surface was inclined at about 28°; while the lower beds of the succeeding marls were inclined at 15°.

One of the best examples of breccia in a gully is seen in the Bardon Hill Quarry, where a gully on the northern face is filled with angular stones to a depth of 20 feet.

(2) Breccia and grit-beds interbedded with the marls.—These are common in almost every quarry-section. Generally, the thickness is less than 3 feet; and the bed consists of fine grit, with a few larger stones which rarely exceed 2 feet in diameter.[2]

Even within the limits of a quarry-section, these beds often are seen to thin away, though more commonly they pass into normal grey 'skerry' bands.

(3) Stones in the marl.—In the marl similar large and small stones occur separately, and many beds contain small particles of grit in abundance.

At Mountsorrel, stones, sometimes as large as 5 feet across, are seen as much as 8 feet or more above the rock-floor, the marl beneath appearing depressed, as though the stone had fallen in.

Almost wherever the stones occur, whether in the marl or in aggregates, there is associated with them a small proportion of far-travelled sand consisting of quartz-grains, sometimes nearly spherical, together with magnetite, zircon, and rutile (these three

[1] See Trans. Leicester Lit. & Phil. Soc. vol. xii, pt. i (1908) fig. vii; or Geol. Mag. dec. 5, vol. v (1908) pl. xvi, fig. 4.

[2] See Geol. Mag. dec. 5, vol. v (1908) pl. xv, fig. 1.

possibly in part of local origin), and greatly-worn tourmaline, staurolite, and garnet, which are certainly from afar.

The garnet occurs in extraordinary amount in the basal breccias resting on or against the Charnian rocks. The grains, which are large and intensely worn, will be described later.

Inclination of the Strata.

Away from Charnwood the dip seldom exceeds 2°, and is generally towards the east or south-east. But around the Charnian hills the Keuper Marls are found inclined in all directions, sometimes to the extent of 20° or even 30° (see Pl. XXI). The inclination everywhere is in the direction of the rock-slope beneath, and consequently is radial around each buried hill. To this curious fact attention was called by me in 1907.[1]

It is now brought out clearly on the maps of the quarries (see, for example, Pls. XXIII–XXVI). The observed inclination of the Trias is marked with red arrows, and everywhere these arrows are at right angles to the contours of the buried rocks.

The inclination of the beds is much less than that of the slopes against which they lie: so that, when followed towards a buried hillock, many of the beds are seen to end off, abutting against the rock (see Pl. XXI, fig. 3). The same beds, dipping in the opposite direction, may generally be found on the other side of the hillock.

Likewise the beds in the gullies sag down, but at an angle less than the slope of the floor, so that the lower beds end off against the gully-sides (see Pl. XXI, fig. 2 & Pl. XIX, fig. 1). Thus, where the rock-surface is irregular, a single bed may show many undulations and abut against a number of different crags; but it is noteworthy that generally all its points of contact with the old rocks lie on a horizontal plane. Probably the strata lay across the larger valleys also in similar catenary manner.

The longest distance to which the marls can be continuously viewed in section leading away from the old rocks is 120 yards, revealed in the mineral line of the Lane's Hill Quarry, Stoney Stanton (see Pl. XXI, fig. 3). Here the rock-surface sloping 35° to 40° is seen to a depth of 40 feet, and the marls near it are inclined at 15°, diminishing to 10° at a distance of 110 yards.

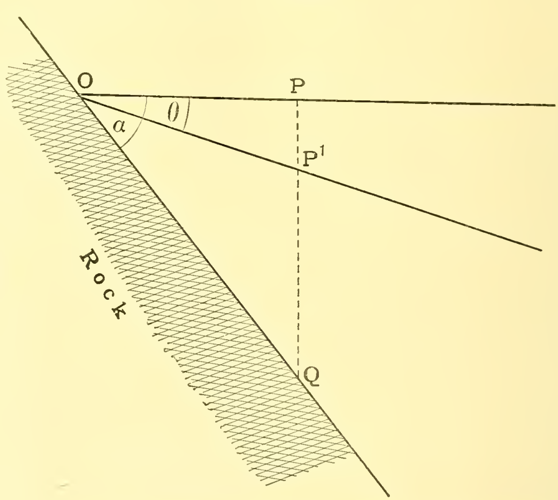
There is no evidence of any appreciable post-Triassic movement whatever in Charnwood. The inclination of the strata may be in part original. The inclined strata, however, in no way differ from those which are horizontal, and contain similar thin seams of dolomitic 'skerry' bearing salt-pseudomorphs and ripple-marks.

It is difficult to explain the extent of these thin shallow-water seams, unless they were laid down almost horizontally. It is, therefore, concluded that the inclination may be largely due to subsequent contraction of the marl under pressure and loss of moisture.

[1] Rep. Brit. Assoc. (Leicester) 1907, p. 505; see also Geol. Mag. dec. 5, vol. v (1908) p. 354.

For example, an inclination of 15° would be thus produced in strata resting against a 35° rock-slope, if the marl were to contract to three-quarters of its former thickness (see fig. 2, below).

Fig. 2.



Let O P be a bedding-plane and let the thickness of marl beneath it shrink from P Q to P^1 Q

$$\text{Then } R = \frac{P\,P^1}{P\,Q} = \frac{\tan\theta}{\tan a}$$

$$\therefore \tan\theta = R \tan a$$

The above-described inclination resulting from deposition upon rock-slopes is conveniently referred to as the 'tip' of the strata.

Petrography of the Upper Keuper.

In this section of the complete paper it is shown that a considerable variety both of red and of grey rocks occur, and certain types characterize certain horizons.

One important variety of grey rock described as quartzose dolomite may be mentioned here. This occurs chiefly in the upper half of the Keuper Marls, as thin seams often less than half an inch thick. It is a very hard compact rock of semicrystalline appearance, composed of fine angular sand, dolomite rhombs often accompanied by barytes, and some fine argillaceous matter.

The composite character of the grey bands is discussed, and it is pointed out that usually they contain one or more porous seams with grey marl above and below, some of which was originally red but has been bleached by water percolating along the porous seams. Often 'pendents of discoloration' extend down into the underlying red beds.

Gypsum.

The different kinds of gypsum are described, and it is shown that the original beds have been greatly affected by solution and redistribution and recrystallization of the mineral.

The Bedding.

Continuity and lenticularity both in red and in grey beds are described, as also the current-bedding in the sandstones and in certain types of marl.

The stratigraphy of the area is discussed, and it is shown that certain horizons have distinctive characteristics.

It is urged that stratigraphical sequence should be sought for in other areas, in the hope of proving more certain relations or differences between the red deposits in different parts of England.

Mineral Composition of the Rocks.

Detailed investigations on this subject were carried out.

By treatment with acids and by decantation processes, etc., it was found that the marls consist of:

(1) A large proportion of a certain aluminous mineral.
(2) A smaller proportion of fine quartz-sand.
(3) A considerable proportion of dolomite, in the form of minute rhombs.

They are indeed well described as 'marls.' Nearly all the rocks, both red and grey, contained these three constituents.

The carbonate.—Almost every rock, red or grey, was found to contain a considerable amount of carbonate.

Samples of red marl from near the top of the series contained 13 per cent. of carbon dioxide, corresponding to 28 per cent. of dolomite, and some contained considerably more.

The dolomite obtained from the fine marl, when viewed with a 1/12 oil-immersion lens, proved to be in the form of minute rhombs, the largest of which measured only about ·006 mm. across, and most of them were still smaller—say ·0015 mm.

The crystals appear well-shaped and sharp. Probably they were formed by precipitation during accumulation of the sediment.

In the grey rocks the proportion of dolomite is greater, and the rhombs are often considerably larger, as, for instance, in the quartzose-dolomite seams.

The argillaceous mineral. (The results of the observations on the argillaceous material are so unexpected that I feel some diffidence in putting them forward, and only do so because it may be long before I have an opportunity of carrying out the further confirmatory observations which seem desirable.)—This occurs in crystals so minute that they remain in suspension for more than ten minutes, the materials settling before that time being aggregations of these crystals. When dried, this sediment is an exceedingly fine powder which, if it be handled, clogs up the pores of the skin. If water be added it forms a plastic paste.

The mineral is in the form of minute laths, some of which are curved. Straight specimens are clearly defined, have rectilinear edges, and give a low grey interference-colour, with straight extinction. Some of the laths which are clearly single crystals measure ·004 × ·0008 mm., but the majority are much smaller.

The refractive index is so near that of Canada balsam that, except between crossed nicols, the mineral can hardly be discerned. Mounted in water it is more visible. The laths are best seen through a selenite-plate and crossed nicols, in which case they are rendered conspicuous by their high double refraction. The shorter axis shows the greater elasticity, and so great is the difference that, despite their extreme thinness, the laths change colour from blue to orange on rotation.

The bulk of the material, however, is in the form of irregular grains or laminæ, with fibrous texture, which readily break up into the laths above described.

The density was determined only after much difficulty; but at length a specific-gravity bottle method was devised, which yielded consistent results about 2·48. The mineral is somewhat hygroscopic, and absorbs water during weighing. A correction on this account reduced the value to somewhere near 2·40.

Result of chemical analysis (kindly carried out for me by Mr. L. V. Wright, M.A., F.I.C.) of the finest detrital residue:—

Water	4·98
Silica	58·99
Alumina	17·02
Ferric oxide	7·07
Lime	0·98
Magnesia	2·73
Potash	6·64
Soda	1·07
Total	99·48

This corresponds fairly well with a composition represented by the formula

$$2(H:K:Na)_2\,SiO_3\,Al_2\,(SiO_3)_3\,(Fe:Mg:Ca)\,SiO_3.$$

Thus the mineral appears to have the following properties:—

Chemical composition	Silicate of aluminium, potassium, iron, and magnesium.
Specific gravity	About 2·40.
Refractive index	About equal to that of Canada balsam.
Double refraction	Very high; elasticity greater along the shorter axis.
Shape	Lath-like.
Extinction	Straight.

The chemical composition indicates that the Keuper Marls accumulated under conditions unfavourable to the abstraction of alkalies from silicates, a process which under present conditions probably takes place readily enough. To-day these red marls form rich wheat land.

The fine quartz-sand comprises less than 10 per cent. of the normal marl. The grains are very angular and ill-assorted. The majority measure less than ·05 mm. across; but there are plenty of larger grains up to, say, ·2 mm.

Lower down in the Keuper the proportion of quartz in the marls is often much greater. In the Tea-Green Marl the amount of quartz is very small.

The same heavy minerals occur in the sand present in the marl as in the Upper Keuper Sandstones.

Quite unweathered fragments of plagioclase are fairly plentiful in the impervious bands of marl and quartzose dolomite, etc.

Heavy Minerals in the Upper Keuper.

The same heavy minerals are present in almost every rock, and indicate a distant origin for the bulk of the sediment.

The grains are intensely worn, and exactly resemble heavy mineral grains extracted from æolian sands for comparison. Their rounding and smoothing is probably far more significant than the occasional seams of spherical quartz-grains.

Comparison is also made with a series of heavy mineral grains taken from Carboniferous sand. The contrast is remarkable.

Garnets.—This is one of the most abundant minerals, and must have come from afar.

The garnets from a number of different deposits are compared, and it is shown that the garnets in deposits such as the Carboniferous have angular re-entrant shapes due to development of the (1, 1, 1) cleavage; but the garnets from the Trias and from recent desert sand have an entirely different appearance, being smooth and round.

The surface exhibits a very fine granulation which, under a quarter-inch objective, is seen to be due to pyramidal depressions bounded by the (1, 1, 1) cleavage-plane.

The amount of garnet in the basal beds resting upon the South Leicestershire syenites is remarkably great.

Zircon.—This mineral is very abundant, and the majority of grains are small, due to smallness of the original crystals.

There are intensely worn zircons from afar and a variable proportion of unworn zircons derived locally from the Charnian rocks, especially around the Mountsorrel Granite, which contains a large amount.

Staurolite.—The proportion of this mineral varies greatly, and sometimes it is very abundant.

On account of cleavage, the grains seem hardly able to resist fraying. Even spherical grains bristle with small sharp protuberances. In some sands, however, the rounding is so intense that the grains are almost spherical, with minute pits like those described on the garnets.

Rutile occurs chiefly as smooth round grains or as worn prisms; but some angular fragments are derived from local rocks, as, for example, from the South Leicestershire syenites. The colour varies from deep to pale amber.

Geniculate twins are not uncommon. Occasionally in the marls occur slender golden-yellow crystals of almost perfect form.

Tourmaline occurs abundantly as rounded grains and worn prisms. Green, blue, and mauve grains are fairly plentiful.

Magnetite is abundant, both as rounded grains and as angular fragments locally derived.

Anatase is present in a few cases, notably close to the igneous inlier of Sapcote and Stoney Stanton.

It occurs in well-formed plates parallel to (001), bounded by narrow (100) and (001) faces with bevelled edges. The largest plate measured ·08 mm. The colour is pale straw-brown.

Barytes is fairly common in the seams of quartzose dolomite, probably as a crystalline precipitated cement.

[In the complete paper a table is given, showing the relative distribution of the minerals.]

The Ripple-Marks and Salt-Pseudomorphs.

These were found on almost every grey bed, when suitably weathered. The quartzose-dolomite seams are almost invariably rippled, and bear salt-pseudomorphs in swarms upon the crests. Probably the ripples were formed in shallow desiccating pools, and were controlled by wind.

Data as to the trend of the ripples are tabulated, and it appears that, although there are ripples trending in almost every direction, the majority trend north-westwards, and are steepest on the north-east side, indicating a prevalent south-westerly wind.

Summary of Facts established.

(1) The Charnian Hills were covered up under conditions which precluded rock-decay.

(2) The rock-surface was affected by wind-erosion.

(3) Screes, breccias, stones, and grit were derived only from the rock immediately at hand.

(4) The stones may be angular or fretted, but they never resemble beach or river-pebbles. (Neither is there any evidence of littoral drift.)

(5) Around each buried hill the beds dip radially away, and they lie in catenary fashion across the valleys.

Nevertheless, the beds which are inclined do not differ from those which are horizontal, and the contacts of each one with the Charnian rocks lie on a horizontal plane.

(6) The red marl consists of an argillaceous mineral, fine sand, and minute rhombs of dolomite.

(7) The argillaceous mineral is a silicate of aluminium, potassium, iron, and magnesium. It occurs as minute laths, with straight extinction and having greater elasticity along the shorter axis.

μ	Refractive index of Canada balsam.
$\mu\mu$	Very high.
Specific gravity ...	2·40.

(8) The grey bands are more porous than the red, and above and below them the red marl is often bleached.

(9) The grey bands consist of seams of several different rocks, often including one or more current-bedded seams containing sand coarser than that in the marl, and also one or more seams of quartzose dolomite rippled and bearing salt-pseudomorphs.

(10) The ripples mainly trend north-westwards, and are steepest on the north-east side.

(11) Every sediment contains garnet, zircon, tourmaline, staurolite, rutile, and magnetite. Of these the garnet, tourmaline, and staurolite are probably derived entirely from a distant source.

(12) The heavy minerals are intensely worn, resembling only those of desert sands. In some seams of sandstone the quartz-grains exhibit æolian rounding.

Conclusions.

Finally, the mode of deposition of the sediment is discussed, and an interpretation of the geology is offered.

It is suggested that the Upper Keuper accumulated in an inland basin wherein evaporation greatly exceeded precipitation. The basin was always partly dry and partly occupied by pools of standing water.

Prevalent south-westerly winds were continually precipitating moisture on the hills south and west of the basin, and from these hills streams of fresh water were constantly pouring down into the desert, often uniting into extensive sheets, which would sweep far and wide over the desert, and frequently be completely desiccated ere they reached any pre-existing pool.

The grey bands of far-travelled coarser sediment were formed by these water-flows, and the quartzose-dolomite seams mark the desiccation which ensued.

The red marls were laid down in the standing waters which were comparatively deep, although the repeated alternations of red and grey beds imply that the distribution of these deeps must have been continually changing, the alteration being brought about partly by silting up and partly by evaporation.

EXPLANATION OF PLATES XIX–XXVI.

Plate XIX.

Fig. 1. Croft Quarry, showing a view of the localities C, D, A, B, marked on the map, Pl. XXIII.
2. Steep rock-slope found beneath Keuper Marl at the north side of Clint Hill Quarry, Stoney Stanton.

Plate XX.

Fig. 1. Fretted 'nuggets' of 'syenite' found in Keuper Marl at Croft Quarry.
2. Unweathered angular rock-fragment, 12 inches long, found in Keuper Marl 5 feet above rock, at Sheet Hedges Wood Quarry, Groby, in 1906.

Plate XXI.

Fig. 1. Complete section around Groby Village Quarry, lettered to correspond with fig. 1 (p. 282) and Pl. XXIII.
2. Section in Sheet Hedges Wood Quarry, Groby, showing catenary bedding in a gully.
3. Section in the mineral railway-line leading out of Lanes Hill Quarry, Stoney Stanton, showing Keuper Marls tipping away from a buried rock-slope.

Plate XXII.

General geological map of the country around Charnwood, on the scale of 2 miles to the inch (or 1:126,720), showing the relation of the Trias to the Charnian rocks, and also indicating the direction of the winds which controlled the water-ripples.

Plate XXIII.

Map of quarry in Groby Village, showing the contours of the buried hill. (Scale, 1:2500.)

Plate XXIV.

Map of Croft Quarry, showing the contours of the buried rocks. (Scale, 1:2500.)

Plate XXV.

Map of Bardon Hill Quarries, showing the contours of the buried hills. (Scale, 1:2500.)

Plate XXVI.

Map of Sheet Hedges Wood Quarry, Groby, showing the contours of the buried hills. (Scale, 1:2500.)

Discussion.

Mr. Bernard Smith drew attention to the conditions obtaining during Keuper times in Nottinghamshire, where the recent geological survey had just been brought to a close. This area lay to the east of high land, composed of uplifted Carboniferous rocks, upon which dry continental conditions of climate prevailed. During Keuper times the east and south of Nottinghamshire appears to have been the site of a very shallow (but widespread) inland sea or lake, subject to fluctuation in breadth and depth during wet and dry seasons. As a result of investigation, more particularly upon the 'skerries,' he concluded that the marls were laid down almost entirely in water; but that dry land may have been from time to time exposed, owing to fluctuations in water-level. Direct evidence of this was difficult to find, because the Keuper escarpment, since its initiation, had been retreating eastwards; but shore-line phenomena occurred in the Waterstones near Nottingham.

The 'skerries' were in many respects similar to those described by the Author; but, as the speaker recently pointed out, sometimes contained as much as 50 per cent. of dolomite. An interesting point was the occurrence of æolian sand, in a 'skerry' exposed 20 miles east of the nearest Carboniferous outcrop. In upward succession it was common to find a 'skerry'—with salt-pseudomorphs upon its under surface—followed by sandy and dolomitic shales, which pass upwards into the finer marls. He suggested that the dolomite rhombs, precipitated from solution, were swept along with river-borne detritus and deposited as ripple-marked and current-bedded sandstone, similarly to the sandstones described by Sorby. The finer detritus settled later, but a large portion of the marls might consist of wind-borne dust, blown off the land. The term 'prevalent winds' seemed unfortunate, since monsoon conditions may have obtained, and the winds, during a large portion of the year, might have been blowing inland.

Prof. Boyd Dawkins complimented the Author on the detailed and interesting nature of his communication, but was not at all satisfied that the desert conditions of the Trias were those which are usually associated with the idea of a desert. In all his experience he had found it difficult to get any microscopic slide of sandstone which did not contain rounded grains. The marls, etc. described by the Author as being ripple-marked were undoubtedly deposited under water, as was indeed the main mass of the Trias. The existence of worm-tracks therein also told against its desertic origin *sensu stricto*. The occurrence of dreikanters proved no more than did the presence of enormous numbers of dreikanters in recent deposits in New Zealand. The speaker finally referred to the minute structure and varied mineral constituents of the marls, and said that he did not for a moment deny the presence of a large amount of wind-borne sand in the Trias.

Mr. H. H. Thomas, in adding his congratulations to those of previous speakers, asked permission to call attention to a somewhat unimportant point. He cautioned the Author not to pay too much attention to the spherical form of garnets—for the speaker had met with heavy residues, from the Old Red Sandstone and other deposits in South Wales, consisting largely of minute idiomorphic garnets which the least attrition would render spherical. It had been suggested by a previous speaker that certain minerals, such as rutile, tourmaline, etc. had been derived from older deposits. That was possible for these minerals, but not so for a mineral like staurolite, which the speaker had never detected in any pre-Triassic sediment.

Dr. C. A. Matley, in joining in congratulations to the Author, stated that his own experience of the Keuper Marls was mainly confined to Warwickshire, where no masses of older formations projected through them as in Leicestershire. In the former county, their widespread extent, combined with their fairly-constant thickness and with the regularity of the intercalated sandstones, indicated regularity of deposition; while the presence of marine mollusca at the base of the Upper Keuper Sandstone of Warwickshire pointed to at least one invasion of the sea in that area. He had not found worm-tracks in this formation. He had found dreikanters as surface-specimens in the Marl country near Birmingham, and those exhibited, he thought, might well be of Drift, and not of Triassic age.

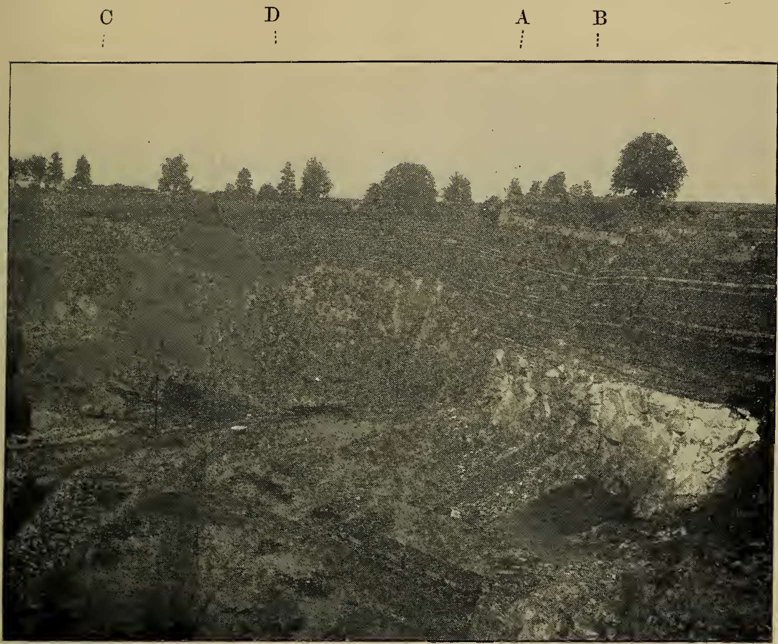
Mr. E. E. L. DIXON referred to a number of dreikanters on exhibition which he had picked up on the surface near Lichfield, where they appeared to be numerous. He had thought that they might have been derived from adjacent Triassic outcrops, either directly or by way of Glacial Drift; but, unless such derivation were satisfactorily demonstrated, he was prepared, after hearing the previous speaker's remarks, to accept the view that they were chiselled during a dry epoch of the Pleistocene.

Prof. W. J. SOLLAS remarked that this paper would lead to more definite ideas of what was intended when speaking of the Upper Keuper as a desert formation, especially as to what parts of it were subaërial, and what subaqueous, deposits. Ripple-marks were equally well-developed in each kind of deposit. The rounding of sand-grains was a subject that still required investigation; such rounding was far from universal in sandy deserts. In addition to the rounded garnets already mentioned, attention might be called to the rounded blebs of quartz which occurred in some of the quartz-felsites of the Midlands; on the other hand, the rounded grains of other minerals—such as staurolite, tourmaline, and rutile, furnished unimpeachable testimony to æolian action. As to the prevalence of desert conditions during the Upper Trias in England, the evidence was cumulative and, to his mind, convincing.

The AUTHOR, thanking the Fellows for their attention to his paper, said that he had apparently been misunderstood on several points. In this paper not one single seam in the Upper Keuper had been attributed to æolian deposition. Both red and grey bands were deposited under water—the former in lakes of standing water, and the latter by shallow inflowing waters from the surrounding hills. Nevertheless, some of the materials evidently had undergone æolian corrasion ere finally coming to rest. In the case of the garnets, it was not so much their spherical shape—indeed many were very irregular—, but the character of their surfaces to which attention had been called.

Every grey band bore witness to the existence of dry land in the desert basin. These thin seams of coarse current-bedded sediment, brought from a distant source, could not have been extended into the centre of the area at a time when it was occupied by standing water. The coarse sand in a grey band was commonly followed by a thin seam of quartzose dolomite, rippled and bearing salt-pseudomorphs. Such seams would be formed when the newly-arrived water-spread dried up. Many grey bands contained several alternations of such seams.

In his paper it was never suggested that any ripples had been formed dry, but that they were produced in these shallow water-spreads during their desiccation under the control of wind.

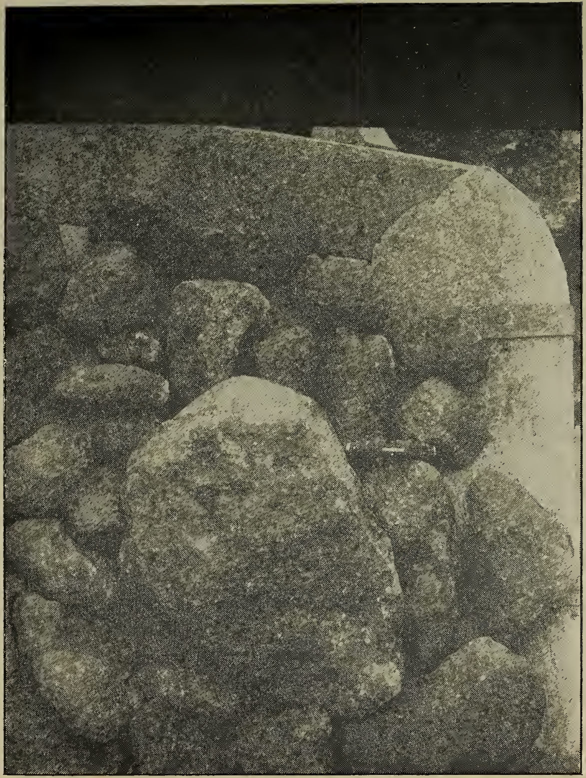


T. O. B. photo.

Fig. 1.—*Croft Quarry, showing a view of the localities* C, D, B, A, *marked on the plan, Pl. XXIV.*

T. O. B. photo.

Fig. 2.—*Steep rock-slope found beneath Keuper Marl at the north side of Clint Hill Quarry, Stoney Stanton.*



T. O. B. photo.

Fig. 1.—*Fretted 'nuggets' of 'syenite' found in Keuper Marl at Croft Quarry.*

T. O. B. photo.

Fig. 2.—*Unweathered angular rock-fragment, 12 inches long, found in marl 5 feet above rock, at Sheet Hedges Wood Quarry, Groby, in 1906.*

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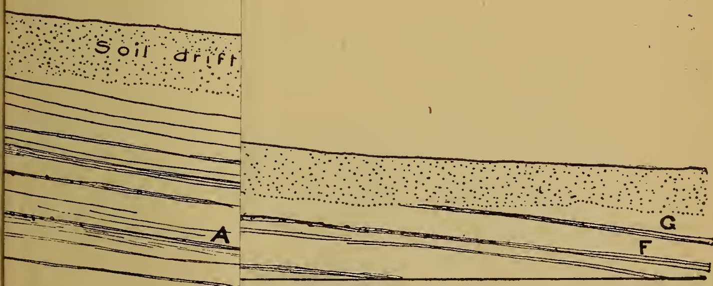

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d ɔck-surface is not accurate; it is largely concealed
b

Fig. 1.—Section seen inside Groby Village Quarry, on walking the whole way round the Quarry.

[The letters A, B, C, etc., correspond with the lettering on the small sketch-map of the Quarry, fig. 1, p. 282].

Fig. 2.—Section at Sheet Hedges Wood Quarry, Groby, showing catenary bedding in a gully.

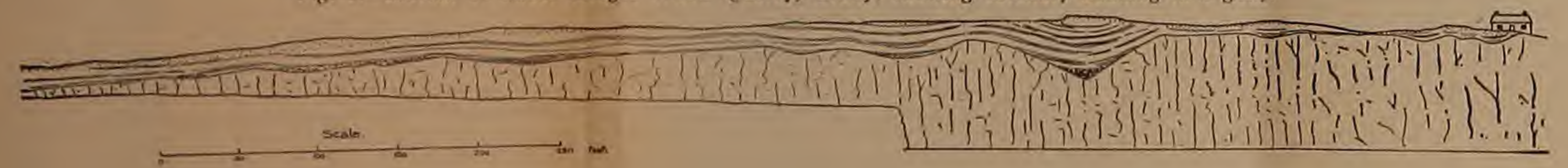
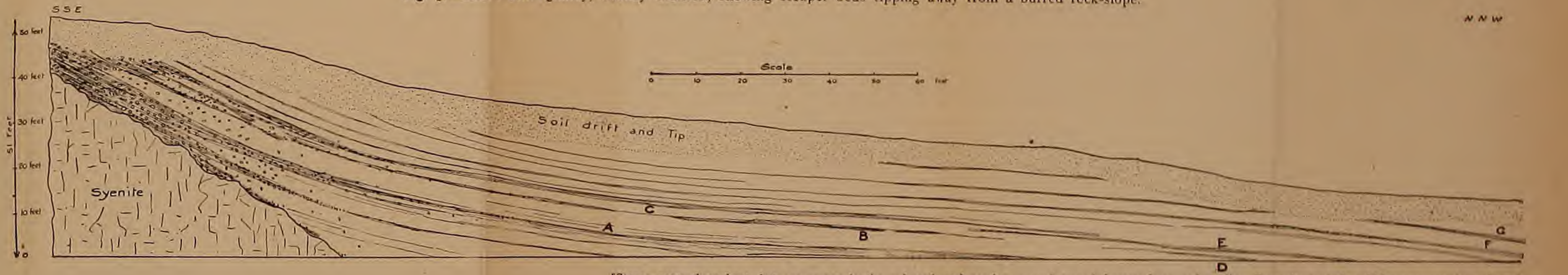
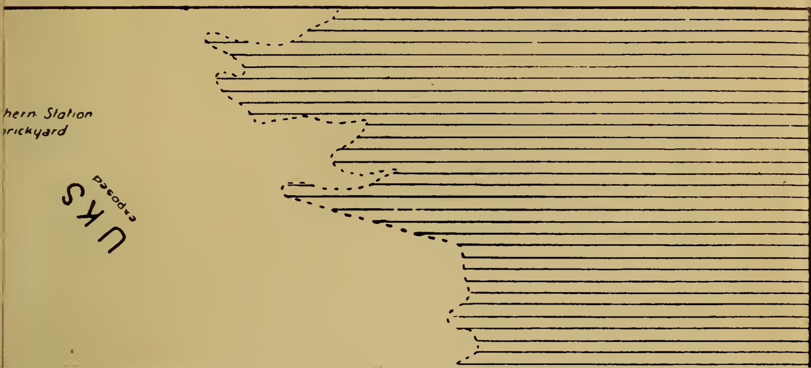


Fig. 3.—Lane's Hill Quarry, Stoney Stanton, showing Keuper beds tipping away from a buried rock-slope.



[Stones occur throughout, but are scarcer in the red marl, and passing away from rock become fewer and smaller. Some about 2 inches thick occur near the end of the section. Hard sandstone forms the core of many grey beds, notably A, B, C, D, E, and F, but the sandstone dies out in every case towards the rock. It contains stones, but does not reach the breccias. The apparent flattening of the dip towards the middle of the section is probably because the section is not straight. The true dip is away from the observer along a direction making, say, 30° with the direction of this section. The shape of the rock-surface is not accurate; it is largely concealed by talus].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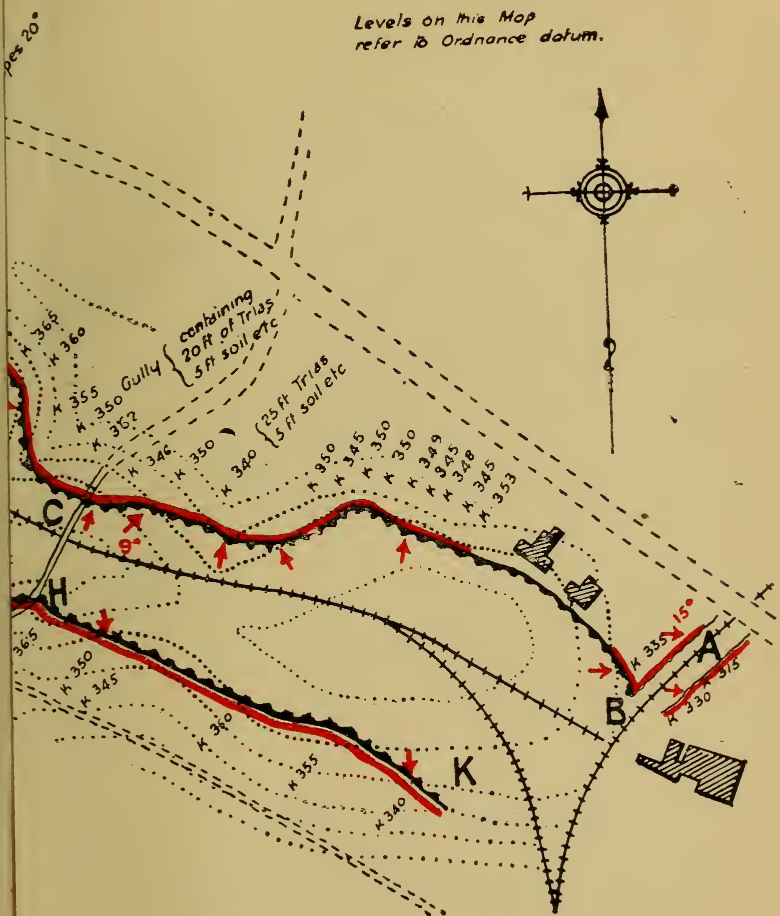
GENERAL GEOLOGICAL MAP OF THE COUNTRY AROUND CHARNWOOD.
(The directions of the winds which controlled the water-ripples are indicated by long red arrows).


Levels on this Map refer to Ordnance datum.
Gully
containing 20 ft of Trias 5 ft soil etc
25 ft Trias 5 ft soil etc
C
H
K
A
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9°
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365
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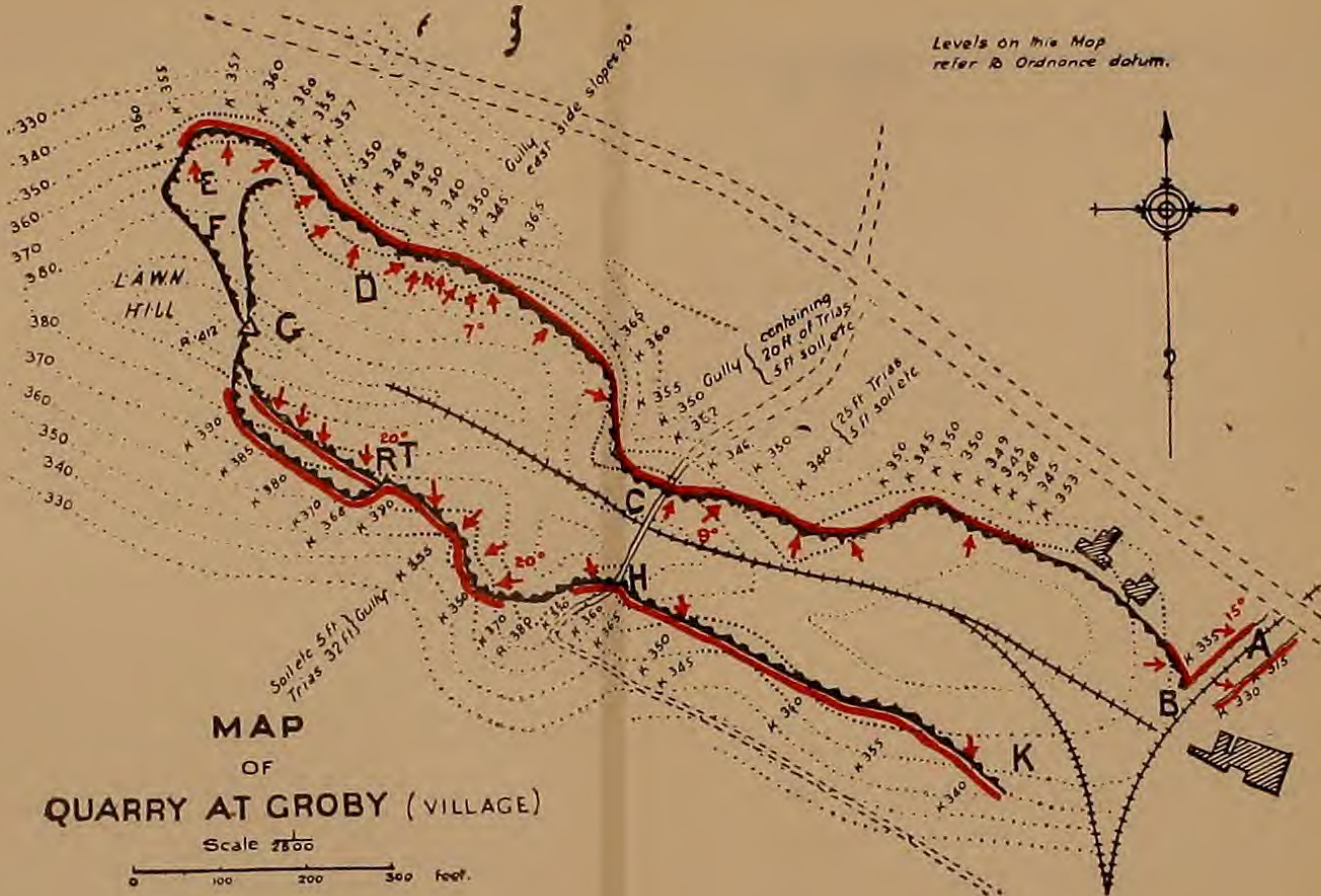

MAP
OF
QUARRY AT GROBY (VILLAGE)

MAP
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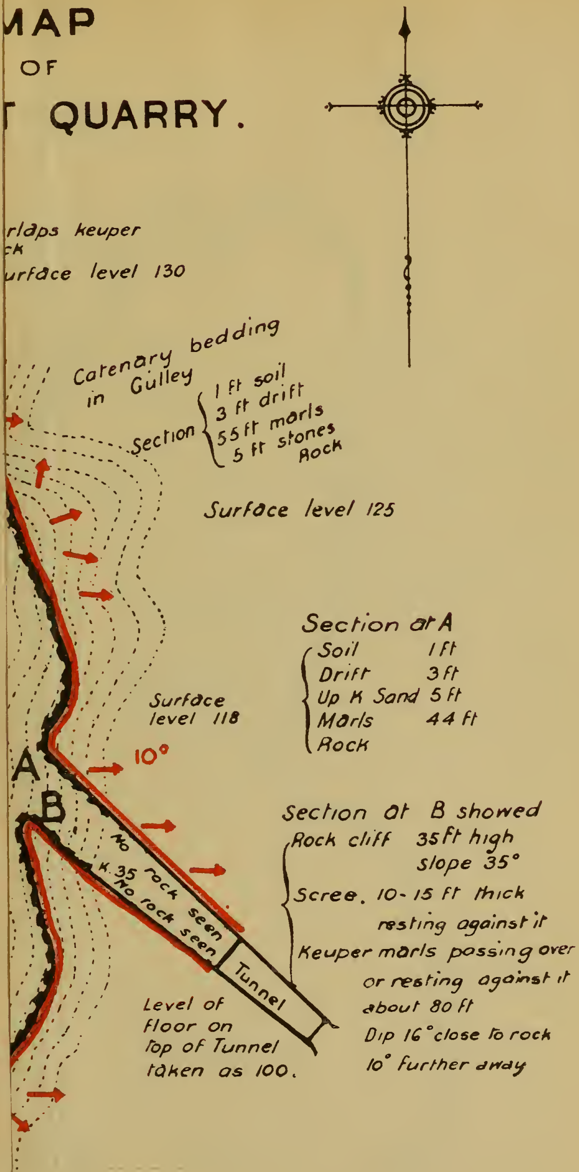
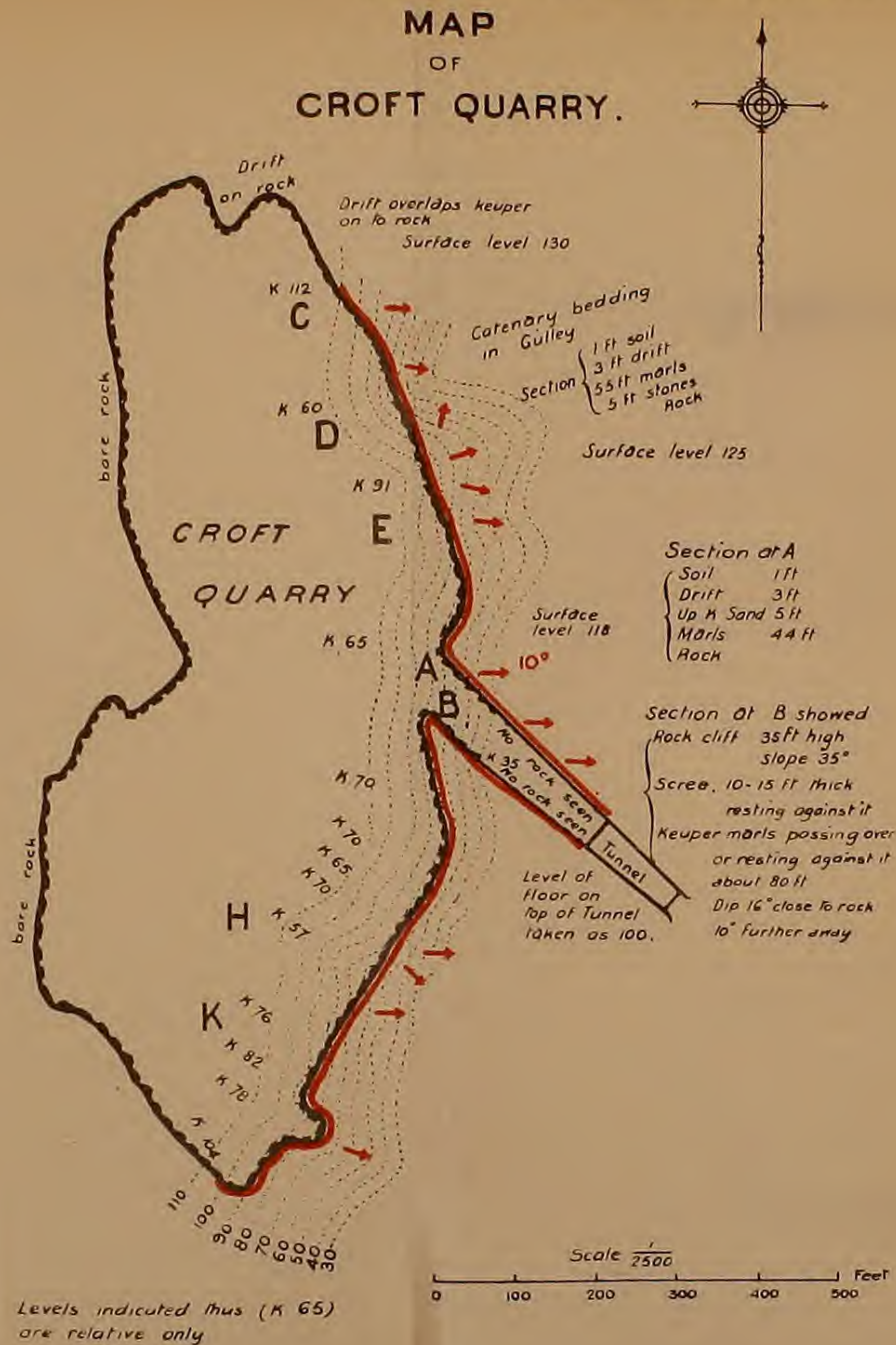
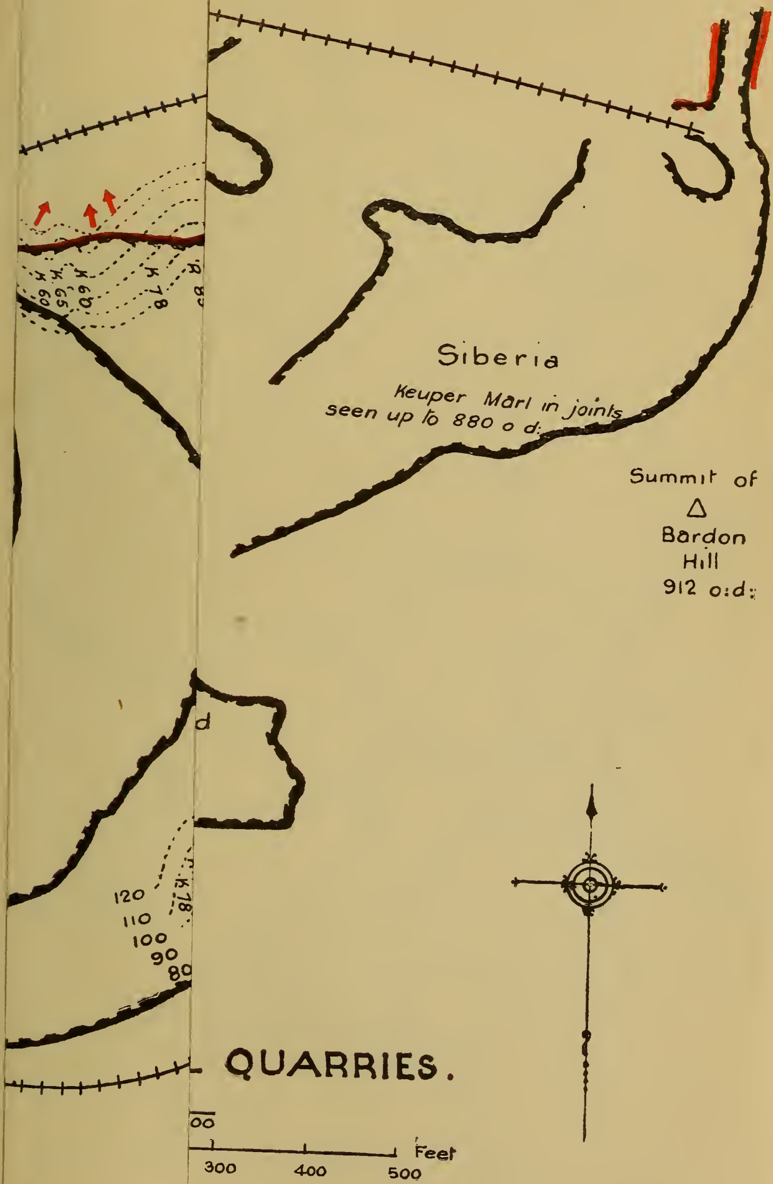


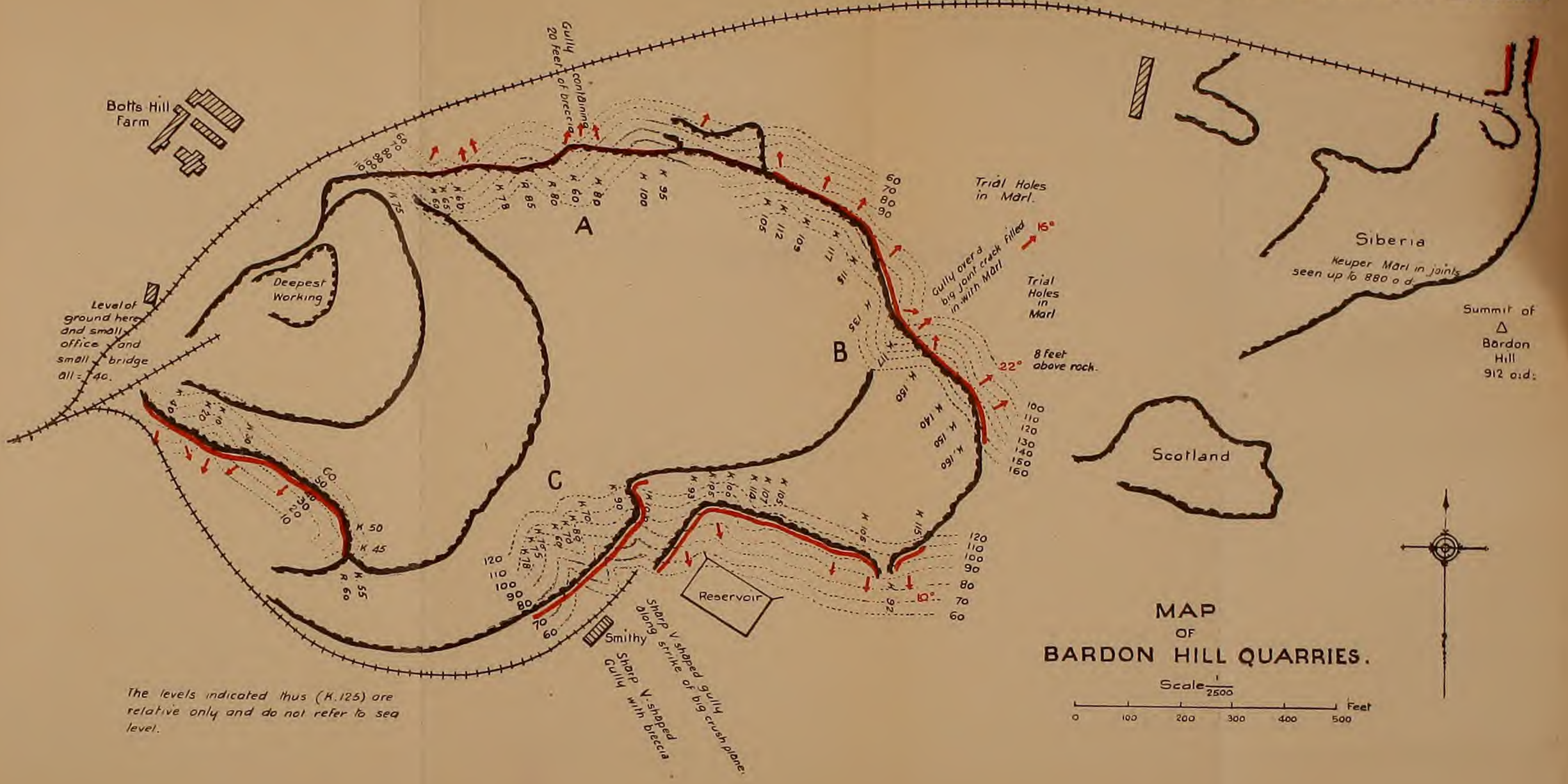
NOTE.—Thick black lines indicate quarry margins. When a red line runs parallel with a black line, Keuper Marl overlies the rock. The small numerals around the margins express the heights above sea-level (or other datum) of the rock-floor upon which the Trias rests. The letter K placed in front of a numeral indicates that Trias rests upon the rock; the letter R similarly placed indicates that there is no Trias, and that the level taken is the top of the rock at the present time. The dotted lines are contours of the buried rock, inferred from the measurements and from other observations; the contours are for 10-foot intervals. The red arrows indicate the dip of the Triassic deposits, and the red numerals show the angle of the dip.




Siberia
Keuper Marl in joints seen up to 880 o d:
Summit of
Bardon
Hill
912 o:d:
K 60
K 65
K 60
K 78
R 83
d
120
110
100
90
80
K 78
00
300
400
500
Feet

QUARRIES.

NOTE.—Thick black lines indicate quarry margins. When a red line runs parallel with a black line, Keuper Marl overlies the rock. The small numerals around the margins express the heights above sea-level (or other datum) of the rock-floor upon which the Trias rests. The letter K placed in front of a numeral indicates that Trias rests upon the rock; the letter R similarly placed indicates that there is no Trias, and that the level taken is the top of the rock at the present time. The dotted lines are contours of the buried rock, inferred from the measurements and from other observations; the contours are for 10-foot intervals. The red arrows indicate the dip of the Triassic deposits, and the red numerals show the angle of the dip.



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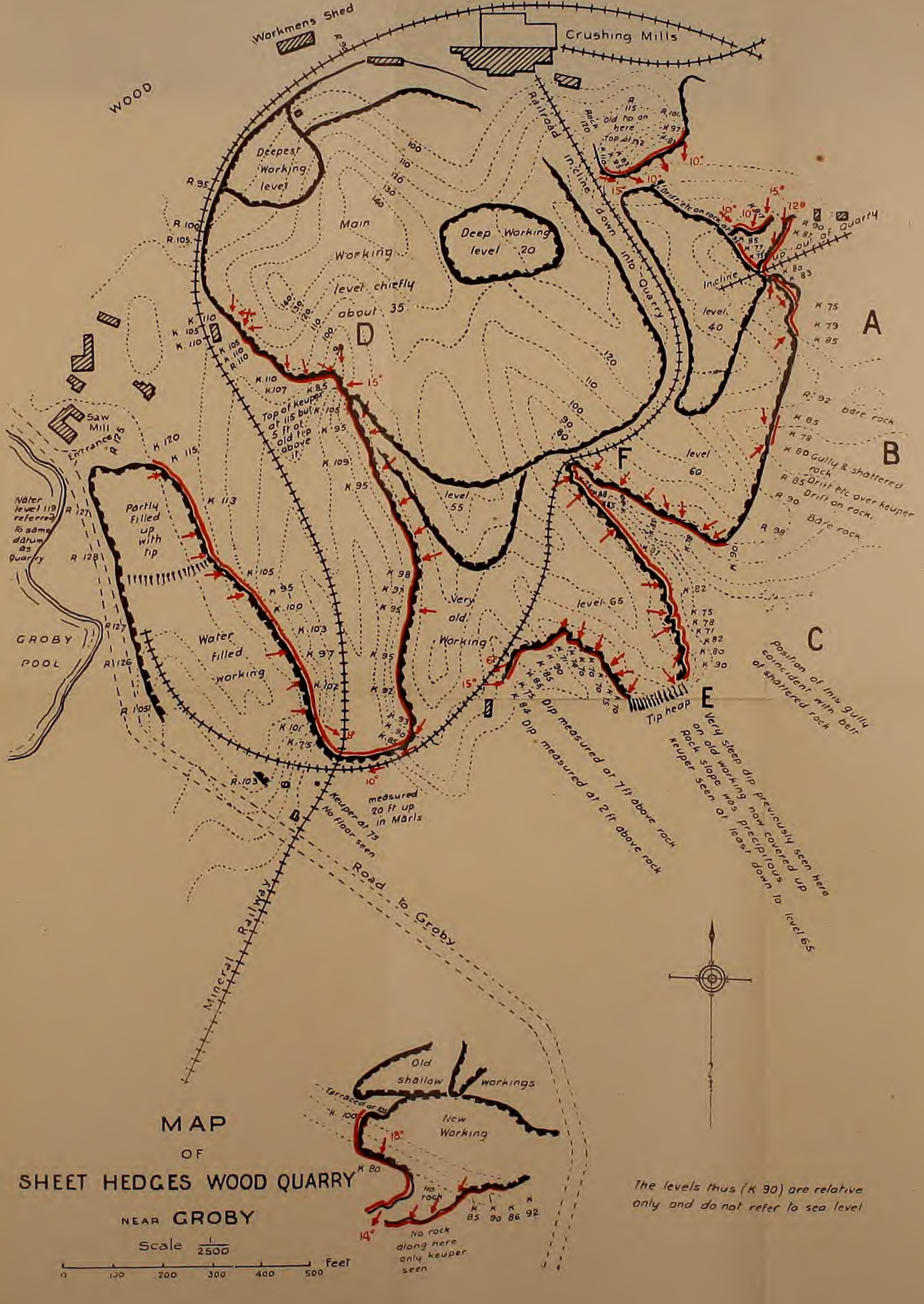

MAP OF SHEET HEDGES WOOD QUARRY NEAR GROBY

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Vol. LXVIII. SEPTEMBER 12th, 1912. **No. 271.**
PART 3.

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

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Session 1912–1913.

1912.	
Wednesday, November	6*—20*
„ December	4 —18*
1913.	
Wednesday, January	8*—22*
„ February (*Anniversary*, Friday, Feb. 21st)	5*—26*
„ March	5 —19*
„ April	9 —23*
„ May	7 —28*
„ June	11 —25*

[*Business will commence at Eight o'Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

15. *Some* New Lower Carboniferous Gasteropoda. By Jane Longstaff (*née* Donald), F.L.S. (Communicated by Dr. G. B. Longstaff, M.A., F.G.S. Read March 13th, 1912.)

[Plates XXVII–XXX.]

Eight species are here described, all characterized by the presence of a band on the whorls: in seven it is probably the result of a sinus or slit in the outer lip, but in the eighth it is merely ornamental, as the lines of growth pass over it. These species are referable to six genera or subgenera, five of which are new, namely *Tropidostropha, Trechmannia, Foordella, Tmetonema*, and *Microptychis*; the other genus, *Pithodea* De Kon., has not been previously recorded from the British Isles.

Family ? Raphistomidæ Ulrich.

Tropidostropha, gen. nov.

Diagnosis.—Shell conical, of medium height. Whorls with a prominent, flange-like keel a little above the middle of the body-whorl, and considerably below the middle of the penultimate whorl; convex, except immediately above and below the keel, where they are concave. Test thin, composed of two layers. Outline of the keel slightly convex below, and slightly concave above. Under the keel is an inner, flat or somewhat concave band, covered with arched striæ, and formed of the inner shell-layer. Lines of growth strong and irregular: above they slope backwards with moderate obliquity to the edge of the keel, over which they pass without break; while below they at first curve sharply forwards, and then run almost vertically into the umbilicus. Aperture subquadrate. Umbilicus open.

Genotype.—*Pleurotomaria griffithi* M'Coy.

Remarks and resemblances.—This genus is suggested for two species, the characteristics of which do not exactly agree with any genus or subgenus known to me. These are *Pleurotomaria griffithi* M'Coy and *Tropidostropha punctata*, sp. nov. Both are remarkable for the structure of the spiral band. Owing to imperfect preservation, this is rarely well shown: the outer flange-like keel being often so worn and broken, that merely a blunt or rectangular ridge is left. Three specimens of *Tr. griffithi*, however, exhibit portions of the flange resting on an inner blunt keel, and one of these in the National Museum of Ireland, Dublin, is sufficiently well preserved to show the structure fairly well. Near the aperture part of the sharp flange is intact, and it is seen to rest upon a band which is almost flat, limited on each side by a thread, and covered with closely packed crescents; this rectangular band alone remains on the earlier whorls. All the specimens of *Tr. punctata* that I have seen have only the flange preserved; and, when this is broken, the interior is crystalline and no further structure is perceptible. In one of these the centre is darker, and suggests the primary existence of a cavity which has been gradually filled up. This fact, however, does not preclude the possibility of a previously existing additional structure: it shows that, if there had been such structure, it was either destroyed before the original substance of the shell was replaced, or else that the shell was not fossilized in such a manner as to preserve the inner parts.

The form of the band bears a strong resemblance to some of the Silurian shells referred by Lindström to his *Alatæ*[1] division of *Pleurotomaria*. This likeness is more especially remarkable in *Pl. cirrhosa* Lindstr.,[2] which also comes near in size, in the direction of the lines of growth, and in the shape of the section of the whorls. It must be noted, however, that Prof. Koken separates *Pl. cirrhosa*[3] from the rest of the *Alatæ*, because its whorls are quadrangular instead of circular in section. *Tropidostropha* is distinguished by having the keel less produced, in its being situated higher, and never adhering to the succeeding whorl. The members of this genus also resemble *Pl. limata* Lindstr.,[4] which belongs to his *Incisæ* group; in it, however, the margins of the band, though greatly produced, do not unite, but always leave a furrow: moreover, the lunules are very peculiar and distinctive in shape. The keel is somewhat like that of *Trochus lundgreni* Lindstr.,[5] and also of some of the genera allied to *Trochus* described by Prof. Perner. The genus, however, differs from all of these, as well as from *Palæotrochus* Hall[6] and *Eotrochus* Whitfield,[7] in the form of the aperture, which does not recede below, in the higher position of the keel, in its not adhering to the anterior whorl, and in the base being more produced.

When the outer sharp keel is broken off, it resembles some species of *Mourlonia*,[8] to which genus L. G. de Koninck has referred it; but it is distinguished by the structure of the keel, as well as by the lines of growth being nearly vertical below.

Another interesting feature is observable in the two species here described as belonging to this genus, namely the presence of numerous pittings scattered over the surface; they occur in both the outer and inner shell-layers, and their impression is left on the internal mould; they vary in size, being sometimes small and in

[1] 'Silurian Gastropoda & Pteropoda of Gotland' Kongl. Svensk. Vetensk.-Akad. Handl. n. s. vol. xix (1884) no. 6, p. 115.

[2] *Ibid.* p. 121 & pl. xi, figs. 27–29, pl. xii, figs. 1–3.

[3] 'Ueber die Entwickelung der Gastropoden vom Cambrium bis zur Trias' Neues Jahrb. Beilage-Band vi (1889) p. 438.

[4] K. Svensk. Vetensk.-Akad. Handl. n. s. vol. xix (1884) No. 6, p. 114 & pl. x, figs. 2–17.

[5] *Ibid.* p. 149 & pl. xiv, figs. 46–53.

[6] 'Palæontology of New York' vol. v, pt. ii (1879) p. 133.

[7] Bull. Amer. Mus. Nat. Hist. vol. i (1881–86) pp. 77–78.

[8] 'Faune du Calcaire Carbonifère de la Belgique' pt. iv, Ann. Mus. Roy. Hist. Nat. Belg. vol. viii (1883) p. 75.

clusters, at other times larger and at some distance apart; they are circular, oval, or elongated. It is difficult to determine their nature, for it is a question whether they constitute part of the structure of the test; or whether they are the scars left by the loss of hairs from the epidermis; or whether, again, they were formed by some small boring parasite such as has been observed by Lindström and Perner. The latter states that small perforations are especially frequent in shells found in 'Bande' E–*e*2 (Sil.), and he thinks that they are probably due to parasitic organisms, perhaps boring-sponges. When describing these in *Umbotrochus aspersus* (Barr.),[1] and giving this view with regard to them, he states that Barrande, on the contrary, considered them part of the ornamentation of the test. The figures do not clearly show their exact character; but certainly the impression given is that they break through the test of the shell, and hence must have originated later. I showed the British specimens to Dr. J. G. Hinde, Mr. Gude, and Mr. Edgar Smith, all of whom agree with me in thinking that these pittings are due to irregularities in the growth of the shell-laminæ. Mr. Gude says that they are not regular enough in their disposition to have been caused by deciduous hairs, also hairs of this character do not occur on marine shells. I have examined a number of recent marine shells, *Pleurotomaria adansoniana* Crosse & Fischer and *Pl. beyrichi* Hilgendorf among them, and none of them exhibit a similar structure. Dr. Hinde is of opinion that the pittings are not such as could have been made by boring sponges. As evidence in favour of their having been formed during the growth of the shell, it may be mentioned that they do not break the lines of growth, but either form depressions along these lines or else the lines curve round them. Also they occur in shells from several different localities, namely Kildare, Dublin, Lowick, and Weardale.

As the entire structure of the band is unknown, it is at present impossible to ascertain the exact affinities of this genus. It appears to come nearest to the *Alatæ* group of *Pleurotomaria*, which both Prof. Koken[2] and Prof. Perner[3] place in the genus *Euomphalopterus* Rœmer.[4] They consider that the crescents on the inner band are not formed by the filling up of a slit in the outer lip as in the true *Pleurotomaria*, but that they are the result of the breakage of chambers formed during the growth of the superposed keel or flange. Lindström,[5] however, states that he has seen no evidence of these inner chambers; and he considers that, at the most, his '*Alatæ*' should merely constitute a subgenus, but certainly not a distinct genus. I also have seen no specimens showing any signs of internal chambers, and the lines of growth appear to me suggestive of the former presence of a sinus of moderate depth in the outer lip, over which the keel has been formed. This peculiar structure

[1] 'Système Silurien du Centre de la Bohême' pt. i, vol. iv, Gastéropodes: par J. Perner, tome ii (1907) p. 240.

[2] Neues Jahrb. Beilage-Band vi (1889) p. 439.

[3] *Op. supra cit.* p. 150.

[4] 'Lethæa Geognostica' 1876, pl. xiv, figs. 9 *a* & 9 *b*.

[5] K. Svensk. Vetensk.-Akad. Handl. n. s. vol. xix (1884) No. 6, p. 118.

of the band, together with the general shape of the shell, is quite sufficiently distinctive to indicate the advisability of separating these forms from *Pleurotomaria sensu stricto*. They probably belong to the Raphistomidæ as defined by Ulrich,[1] and constitute a genus intermediate between *Raphistomina* Ulrich and *Euomphalopterus* Rœmer. Ulrich thinks the former genus the more ancient, and suggests that *Euomphalopterus* has been derived from it; if this be the case, we may perhaps further regard *Tropidostropha* as another derivative.

Tropidostropha griffithi (M'Coy). (Pl. XXVII, figs. 1–4.)

Pleurotomaria griffithii F. M'Coy, 1844, 'Syn. Char. Carb. Limest. Foss. Irel.' pp. 40–41 & pl. vi, figs. 1–1 *b* (non *Pl. griffithii* L. G. de Koninck, 1851: 'Descr. Anim. Foss. Terr. Carb. Belg.' Suppl. p. 695 & pl. lviii, fig. 10).
Pleurotomaria griffithii J. Morris, 1854, 'Catal. Brit. Foss.' p. 273.
Pleurotomaria griffithii (pars) F. M'Coy, 1855, 'Brit. Pal. Foss.' pp. 528–29.
Pleurotomaria griffithii R. Griffith, 1860, Journ. Geol. Soc. Dublin, vol. ix, pp. 90 & 125.
Pleurotomaria griffithii J. J. Bigsby, 1878, 'Thes. Dev.-Carb.' p. 331.
Mourlonia griffithi L. G. de Koninck, 1883, 'Faune du Calc. Carb. de la Belgique' pt. iv, Ann. Mus. Roy. Hist. Nat. Belg. vol. viii, p. 78 & pl. xxiii, figs. 29–30.
Pleurotomaria griffithii R. Etheridge, 1888, 'Foss. of Brit. Is.' vol. i, Pal. p. 305.

Diagnosis.—Shell very large. Whorls about six, moderately convex above, slightly concave on each side of the band. Band situated near the middle of the body-whorl, and on the lower fourth of the penultimate whorl, composed of a sharp prominent keel overlying a slightly-concave rectangular band, which is limited on each side by a strong thread, with a much finer thread down the middle and crossed by fine crescentic threads. Test thin. Lines of growth coarse, irregular, broken and sometimes bifurcating, sweeping obliquely backwards to the edge of the keel above, forwards at first below, and then passing almost vertically into the umbilicus. Base convex, with a subangularity or broad rounded ridge surrounding the umbilicus. Aperture wider below than above, sharply angular at the periphery where the keel occurs. Inner lip unknown. Umbilicus wide.

Remarks and resemblances.—M'Coy ('Syn. Char. Carb. Limest. Foss. Irel.' p. 40) describes this species as having 'a single, very prominent, square keel,' evidently founding his description upon a specimen in which the band was imperfectly preserved. That such was the case I have been able to ascertain through the kindness of Dr. Scharff, who sent me a good model and several photographs of the holotype. He also lent me specimens which are conspecific, and exhibit the surface and band in better condition. Prof. Hughes, at the same time, was most obliging in lending me the examples in the Sedgwick Museum referred to by M'Coy in 'Brit. Pal. Foss.' pp. 528–29. I discovered that he was mistaken

[1] Final Rep. Geol. & Nat. Hist. Surv. Minnesota, vol. iii, pt. ii (1897) p. 930.

in identifying a shell from Lowick with the species under discussion; he states that it possesses

'an extremely prominent, flat keel, truncated or quadrate at its narrow, outer edge, and having the sinal band along its upper flat side, bounded internally by a faint obtuse ridge.'

Though both species when entire have a prominent keel and similar test-structure, I am convinced that they are distinct: for in the Lowick shell this keel is more prominent, and there is a strong thread at a little distance above which is not present in the Irish specimens; the former is also smaller, the sutures are deeper, and the convexity of the whorls is greater.

One example of *Tr. griffithi* shows traces of several fine spiral threads on the base, and another has a single strong thread on the body-whorl a short distance below the band.

Dimensions.—The holotype (Pl. XXVII, fig. 2) is in the Griffith Collection, National Museum of Ireland, Dublin; it consists of five whorls the length of which =7·6 centimetres, and its greatest width =10·9 cm. Another example in the General Collection of the same Museum (Pl. XXVII, figs. 1 *a*–1 *c*) has three whorls preserved, which =10·3 cm. in length and 12·6 cm. in greatest width. The specimen (Pl. XXVII, fig. 3), presented by Sir Richard Griffith to the Sedgwick Museum, consists of the half of a single whorl which measures 8 centimetres in width.

Localities.—The holotype is from Millicent, Clane (Kildare); two shells associated with it, as well as an individual in the Sedgwick Museum, are from Ardclogh, Rathcool (Dublin). Three specimens in the General Collection of the National Museum of Ireland, Dublin, are simply labelled 'from Kildare' and another in the British Museum (Natural History) has no more definite locality ascribed to it than Dublin.

Horizon.—Lower Carboniferous Limestone.

TROPIDOSTROPHA PUNCTATA, sp. nov. (Pl. XXVIII, figs. 1–2 *c*.)

Pleurotomaria griffithii (pars) F. M'Coy, 1855, 'Brit. Pal. Foss.' pp. 528–29 (non *Pl. griffithii* M'Coy, 1844, 'Syn. Char. Carb. Limest. Foss. Irel.' p. 40).

Diagnosis.—Shell large. Whorls about six, with a sharp flange-like keel a little above the middle of the body-whorl, and on the penultimate whorl about a third of its height from the suture; very convex, except above and below the keel, where they are concave. A strong thread a short distance above, and a very fine one immediately below, the keel. Lines of growth strong, irregular, varying in thickness, and sometimes interrupted or bifurcating. Whole surface of the test covered by numerous very fine spiral lines. Umbilicus wide, partly covered by a reflection of the inner lip, which has strongly impressed lines running down it.

Remarks and resemblances.—It has already been stated that M'Coy erroneously considered a specimen of this species in the Sedgwick Museum from Lowick conspecific with *Tr. griffithi*, and the distinctive features were pointed out. The space between the keel and the thread above is suggestive of a sinual band, and it was mistaken for such by M'Coy; the lines of growth, however, pass over unbroken with very slight deflection, showing clearly that there was no sinus or slit in this position. Though none of the specimens of this species with which I am acquainted are preserved in such a manner as to exhibit a structure underlying the keel similar to that existing in *Tr. griffithi*, I consider it advisable to group the two species together at present, since their general characteristics are very similar. The discovery of further details, not only of the keel but also of the inner lip, may, however, prove them to be distinct—so far the form of the latter is unknown in *Tr. griffithi.*

Dimensions.—The largest specimen met with is that in the Sedgwick Museum (Pl. XXVIII, fig. 1): the apex is broken, and the five remaining whorls measure 6·2 centimetres in length; the greatest width seen is 6·5 cm.: it must really be greater than this, but the aperture is embedded. The shell (Pl. XXVIII, figs. 2*a*–2*c*) in Dr. Trechmann's collection is remarkable for having the inner lip preserved, and is therefore chosen as the holotype. The apex is broken, and only three whorls remain: these have a length of 5·5 cm. and a maximum width of 4·8 cm. Another example in the same collection, of which the apex is also imperfect, has five whorls in a length of 4·4 centimetres.

Localities and horizon.—The specimen in the Sedgwick Museum is from the Lower Carboniferous Limestone of Lowick. Two in Dr. Trechmann's collection are from the Great Limestone at Stanhope-in-Weardale.

Family **Pleurotomariidæ** d'Orb.

Genus Pleurotomaria Defrance: Subgenus Foordella, nov.

Diagnosis.—Shell turbinate, composed of numerous convex and smooth whorls. Spire somewhat elevated. Band submedian; lines of growth curving very obliquely backwards to it above, and forward from it below. Aperture subcircular. No umbilicus. Test thin.

Genotype.—*Foordella hibernica.*

Dimensions.—Length = from about 4·5 to 7·5 centimetres.

Remarks and resemblances.—In my paper in this Journal vol. li (1895) p. 231, I erroneously identified species of this subgenus from Ireland with *Caliendrum vittatum* (Phill.), all the Irish specimens that I had then seen being very imperfect. After the examination of better-preserved examples I feel convinced that not only are they distinct species, but that they also constitute a new subgenus. It is distinguished from *Caliendrum* Brown by its shorter and broader form, the spiral angle being from 60° to 65°, whereas that of the latter genus is from 50° to 55°; by its more oblique lines of growth; and by its aperture being more nearly circular. It differs from *Ptychomphalina* Bayle, *Mourlonia* De Kon., and *Euryzone* Koken, in the higher position of the band, and from the two last-named also in the absence of an umbilicus; it comes nearest to *Bembexia* Œhlert, but has less angular whorls and the columellar lip simple. From these genera it is further separated by its very oblique lines of growth. The character of these latter and of the band suggests that there was a slit of some depth in the outer lip. The structure of the test somewhat resembles that of *Tropidostropha*, the lines of growth being irregular and broken, and there are also numerous pittings; the former, however, are finer, and the latter smaller.

Range.—I am acquainted with only two species, which are from the Lower Carboniferous of Ireland.

FOORDELLA HIBERNICA, sp. nov. (Pl. XXIX, figs. 3 & 4.)

Caliendrum vittatum (Phill.) (*pars*) J. Donald, 1895, Q. J. G. S. vol. li, p. 231.

Diagnosis.—Shell large, composed of more than seven whorls. Whorls convex, somewhat flattened above, ventricose, increasing rather rapidly. Surface smooth, with the exception of the lines of growth. Sinual band broad and flat or slightly concave. Lines of growth distinct, varying in strength, strong ones being intercalated with fine.

Remarks and resemblances.—The holotype was in the collection of Dr. A. H. Foord (Dublin), but it is now in the Munich Museum. This species bears some resemblance to *Ptychomphalus turbiniformis* De Kon.[1] and *Pt. mucronatus* De Kon.,[2] with the types of which I have compared it; it differs from both in the character of the lines of growth, and from the former also in the higher spire and greater width of the whorls. The general form is nearer that of the latter; but the only specimen of this species to be seen in the Brussels Museum is smaller, and too badly preserved for accurate comparison.

Dimensions.—The holotype = 7 centimetres in length and 5·6 cm. in width.

Localities.—The holotype (Pl. XXIX, fig. 3) is from St. Doulaghs, about 6 miles north of Dublin. Another fairly-preserved specimen, which is in Trinity College Museum, Dublin, came from Kildare. An individual (No. 25,513) in the Museum of Practical Geology London, but small portions of the test of which are intact, appears to be conspecific, and comes from the same locality. It is remarkable for having a fold behind the columella at the base of the aperture which is suggestive of channelling, a feature that I have not observed in any other specimen of the genus (Pl. XXIX, fig. 4).

Horizon.—Lower Carboniferous Limestone.

FOORDELLA TERETICINCTA, sp. nov. (Pl. XXIX, figs. 1 & 2.)

Diagnosis.—Shell large, composed of more than seven convex whorls. Sinual band rather wide, convex, submedian on the

[1] 'Faune du Calcaire Carbonifère de la Belgique' pt. iv, Ann. Mus. Roy. Hist. Nat. Belg. vol. viii (1883) p. 39 & pl. xxiv, figs. 7–8.
[2] *Ibid.* p. 39 & pl. xxix, figs. 1–2.

whorls of the spire and above the middle of the body-whorl, lines of growth acutely bent upon it. Ornamentation consisting of very fine spiral striæ. Columella but slightly curved.

Remarks and resemblances.—This form resembles the last to such a degree that I hesitated at first as to whether it should be regarded as a distinct species, or merely as a variety. The shape of the band, however, appears very different, being narrower and convex, and the lines of growth are more acutely bent upon it; also the whorls are rather more evenly convex, whereas those of *F. hibernica* are somewhat quadrangular. It is distinguished from *Ptychomphalus walciodorensis* De Kon.[1] by having a higher spire, band not quite so wide, columella nearly straight, and lines of growth more oblique. The holotype (Pl. XXIX, fig. 2) and an associated specimen (fig. 1) were in Dr. Foord's collection, Dublin, but they are now in the Munich Museum. They are both remarkable for having the columella fairly well preserved, and fig. 1 has the body-whorl near the aperture rather inflated and squeezed into wide folds.

Dimensions.—The apex of the holotype is broken: the remaining seven whorls = 6·5 centimetres in length and 5·1 cm. in width. The other example (fig. 1) is still larger, having three and a half whorls in a length of 7·2 cm., and its width = 6·25 cm.

Localities.—The holotype and its associate are from St. Doulaghs, Dublin. A specimen in Trinity College Museum, Dublin, one in the British Museum (Natural History) No. 26255, and perhaps also an example having merely the upper part of the spire preserved in the Museum of Practical Geology, London, are conspecific, and all come from Kildare. Another individual in the last-named Museum is from Cloonlara (County Clare). A second shell on the tablet, No. 26255, is too much worn for identification.

Horizon.—Lower Carboniferous Limestone.

Genus Mourlonia De Kon.: Subgenus Trechmannia, nov.

Diagnosis.—Shell trochoidal. Whorls rapidly increasing, more than three in number, flattened above, with a prominent keel considerably below the middle, which appears a very short distance above the suture on the penultimate whorl: below the keel the whorls are slightly concavo-convex, and slope rapidly into the sutures. Sutures deep. The ornamentation on the upper part of the whorl consists of strong raised threads, sloping very obliquely backwards along the course of the lines of growth; these continue to the edge of the keel, below which they run slightly backwards with much less obliquity than those above. A rather wide and deep groove encircles the whorls immediately above the keel, bounded on the upper side by a blunt ridge. Entire surface covered by very fine spiral lines. Contour of the keel concave above and below. Beneath it there is a slightly grooved band, only seen when the keel is broken, with a fine thread running

[1] Ann. Mus. Roy. Hist. Nat. Belg. vol. viii (1883) p. 38 & pl. xxiv, figs. 2–3.

down the middle and covered by distinct, deeply bent, more or less horseshoe-shaped, raised threads, some of which are almost angular at the extremity of the bend. Base flat. Aperture obliquely oblong.

Genotype.—*Trechmannia trochiformis*, sp. nov.

Remarks and resemblances.—So far I have only met with one species belonging to this genus that has the distinctive characteristics well preserved. But I have seen several specimens that may belong to another species which is larger and possesses more convex whorls; the band on these, however, is not in sufficiently good condition to exhibit its structure clearly.

Only one example of the genotype is known to me, and on it the form of the band is distinctly seen. The sharply bent lunules are suggestive of the existence of a deep slit in the outer lip; they cannot be the remains of broken chambers, such as have been suggested for *Euomphalopterus*, as each curve has a finished and unbroken appearance. The band greatly resembles that of *Murchisonia deflexa* Lindstr.[1]; but in that species only the lower margin is produced, and the upper remains normal, leaving an opening. In the present instance the lower margin is not only similarly produced upwards, but the upper margin also is produced, though not to such an extent, for the apex of the keel is above the centre of the band. It is not clear whether the margins actually united; but, if they did not do so, the opening left was evidently not so wide as that of *M. deflexa*, and was probably not more than a hair's breadth. The lunules also differ, those of *M. deflexa* being less sharply bent. In general form this subgenus greatly resembles species referred to *Ptychomphalina* and *Mourlonia*, but the character of the band distinguishes it from those genera. It also probably differs from the former in having an open umbilicus; but, as the only individual that I have seen has a portion of the matrix adhering to the base, and the opening is merely indicated by the shell-structure, this is not absolutely certain.

It is distinguished from *Euomphalopterus* not only by the character of the lunules, but also by the keel being less prominent and being situated higher on the whorl; from *Tropidostropha* by its much smaller size, flattened base, aperture receding below, and deeper lunules on the band.

TRECHMANNIA TROCHIFORMIS, sp. nov. (Pl. XXX, figs. 5 *a*–5 *d*.)

Diagnosis.—As only one species is known at present, it is impossible to add anything more distinctive than has already been stated in the description of the subgenus.

Remarks and resemblances.—This species greatly resembles *Pleurotomaria conica* Phill., as figured in 'Illustr. Geol. Yorks.' vol. ii (1836) pl. xv, fig. 22. The holotype of Phillips has not been recognized, although among seven specimens on tablet G 148 in

[1] K. Svensk. Vetensk.-Akad. Handl. n. s. vol. xix (1884) No. 6, p. 134 & pl. xx, figs. 1–6.

the Gilbertson Collection in the British Museum (Natural History) from Bolland, there is one which is very like his figure, not only the structure, but the colour-markings also being almost identical. With this I have compared the only specimen of the species under discussion and find that it differs in having a greater spiral angle; in the whorls being wider, more flattened above, and sloping out more obliquely; in the groove above the band being much deeper; and in the colour-blotches also being somewhat broader and irregular. The band of this Bolland example agrees with the figure in having simple bordering threads; these, however, are much worn. Two smaller individuals on the same tablet, which are conspecific, have the band filled in between the margins in such a manner as to suggest the possibility that they were produced to form a keel. If the discovery of better preserved specimens should prove this to have been the case, *Pleurotomaria conica* Phill. should be referred to this subgenus instead of to *Mourlonia* De Kon.

Dimensions.—The holotype, which is the only known specimen, is in Dr. Trechmann's collection. It has but three whorls preserved, which measure 14 millimetres in length, while 19 mm. is the greatest width.

Locality and horizon.—Stanhope-in-Weardale, in the Great Limestone.

Family **Murchisoniidæ** Koken.

Genus Pithodea De Koninck.

Diagnosis.—Shell of large size, buccinoid, ventricose; spire relatively short. Whorls convex, increasing rapidly, having a flat band formed by the gradual filling-up of a broad but shallow sinus in the outer lip. Ornamentation consisting of numerous raised spiral threads. Aperture large, oval. Columella simple, thin, and straight towards the base. No umbilicus.

Genotype.—*Pithodea amplissima* De Kon.

Dimensions.—The specimens vary in length from 14 or 15 centimetres down to about 6; in width from 10 down to 5·4 cm.

Remarks and resemblances.—De Koninck places this genus provisionally in the family Turbinidæ, because of its very thin test, which does not appear to have been nacreous. Fischer, however, refers it to the Pleurotomariidæ, from which the absence of a nacreous layer separates it. On this account, as well as from the fact that it has a sinus in the outer lip represented by a band on the whorls, I consider it better to place it in the Murchisoniidæ. It should stand in proximity to *Caliendrum* Brown,[1] which it resembles in contour, in the form of the lines of growth, and in the character of the band. It is distinguished from that genus by possessing numerous raised spiral threads, and possibly by the structure of the columellar lip, which does not appear to have been reflected.

[1] 'Illustrations of the Fossil Conchology of Great Britain & Ireland' 1849, p. 52 & pl. xxxii, fig. 20.

Pithodea amplissima De Kon. (Pl. XXX, figs. 1–3.)

Pithodea amplissima L. G. De Koninck, 1881, 'Faune Calc. Carb. Belg.' pt. iii, Ann. Mus. Roy. Hist. Nat. Belg. vol. vi, p. 88 & pl. viii, figs. 1–3.

Diagnosis.—Shell composed of more than six whorls. There is a flat band bordered by raised threads, situated below the middle of the penultimate whorl, and above the middle of the body-whorl. Fine lines of growth curve slightly backwards to this band, form indistinct crescents on it, and then pass downwards almost vertically. The ornamenting spiral threads are irregular in strength, fine threads being sometimes intercalated between strong ones. Columellar lip nearly straight.

Remarks and resemblances.—Portions of two shells in the collection of Mr. Joseph Wright, Belfast, appear conspecific with De Koninck's *Pithodea amplissima*. Neither of them has attained the proportions of his largest specimen, but one must have been of about the same size as the smallest shell which he figured in pl. viii, fig. 3. A new drawing from the original is here reproduced for comparison (Pl. XXX, fig. 3).

Dimensions.—The largest fragment (Pl. XXX, fig. 1) consists of parts of two whorls which measure 4·7 centimetres in length, the width of the penultimate whorl = about 3·2 cm. The other specimen (fig. 2) has four broken whorls in a length of 3·9 cm.

Locality and horizon.—Cork; Lower Carboniferous Limestone (Étage de Visé, Assise vi).

Pithodea percincta (Portlock). (Pl. XXX, fig. 4.)

Macrocheilus percinctus J. E. Portlock, 1843, 'Report on the Geology of Londonderry, &c.' p. 419 & pl. xxxi, fig. 10.

This shell greatly resembles *P. amplissima* De Kon. It differs in the band not being so distinctly defined, and in the ornamenting threads being more nearly equal in strength. De Koninck noticed the resemblance, but evidently had merely seen the figure and not the actual specimen: therefore, owing to the band not being represented, he considered that the shells belonged to different genera. They are certainly congeneric and possibly conspecific, but since only one worn example of Portlock's species is known to me it is impossible to decide as to the value attaching to the differences. It is thus advisable to retain both names for the present, although the acquisition of more specimens may make it necessary for De Koninck's specific name to give way to that of Portlock.

Dimensions.—The holotype is the specimen described by Portlock, which is in the Museum of Practical Geology, London. It is imperfect, and the three existing whorls = 8·7 centimetres in length and about 5·4 cm. in width; the latter dimension would probably have been greater if the shell had been entire.

Locality and horizon.—Derryloran (Tyrone). Lower Carboniferous Limestone.

TMETONEMA, gen. nov.

Diagnosis.—Shell conical, of moderate height, composed of convex whorls ornamented by numerous strong, raised, sigmoidal and slightly oblique threads. Above the middle of each whorl is a narrow groove cutting across the oblique threads; the portion of these above is concave forwards, and ends somewhat abruptly at the groove: that below is at first for a very short length greatly curved forwards, and then passes downwards with less obliquity. No lines of growth are observable in the groove, and it is devoid of bordering lines. Base slightly produced. Columella straight. Inner lip reflected. Aperture subovoid. No umbilicus.

Genotype.—*Tmetonema subsulcatum*, sp. nov.

Remarks and resemblances.—The only species known to me is represented by two specimens which are remarkably well preserved. The genus is like *Macrochilina* Bayle in shape, *Loxonema* Phill. in having strong oblique threads, and *Aclisina* De Kon. in the curve of the latter. It differs from all three in possessing a very fine spiral groove on all the whorls, and is further distinguished from *Macrochilina* by the form of the aperture, from *Loxonema* in the whorls not being adpressed at the suture, and from *Aclisina* in being less slender and without spiral threads. The narrow groove, which is suggestive of a slit in the outer lip, causes it to resemble *Murchisonia* D'Arch. & De Vern. It is not clear, however, whether this groove really represents a slit or whether it is merely a deep narrow depression in the test, as neither specimen has the outer lip entire. It differs from *Murchisonia* in the lines of growth above not curving backwards, and in the groove being devoid of bordering threads or lines of growth. The commencement of the ornamentation cannot be ascertained, as the earlier whorls are worn smooth. The protoconch appears to be simply coiled on the same plane as the rest of the spire, but it is impossible to define on account of imperfect preservation.

It is difficult to know where to place this genus, and for the present it is perhaps best to refer it to the family Murchisoniidæ.

TMETONEMA SUBSULCATUM, sp. nov. (Pl. XXVIII, figs. 3 *a*–4 *b*.)

Diagnosis.—Shell very small, composed of about seven whorls. As only one species is known, there is little to add to the generic description.

Dimensions.—There are but two specimens in the collection of Mr. John Smith, Dykes (Ayrshire). The larger example consisting of seven whorls, measures 2·5 millimetres in length and 1·5 mm. in width. The other has six whorls in a length of 2·25 mm.: its greatest width = 1·25 mm. This latter must be regarded as the holotype, as it shows the aperture as well as the apex.

Locality.—High Smithston, Kilwinning (Ayrshire).

Horizon.—Upper Limestone Series (of Scotland).

Family Loxonematidæ Koken.

Microptychis, gen. nov.

Diagnosis.—Shell elongated, conical. Whorls numerous, increasing gradually, adpressed at the suture, flattened, convex at the periphery. Earlier whorls ornamented by ribs nearly parallel to the axis of the shell, later whorls devoid of ribs. A flat band is situated on the widest part of the anterior whorls. Aperture unknown.

Genotype.—*Microptychis wrighti*, sp. nov.

Remarks and resemblances.—The lines of growth are imperfectly seen: apparently they are not so strongly sigmoidal as in *Loxonema* Phill.[1] *sensu stricto*, but more nearly resemble those of *Stylonema* Perner.[2] They, as well as the ribs, seem to pass over the band without break, therefore the latter cannot indicate a slit in the outer lip. This genus is further distinguished from *Loxonema* by the possession of this band, and also of ribs on the earlier whorls. The more flattened form of the spire as well as the ribs separate it from *Rhabdostropha* Donald.[3] From *Zygopleura* Koken[4] it differs in having a band and the whorls adpressed at the suture. The latter feature also distinguishes it from *Eustylus* Kittl.[5] In general character it bears most resemblance to *Anoptychia* Koken,[6] but that genus has the whorls subimbricated and not adpressed at the sutures.

Range.—At present only known in the Lower Carboniferous.

Microptychis wrighti, sp. nov. (Pl. XXX, figs. 6 *a* & 6 *b*.)

Diagnosis.—Shell of medium size, composed of more than eleven whorls. Ribs sharp and slightly curved on the upper five whorls, becoming gradually less defined on the sixth and seventh; band discernible on the sixth, and becoming more distinct on the later whorls.

Remarks and resemblances.—So far I have only met with one specimen of this species, which is in the collection of Mr. Joseph Wright, Belfast. This is, therefore, the holotype. It is quite distinct from any other described British species, but is probably allied to *Loxonema semicostatum*,[7] the first species described by De Koninck in his group *Costata*, which has ribs only on the upper part of the spire; it is, however, less slender, the whorls are not so convex at the periphery, and the base is more produced. *L. murchisonianum* De Kon.[8] also possesses a band, but it is

[1] Q. J. G. S. vol. lxv (1909) p. 212 & pl. x, figs. 1 *a*–1 *b*.
[2] 'Système Silurien Centre de la Bohême' pt. i, vol. iv, Gastéropodes, tome ii (1907) p. 325.
[3] Q. J. G. S. vol. lxi (1905) p. 565.
[4] Neues Jahrb. vol. ii (1892) p. 30.
[5] Annalen des k. k. Naturhist. Hofmuseums, vol. ix (1894) p. 192.
[6] Neues Jahrb. vol. ii (1892) p. 32.
[7] 'Faune du Calcaire Carbonifère de la Belgique' pt. iii, Ann. Mus. Roy. Hist. Nat. Belg. vol. vi (1881) p. 51 & pl. iv, figs. 8–9.
[8] *Ibid.* p. 60 & pl. vi, figs. 2, 33.

distinguished by the band being situated above instead of below the ribs, and the ribs continue on all the whorls.

Dimensions.—Length = 25 millimetres. The specimen is embedded in the matrix, so the exact width cannot be ascertained. Height of body-whorl = 5·5 mm.

Locality.—Little Island, Cork.

Horizon.—Top of the Carboniferous Limestone (D^2 of Dr. Vaughan).

For the loan of specimens I am indebted to Prof. T. McKenny Hughes, F.R.S., Prof. W. J. Sollas, F.R.S., Dr. Scharff, Dr. Trechmann, Mr. John Smith (Dalry), Mr. Joseph Wright, Prof. Rothpletz, and the Geological Survey, Jermyn Street. For very valuable assistance in various ways I desire to express my cordial thanks to Dr. A. Smith Woodward, F.R.S., Mr. G. C. Crick, Dr. F. L. Kitchin, Mr. H. A. Allen, Mr. F. R. Cowper Reed, Mr. E. A. Smith, Dr. G. J. Hinde, F.R.S., Mr. G. K. Gude, Prof. Dollo, and M. Rutot.

The figures 1 *a*, 3, & 4 on Pl. XXVII, and figs. 1 & 2 *a*–2 *b* on Pl. XXVIII, are reproduced from photographs by Mr. H. Herring, British Museum (Natural History). I am indebted to Dr. Scharff for the photograph of Pl. XXVII, fig. 2. The originals of Pl. XXVIII, figs. 3 *a* & 4 *a*, were taken by myself.

EXPLANATION OF PLATES XXVII–XXX.

Plate XXVII.

Figs. 1 *a*–1 *c*. *Tropidostropha griffithi* (M'Coy). Fig. 1 *a*. Front view, × ½. Fig. 1 *b*. Outline of keel near the aperture, natural size. Fig. 1 *c*. Portion of band which underlies the keel from the penultimate whorl, × 2. Kildare. General Collection, National Museum of Ireland, Dublin. (See p. 298.)

Fig. 2. *Tropidostropha griffithi* (M'Coy) (*Pleurotomaria griffithi* M'Coy). Holotype. Back view, × ½. Millicent Clane (Kildare). Griffith Collection, National Museum of Ireland, Dublin. (See p. 298.)

3. *Tropidostropha griffithi* (M'Coy). Section of whorl showing wide, open umbilicus, × ½. Ardclogh, Rathcool (Dublin). Sedgwick Museum, Cambridge. (See p. 298.)

4. *Tropidostropha griffithi* (M'Coy). Portion of surface of upper part of whorl, showing lines of growth and pittings on both shell-layers and the internal mould, × 2. Kildare. General Collection, National Museum of Ireland, Dublin. (See p. 298.)

Plate XXVIII.

Fig. 1. *Tropidostropha punctata*, sp. nov. Back view, natural size. Lowick. Sedgwick Museum, Cambridge. (See p. 299.)

Figs. 2 *a*–2 *c*. *Tropidostropha punctata*, sp. nov. Fig. 2 *a*. Front view, natural size. Fig. 2 *b*. Portion of the lower surface of the whorl, × 2. Fig. 2 *c*. Portion of the upper surface of the whorl, showing lines of growth with pittings, × 2. Stanhope-in-Weardale. Trechmann Collection. (See p. 299.)

3 *a* & 3 *b*. *Tmetonema subsulcatum*, gen. et sp. nov. Fig. 3 *a*. Back view, × 9. Fig. 3 *b*. Lines of growth and groove, × 18. (See p. 306.)

1a.

× ½

1b.

Nat. size.

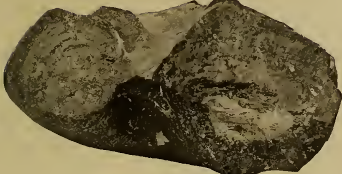
1c.

× 2

2.

× ½

3.



× ½

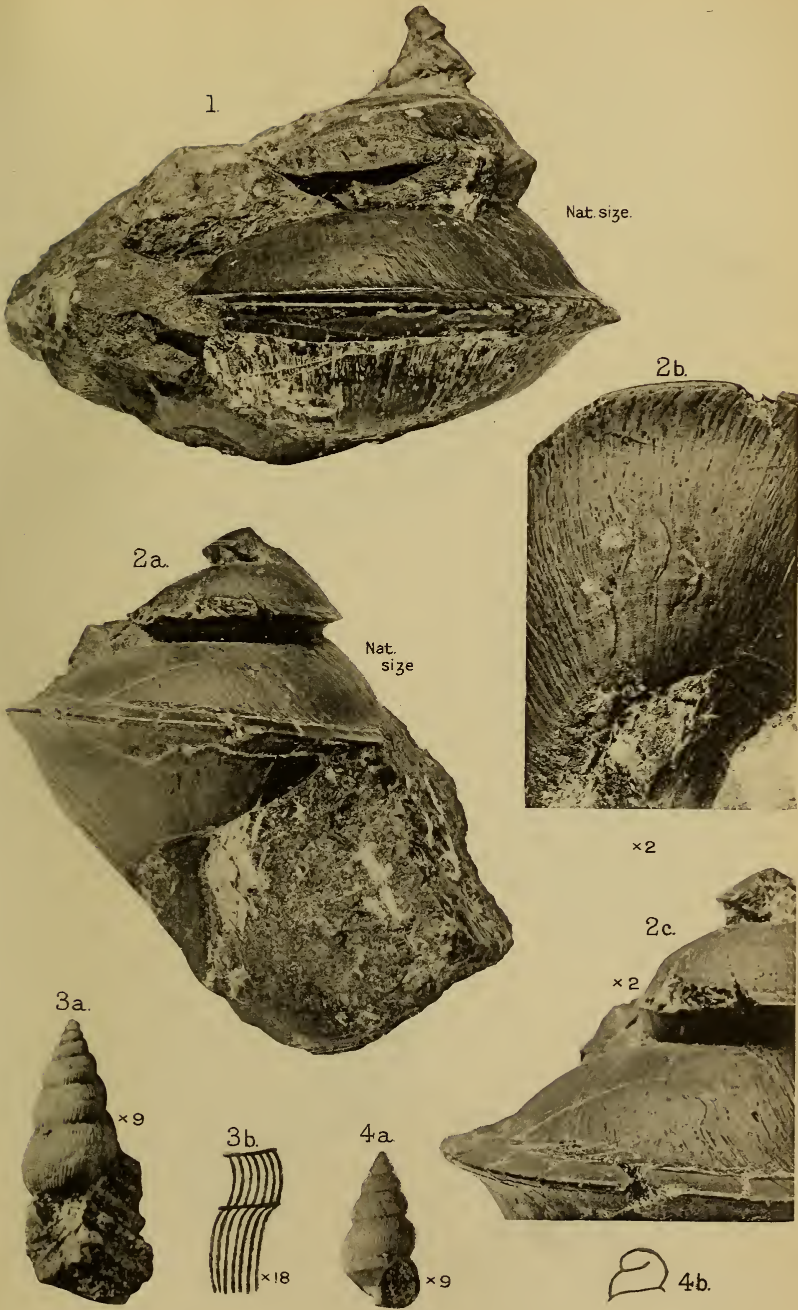
4.

× 2

H. Herring, Photogr. Figs. 1a, 3, 4.
J. Longstaff, del. Figs. 1b, 1c.

Bemrose, Collo., Derby.

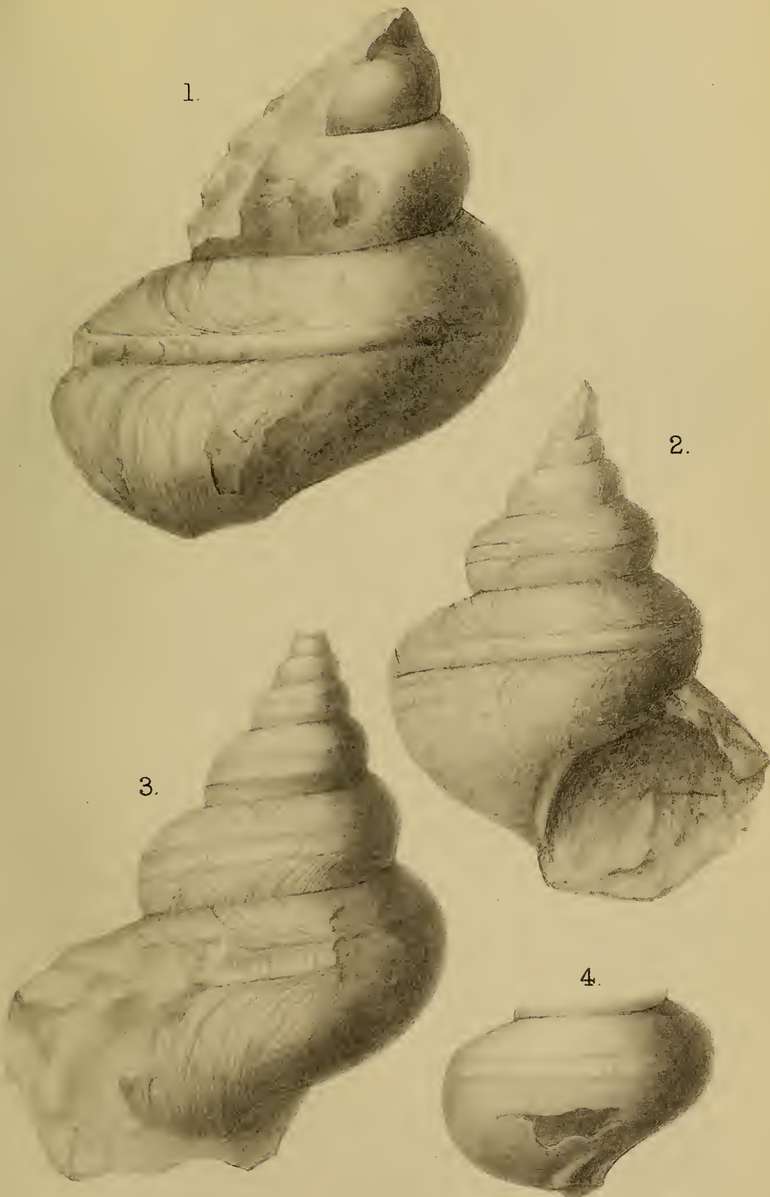
TROPIDOSTROPHA GRIFFITHI (M'COY).



H. Herring, Photogr.
J. Longstaff, del.

Bemrose, Collo., Derby.

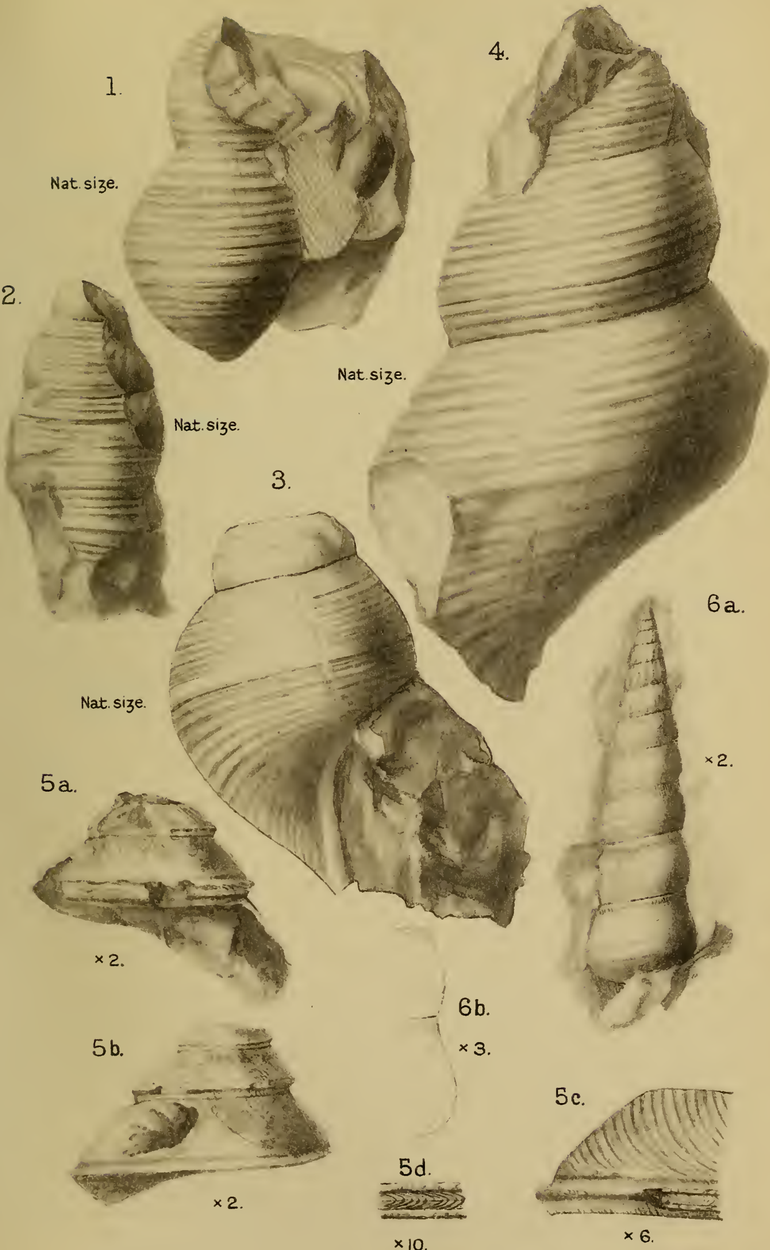
TROPIDOSTROPHA PUNCTATA & TMETONEMA SUBSULCATUM.



J. Longstaff, del.

Bemrose, Collo., Derby.

FOORDELLA subgen. nov. (All the figures are of the natural size.)



J. Longstaff, del.

Bemrose, Collo., Derby.

PITHODEA, TRECHMANNIA, and MICROPTYCHIS.

Figs. 4 *a* & 4 *b*. *Tmetonema subsulcatum*, sp. nov. Fig. 4 *a*. Front view of another specimen, × 9. Fig. 4 *b*. Protoconch greatly enlarged. High Smithston, Kilwinning (Ayrshire). Collection of Mr. John Smith. (See p. 306.)

Plate XXIX.

[All the figures in this plate are of the natural size.]

Fig. 1. *Foordella tereticincta*, subgen. et sp. nov. Back view. (See p. 301.)
2. *Foordella tereticincta*, sp. nov. Front view of another specimen. St. Doulaghs, Dublin. Munich Museum. (See p. 301.)
3. *Foordella hibernica*, sp. nov. St. Doulaghs, Dublin. Munich Museum. (See p. 301.)
4. *Foordella hibernica*, sp. nov. Body-whorl of another specimen, showing the fold behind the columella. Kildare. Museum of Practical Geology, London. (See p. 301.)

Plate XXX.

Fig. 1. *Pithodea amplissima* De Kon., natural size. (See p. 305.)
2. *Pithodea amplissima* De Kon. Another specimen, natural size. Cork. Collection of Mr. Joseph Wright, Belfast. (See p. 305.)
3. *Pithodea amplissima* De Kon. A specimen figured by De Koninck, natural size. Visé. Brussels Museum. (See p. 305.)
4. *Pithodea percincta* (Portlock). Holotype, natural size. Derryloran (Tyrone). Museum of Practical Geology, London. (See p. 305.)

Figs. 5 *a*–5 *d*. *Trechmannia trochiformis*, subgen. et sp. nov. Fig. 5 *a*. Front view, × 2. Fig. 5 *b*. Back view, × 2. Fig. 5 *c*. Portion of penultimate whorl showing structure of band, × 6. Fig. 5 *d*. Portion of band showing lines of growth, × 10. Stanhope-in-Weardale. Trechmann Collection. (See p. 303.)

6 *a* & 6 *b*. *Microptychis wrighti*, gen. et sp. nov. Fig. 6 *a*, × 2. Fig. 6 *b*. Portion of two whorls, showing outlines, × 3. Little Island, Cork. Wright Collection. (See p. 307.)

16. INSECT-REMAINS *from the* MIDLAND *and* SOUTH-EASTERN COAL MEASURES. By HERBERT BOLTON, F.R.S.E., F.G.S., Reader in Palæontology in Bristol University and Director of the Bristol Museum. (Read May 1st, 1912.)

[PLATES XXXI–XXXIII.]

I AM indebted to Dr. L. Moysey for the opportunity of describing an interesting series of insect-wings obtained by him from the Shipley Clay-pit, about a mile and a half north of Ilkeston (Derbyshire). They formed a part of a valuable and interesting suite of remains, most of which have been already described by Dr. Moysey.[1]

The material in which the insect-wings are found is greyish-brown ironstone occurring in the form of nodules, which lie in bands in a yellow clay, probably about 30 or 40 feet below the Top Hard Coal (*op. cit.* p. 506). The nodules also contain comminuted fragments of plants.

I am indebted to Dr. Malcolm Burr, M.A., for the opportunity of examining the Coal-Measures cores from the Kent Coal Concessions Company's bores in the east of Kent, during which examination I found the blattoid wings and other wing-remains which are described later in this paper.

ORTHOCOSTA SPLENDENS, gen. et sp. nov. (Pl. XXXI, figs. 1–3.)

Only a portion of the wing is preserved. It has a length of 84 millimetres, and a width from the outer to the inner margin of 33 mm. The complete wing must have had a length of not less than 100 mm. (4 inches) and a width of 35 to 40 mm. The increased breadth given to the wing takes into account a slight inflexion of the costal margin. The whole insect had in all probability a span of wing measuring 25·5 centimetres (10 inches or more).

Description.—The outer third of the wing is differentiated from the rest by its uniform and gentle convexity, and by the character of the costal, subcostal, radial, and median veins, which pass outwards towards the wing-apex in straight lines, and show no trace of division until well beyond the middle of the wing. All the veins stand out in relief in the outer third of the wing, and contrast strongly with the areas occupied by the marginal divisions of the median, cubital, and anal veins.

The inner two-thirds of the wing is marked by deep sulci, in which lie the marginal branches of the median vein, the whole course of the cubital vein, and the veins which occupy the anal area. The areas between any two veins in this region are markedly convex. The differences in character of the outer and inner portions of the wing are emphasized by a line of fracture which fairly accurately separates the two. Its occurrence would

[1] Geol. Mag. dec. 5, vol. viii (1911) pp. 497–507.

lend colour to the belief that it has followed a natural line of weakness, the more delicate inner part of the wing breaking away from the outer stronger portion.

The costal, subcostal, radial, and median are all well-developed veins, stout in structure, and standing out in relief. The first three retain this evidence of strength over two-thirds of the wing, the median vein showing signs of attenuation beyond the proximal third. The general structure of the wing is indicative of considerable powers of flight. The costal margin, of which only a small distal portion is shown, was fairly straight for the greater part of its length. The remnant preserved shows up as a stout, slightly elevated, and well-rounded ridge.

The subcostal closely follows, and agrees in general character with the costal remnant. It is present, or indicated, over the greater part of its length. It pursues a straight course, giving off a forwardly directed branch 4 mm. from the broken distal end and about 25 mm. before reaching the (estimated) tip of the wing. It originates low down near the body, and in contact with the radius. The radius, at a little over 10 mm. beyond its source of origin, divides into two main branches: the outer branch (radius) pursuing an unbranched course parallel to the subcostal, from which it is nowhere separated more than 2 mm. The inner branch (radial sector) diverges widely from the former, the two enclosing a long, narrow, triangular area. At 50 mm. beyond the first forking, the inner branch divides into two equal rami, which open out quickly to a distance of 3 mm., and then pursue an almost parallel course towards the tip of the wing. The direction of the branches of the radial sector is such as to show that they finally ended upon the inner half of the wing-tip, the outer ramus almost certainly forking again before reaching the wing-margin. The radial area is 16 millimetres wide at the broken edge of the wing, its branches showing a divergence sufficiently great to include the greater part of the wing-tip.

The median vein consists of two branches, the common origin of which is not shown. Up to the middle of the wing the two remain parallel.

The outer branch of the median attains a length of 66 mm. before branching. It then gives off four branches on its outer side, the last arising quite close to the inner margin, upon which the main stem also ends. The first forward branch continues almost in the line of the stem, following a direction which would bring it out upon the inner margin of the wing-tip. The second, third, and fourth branches pursue a parallel course, the second bifurcating just in front of the broken edge of the wing.

The inner stem of the median keeps parallel to its fellow for two-thirds of its length. It then gives off a strong backwardly-directed vein to the wing-margin, and at 11 mm. farther out divides into two unequal veins, the outer and feebler disappearing in a small plexus of polygonal reticulation. The inner vein runs out to the wing-margin parallel to the branch-vein first thrown off.

Although I have spoken of the median as consisting of two distinct stems, or as uniting near the body on the missing proximal portion of the wing, the two are united, at no great distance from their points of origin, by an oblique commissural vein which comes off at an acute angle low down on the outer stem, and passes obliquely inwards to the inner one. It has a length of 15 mm.

The basal portion of the cubitus has been broken away, so that its branching is not readily determinable.

Enlarged photographs taken with oblique lighting show that the main vein divided low down near its point of origin into two almost equal branches, which curved first gradually and then more rapidly to the inner wing-margin, bifurcating twice in each case before the margin was reached. The eight marginal rami of the cubitus thus produced enclose the middle third of the inner wing.

The anal area is wholly destroyed on the wing itself, and only a trace of one vein can be distinguished on the counterpart. This is a narrow, deeply-sunken vein, which gives off feeble offshoots on both sides, that is, on its outward and inward sides, and diminishes in strength as it passes to the wing-margin, so that the last portion of its course can only be detected with difficulty. The anal area is comparatively small and narrow, and exhibits few veins.

Affinities.—It will be evident from the foregoing description that the wing is of an unusual type, and possesses several remarkable features. Not only is it one of the largest (if not the largest) wings hitherto found in the British Coal Measures, but the wing-structure in many respects differs from all known forms.

There is no doubt of its Palæodictyopterous character, but it agrees with no known family of that order. The nearest related family is that of the Dictyoneuridæ, Handlirsch. It does not possess that close, irregular, reticulate venation so characteristic of the genus *Dictyoneura*, which is the type of the family, but shows instead a few longitudinal intercalary veins breaking up into widely open polygonal venation.

The costal and subcostal areas are very narrow, and the outer wing-margin almost straight. The radius is almost furcate near the tip of the wing, while the radial sector is relatively simpler than in *Dictyoneura*. It originates far below the middle of the wing, very near the base in fact, and diverges widely from the radius. Notwithstanding this, positive evidence of only one bifurcation is to be found, and it is not conceivable that its ultimate branches could have produced more than four terminal twigs. Judging by the course of the subcostal and radial veins, the two were united for some little distance after their origin. The median had clearly two main stems united by a commissure, the outer stem being much divided in the wing-apex, the inner giving off two branches to the inner wing-margin, and then becoming lost in the intercalary veins.

The cubitus is a much-branched and widely divergent vein, and, like the median, is deep-seated. It is unlike the cubitus in any other member of the Palæodictyoptera that we know of, by reason of its branching and the area which it serves.

The radial sector sends its branches outwards and not inwards, in this respect showing a marked contrast to what obtains in the Dictyoneuridæ. Similar distinctive features mark the median vein, which either divides very low down into two branches, or possesses two points of origin. The commissure uniting the two is also an unusual feature. The anal area is elongate-elliptical in outline, crossed by one, possibly two, veins which pass obliquely forwards towards the apex of the area. The undoubted and clearly distinguishable anal vein gives off branches alternately on either side, which also run towards the inner margin, but die out in large polygonal cells before reaching it.

These large polygonal cells are more suggestive of the family Hypermegethidæ than of the Dictyoneuridæ. The general form of the wing somewhat resembles that which obtains in the Heolidæ, and the divergence of the cubitus is somewhat similar. Here, however, the resemblance ends. The wing seems clearly to belong to a new family related to the family Dictyoneuridæ, and with some suggestion of the family Heloidæ.

To this new family I propose to assign the name of Orthocostidæ.

Family Orthocostidæ.

Characters.—Costal border almost straight, subcostal approaching the costal border; radius straight, parallel, and close to the subcosta; radial sector diverging, not more than twice furcate; median divided into two branches united by a basal commissure; cubitus stout, forked near the base, the outer branch forking twice and the inner branch once before reaching the inner margin; anal area oblong-elliptical; areas between veins filled by widely-open polygonal subsidiary venation.

Genotype: *Orthocosta*. Characters as above.

I propose the name of *splendens* for the species.

The diagnostic description is as follows:—Wing two and a half to three times as long as wide; costa, subcosta, and radius closely approximated and parallel. Radial sector divergent, reaching the inner half of the tip of the wing. Median dividing near the base; outer branch four or five times divided, inner branch simpler and forked. Cubitus dividing low down into two main stems, the outermost being the strongest, each branch doubly forked. Anal veins one or two in number, alternately branched. Venation an open polygonal network.

Horizon and locality.—30 or 40 feet below the Top Hard Coal, Middle Coal Measures, Shipley Clay-pit, Ilkeston (Derbyshire).

Pteronidia plicatula, gen. et sp. nov. (Pl. XXXII, figs. 1–3.)

This is a long, delicate left wing, of which the inner half only has been preserved. The hinder margin is straight or nearly so, and the wing must clearly have possessed an acute tip. No evidence is forthcoming as to the character of the anterior portion of the wing, nor as to that of the costal and subcostal veins.

Description.—The radius is represented by a single forked vein, the stem of which has not been preserved. The radial sector gives off four (possibly five) branches backwardly, which occupy the distal sixth.

The median is close to the origin of the radial sector, and divides low down into two principal branches, the outer of which divides into two and the inner into three rami before they reach the inner margin. The marginal area occupied by the median is a little longer than that occupied by the radial sector, and together with the latter forms the outer half of the inner wing-margin.

The cubitus is a relatively short and stout vein. It divides into two principal branches, the foremost having two rami and the hinder breaking up into four by a double bifurcation. Owing to the wide divergence of its branches, the cubital area is larger than that of the median.

The anal area was evidently large, but the whole surface has been pitted by attempts to clear the matrix, and so the presence and character of veins cannot be distinguished with certainty. It is possible that certain surface-indications are evidence of two simple widely-separated anal veins.

The wing-surface exhibits a strong plication, the area between any two veins dipping down straightly and smoothly on each side towards a clearly-defined furrow. Viewed obliquely, the wing shows a series of ridges formed by the veins with V-shaped intervening sulci, which only flatten out close to the wing-margin. Springing from the principal veins are a close series of stout cross-veins, which follow an oblique course in the direction of the wing-margin. The portion of wing preserved is sufficient to indicate that the wing was strongly triangular in outline, the proximal portion being probably over 20 millimetres wide, and the width of the wing near the tip measuring not more than 8 mm.

Affinities.—The attempt to classify this wing has been a task of considerable difficulty. I finally came to the conclusion that it had affinities with the genus *Polycreagra*, but was of a more simple and more Dictyoneurid type. With the latter view Dr. Handlirsch agrees, and has pointed out that it is not possible to bring it within the family Polycreagridæ, but that it must be taken as the type of a new family of the Palæodictyoptera.

To this new family, which is not remote from the Heolidæ, I propose to assign the name of Pteronidiæ.

Family Pteronidiæ.

Characters.—Wing three times as long as wide. Costal border gently arcuate. Subcosta and radius closely approximate to the costa, and reaching the latter near the tip of the wing.

Radial sector with five simple, backwardly-directed rami. Median divided low down, with two principal branches, and ending on the inner margin in five rami.

Cubitus stout, widely spaced, divided into two principal branches, the foremost with two rami and the hinder ending in four.

Genotype: *Pteronidia*. Characters as above.

Species, *plicatula*. Characters.—Wings triangular in outline, with subacute tip. Characterized by a strong plication.

Radius as long as the wing, radial sector dividing into five simple rami. Median with two principal branches and five marginal rami. Cubitus wide-spaced; two principal branches, the inner one being doubly furcate.

Horizon and locality.—Some 30 to 40 feet below the Top Hard Coal, Middle Coal Measures, Shipley Clay-pit, Ilkeston (Derbyshire).

CRYPTOVENIA MOYSEYI, gen. et sp. nov. (Pl. XXXII, figs. 4–6.)

The inner two-thirds of a left wing, contained in a portion of a brown, earthy ironstone-nodule. The length of the portion preserved is 16 millimetres, and the maximum width does not exceed 8 mm.

The costal vein is stout, and raised above the general level of the wing in the outer third of its length. It forms a strong sweeping curve backwards, so that the apex of the wing is brought near the inner margin.

The subcostal vein is a weaker vein than the costal, runs parallel and very close to the latter, and dies out where the backward sweep of the costal begins.

The radius is a powerful undivided vein, which gives off the radial sector below the middle of the wing and curves first inwards and then outwards, in the latter part of its course becoming parallel to the subcostal, but three times as widely separated from it as the latter is from the costal. It reaches the margin in the middle of the outer half of the wing-tip.

The radial sector, like the radius, first curves inwards and then outwards, and diverges somewhat widely from the radius. It gives off two forwardly directed branches, the outer of which forks twice, the inner branch remaining simple. The outermost ramus of the radial sector runs out into the extreme tip of the wing, the other four rami covering the whole of the inner half of the tip. The outer half of the whole wing-tip is thus occupied by the curved costal and the radius, and the inner half by the inner four rami of the radial sector.

The median vein is of comparatively simple structure, forking low down below the middle of the wing into two nearly equal branches. The outer branch remains undivided, and passes outwards and backwards in a gentle curve to the inner margin. The inner branch divides twice, first at a point a little below the middle of the wing, and again before reaching the margin. The median vein therefore ends upon the margin in four rami, three of which arise from the inner of the two members of the first division.

The branches of the median and of the radial sector occupy all the distal half of the inner wing-margin.

The cubital vein is strongly arcuate, dividing near the base into two branches, the outer of which forks twice and the inner once. The cubital vein therefore ends upon the inner margin in five rami.

Only a portion of the anal area is preserved, but traces of five anal veins can be distinguished. The first anal is a strong vein which forks at the middle of its length. The remainder are simple.

The branches of the cubital and anal veins occupy the proximal half of the inner margin. The wing is somewhat plicated, the veins lying in shallow angular troughs. No definite trace of intercalary venation can be made out, owing to the existence of a complex series of irregular wrinkles, some of which stretch across several of the marginal veins, while others pass between them. This wrinkled area is restricted to the distal half of the inner margin of the wing.

By projecting the terminal branches of the veins towards the base of the wing, some attempt has been made to reconstruct the whole. The wing was undoubtedly very broad in comparison with its length, and, notwithstanding its short broad outline, was very delicate. Both inner and outer margins were convex, and both bent round at the tip of the wing to meet almost at an angle, at the point where the outermost ramus of the radial sector reached the margin.

Affinities. — The wing is typically Palæodictyopterous in character, and agrees remarkably closely with Dr. Handlirsch's type figure.[1] It differs from that form in the greater division of the cubitus, which ends in five rami instead of three. The greatest depth of the wing was also, in all probability, nearer the base than in his species.

With the genus *Athymodictya*[2] the relationship is even closer. As in that genus, the costal and subcostal are close together, the radial sector arises low down and is divergent from the radius, the median is a simple vein ending in three branches, while the cubitus is almost identical in its divisions, the difference being that the first forking arises at a higher point than that in *Athymodictya parva*, and that the inner simple ramus of the outer branch comes off a little below the middle of the wing. The anal veins number four in *A. parva*, as against five in the form under consideration. One point to which I attach some importance is that the outer margin in both is almost straight, bending sharply round distally to meet the more convex inner margin in the neighbourhood of the outermost ramus of the radial sector. In both cases the wings are comparatively small.

[1] 'Die Bedeutung der Fossilen Insekten für die Geologie' Mitt. Geol. Gesellsch. Wien, vol. iii (1910) p. 505, fig. 1.

[2] A. Handlirsch, 'New Palæozoic Insects from the Vicinity of Mazon Creek, Illinois' Am. Journ. Sci. ser. 4, vol. xxxi (1911) p. 298.

I was strongly inclined to refer the species to the genus *Athymodictya*—a conclusion, however, with which Dr. Handlirsch does not agree, as he is of opinion that the wing does not possess the reticular intermediate venation of that genus. What the intermediate venation is like I am unable to determine. If it consists, as Dr. Handlirsch surmises, of single transverse veins, its affinities may well lie near the Homoiopteridæ, or, as I believe, still nearer the Lithomantidæ. It does not fall within either of these families, however, nor can Dr. Handlirsch place it in any family with which he is acquainted. It is inevitable, therefore, that a new family should be formed in which to place it; and to this new family I would give the name of Cryptovenidæ.

Family **Cryptovenidæ.**

Characters.—Wing twice as long as broad; inner and outer margins gently convex; apex rounded. Subcostal weaker than costal, and merging in the latter before reaching the apex of the wing. Radius giving off a radial sector below the middle of the wing, the two enclosing a wide area. Radial sector and median comparatively simple and with few divisions, the former ending on the wing-margin in five rami, the latter in four. Cubitus with five marginal rami. Anal veins strongly arcuate.

Genotype: *Cryptovenia*. Characters as above.

I propose the specific name of *moyseyi* in honour of Dr. L. Moysey, to whom I am indebted for the opportunity of describing these insect-wings from the Middle Coal Measures.

Horizon and locality.—Some 30 to 40 feet below the Top Hard Coal, Middle Coal Measures, Shipley Clay-pit, Ilkeston (Derbyshire).

Lying at a lower level in the nodule, and partly obscured by the wing of *Cryptovenia moyseyi*, was what appeared to be a second wing. The position occupied by this structure will be seen by reference to fig. 5 (Pl. XXXII). The obscuring layer was an extremely thin film of ironstone, which, as it bore the impress of *Cr. moyseyi*, could not well be chipped away. By the kindness of Dr. A. Smith Woodward, F.R.S., the specimen was entrusted to Mr. R. Hall, of the Geological Department of the British Museum (Natural History), who succeeded with remarkable skill in lifting, undamaged, the upper ironstone film and wholly exposing the structure beneath.

To Mr. Hall I am indebted for means of examining what appeared to be a wing when partly exposed, but which, when fully seen, resolved itself into a pinnule of *Neuropteris*. My inability to regard it as a wing caused me to submit the question to Dr. Handlirsch, who suggested that it might belong to *Dictyopteris* or *Neuropteris*. Dr. E. A. Newell Arber, who has seen the specimen unhesitatingly refers it to the latter genus.

SOOMYLACRIS (ETOBLATTINA) BURRI, sp. nov. (Pl. XXXIII, figs. 1 & 2.)

A short, broad left tegmen, 14 millimetres long and 8 mm. broad. A small portion of the tip of the wing is missing. The length of the wing is thus barely twice its greatest breadth.

The wing lies in an inverted position upon the surface of a dark shale. The upper surface evidently is evenly and regularly convex, the concavity of the under surface only being presented to view. The wing-margin is well marked, and stands up in slight relief.

The costal and anal angles are well rounded, the former being unusually well developed and prominent.

The wing is broadest across the middle of the costal and anal areas, and tapers equally on the inner and outer margins to the obtuse tip. A slightly-flattened marginal area stretches from the centre of origin of the veins across the costal angle, diminishing in width, and dying out along the inner margin at a point about five-sixths of its length. The costal angle is broad, strongly rounded, and triangular. The subcosta is sunken, and arises as a short stout vein giving off forwards two forked branches which die out in the middle of the costal angle. Very slightly above the origin of these branches it divides into two, the inner of which divides again into two somewhat widely-spaced rami. These, and the outer branch which forks near the margin, pass obliquely forwards to the outer margin. As their obliquity is considerable, the outer branch reaches the margin at the middle of the wing.

The radius is a large vein dividing low down, and occupying the greater part of the area of the outer half of the wing. The main stem has an outwardly-directed curve in its lower fifth, after which it passes straight upwards to the middle of the wing-tip. Seventeen marginal rami arise from seven branches of the main stem of the radius. Of these, the fourth and sixth only are simple, all the rest forking once, with the exception of the first, which forks three times, and ends upon the margin in six rami. All the branches of the radius remain parallel one to the other and to the marginal rami of the subcosta.

The general course of the main stem of the radius is such that it marks off an outer half of the wing from an inner portion, which contains the median, cubital, and anal veins. Over the greater part of its course the main stem of the radius is parallel to the costal margin. The rami pass out very obliquely to the margin: their point of origin being low down, as contrasted with the distal terminations on the margin.

The median vein is continuous at its base with the basal portions of the radius and cubitus. At a very short distance above its separation from the common stem it bifurcates in two unequal branches, the outer of which runs almost straight to near the tip of the wing, forking twice in the upper part of its course. The marginal rami of the median vein occupy the outer fourth of the inner margin of the wing and the inner half of the wing-tip.

The inner branch takes a broad shallow inward sweep as it runs outwards to the distal portion of the inner margin. It gives off, quite low down and on its outer side, a single ramus which forks three times before ending in the inner half of the wing-tip.

The cubitus pursues a course parallel to the inner division of the median, giving off six inwardly-directed oblique and simple branches, all of which reach the wing-margin without further division. The marginal area of the cubitus is a little less than that of the median, while all the branches have the same degree of obliquity.

The anal furrow is deeply sunken, and bent almost at a right angle at the junction of the first and second fourths of its length, beyond which point it passes obliquely outwards to the margin. As the angulation of the furrow takes place at some little distance below the point of origin of the first branch of the cubitus, the space between the latter and the anal furrow is very broad near the middle line of the wing, and diminishes to a normal width as the margin of the wing is reached.

The anal area is large, broadly triangular, and shelves off steeply near the middle line of the wing into the deep anal furrow. It is almost as large as the costal area, but the anal angle is more pronounced, being not so well rounded as the costal. Four anal veins are present, the first dividing twice before it reaches the margin in three rami; the second forks low down, and then follows a curved course to the margin, the convexity of the curve being directed towards the inner margin. The third vein is simple, and follows a parallel course of the inner ramus of the second, while the fourth vein is forked twice and similarly curved.

The general character of the wing is that of a strong, horny or leathery structure, articulated to the body by a powerful and rigid base composed of the united subcostal, radial, median, and cubital veins.

Affinities.—Fortunately this wing is a well-marked type, and there can be no hesitation in referring it to the family Mylacridæ.

The broadly-triangular costal and anal areas, the short stout character of the wing itself, and the general mode of division of the radial, median, and costal veins, are alike all distinctive.

Dr. Handlirsch has already pointed out [1] that the family has certain Archimylacrid affinities, due, he believes, to the family being a lateral branch which arose at an early date, and still preserved certain primitive characters. These Archimylacrid affinities are seen in the much-branched radius, and in the presence of two main branches of the median.

The relation of this wing to *Hemimylacris obtusa* Bolton, from South Wales, is remarkably close.[2] In both, the costal area is

[1] 'Revision of American Palæozoic Insects' Proc. U.S. Nat. Mus. vol. xxix (1906) p. 766.

[2] 'Insect-Remains from the South Wales Coalfield' Q. J. G. S. vol. lxvii (1911) p. 154 & pl. x, figs. 4–5.

triangular and strongly convex. The radius is a much-branched vein, with the inner branch considerably divided. The main stem of the radius runs out in the tip of the wing in each case. The anal area is angulated, and in each the anal furrow is sharply bent almost at a right angle, while the chief anal veins are forked. Important differences are observable in the case of the subcostal, median, and cubital veins. The costal vein in the wing under consideration is a relatively simpler structure than in *H. obtusa*, the median is more Archimylacrid also in its division into two main branches, and the cubitus throws off a series of simple undivided branches. These differences are, I believe, of more than generic importance—a view already upheld by Dr. Handlirsch, who has taken the division of the median into two main branches as the distinctive feature of a new genus, *Soomylacris*.[1] To this new genus Dr. Handlirsch has also referred the *Etoblattina deanensis* described by S. H. Scudder.[2]

I am indebted to Dr. Handlirsch for drawing my attention to his genus *Soomylacris*, otherwise I should have unhesitatingly referred the specimen to *Hemimylacris*, with which it has much in common.

A comparison of the specimen with the type-species of *Soomylacris* (*Etoblattina*) *deanensis* shows that in the form now described the subcosta is relatively simpler and has fewer divisions than that of *S. deanensis*. The radius is a much-branched vein, with the lowest ramus considerably divided in both cases, and occupying the same area. The biramal division of the median is a marked feature in the type-species, and still more so in the form under discussion.

In *S. deanensis* the splitting into two rami takes place at the middle of the wing, and of the two divisions the outer is the more complex, ending upon the wing-tip in at least six rami. In the Dover form the outer division of the median is much the simplest, and ends just behind the wing-tip in three rami only. The biramal division of the vein also takes place below the middle of the wing. In *S. deanensis* there are twelve marginal rami for the whole vein; in the Dover specimen there are but eight.

The cubitus in *S. deanensis* has its branches forking before reaching the margin, while the branches of the same vein in the Dover form are wholly simple and parallel one to the other throughout their entire length. In both forms the first anal vein shows repeated bifurcation.

The differences are quite obviously of specific rank, and I have therefore much pleasure in giving the name of *Soomylacris (Etoblattina) burri* to the Dover specimen, in honour of Dr. Malcolm Burr, to whom I am indebted for the opportunities of research in the Dover Coalfield which resulted in the discovery of the specimen.

[1] 'Die Fossilen Insekten & die Phylogenie der Rezenten Formen' Leipzig, 1906–1908, p. 259.

[2] 'The European Species of *Etoblattina*, with Description of a New Form' Geol. Mag. dec. 4, vol. iii (1896) p. 12.

Phylloblatta (?) sp. (Pl. XXXIII, figs. 3–5.)

Portion of a blattoid wing-fragment, 5 millimetres long and 2·5 mm. broad.

The impression shows a portion of the subcostal and radial region of a right tegmen. The outer margin is very gently rounded, while the depth of the venous impressions indicates that the wing was of a robust type.

The subcostal area must have been broadly ovate in shape. The course of the two outer rami only is shown, and these gradually curve forward to the costal margin, the outer ramus reaching it at a little above the estimated third of its length.

The radius is a strong, much-branched vein arising in close proximity to the subcosta, but diverging from it as it bends outwards towards the margin. Five branches can be distinguished, the two outermost only remaining single. The first gives off two faint rami on its outer side, neither of which reaches the margin. The second branch forks into two and then into four, while the third branch forks once. The course pursued by the branches of the radius is such that they must have occupied the greater portion of the distal outer margin of the wing. It was not possible to determine whether the main stem was continued into other branches ending in the tip of the wing, but this was probably the case. The interspaces between the veins are filled with a series of straight closely-set cross-veins.

The broad and shortened form which this wing must necessarily have possessed, as determined by the characters of the radius, the manner in which that vein branches, and the shape of the costal area, is a character which places the wing-fragment in the family Mylacridæ. Generic and specific distinction is not possible.

Horizon.—At 1028 feet in the Coal Measures, Kent Coalfield.

Impression of a blattoid wing-fragment, 3 millimetres long and 2·25 mm. wide. (Pl. XXXIII, figs. 6 & 7.)

The impression shows the course of three branches, the two outer dividing by forking into two equal branches. In the case of the longer branch, the division occurs some distance from the margin. The shorter branch divides quite close to the margin.

The margin of the wing-fragment is strongly curved, so much so as to indicate clearly the tip of the wing. The branches must, therefore, belong either to the radial or to the median vein. The areas between the branch-veins are filled with a close meshwork, a feature which is common to several genera.

Genus and species indeterminable.

Horizon.—At 2381–6 feet from the surface, in the Coal Measures, Kent Coalfield.

Phylloblatta (?) sp. (Pl. XXXIII, figs. 8 & 9.)

Impression of a portion of a blattoid wing, 6 millimetres long and 3 mm. broad. The fragment forms more than a quarter of the whole wing, and represents the proximal outer portion of the wing, including the subcostal and radial regions.

The subcostal area is strap-shaped; the costal vein gives off four branches which pass off obliquely to the margin, extending over two-fifths at least of the margin.

The radial vein is less impressed upon the shale than the subcostal, and the proximal portion of the stem is indistinguishable. At a point in line with the last division of the subcostal vein the stem of the radius is clearly seen. The radial vein is represented by a portion of the main stem and two branches, the inner of which breaks up into three rami before reaching the margin, while the second, so far as it is preserved, shows no signs of bifurcation. The forward course of the radius cannot be determined. Enough, however, of the radius is seen to demonstrate that it must have occupied the whole of the outer margin of the wing beyond the subcostal margin.

In this respect, and in the character of the subcosta so far as shown, the wing-fragment agrees with the genus *Phylloblatta* of Dr. Handlirsch. To this genus I refer it, but somewhat doubtfully because of its fragmentary and inconclusive character.

I have pleasure in warmly acknowledging my indebtedness to Mr. J. W. Tutcher, who prepared enlarged photographs of the wings, without which the work could not have been undertaken; to Mr. R. E. J. Bush, A.R.C.A., who prepared the wing-diagrams from my rough drawings; and to Dr. A. Handlirsch, of Vienna, who has given me much help by advice and criticism.

EXPLANATION OF PLATES XXXI-XXXIII.

Plate XXXI.

Orthocosta splendens, gen. et sp. nov. (P. 310.)

Fig. 1. Impression of left wing. Natural size.

2. Left wing (natural size), showing the outer third with veins in relief, and the inner two-thirds with the marginal divisions of the median, cubital, and anal veins, lying in deep sulci.

3. Restoration of wing-outline, showing portion preserved. Natural size.

Plate XXXII.

Fig. 1. *Pteronidia plicatula*, gen. et sp. nov. (P. 313.) Inner half of the left wing, showing the almost straight margin and plicate folding. Natural size.

2. The same. Impression of the greater part of the left wing, showing stout oblique cross-veins. Natural size.

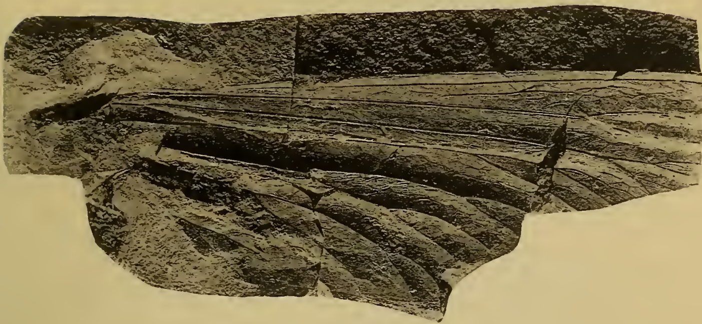
3. The same. Restoration of the left wing. Natural size. (This drawing ought to be reversed, the tip to point to the left.)

4. *Cryptovenia moyseyi*, gen. et sp. nov. (P. 315.) Greater part of the left wing, showing the backwardly-curved tip. Magnified × 3·5.

5. The same. Impression of the left wing, showing the complex series of wrinkles crossing the marginal veins. Magnified × 3·5. (The pinnule of *Neuropteris*, mentioned in the text, p. 317, is seen partly embedded in the nodule under the wing-impression.)

6. The same. Restoration of the left wing. Magnified × 2·5. (This restoration, like that of fig. 2, ought to have the tip turned to the left.)

1.



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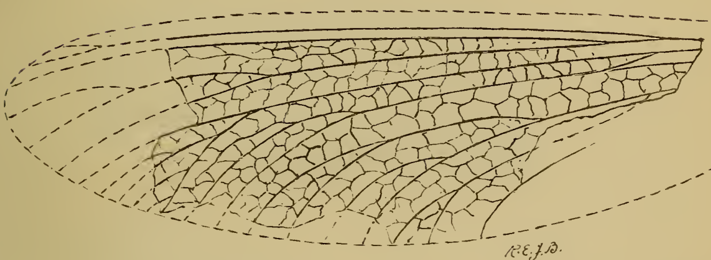


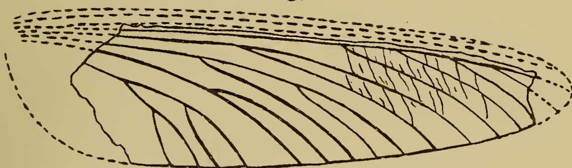
2.

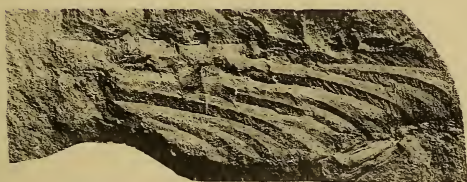
J. W. Tutcher, Photo. Bemrose, Collo., Derby.

ORTHOCOSTA SPLENDENS, gen. et spec. nov.

1.

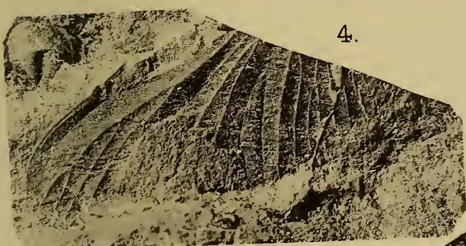
3.





2.

4.



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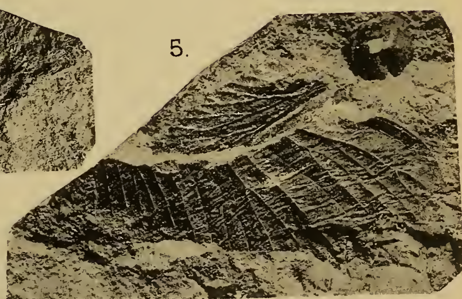
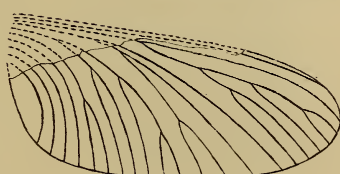


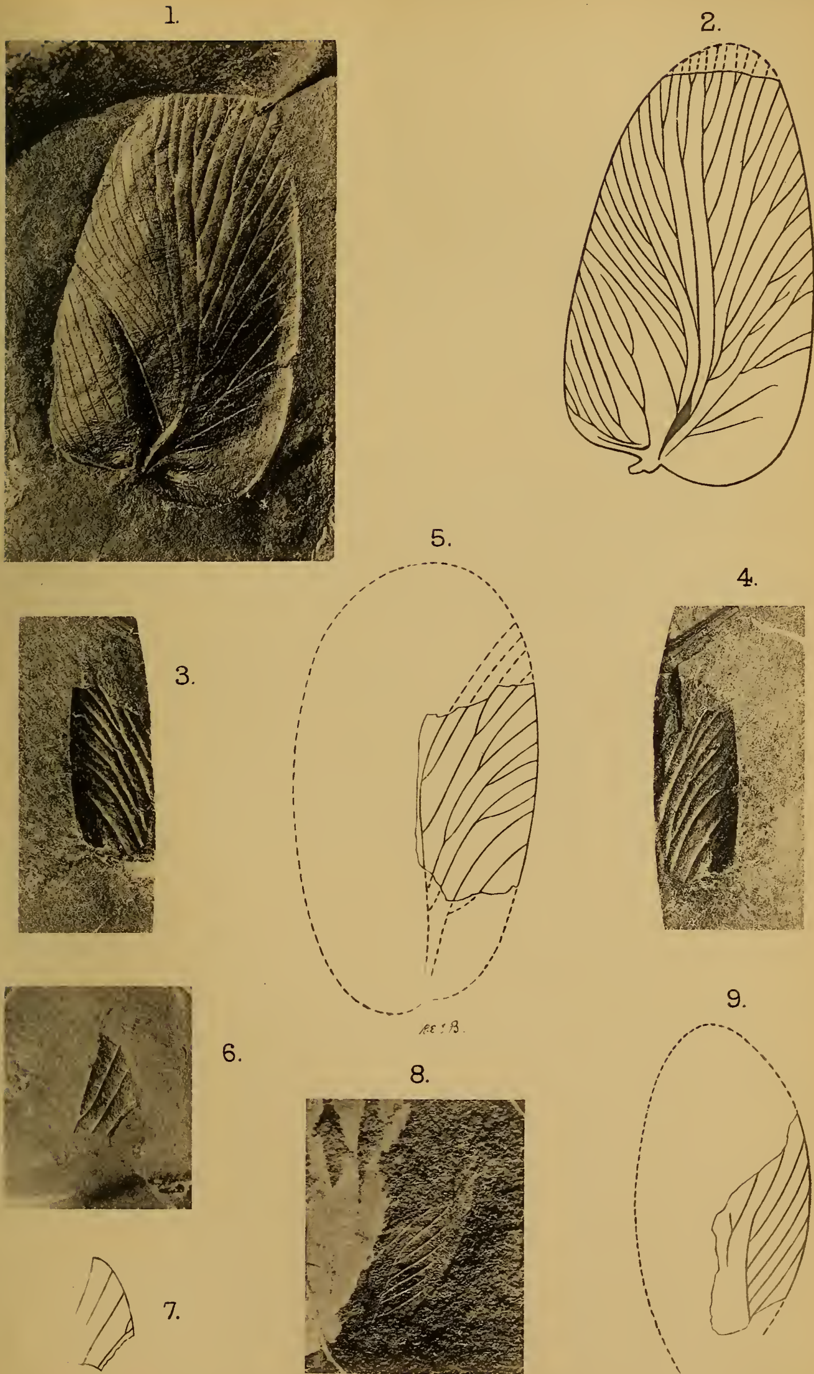
6.



J. W. Tutcher, Photo.

Bemrose, Collo., Derby.

PTERONIDIA PLICATULA, gen. et spec. nov., and
CRYPTOVENIA MOYSEYI, gen. et spec. nov.



J. W. Tutcher, Photo.

Bemrose, Collo., Derby.

SOOMYLACRIS (ETOBLATTINA) BURRI, sp. nov., and PHYLLOBLATTA, sp., etc.

Plate XXXIII.

Fig. 1. *Soomylacris* (*Etoblattina*) *burri*, sp. nov. (P. 318.) Left tegmen seen from underneath. Magnified × 4·5.
2. The same. Outline restoration of the wing. Magnified × 4·5.
3. *Phylloblatta (?)* sp. (P. 321.) Middle portion of the anterior border of a right tegmen or wing-fragment. Magnified × 4·5.
4. The same. Impression of tegmen or wing-fragment. Magnified × 4·5.
5. The same. Restored outline of tegmen, showing the part preserved.
6. Impression of blattoid wing-fragment. (P. 321.) Magnified × 4·5.
7. Outline of wing-fragment shown in fig. 6.
8. *Phylloblatta (?)* sp. (P. 321.) Impression of blattoid wing-fragment, showing rami of the costal vein and a portion of the radius. Magnified × 4·5.
9. The same. Restoration of the outline of the wing, to show the portion preserved.

Discussion.

The President (Dr. A. Strahan) complimented the Author on producing an admirable piece of work from most difficult material. A point of considerable interest was the possible correlation of the Kent Coal Measures with those of the Forest of Dean. The stratigraphical sequence was of little help; but, if insect-remains aided in the determination of a horizon, they would prove of the greatest importance.

The Author thanked the President and Fellows for their kind reception of his paper, and, in reply, said that the occurrence of blattoid wings in the Kent Coal Measures was accompanied by a molluscan fauna of some interest which might yet serve to link up the rocks of Kent with the Coal Measures of Somerset. The occurrence of a species of *Soomylacris* in Kent, and of another species of *Soomylacris* in the Forest of Dean, was also significant.

17. Shelly Clay Dredged *from the* Dogger Bank.

By John Walker Stather, F.G.S. (Read June 5th, 1912.)

Some little time ago my attention was drawn to some notes[1] in the 'Essex Naturalist' on the subject of 'moorlog,' a tough compact peaty deposit, which is dredged from various parts of the southern portion of the North Sea, but principally from the Dogger Bank.

It occurred to me that a comparison of this 'moorlog' with the post-Glacial peat-deposits, which are found at various points on the coast of East Yorkshire, might prove of interest, and I consequently arranged with Capt. H. G. Foot, of the Hull trawler *Grosbeak,* to bring me any of the material of this kind that came into his nets. He informed me that the 'moorlog' is well known to the fishermen of the North Sea, and that great cakes of it are frequently brought up in the trawls. Since then, from time to time, he has procured for me large pieces of this peaty material, which coincides precisely with the description of the 'moorlog' given by Mr. Clement Reid, and supports his suggestion that it represents a land-peat accumulated on boggy ground.

One large slab which Capt. Foot brought in, however, was of peculiar interest, as it showed adhering to the peat a portion of another deposit of altogether different character. This adherent material was not peaty, but consisted of dark silty clay with shells, and when dried bore some resemblance to the shelly marls that occur in some of the post-Glacial lacustrine deposits of the coast, though differing in the character of the shells, which in this case were marine.

On questioning Capt. Foot, I learnt that the dark shelly clay associated with the 'moorlog' was well known to the fishermen, and was frequently brought up in the trawls. Further, I was informed that on one portion of the sea-bed, along the northern edge of the Dogger Bank, called by the fishermen the 'Clay-banks,' a large surface of this clay is exposed. The position of the submerged clay-bed is common knowledge to the fishermen, who avoid that particular part of the fishing-ground because of the danger of losing their tackle in the sticky clay. I may add that Capt. Foot (who is admiral of the *Gamecock* fleet of trawlers, and has acquired by long experience a thorough knowledge of the fishing-grounds of the North Sea) expressed the opinion that there is a distinct outcrop of 'moorlog' resting directly upon the shelly marl, and that both materials occupy large areas in the North Sea basin, south of the line drawn from Whitby to Jutland.

[1] H. Whitehead & H. H. Goodchild, 'Some Notes on "Moorlog," a Peaty Deposit from the Dogger Bank in the North Sea.' With Report on the Plant-Remains, by Clement Reid, F.R.S., & Mrs. Reid (with map & illustrations), 'Essex Naturalist' pts. i & ii, vol. xvi (April–July, 1909) p. 51.

In a recent letter (May 8th), received from Capt. Foot, he says :—

'I find :

"Moorlog" and light-coloured clay in	Lat. 55° 30′ N. Long. 3° 10′ to 3° 15′ E.
"Moorlog," dark clay, and stones in...	Lat. 55° 10′ to 55° 20′ N. Long. 2° 30′ to 2° 45′ E.
"Moorlog" in	Lat. 54° 50′ N. Long. 4° 40′ to 4° 55′ E.
Light-blue clay in	Lat. 55° 55′ N. Long. 5° 35′ E.'

The actual specimens of 'moorlog' and associated shelly clay, which I received from Capt. Foot, were dredged in lat. 55° 24′ N., and long. 3° 10′ E., at a depth of 20 fathoms.

The position of these places in relation to the Dogger Bank is shown on the accompanying sketch-map.

Map showing the localities where 'moorlog,' etc. was dredged.

[1 = Pale-blue clay; 2 = 'Moorlog' and light-coloured clay; 3 = 'Moorlog,' with dark shelly clay; 4 = 'Moorlog,' with dark clay and stones; 5 = 'Moorlog.']

The clay is almost black when wet, but lighter in colour when dried. It consists mainly of sandy and silty particles, so fine in texture as to give a clayey character to the mass, and is not unlike some of the varieties of mud found in the lower reaches of the

Humber. In parts it is crowded with marine shells, in a semi-fossil state, the larger bivalves showing signs of crushing, though in some cases the cuticle and colouring are also preserved. Some of the bivalves occur with their valves united, in the attitude of life. Foraminifera are also abundant.

I submitted the specimens of mollusca to Mr. Clement Reid, F.R.S., for identification, and he kindly sent me the list and notes which follow :—

'From the marine clay—

Flustra.	*Littorina rudis* Maton.
Anomia ephippium Linn.	*Onoba striata* J. Adams (=*Rissoa*).
Cardium edule Linn.	*Paludestrina stagnalis* Baster (=*Hydrobia ulvæ*).
Montacuta, sp.	*Zippora membranacea* J. Adams (=*Rissoa*).
Mytilus or *Modiola.*	
Littorina obtusata Linn.	

'These are all very shoal-water species, and probably flourished just below low-water level; they point to a subsidence of the Dogger Bank to the extent of 50 or 60 feet.'

The chief interest of the shells lies in the support which they afford to the evidence of the 'moorlog' as to the post-Glacial change of level in the North Sea basin. Granting that the overlying peat was accumulated on low flat land, we find in the shelly clay proof that some part of the same area was previously occupied by shallow salt water, until a slight upward movement brought it above sea-level, and allowed the formation of peat.

Then, at some time after the 'moorlog' was formed, the whole area was depressed to its present level. The shelly clay is very different in composition from the sandy deposits at present forming on the shallow bed of the North Sea, and indicates the proximity of land and the presence of shallow, almost undisturbed waters.

In conclusion, I may add that I hope, with the help of my friend of the Trawler Fleet, to secure more of this interesting shelly material.

Discussion.

Mr. Clement Reid spoke of the importance of these discoveries, which threw light on the origin of the North Sea. Three, or perhaps four, different late-Tertiary deposits had now been found on the Dogger Bank. In addition to the 'moorlog' and its underlying estuarine clay, former dredgings seem to show that there was a bed containing large striated erratics, and another bed containing various extinct Pleistocene mammals; but, unfortunately, the latitude and longitude of these earlier finds had not been recorded.

He thought it possible that the considerable depth at which the 'moorlog' and estuarine deposits had now been found might be due, in part, to subsidence through the compression of a thick mass of underlying soft strata containing much organic matter. The submerged peat-bed of the Dogger Bank was fully 30 feet lower than the lowest met with in our valleys.

These discoveries seem to dispose of the idea that the Dogger Bank is in any way connected with a submerged escarpment of the Mesozoic rocks.

Mr. A. S. KENNARD congratulated the Author on his work, and on the importance of the fresh evidence which he had collected. In the speaker's opinion the deposits are of late Pleistocene age, and may well be correlated with the buried channel of the Thames. The occurrence of these soft strata and of the well-known buried river-channels beneath the North Sea seem to the speaker to show that the subsidence had been very rapid; for these clays and peats, if they had been exposed between tide-marks, would have been quickly destroyed.

Mr. S. H. WARREN remarked upon the variety presented by the deposits which underlay the salt-marshes of the east coast of England. In some cases these are of the Early Bronze Age; in others they are Pleistocene, and contain remains of *Elephas primigenius* or *E. antiquus*, and *Unio littoralis*. In one case the speaker had found that a freshwater deposit with *U. littoralis* had been redistributed, during the Pleistocene Period, under marine conditions. Similar conditions might be expected to obtain on the Dogger Bank, and this would make the unravelling of such hidden deposits a matter of great difficulty. Careful records, such as those presented by the Author, were of great value.

Mr. H. WHITEHEAD stated that, since the publication of a paper by Mr. Goodchild and himself, they had received a specimen of 'moorlog' from lat. 55° 10′ N. and long. 4° 20′ E., which was similar in character to the specimen exhibited by the Author. It contained shells (chiefly *Cardium*), several of which had the valves united; the matrix was a blackish mud which yielded many seeds, identified by Mr. Clement Reid as those of *Ruppia rostellata*. Other plant-remains were present, some of which were in a state of fine division.

18. *The* Geological Structure *of* Central Wales *and the* Adjoining Regions.

By Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S.

(Read April 17th, 1912.)

[Plate XXXIV—Geological Map.]

Contents.

I. Introduction.

The region herein discussed is that portion of Wales which lies, roughly, between the River Dovey and Pembrokeshire; it is bounded on the west by the coast of Cardigan Bay, and on the east by an irregular line coinciding in part with the base of the Wenlock rocks and in part with the margin of the Upper Palæozoic rocks.

It comprises, therefore, the whole of Cardiganshire and a great part of Carmarthenshire and Pembrokeshire, together with portions of Montgomeryshire, Breconshire, and Radnorshire—an area exceeding 1800 square miles in extent. This tract is represented upon geological maps by 'Lower Silurian' colour, only diversified by small areas indicating igneous rocks, or by tracts of yellow dots indicating grits and sandstones.

Ever since the days when Sedgwick and Murchison laboured to introduce order among the old slaty and volcanic rocks of Wales the region defined above has always remained something of a geological puzzle: the apparent uniformity and unfossiliferous character of the strata over wide areas, and the compression which they have suffered by folding, faulting, and cleavage, combined to defy for a long time all attempts at unravelling its structure.

In more recent years the discovery of numerous fossiliferous beds among these strata has made possible the application of the zonal method, based in this case upon the range in time of various genera and species of graptolites. By this method, combined with close attention to the lithological characters of the rocks, attacks have been made upon this 'geological wilderness,' which have met with a certain measure of success.

At the present time the general rock-succession of this territory is firmly established, and the characteristic organisms of the different groups are well known; it is believed also that enough is now known of the distribution of the great rock-groups to enable us to indicate in broad outline the chief structural features of the area.

In the present communication the attempt is made to bring together a summary of the results of various investigations which bear closely upon the rock-succession and structure of the area, and to add various personal observations made at different times which have not hitherto been recorded. On the basis of these combined investigations a map has been prepared showing the general distribution of certain rock-groups which are comparatively easy to recognize, either by their lithology or by their organic contents.

This map has been constructed without reference to the physical interpretation of the region, but it is obvious at a glance that certain structural features and their relation to the present topography are brought out with great clearness. (See Pl. XXXIV.)

The detailed structure must, however, still remain a subject for further research. There are other problems also which await solution; some of these are indicated below.

II. Historical Review.

The series of slaty rocks, sandstones, and conglomerates which occurs to the west of the main Wenlock boundary was not closely investigated by Murchison; he remarks [1] that

'there is, indeed, no well-defined line of separation between the coarse quartzose slates of Rhayader and the masses of more crystalline slate which are repeated upon parallel lines between that town and Plinlymmon. . . . They all belong to the upper group of the Cambrian System, and are of the same age as many mountains in Montgomeryshire (Moel-ben-tyrch, &c.), the whole of which have been proved by Professor Sedgwick to be of younger date than the slates of Merionethshire, &c.'

It is clear that the structure of this tract was unknown to Murchison, and on p. 360 (*op. cit.*) it is stated that the

'separation of the Lower Silurian rocks from the Upper Cambrian has been generally effected by assigning to the former those beds which contain fossils and to the latter those which do not.'

Sedgwick's connexion with the district was brief; in 1846 he

'made two hasty traverses through it between the Upper Silurian groups and the sea—one from Aberystwyth to Builth, the other from Llandovery to Aber Aeron by Llampeter, and thence back by the road from Llampeter to Carmarthen.' [2]

He had previously traversed the same lines in 1832. As a result of these visits he distinguished four principal groups among these rocks, which he described as the System of South Wales and later as Upper Cambrian (meaning thereby the strata between the Bala Limestone and the base of the May Hill Sandstone, or what is now generally known as the Upper Llandovery).

[1] 'Silurian System' 1839, p. 317.
[2] Q. J. G. S. vol. iii (1847) p. 150.

In the above-cited paper, p. 155, he asserts

'that all the groups . . . . are superior to the slates and porphyries of the whole Cader Idris range, and I think also superior to the Bala limestone ; . . . . The groups occupy . . . . a kind of trough between the older rocks of Pembrokeshire and the chain of Cader Idris, and are thrown into astonishing undulations.'

The groups that he established were not mutually exclusive, and are not arranged (as he believed) in a general ascending sequence from west to east. It is pleasant to find, however, that as the result of so brief a visit he had discovered the true stratigraphical position of the group of rocks as a whole, and also their general structure. Two of his sub-groups were subsequently adopted by Walter Keeping and myself, namely, the Aberystwyth Group and the Plynlimon Group. Reference will be made to other results below.

About the year 1845 appeared Sheets 4, 5, and 6 of the Horizontal Sections of the Geological Survey, which crossed in various places the district lying between the Old Red Sandstone and Cardigan Bay. These indicate in a beautiful manner the nature of the small-scale folding of the area; further, it is clear from these sections that the more important structural lines were made out. From the remarks accompanying the sections it is easy to construct a table of the various groups of rocks along these sections which the surveyors regarded as contemporaneous. The order of the strata in the various districts is everywhere correct, but the correlation of the rocks along the Vale of Towy with those lying between the Vale of Teifi and the sea is at fault. Considering, however, the highly folded nature of the country and the absence of any guiding fossils, it is remarkable how truthful these sections are, although made nearly 70 years ago.

Sir Andrew Ramsay[1] in the 'Geology of North Wales,' records fossils from several localities within the area, as, for instance, Fishguard (graptolites), Abereiddy (various fossils), Cardigan (graptolites), Newcastle Emlyn (various fossils), etc.

Another attempt to unravel the rock-groups and internal structure of Central Wales was made by Walter Keeping.[2] The most important result of his investigation was the discovery of graptolites in several localities, thus proving that the rocks were not everywhere so unfossiliferous as had been supposed by earlier investigators. By this time the value of graptolites as an aid in identifying rocks had been demonstrated by the researches of Prof. C. Lapworth, Mr. J. Hopkinson, and others. By some means, however, the fossils obtained by Keeping at several points represent, as is now known, various horizons, as if they had been obtained mainly from loose material. He was thereby prevented from recognizing the true succession of the rocks, and was led to believe that only one great group existed over the whole area; most of the graptolites were assigned to the Upper Birkhill Group of the South of Scotland.

[1] Mem. Geol. Surv. vol. iii, 2nd ed. (1881) p. 8.
[2] Q. J. G. S. vol. xxxvii (1881) p. 141.

Several of the principal axes of folding were detected by Keeping; but, as he had unfortunately misinterpreted the succession, the anticlinal axes were regarded as synclinal and *vice versâ*. As the result of the discovery of graptolites near Newport and Cardigan [1] he was able to prove that the gritty beds of those districts indicated on the Geological Survey map as Lower Llandovery (b^4) should be assigned to the Bala.

This discovery was confirmed many years later by Dr. C. A. Matley,[2] who examined the coastal tract to the north of Newport.

The investigation of the Rhayader district by Dr. H. Lapworth [3] led to the discovery of lower rocks than had been suspected by Keeping, for Lower Birkhill graptolites were found in abundance, and there was strong probability that the strata underlying the fossiliferous rocks were of some Bala age, although no palæontological evidence was forthcoming to support this conclusion.[4]

This area, however, afforded no sufficient clues for the solution of the structure in the region to the west, inasmuch as it was difficult to correlate the rock-groups described by Keeping with those established on a firmer basis in the Rhayader area, and it became therefore necessary to re-examine Central Wales in the light of these discoveries.

More recently Miss Drew & Miss Slater [5] proved the extension of the rocks of the Rhayader district along the strike south-westwards, at least as far as the district of Llansawel, although certain differences in detail were observed.

The most important results, in their bearing upon the rock-succession of Central Wales, were obtained by Mrs. Shakespear [6] during the investigation of the Tarannon area. It was then shown that the Birkhill rocks were of almost insignificant thickness, as compared with the equivalents of the Gala Group of the South of Scotland (Tarannon Group of Mrs. Shakespear). It would appear from this that the representatives of the great thicknesses of rock which Keeping discovered in Central Wales should be looked for chiefly among the Gala rocks and not among the Upper Birkhill.

Three years later the above results were confirmed in the Plynlimon district [7] in regard to the general rock-sequence, though the succession there exposed does not include the upper portion of the Gala Group. The presence of graptolitic beds of Upper Bala or Upper Hartfell age was also demonstrated, and an enormous thickness of barren beds was found to intervene between them and the base of the Birkhill Group. As these barren strata resemble

[1] Geol. Mag. dec. 2, vol. ix (1882) p. 519.

[2] Proc. Birmingham Nat. Hist. & Phil. Soc. vol. x, pt. ii (1897).

[3] Q. J. G. S. vol. lvi (1900) p. 67.

[4] *Diplograptus foliaceus* was recorded by Dr. H. Lapworth from the rocks some 4 or 5 miles east of Rhayader, indicating that in that direction the strata may even be of Llandeilo age. See 'The Silurian Sequence of Rhayader,' Q. J. G. S. vol. lvi (1900) p. 96.

[5] *Ibid.* vol. lxvi (1910) p. 402.

[6] *Ibid.* vol. lxii (1906) p. 644.

[7] *Ibid.* vol. lxv (1909) p. 463.

closely the beds underlying the Gwastaden Grits of Rhayader, this may be regarded as confirming the Bala age suggested for the latter by Dr. H. Lapworth.

By a fortunate chance, the position of the Plynlimon area proved to be exceptionally favourable for demonstrating the internal structure of the surrounding tract of Central Wales; and, as I have been able to recognize over a considerable stretch of country the rock-groups there established, it is possible approximately to indicate their distribution. These observations, with others made in various parts of the district between the River Dovey and Pembrokeshire, are embodied in the map accompanying this paper (Pl. XXXIV).

In 1910 appeared the 'Geology of North & Central Wales' by Mr. W. G. Fearnsides,[1] where the structure of the district herein described is indicated. The region was compared with the Southern Uplands of Scotland, and a prophetic account is given (p. 816) of the partition of the area among the Ordovician and Silurian rocks. The structure of the area is, however, in several respects simpler than that of the Southern Uplands of Scotland, and the formations occupy larger and more continuous tracts than is suggested in the above-mentioned paper and the accompanying map.

III. The Distribution of the Rock-Groups.

For the purpose of indicating the major structures, it is only necessary to consider a broad grouping of the strata. It is possible, as a rule, to distinguish the rocks belonging to the larger groups by inspection of their lithological characters, although in many instances the discovery of graptolites enables the precise horizon to be determined.

In most cases a subdivision into Ordovician and Silurian rocks suffices; but it is convenient to consider in addition the distribution of the rocks called by earlier observers (Sedgwick, Keeping, etc.) the Aberystwyth Grits. In Pembrokeshire, more particularly, certain additional lines have been added, as they have a bearing upon the structure. In fixing the boundary between the Ordovician and the Silurian the peculiar characters and mode of weathering of the Lower Birkhill rocks have been found useful.

I have refrained, as far as possible, from introducing theoretical considerations as to the structure in drawing the lines on the map. Consequently, they may be regarded as defining the general course of the boundaries. The actual boundaries are almost certainly more complicated than here appears; these, however, are matters of minor detail which are unessential in the present connexion.

(*a*) The Ordovician Rocks.

On the published maps an enormous area of the western and central portions of Wales is coloured as Lower Silurian, which may

[1] 'Geology in the Field' (Jubilee vol. Geol. Assoc.) p. 786.

be taken to indicate in different districts rocks ranging in age from Menevian to Llandovery inclusive. Different series are indicated by letters where supposed rocks of the series have been recognized or proved. Over the greater part of the area herein considered, b^3 indicates that the rocks were regarded as predominantly of Bala or Caradoc age, while b^4, scattered about mainly on the outcrops of the more gritty beds, suggests that those are of Lower Llandovery age.

The Ordovician rocks in the neighbourhood of Fishguard have been described by Mr. F. R. C. Reed,[1] while rocks of the same general type have been observed in other parts of Pembrokeshire. They consist of black graptolitic slates of Arenig and Llandeilo age alternating with felsitic flows, tuffs, and breccias. Their distribution on a large scale may be assumed to coincide generally with the igneous area of North Pembrokeshire; on a geological map these igneous rocks end off abruptly along a fairly even line (see Pl. XXXIV).

In the Newport district the volcanic series is succeeded by graptolitic shales of the age of the black *Dicranograptus* Shales of South Pembrokeshire; the graptolites recorded by Mr. Reed indicate, as is now known, a low horizon in those shales.

These are followed north of Newport by a great slaty and gritty series. According to Keeping and Dr. Matley (*opp. supra cit.*) these consist of black slates containing Diplograptidæ, alternating with pale-blue and grey felspathic grits. In the latter, near Pwll-y-wrach, I discovered, some years ago, numerous impressions of shelly fossils; they deserve further study. The graptolites found in this series by Keeping and Dr. Matley (especially by the former at Cardigan) indicate a horizon about the top of the *Dicranograptus* Shales, which seem, therefore, to be represented in this district by an altogether peculiar facies.

In the more southerly parts of Pembrokeshire the *Dicranograptus*-Shales are succeeded by blue mudstones, probably of the same general age as the Redhill and Slade Beds described by Dr. Marr and the late T. Roberts [2] in the Haverfordwest district.

The same general change takes place in North Pembrokeshire, for, in a lane south of the Glogue quarries, between Crymmych Arms and Llanfirnach, I observed typical black *Dicranograptus*-Shales or slates (for they were highly cleaved) with abundant specimens of *Mesograptus* sp. and *Dicranograptus brevicaulis*, representing, therefore, a low horizon in those shales. Similar shales occur at Crymmych Arms and southwards, where they appear to succeed the felsitic rocks of Foel Trigarn. Farther north, between Crymmych and Cardigan, blue-grey cleaved mudstones and slates occupy an enormous area; as these cannot be compared with any part of any facies of the *Dicranograptus* Shales or lower beds, it is probable that they occur on a higher horizon.

[1] Q. J. G. S. vol. li (1895) p. 149.

[2] *Ibid.* vol. xli (1885) p. 476; *cf.* D. C. Evans, *ibid.* vol. lxii (1906) pp. 602 & 640.

Strata of this nature form the coast-line for several miles north of the mouth of the Teifi, and cover an extensive area between Cardigan and Newcastle Emlyn, and around the latter place. They consist generally of greenish-blue or blue-grey mudstones, sometimes containing thin bands of fine-grained sandstones or sandy seams. They present often a striped appearance, but in other cases have a very uniform aspect. They are traversed by an imperfect cleavage, which causes them to break up into rough elongated slabs.

Along the Cardigan road near Newcastle Emlyn the mudstones contain numerous thin bands of dark pyritous shales; some of these yielded abundantly specimens of a small *Climacograptus* (probably *C. miserabilis* Elles & Wood), and near a place called Craig-yr-huad, a mile and a half north of Newcastle Emlyn, a thin dark seam yielded several specimens of *Diplograptus truncatus* Lapw. These forms point to an Upper Bala or Upper Hartfell age for these rocks, similar to those of Plynlimon. The most important evidence, however, was obtained in the west, between Aberporth and Penbryn, south-west of Llangranog, for greenish-blue sandstones of the type described above pass up into dark-blue thick-bedded mudstones with shaly iron-stained bands. These yielded, some years ago, beautifully preserved specimens of *Diplograptus truncatus*, *Dicellograptus* sp., and *Orthoceras*, thus establishing beyond question their Hartfell age. It is clear, therefore, that North and South Cardiganshire are both occupied by late Ordovician rocks.

On account of similarity in lithological characters to the rocks of the Plynlimon district, the mudstones underlying both the Gwastaden Grits of Rhayader and the conglomerates and sandstones of the Llansawel district are probably of similar age. These rocks appear to form a strip to the west of the Towy valley as far as Rhandirmwyn, and thence strike north-eastwards towards Rhayader. They were recognized by Sedgwick[1] as being below the Bwlch Trebannau conglomerates, which have been shown by Miss Drew & Miss Slater to occur at the base of the Silurian.

(*b*) The Silurian Rocks.

The succession of the Silurian rocks in Central Wales is sufficiently described in the papers on Rhayader, Tarannon, and Plynlimon quoted above. The peculiar rusty-weathering dark shales and flags forming the lower part of the Silurian have lately been recognized in several localities in North Cardiganshire, as, for example, at the mouth of the Llyfnant valley, near Treddol, east of Talybont, near Craig-y-Pistyll, etc., so that the boundary between the Ordovician and Silurian can be indicated with fair success in that district.

Similar strata were observed also close to the River Towy, near Ystradffin, about 9 miles north of Llandovery, where they are succeeded by pale striped mudstones of Upper Birkhill type. Some poorly preserved Monograptidæ and crowds of *Climacograptus* sp.

[1] Phil. Mag. ser. 4, vol. viii (1854) p. 481.

were observed near the junction. These rocks are followed north-westwards along the deep and picturesque valleys of the Pysgottwr, Doethie, etc., by a great thickness of pale mudstones and shales of Gala type, which appear to form an ascending series towards the Towy watershed. I have traced a similar succession for several miles to the south-west, past Cilycwm and Bwlch Trebannau, where the red-stained rocks overlie the fossiliferous conglomerates described by Sedgwick (*loc. supra cit.*). They were observed also by Miss Drew & Miss Slater in the Llansawel area, and were traced along the strike for some distance to the south-west, there following in the main the Cothi Valley. There is little doubt, consequently, that Lower Birkhill rocks form a continuous outcrop from Rhayader to beyond Llansawel. Their base-line probably occurs some distance to the east, following in all likelihood a belt marked on the maps by frequent outcrops of grits. In some cases these grits have proved to be of Bala age (for instance, Taliaris), in others (Llansawel) they form the base of the Silurian. Without further investigation, therefore, it is impossible to say at what precise point the boundary should be drawn, but that it lies within this arenaceous belt is clear. Along this belt, farther south-west, lie the massive grits of Conwil, which appear to have yielded shelly fossils to Ramsay and others, and were assigned to the Lower Llandovery. They bear a close resemblance lithologically to those of Moelfre, near Llansawel (base of Birkhill), and the sandstones forming the base of the Lower Llandovery south of Llandovery. This range of grits in its westward prolongation passes some distance to the north of Mydrim, where the succession has been described by Mr. D. C. Evans,[1] and in the Geological Survey Memoir on the District around Carmarthen. The rocks of that district lie on the northern limb of a great anticline which passes near St. Clears and Whitland, and the gritty strata occupy either a high horizon in the blue mudstones (Upper Bala ?) which succeed the *Dicranograptus* Shales, or lie immediately above them at the base of the Silurian. What leads to some doubt as to their precise stratigraphical position, is the fact that the Slade and Redhill Beds (or blue mudstone group) along the Eastern Cleddau contain beds of grit in the upper part similar to those at the base of the Silurian.

In the southern limb of the St. Clears anticline the first important grit horizon lies at the base of the Silurian, and above the blue mudstone group. Whatever the precise age of the Conwil Grits, the stratigraphical error of regarding them as the base of the Silurian is comparatively unimportant, so far as regards the structure.

Along the strike of these grits, farther west, *Dicranograptus*-Shales and other Ordovician rocks were traced by Mr. D. C. Evans, and similar rocks probably occur almost continuously between Mydrim and Llanfirnach or Crymmych Arms (see Pl. XXXIV). The grit outcrop must, therefore, come to an end not far to the north of Mydrim.

[1] Q. J. G. S. vol. lxii (1906) p. 597.

Between Conwil and Newcastle Emlyn is an extensive tract of slaty rocks indicated on the Geological Survey map (Sheet 40) as 'argillaceous slates,' 'argillo-arenaceous slates,' 'argillaceous slates with thin grit-bands' and occasional sandstones. As the rocks around Newcastle Emlyn are of Ordovician age, while those of Conwil are at or near the base of the Silurian, the intervening slaty tract must be synclinal in form and shared by rocks of the two systems. Their line of demarcation is entirely unknown. At New Quay Road Station are dark-blue cleaved mudstones resembling very closely the higher Bala rocks of Cardiganshire; while, between that place and the next station (Maesycrugiau), are exposures of bright rusty-weathering shales of Lower Birkhill type. It is suggested, therefore, that the Ordovician-Silurian boundary lies somewhere near these localities.

The only other district concerning which information is forthcoming is the coast south of Llangranog. The *Dicellograptus*-bearing mudstones (p. 334) are there succeeded by a considerable thickness of grey grits; these are followed by 200 to 300 feet of dark-blue, flaggy, sandy shales and mudstones, which are exposed on the steep slopes south of Traeth Bach (three-quarters of a mile south-west of Llangranog). I have searched these shales for fossils, but without success. They appear to be followed conformably by dark shales with thin bands of dark-grey grits showing curious markings like annelid trails, and closely resembling in their lithological characters the beds at the base of the Aberystwyth Grits farther north. On the Geological Survey map the Aberystwyth-Grit formation reaches the coast at this point.

Owing to the nature of the cliffs, I have been unable, so far, to examine closely the junction of the Bala and the overlying grits; but there is little doubt that we reach here the junction between the Bala and the Silurian rocks sought for by Keeping. As, however, the base of the Aberystwyth Grits lies in this locality only a few hundred feet above the base of the Silurian, whereas farther north the underlying beds are probably ten times as thick, some explanation of their anomalous position is required. Several explanations are possible, namely:—(1) The Aberystwyth Grits may here be equivalent palæontologically to the greater part of the Birkhill and Gala rocks, whereas farther north they represent only a part of the higher Gala rocks: that is, the grit facies commences at successively lower horizons towards the south, as has been described among the Ordovician and Silurian rocks of the South of Scotland. (2) There may be an unconformity or overlap, either at the base of the grits overlying the Bala, or at the base of the Aberystwyth Grits, or even at both levels. The conditions would then be similar to those among the Upper Birkhill and Gala rocks of Rhayader, as described by Dr. H. Lapworth. This section requires further investigation, but it is only at certain times that the state of the tide will admit of its examination.

The course of the base of the Silurian between this point and New Quay Road is hypothetical, but the line drawn on the map appears to separate in a general way the tracts of Silurian and Ordovician rocks.

The Aberystwyth Grits.—Fortunately the base-line of these grits can be traced with greater precision than that of most of the other groups, and it affords useful information regarding the structure. The grits form two belts, one lying between the Teifi Valley and the coast of Cardigan Bay, and extending from Borth to near Llangranog. This outcrop is indicated on the Geological Survey map, but it is possible that, in certain cases (near Mydroilyn and Dihewid), other grits occupying a lower horizon have been included with them. The range and characters of these grits have been described by Keeping.

The other outcrop occupies the high tableland east of the Teifi Valley. Until recently these grits were confounded with those of Plynlimon, which are separated from them by a thickness of nearly a mile of rocks. The discovery of characteristic late Gala graptolites close to the base of the eastern grits near Llyn Rhuddnant and in the western grits near Aberystwyth, together with the great similarity in their lithological characters, conclusively proved their identity.

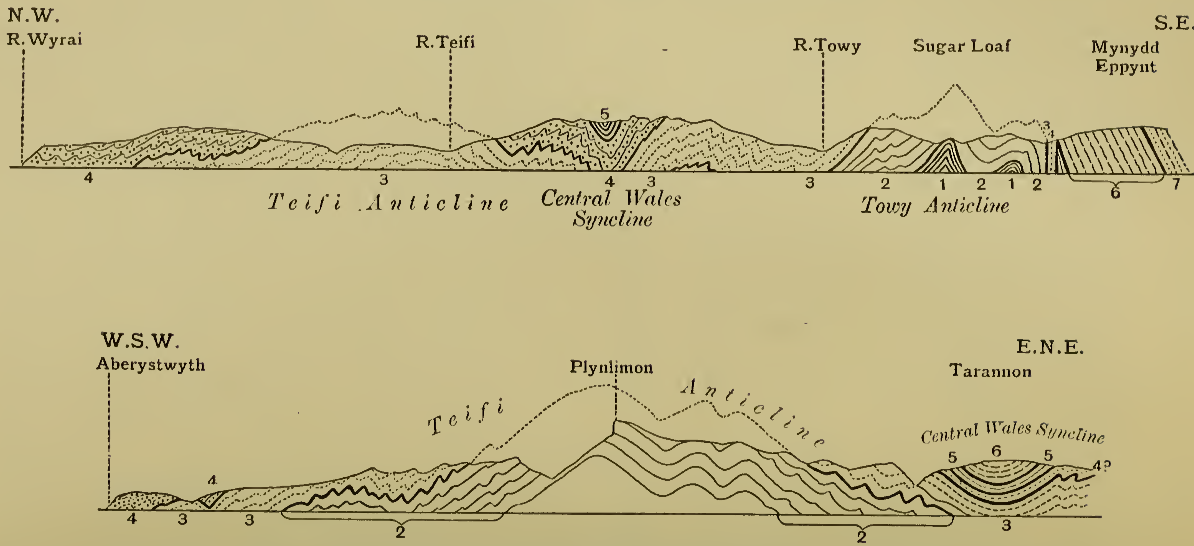
On the Geological Survey map the eastern grits are represented by long lines of yellow dots following the prominent strike-ridges; on the whole, their distribution appears to be fairly correctly indicated.

The grits are best developed on the hills east of Tregaron and Llanddewibrefi, and there extend considerably farther west than is shown on the Survey map. They appear to succeed shaly strata with sandy seams, which at Pont Llanio station yielded numerous graptolites, namely: *Monograptus holmi*, *M. marri*, *M. turriculatus*, *M. resurgens*, *M.* cf. *exiguus*, *M. nodifer*, *M. nudus*, and early types of *M. priodon*, an assemblage corresponding closely with that of the Blaen-Myherin Mudstones which occur not far below the base of the Aberystwyth Grits farther north.[1]

East of Llanddewibrefi, massive dark-grey grits are repeatedly thrown into shallow folds, and it is impossible to make out in detail the stratigraphical arrangement of the beds. About 3 miles in that direction occur the massive conglomerates which form the conspicuous ridge of Craig Twrch; while still farther east there is a considerable thickness of pale-green mudstones with thin gritty seams, associated (at a place called Draenllwyndu) with a band of maroon-coloured mudstones. The lithological type is precisely that of the Dolgau Mudstones, which in the Tarannon area succeed the great grit group of Talerddig, and there is little doubt that they form the highest strata exposed in Central Wales west of the Wenlock boundary. They appear to occupy the core of a deep syncline, and to this fact owe their preservation in this remote spot. The credit of discovering these rocks belongs to Mr. Jenkin Lloyd,

[1] Q. J. G. S. vol. lxv (1909) p. 510.

Figs. 1 & 2.—*Diagrammatic sections across Central Wales, showing the principal axes of folding and the general nature of the small-scale folding.*



[Horizontal scale: 1 inch = 5 miles; vertical scale, exaggerated about 5 times, say 5000 feet to the inch.]

1=*Dicranograptus* Shales; 2=Upper Bala; 3=Lower part of the Valentian; 4=Aberystwyth Grits; 5=Purple and Green Beds; 6=Wenlock-Ludlow Beds; 7=Old Red Sandstone.

of Tregaron, a keen amateur geologist, who, having noticed the conglomerates of Craig Twrch and the peculiar red rocks, was struck by the unusual characters of the latter, and conducted me to the place.

It is possible that other undiscovered outliers of these peculiar rocks may exist among these lonely hills, but to the east of Draenllwyndu occur lower beds descending towards the Lower Birkhill rocks near Ystradffin. From the evidence of the section just described, it may be inferred that the area between the Teifi and Towy Valleys is synclinal in form.

IV. The Structure of the Area.

From the manner in which the map has been compiled, it is evident that it can only yield information as to the large-scale structure of this extensive region. Certain broad features can, however, be distinguished at once, namely:—

(1) An anticline, or rather anticlinorium, on the west separating the two outcrops of the Aberystwyth Grits. Its axis follows in part the Teifi Valley, and the structure may accordingly be called the Teifi Anticline. This axis appears to be a southward continuation of the principal axis of uplift in the Plynlimon district, which ranges along the east side of the Rheidol Valley.

(2) A syncline, or synclinorium, the axis of which ranges almost parallel with the above, and coincides in a general way with the watershed dividing the Teifi from the Towy drainage-system. The direction of the axis is clearly indicated by the form of the outcrop of the Aberystwyth Grits; it is assumed also that it passes through the outcrop of green and purple rocks south-east of Tregaron. This may be referred to as the Central Wales Syncline.

(3) Another anticline or anticlinorium, which ranges along the valley of the Towy between Carmarthen and Llandovery. This structure has been referred to by previous observers as the Towy Anticline; it is probably accompanied, unlike the above-named structures, by considerable strike-faulting. The existence of the anticline is clearly shown on the map by the occurrence of the Silurian rocks on both sides of the Towy Valley: for, although the existence of a powerful anticlinal axis along the Towy Valley has long been known, it was difficult to recognize from a study of the geological map, as the equivalents of the Llandovery rocks which occur on its south-east side had not been definitely recognized on the west side (see p. 335).

It will be observed that in the northern area the boundary-lines converge southwards in the limbs of the anticline, and diverge in that direction in the synclines. This indicates that the major structures in that region have all a pitch to the south, and therefore are in accordance with the structures observed in a limited area south of Plynlimon.

Farther south, however, the boundaries tend to approach parallelism, while in South Cardiganshire they (particularly the base of the Aberystwyth Grits, and probably also the base of the Silurian) converge or diverge in the opposite direction. This may be taken to indicate that the direction of pitch has changed to a north-easterly direction. A region of no pitch should occur about the centre of the county, and is indeed indicated by the parallelism of the boundary-lines, also by the fact that the synclinal outcrops reach here their greatest width while the anticlinal outcrops have here their minimum width; this region should also mark the deepest part of the syncline. As the outcrops had been drawn, as stated above, without reference to the possible or probable structure, it is satisfactory to find that the highest strata which have been observed in the district occur exactly where this interpretation of the structure would lead one to expect them.

Again, north of Plynlimon the direction of pitch appears to change towards the north; this can be easily verified in the district about Glandovey and Machynlleth, and is probably universal over the extreme north of the county. The region of change of pitch in the anticline marks locally the greatest elevation of the strata; again, it is in this neighbourhood that the lowest beds in the northern district have been detected (namely, the *Dicellograptus* Beds of Nant-y-Moch, west of Plynlimon). Wherever, therefore, the deductions drawn from a study of the map can be put to the test of observation they are found to be verified.

A brief account of the above-mentioned structures and their continuation into North Wales on the one hand, and south-westwards into Pembrokeshire on the other, may be of some interest, as it will serve to connect up the structure of the former region, so ably discussed by Mr. Fearnsides, with that of other districts of South Wales fully discussed in various memoirs already published, and in some others which are shortly to appear.

It may be noted here that the two axes of uplift had not escaped the attention of Ramsay and others engaged in constructing the horizontal sections across the district, for in Sheet 4 it is stated that

> 'from Castell Craig Gwyddon to Cardigan Bay the country is composed of repetitions of the same series of rocks, under various aspects, carried to the north-west by two principal anticlinal axes, the first ["the north-east continuation of the great anticlinal axis of the Vale of Towy"]; the second spreading wide across the vales of the Teifi and the Aeron.'

On this section, too, the highest beds between the Towy and the Teifi are shown as a synclinorium, but the fold is really much less shallow than is there indicated.

The Teifi Anticline.—It has not been found possible, so far, to follow this axis of uplift as a separate structure much beyond the Plynlimon district; but its south-westerly continuation appears to be an important element in the structure of North Pembrokeshire. The manner in which the igneous rocks of that county terminate eastwards has been referred to above; there is some evidence that this is due to the effects of severe folding upon igneous masses which have a certain parallelism with the strata, that is, either contemporaneous flows or intrusions of sill-like habit. For the outcrop of the *Dicranograptus* Shales and the base of the Blue Mudstone Group which succeeds them appear to pursue between Llanfirnach and Newport a course approximately parallel to the limit of the igneous rocks. Hence we may probably attribute the wedge-like termination of that area to folding along a broad anticlinal axis with an easterly pitch. This does not, of course, preclude the possibility of strike-faults influencing the outcrops in addition.

A similar structure is indicated independently by the wedge-like eastern extremity of the Cambrian and pre-Cambrian rocks of Hayscastle and St. Davids. In this case it can be verified by a detailed study of the structures at the eastern end of the Hayscastle district.[1]

It can hardly be an accidental circumstance, therefore, that the Lower Cambrian and older rocks, the igneous rocks of North Pembrokeshire, and the *Dicranograptus* Shales all terminate in a wedge-like form, and therefore project farthest eastwards along a line which lies in the continuation of the Teifi Anticline.

The Central Wales Syncline.—It is difficult to recognize from the behaviour of the outcrops the course of this structure westwards through Pembrokeshire, and it is probable that the structure flattens out in that direction and ceases to be recognizable as a separate structure. Northwards, however, it seems clearly to fall into the line of the Tarannon Syncline, which is thence prolonged in the great trough that divides the Bala from the Berwyn region. This syncline seems to have been generally overlooked in descriptions of the southern portions of Central Wales.

The Towy Anticline.—This structure appears to have been detected and its importance recognized by all observers except possibly Murchison, though anticlinal dips are indicated in some of the sections across it.[2] Its course northward from Llandovery is indicated by the small outcrop of black *Dicranograptus* Shales forming the Sugar Loaf on the watershed between Llandovery and Llanwrtyd. They are marked by b^2 on the Geological Survey map, are in association with blue or grey mudstones of the Upper Bala type, and appear to be faulted at least on one side. Along the same line farther north are the igneous rocks of Llanwrtyd described by Murchison, and the small masses coloured as 'Greenstone' east of Rhayader. These igneous masses are probably all of early Ordovician age, like those of the neighbouring Builth area, and lie near the axis of uplift. The structure is clearly indicated in each of the horizontal sections which cross it (Sheets 4, 5, and 6).

From the comparatively even course pursued by the Wenlock and higher Silurian rocks north-east of Rhayader it may be assumed that the anticline fades away in that direction, as does

[1] Q. J. G. S. vol. lxviii (1912) pp. 374 *et seqq.*
[2] 'Silurian System' 1839, pl. xxxiii, figs. 6–7, & pl. xxxiv, figs. 5, 9.

the parallel Teifi Anticline. Possibly, however, it may be in part of pre-Wenlock age: this suggestion requires investigation.

To the south-west, its course is clearly marked; along it occur the Upper Cambrian rocks of the Carmarthen district, and the Lower Arenig rocks associated with igneous rocks near Llangynog, 5 miles south-west of Carmarthen. It is probable that hereabouts the main axis of uplift passes beneath later rocks; but, before doing so, it has given off several important branches which range westwards through Pembrokeshire.

From a comparison of these structures it would appear that both the anticlinal axes tend to diminish in importance northwards, while the intervening syncline becomes more pronounced in that direction.

V. Relation of Structure to Topographic Features.

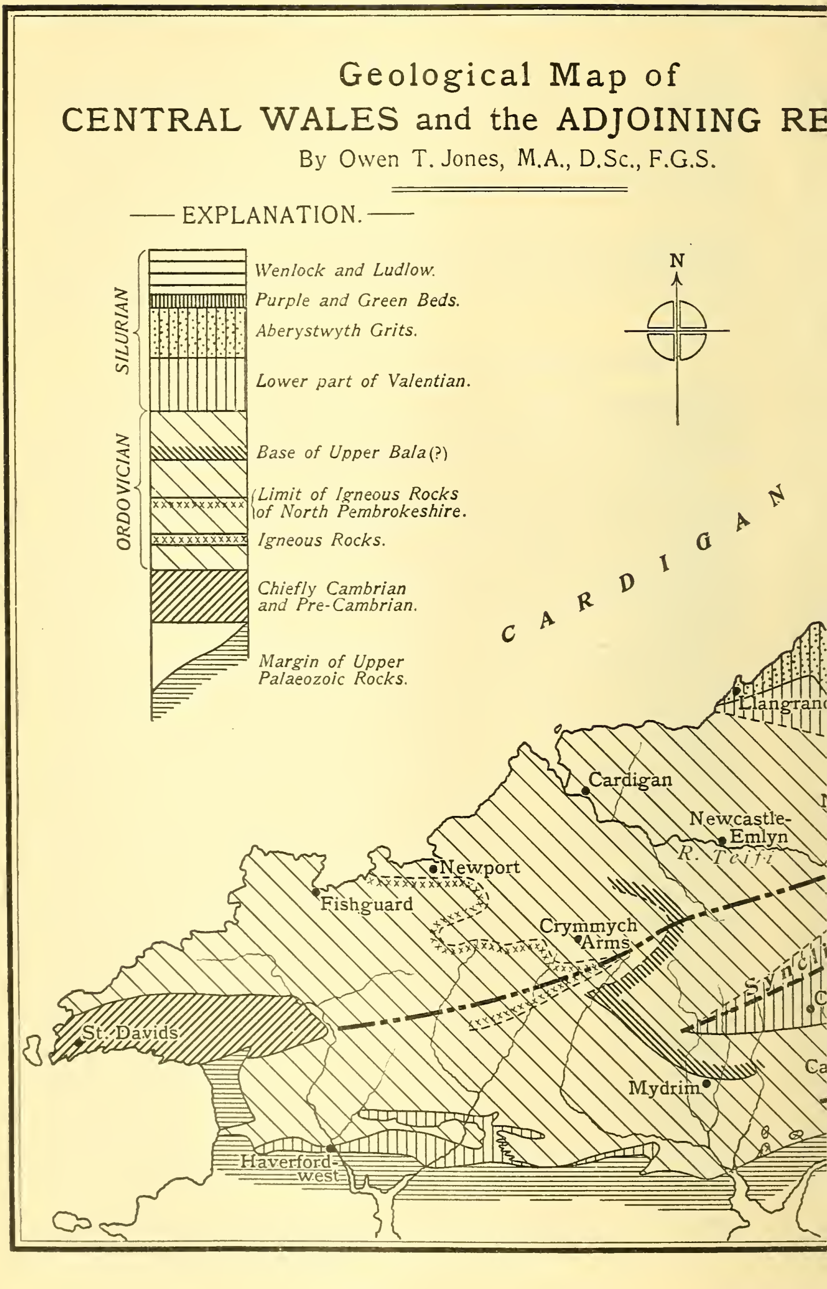
The influence of these structures upon the present topography is too obvious to be ignored. It will be observed that the axes of folding all pursue gently curved lines which show a remarkable correspondence with the form of the coastline of Cardigan Bay.

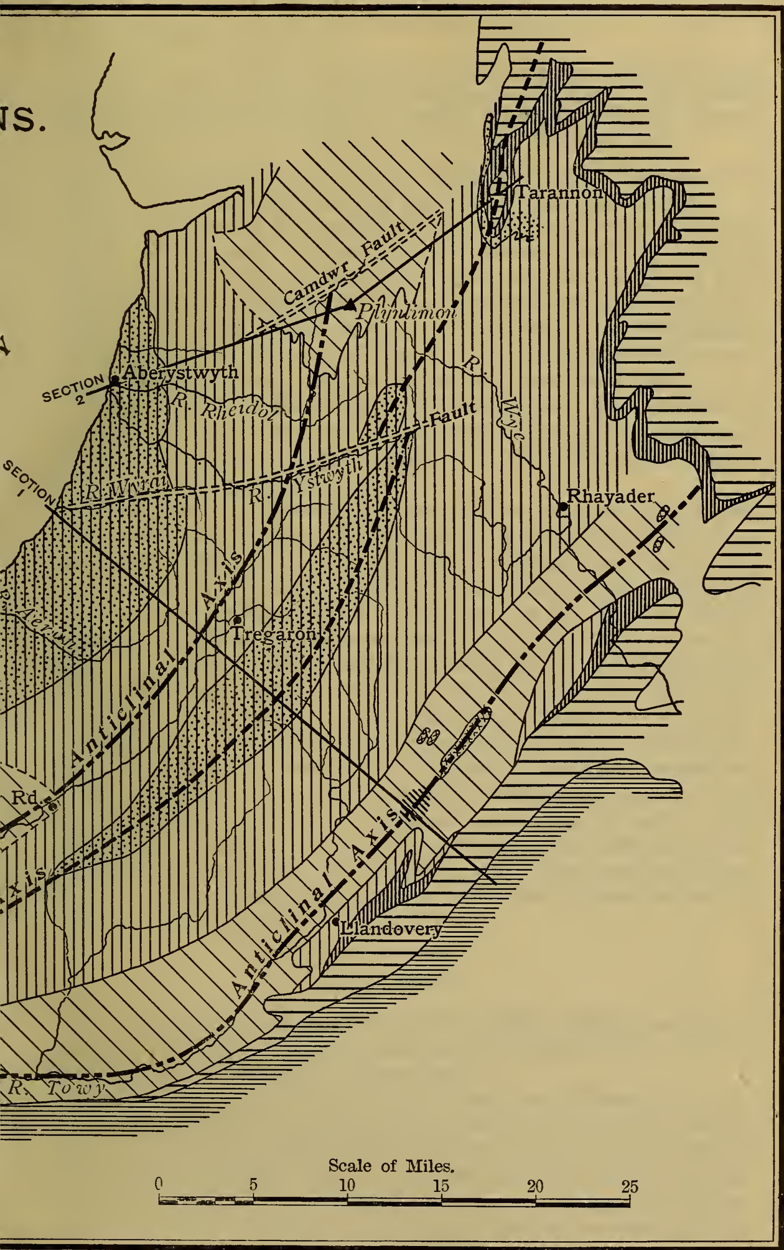
The two anticlinal axes coincide for a great part of their course with the valleys of the principal rivers of the district, the Teifi, the Upper Rheidol, and the Towy; while the intervening syncline appears to have determined in great part the position of the principal watershed of Central Wales. There is thus a fundamental connexion between the great structural lines and the more important topographic features, but exactly how, and at what period, this correspondence came into existence requires much further investigation.

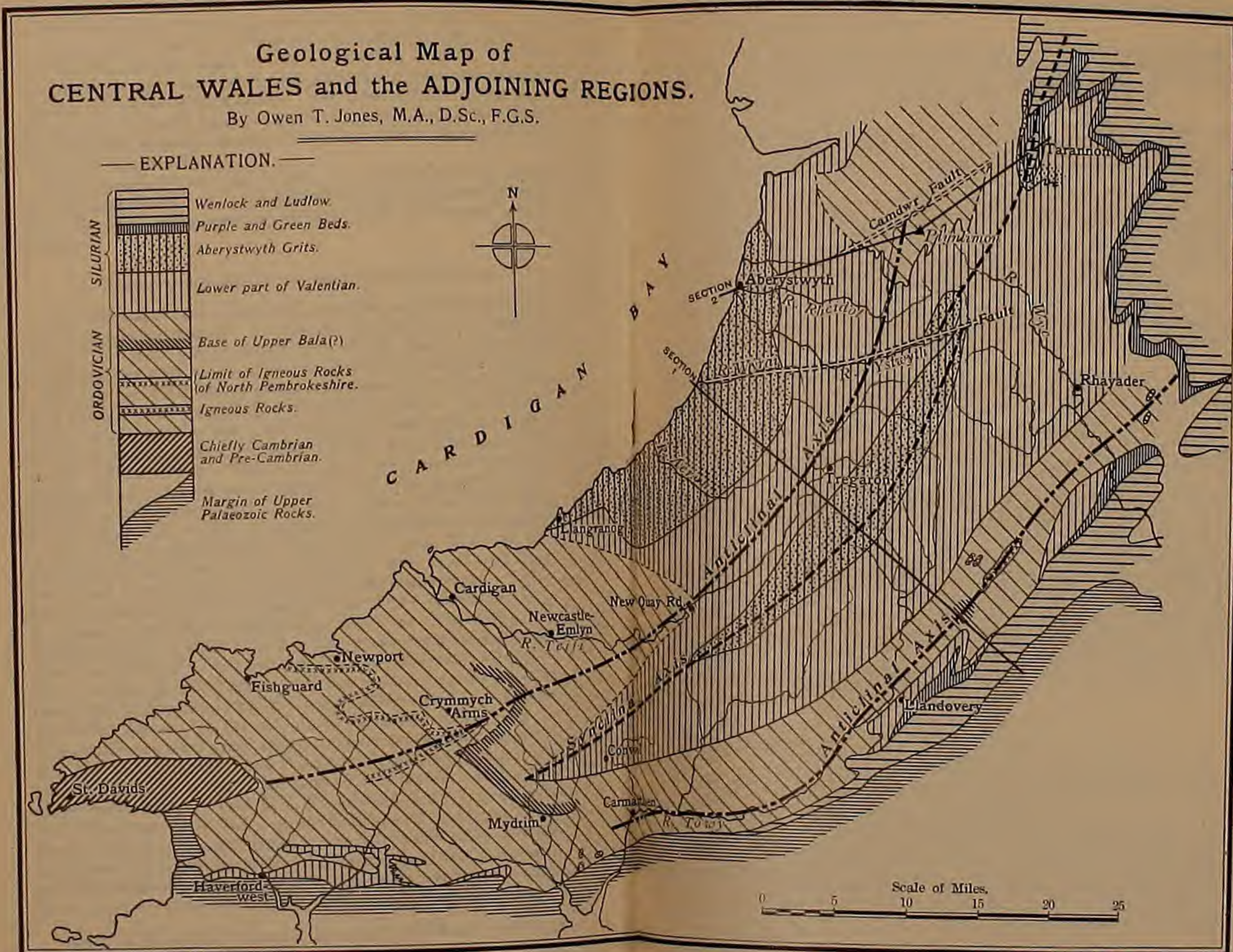
It is clear, however, that at least one of these lines has been marked out from times of great antiquity,[1] and in all probability has shared in more than one period of earth-movement. On its eastern or southern limb the shelly facies of the Llandovery rocks is typically developed (Llandovery, south of Newbridge, and Haverfordwest); while on its other limb rocks of similar age belong almost exclusively to the graptolitic facies (Rhayader, Llansawel, etc.). At this period, therefore, this line appears to have separated the shallow-water areas from the deeper-water tract in which the graptolitic deposits of Central Wales were laid down. As the change of facies takes place with extraordinary rapidity across this line, it is not impossible that the line of the Towy Valley represented the edge of a coastal platform of that period. It has been shown very clearly by Prof. T. C. Chamberlin & Prof. R. D. Salisbury[2] that the outer limits of the continental platforms of the present day form 'concave tracts' from 100 to 300 miles in width, as opposed to the convex outline on a large scale of the land-surface and ocean-bottom; and they consider that under conditions of strain set up in the earth's crust these tracts would yield more readily

[1] See W. G. Fearnsides, 'Geology of North & Central Wales' (Jubilee vol. Geol. Assoc.) 1910–11, pp. 796, 802.

[2] 'Geology' vol. i (1904) chap. ix.


Geological Map of
CENTRAL WALES and the ADJOINING RE
By Owen T. Jones, M.A., D.Sc., F.G.S.
EXPLANATION.
SILURIAN
ORDOVICIAN
Wenlock and Ludlow.
Purple and Green Beds.
Aberystwyth Grits.
Lower part of Valentian.
Base of Upper Bala(?)
Limit of Igneous Rocks of North Pembrokeshire.
Igneous Rocks.
Chiefly Cambrian and Pre-Cambrian.
Margin of Upper Palaeozoic Rocks.
N
C A R D I G A N
Llangranc
Cardigan
Newcastle-Emlyn
R. Teifi
Newport
Fishguard
Crymmych Arms
Syncl
St. Davids
Mydrim
Haverford-west


NS.
Camdwr Fault
Plynlimon
Tarannon
Aberystwyth
SECTION 2
R. Rheidol
R. Wye
Fault
R. Ystwyth
R. Wyrai
SECTION 1
Rhayader
Tregaron
Anticlinal Axis
Rd.
Axis
Anticlinal Axis
Llandovery
R. Towy
Scale of Miles.
0
5
10
15
20
25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R. Rheidol
Fault
SECTION 1
R. Ystwyth
Rhayader
Anticlinal Axis
Tregaron
Llangranog
Cardigan
New Quay Rd.
Newcastle-Emlyn
R. Teifi
Newport
Fishguard
Crymmych Arms
Synclinal Axis
Llandovery
Anticlinal Axis
Conwil
St. Davids
Carmarthen
R. Towy
Mydrim
Haverfordwest
Scale of Miles.
0 5 10 15 20 25

than the complementary convex tracts, thereby giving rise to slow and persistent movements.

'Such movements should be admirably adapted to give those gentle, nearly constant subsidences that furnish the nice adjustments of water-depth required for the accumulation of thick strata in shallow water, and those slow upward warpings that renew the feeding-grounds of erosion' (*op. cit.* p. 561).

The concluding portion of this paragraph exactly illustrates the conditions which prevailed along this line during Silurian times.

The unconformity and overlap in the Llandovery rocks described by Dr. H. Lapworth in the Rhayader district, and the marked overstep at the base of the higher Silurian rocks and Old Red Sandstone near Llandeilo, may probably be attributed to frequently-renewed movements along this line. As shown by Dr. A. Strahan,[1] it is probable that this axis shared in the post-Carboniferous movements, and may even have been active at a much later date.

The influence of these structural lines upon the development of the drainage-system of South and Central Wales has probably been considerable, but the available evidence is not sufficient to indicate the exact part played by them.

It is important to note that, in one instance, these structures have been crossed and apparently displaced by movements of later date than their initiation, namely, the movements that gave rise to the Ystwyth Fault. This line of faulting has exercised a similar trapping influence upon the drainage of that region, as the Vale of Neath, Cribarth, and other disturbances described by Dr. Strahan (*op. supra cit.*). The faulted belt is followed closely by the Upper Ystwyth, which ultimately leaves it to pursue a north-westerly course, along a broad winding valley of very different character, to the sea at Aberystwyth. The line of drainage is taken up farther west by the River Wyrai, which occupies a remarkably straight trough-like valley resembling that of the Upper Ystwyth, and is separated from that valley by a low col situated on the line of fault. This disturbance is known to have cut and displaced certain of the important mineral veins of Cwm Ystwyth. The most important vein was cut out completely, and has never been discovered on the other side of the fault.

VI. Summary.

The tract of Central and South-West Wales consists mainly of rocks of Llandovery age in the centre, and of pre-Silurian rocks at the extreme northern and southern ends.

This tract is traversed by two anticlinal axes following in part the valleys of the Towy and the Teifi, and an intervening syncline (the Central Wales Syncline) occupying the position of the watershed between those streams. These structures are prolonged northwards towards North Wales and south-westwards into Pembrokeshire; but, whereas the anticlinal axes become enfeebled northwards, the

[1] Q. J. G. S. vol. lviii (1902) p. 207.

synclinal axis increases in importance in that direction. These structures have exercised an important influence upon the topography, the nature of which is not fully understood.

EXPLANATION OF PLATE XXXIV.

Geological map of Central Wales and the adjoining regions, on the scale of 10 miles to the inch, or 1 : 633,600.

DISCUSSION.

Dr. H. LAPWORTH welcomed the paper as an exceedingly valuable contribution to the geology of Central Wales. The whole history of geological research in this region furnished an illuminating example of the way in which facts may stare one in the face, and yet be unnoticed. The clue to the greater part of the Central Wales area was the simplest that could be found, and was the fact that, as shown by the work of Mrs. Shakespear, the Tarannon formation of Central Wales was akin to the Gala Group of Southern Scotland—not only in physical characters, but in attaining a thickness of several thousands of feet. The original separation and mapping in this district of the Tarannon Shales (by Ramsay and Aveline) as a comparatively thin deposit lying between the Llandovery and the Wenlock Series had, no doubt, led subsequently to much confusion of ideas.

The Author had stated that the Bala age of the rocks underlying the Gwastaden Grits at Rhayader had not been proved by palæontological evidence: as a matter of fact, the speaker quoted in his paper *Diplograptus foliaceus* from beds south of Rhayader, in material similar to that immediately below the Gwastaden Series.

This paper now provided us with a really satisfactory insight into the geological structure of Central Wales; and it was pleasant to find that, although the Caban rocks were of local occurrence, the main lithological types of the Bala, Llandovery, and Tarannon rocks, as separated by the speaker in the Rhayader district, held good over the greater part of the region.

He hoped that the paper would not give an impression that the geology of this area was now a closed book, for nine-tenths of the 1800 square miles had yet to be worked out in detail.

Mr. E. A. MARTIN remarked on the excellent work which had been done in the district by women-geologists, and desired to emphasize our indebtedness to these earlier investigators.

The AUTHOR, in reply, thanked Dr. Lapworth for his remarks, but stated that, so far from his paper acting as a deterrent to other geologists who wished to work in Central Wales, he thought that the reverse would be the case, for he was fully cognizant of the many points which still required urgent attention.

19. *The* Geology *of* Mynydd-y-Gader, Dolgelly.

By Philip Lake, M.A., F.G.S., and Sidney Hugh Reynolds, M.A., F.G.S., Professor of Geology in the University of Bristol. (Read May 1st, 1912.)

[Plates XXXV–XXXIX.]

Contents.

I. Introduction.

In our previous paper[1] upon this district we described the geology of the area which lies between Dolgelly and Mynydd-y-Gader, a ridge which rises prominently about a mile and a half south of the town, in front of the precipices of Cader Idris. But our observations ended at the foot of Mynydd-y-Gader, and the relations of the dolerite which forms the mass of that ridge to the sedimentary beds of the lower-lying ground were by no means clear. We were led, therefore, to extend our map somewhat farther southwards, and it is chiefly with this southern part of the district that we are now concerned.

Much of the field-work was done by the two authors in company, but each has visited the district at other times alone. One of the authors (P. L.) is primarily responsible for the interpretation of the structure, the other (S. H. R.) for the petrological examination of the rocks.

References to the work of other observers will be found in our previous paper.

II. The Geology of Mynydd-y-Gader. (P. L.)

(1) The General Structure.

Dolgelly stands in the valley of the Wnion. The southern side of the valley is the northern edge of a broad irregular plateau, about 500 feet above sea-level. On the surface of this plateau the Odyn and the Aran, with its tributary the Ceunant, have cut broad and shallow valleys, which near the edge become deep and

[1] 'The *Lingula* Flags & Igneous Rocks of the Neighbourhood of Dolgelly' Q. J. G. S. vol. lii (1896) pp. 511–21.

narrow gorges. The plateau extends southwards to a line running from Gilfachwydd to Tan-y-Gader and Bryn-rhug, and thence, less definitely and less regularly, to Pant-yr-onen and the Aran. From this line the ground rises more steeply, and sometimes with considerable undulations, to the foot of the crags which form the northern face of Mynydd-y-Gader.

Mynydd-y-Gader itself is a very rugged ridge about half a mile wide, highest along its southern border and sloping unevenly downwards to its northern edge, where it presents a steep and rocky face to the lower-lying ground. It terminates abruptly at both its eastern and its western ends.

From the crest of Mynydd-y-Gader the surface falls irregularly to a broad depression at the foot of the Cader Idris range.

The general structure of the area is simple. As we have shown in our previous paper, the strike of the beds upon the slope at the northern foot of Mynydd-y-Gader is approximately from north-west to south-east, the dip being south-westerly. But this dip is not constant throughout. Towards the east, beyond the limits of our former map, a large mass of dolerite has been intruded, apparently in laccolitic fashion, lifting the beds above it in the form of a dome.

On the southern side of Mynydd-y-Gader the dip is different. In general it is almost due south at a high angle, but near the Aran the strike bends round towards the north-east, following the curve of the dolerite intrusion. It is, in fact, evident from the map alone that there is a certain parallelism between the stratified rocks and the dolerite mass of Mynydd-y-Gader. But this parallelism is not complete, and the relations of the two will be considered later.

The structure is complicated by a number of faults, which appear to form two distinct series: some running approximately from north to south, and others from north-west to south-east. All have their downthrow upon the west, so that the newer beds appear in this direction. Only a few of these faults produce any effect upon the northern side of the Mynydd-y-Gader dolerite.

There is, moreover, a fault, or rather a series of faults, along the northern margin of Mynydd-y-Gader; and this is approximately the boundary between the prevalent south-westerly dip in the north and the prevalent southerly dip in the south of the map. The downthrow of this fault or series of faults is evidently upon its southern side.

South of Mynydd-y-Gader there are not uncommonly indications of crushing, which lead us to suspect the existence of strike-faults. Such faults are difficult to detect or prove. In the south-west of our map, however, some of the other faults end abruptly against an east-and-west line. They dislocate the rocks upon the one side of the line, but do not affect the beds upon the other side. We infer, therefore, the presence of a strike-fault, and our inference is confirmed by the abundance of quartz-veins and of signs of crushing along this line.

(2) The Stratified Rocks.

The stratified rocks of the area may be divided as follows, in descending order:—

(5) Ashy Series, consisting chiefly of interbedded slates and volcanic ash, with occasional andesitic and rhyolitic lavas.
(4) Rhyolitic Series, formed almost entirely of rhyolitic lavas and rhyolitic ashes.
(3) Tremadoc Slates.
(2) Upper *Lingula* Flags or Dolgelly Beds.
(1) Middle *Lingula* Flags or Ffestiniog Beds.

(1–3) The *Lingula* Flags and Tremadoc Beds are exposed only in the northern part of the area, and concerning them we have nothing to add to our former account.

(4) The Rhyolitic Series follows the Tremadoc Beds, but the relations of the two are not clear. The *Dictyonema* Zone is seen near Gilfachwydd, east of Llyn Gwernan. In the little gully south of the farm slaty beds continue for some distance; but exposures are poor, and we found no fossils. Towards the top of the gully the Rhyolitic Series appears. There is no evidence of unconformity; but it would be almost impossible to detect an unconformity here, unless it were very strongly marked.

The Rhyolitic Series covers a considerable area on the north-west of the Mynydd-y-Gader dolerite; but its base, following the general direction of the beds below, strikes against the edge of the dolerite south of Tan-y-Gader, and the series accordingly disappears. Narrow strips, however, appear at intervals beneath the dolerite all along its northern boundary. In these strips the dip, wherever it can be determined, is almost due south, and the dolerite rests unconformably upon the edges of the beds.

On the southern side of the dolerite the Rhyolitic Series is absent in the extreme west; but everywhere else it is the Rhyolitic Series that lies next to the dolerite. The dip is almost invariably nearly due south, except at the eastern end of the intrusive mass, where it becomes south-easterly. The angle of dip is usually high.

The Rhyolitic Series consists partly of lavas and partly of ashes, but both lavas and ashes are always acid. The petrology is described in § III of this paper: it may be noted here, however, that on the whole the lower part of the series appears to be ashy, while in the upper part the lavas, sometimes banded and sometimes compact, predominate.

(5) The Ashy Series.—The lavas forming the upper part of the Rhyolitic Series are everywhere followed conformably by a group of ashes and slates with occasional beds of lava. In the eastern part of the map the distinction between the two series is clearly defined, and the boundary is easy to trace. The ashes usually weather much darker than the rhyolites, and their fragmental

character is very clearly shown. Even here, however, there are one or two bands of nodular rhyolite in the midst of the ashes.

Towards the west the difference between the two series is much less marked, and it becomes a very difficult matter to separate them. The colour of the ashes is no longer distinctive, the fragmental character is much less conspicuous, and there appear to be more intercalated lavas. So great, in fact, is the difficulty of distinguishing between the two series at the western end of Mynydd-y-Gader that the boundary drawn in this part of our map (Pl. XXXV) must be looked upon as tentative only.

In the eastern part of the area the series begins with a rather dark tuff, often with large fragments included. One or two lenticular bands of rhyolite occur within the tuff, and upon it lies a bed of black slate, which in a trial-working near the Afon Aran contains *Didymograptus bifidus* Hall.[1]

Above this slate the series consists of alternating beds of tuff and slate, with andesitic lavas appearing towards the south of the area; but, owing in part to the presence of intrusive sills, it is very difficult to map individual beds for any considerable distance.

At the western end of Mynydd-y-Gader is an oblique fault with its downthrow on the west, and on the downthrow side the rocks consist chiefly of slate with occasional beds of tuff and of rhyolitic and andesitic lava. The slates have been extensively quarried at Penrhyn-gwyn, where we found *Orthograptus calcaratus* var. *priscus* Elles & Wood [1] and *Didymograptus murchisoni* (Beck).[1]

Age of the Rhyolitic and Ashy Series.—Since the base of the Rhyolitic Series lies some distance above the *Dictyonema* band and its top is some distance below the zone of *Didymograptus bifidus*, its age is fairly accurately determined. It belongs presumably either to the Lower or to the Middle Arenig.

The Ashy Series, as shown upon the map, includes both the *Didymograptus-bifidus* Zone and that of *Didymograptus murchisoni*. It belongs, therefore, to the Upper Arenig and the Lower Llandeilo. But it is in the lower part that the ashes predominate, while the upper part, the zone of *D. murchisoni*, consists chiefly of slate.

(3) The Forms and Relations of the Intrusive Masses.

In our previous paper we described the form and relations of the masses of dolerite in the immediate neighbourhood of Dolgelly. The only observation that we need add to the account which we then gave is that in the midst of the dolerite south of Bryn-y-gwyn there is a considerable area of volcanic rocks.

Of the remaining masses the largest and most important are those of Parc and of Mynydd-y-Gader, and it is to these that we have devoted most attention.

[1] We are indebted to Miss G. L. Elles, D.Sc., for the identification of these graptolites.

The Parc dolerite—In the angle between the Aran and the Ceunant there is a large area of dolerite of very irregular outline. It is the western end of a mass which extends beyond the limits of our map. The little farm of Parc stands near its northern border.

This mass of dolerite is intruded into the Middle *Lingula* Flags, and in its midst is a small patch of the same beds. At its northern margin the Flags dip beneath it, but along its southern and western borders the beds dip away from the dolerite, and appear to rest upon its surface. Hence we conclude that the intrusion is laccolitic in character, and has lifted up the beds above it. Surrounding the laccolite on its southern and western sides there are several doleritic sills which follow very closely the bedding of the *Lingula* Flags in which they lie.

The Mynydd-y-Gader dolerite.—By far the most important and most interesting of the intrusive masses is the dolerite of Mynydd-y-Gader. It forms an irregularly elliptical patch, with its long axis running from west to east. Its length is about 2 miles and its greatest breadth about half a mile. At each end it thins abruptly, and almost or entirely disappears. It is generally a fine-grained rock, and often shows marked columnar jointing.

The relations of this dolerite to the surrounding rocks are somewhat complex. A glance at the map (Pl. XXXV) shows that it is closely associated with the rhyolitic beds, but it does not lie entirely within that series.

The northern edge is comparatively simple. The crags which form the northern face of Mynydd-y-Gader consist chiefly of dolerite; but at the base there is generally a narrow strip of volcanic rocks belonging to the Rhyolitic Series. Wherever the relations of the two are visible, it is clear that the dolerite lies upon the volcanic beds; and, where the line of crags has been cut back, the rhyolite is almost invariably exposed in the floors of the gullies. Along this edge, therefore, the dolerite lies upon the Rhyolitic Series; yet the two are not conformable. The base of the dolerite is not a plane, but it usually dips at a low angle towards the north. The volcanic rocks, on the other hand, wherever the bedding can be made out, dip southwards at an angle of 30° to 50°. Here the dolerite is certainly not laccolitic in its relations.

But, although along this edge the dolerite is generally in contact with the Rhyolitic Series, in some places, where its margin bends northward, it touches the *Lingula* Flags. Wherever this happens the junction is vertical, and the flags themselves show no signs of metamorphism. We conclude, therefore, that these junctions are faulted. The same fault or series of faults, separates the *Lingula* Flags from the narrow strips of rhyolite at the base of the dolerite. Towards the west the fault enters the Rhyolitic Series itself; but, on account of the similarity of the rocks upon both sides, it can no longer be traced.

The southern edge of the dolerite is much more complex. On this side it sends out several intrusive tongues into the surrounding rocks; but despite these, it will be seen from the map (Pl. XXXV) that at the eastern end there is a rough parallelism between the edge of the dolerite and the boundary between the Rhyolitic and Ashy Series. Moreover, in this part of the area the Rhyolitic Series may be seen resting upon the dolerite like the beds upon the top of a laccolite.

Throughout the greater part of the eastern half of Mynydd-y-Gader the surface of contact between the dolerite and the Rhyolitic Series on the south is approximately parallel to the bedding of the latter. But, west of the fault that crosses the middle of the mass, there is a sudden change in the nature of the junction. Here the Rhyolitic Series begins to spread northwards over the dolerite, although it is no longer conformable with its surface. The dip of the rhyolite remains southerly, while the plane of contact with the dolerite begins to slope towards the north. The relations are as shown in fig. 1.

Fig. 1.—*Section along the line AB on the map (Pl. XXXV) on the scale of 6 inches to the mile.*

[The base is 900 feet above O.D. *a* = Rhyolitic Series; *b* = Ashy Series; *c* = Dolerite.]

Farther still towards the west all parallelism between the two is lost. The Rhyolitic and Ashy Series still dip steeply southwards, while the upper surface of the dolerite slopes at a low angle either northwards or southwards. This is shown clearly enough at the western end of Mynydd-y-Gader, where some of the little valleys are floored by dolerite while the intervening spurs are capped by volcanic rock. Even south of the boundary shown upon the map it is probable that some of the valleys are cut down to the dolerite: for, although the rock is not actually exposed, the valleys all contain an accumulation of doleritic boulders for which no source is visible, the ridges between them consisting of volcanic rock.

Moreover, the nature of the junction is revealed in an actual section near the southern boundary of the dolerite, where a favourably placed crag shows the volcanic series resting upon a nearly horizontal surface of dolerite, the beds of the volcanic series dipping steeply southwards (fig. 2, p. 351).

From this account it will be seen that along its northern boundary the dolerite always cuts across the bedding of the volcanic series. Along the southern boundary its upper surface is nearly parallel to the bedding in the eastern part of Mynydd-y-Gader, but transgressive in the western part.

Fig. 2.—*Sketch of a crag at the western end of Mynydd-y-Gader, showing the relation of the Rhyolitic Series to the dolerite.*

[The overhanging ledge at the top consists of rhyolite dipping steeply southwards (to the right in the figure). The undercut portion is dolerite. The plane of junction between the two is nearly horizontal.]

These relations appear at first sight rather complex, but the key to the explanation will be found in fig. 1 (p. 350).

In this section the thickness of the dolerite is necessarily arbitrary, for the under surface is exposed only at the northern end, where it is seen resting on the Rhyolitic Series. But the general form must be that shown in the figure. It is clear that it consists of a nearly horizontal limb resting in the north transgressively upon the Rhyolitic Series, and a descending limb which plunges conformably beneath the rhyolitic beds on the south. It is only the thickness and the precise shape of these limbs that remain doubtful. As the rhyolitic beds in the north of the section generally dip at a rather lower angle than those in the south, it is probable that the descending limb thins downwards and approaches in shape a typical laccolite rather than a sill, but no attempt has been made to indicate this in the figure.

In the actual line of section the dip of the rhyolitic masses which rest upon the horizontal limb is difficult to determine, for they are so altered that their stratification is almost lost. We do not know, therefore, exactly where the rhyolitic beds cease to run parallel to the upper surface of the dolerite.

It is, moreover, possible that these rhyolitic masses may not be so entirely superficial as is shown in the diagram. They may be slightly sunk into the dolerite, but apparently not to any great depth: for, wherever the ground-level falls much below the line which in the figure is taken as their base, the dolerite is exposed.

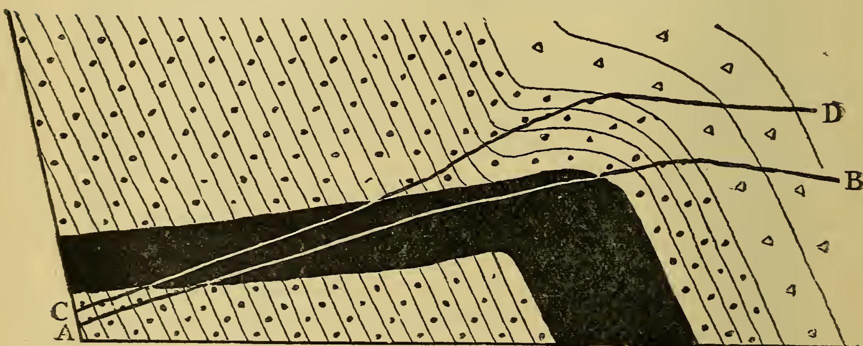
Using this section as a foundation, and restoring the beds above the horizontal limb, we obtain the diagram shown in fig. 3 (p. 352). From this diagram it is clear that the visible relations of the dolerite to the beds in contact with it will depend upon the depth to which the whole mass has been eroded.

If, for example, the line AB is the surface of the ground, the dolerite will be seen at its northern end to lie unconformably upon the rhyolitic beds, at its southern end to plunge conformably beneath them. These are the actual relations observed in the eastern part of Mynydd-y-Gader.

If, however, erosion has not gone so far and the line CD is the surface of the ground, in the north the dolerite will rest unconformably upon the Rhyolitic Series; while in the south the rhyolitic beds will lie upon the dolerite, but not conformably. The junction will be a nearly horizontal plane, and the rhyolitic beds, dipping steeply southwards, will abut against that plane. These are the relations in the western part of Mynydd-y-Gader.

It appears, then, that in section the dolerite is roughly L-shaped, with one limb of the L nearly horizontal and the other dipping steeply southwards. But the angle of the L is not at the same height above the sea throughout the length of Mynydd-y-Gader. It slants downwards from east to west, and the effect of the slant is increased

Fig. 3.—*Diagram illustrating the relations of the Mynydd-y-Gader dolerite to the Rhyolitic and Ashy Series.*



[Symbols as in fig. 1.]

to some extent by the transverse faults. In consequence of this the L stands higher in the eastern part than in the western part of Mynydd-y-Gader. It is accordingly more deeply eroded in the east, and it is on this account that the relations of the dolerite to the volcanic beds are so different at the two ends of the hill.

The form of the intrusion is shown in fig. 4 (pp. 354–55), in which Mynydd-y-Gader is represented as cut up into a series of blocks, so as to exhibit the internal structure. The diagram is not drawn in perspective, nor is it a true projection. It is a purely artificial but convenient representation in which vertical heights and distances along the base-lines (north 30° west to south 30° east, and east to west) are drawn in their true proportions.

In the present position of the mass, it appears as if the intrusion had come up from below along the plane of bedding, and had then cut through the beds and spread out almost horizontally. But the intrusion probably took place before the beds received their present dip; and, if we place the section so that the bedding is horizontal, we shall reproduce more nearly the conditions when the intrusion occurred. The connexion with the molten magma beneath was through the transgressive limb. The igneous rock came up as a dyke, and then spread as a sill in laccolitic fashion along the bedding-planes; but it did not keep strictly to a constant horizon.

It should be observed that a similar explanation may possibly apply in the case of the dolerite masses close to Dolgelly. These also, as we showed in our former paper, appear to spread transversely to the bedding, and we interpreted them as probably laccolites along an unconformity. But the structure of Mynydd-y-Gader suggests another explanation, and it is in fact by no means impossible that they are the actual continuations of the transgressive limb of the Mynydd-y-Gader dolerite.

III. The Petrology of the Igneous Rocks. (S. H. R.)

(*a*) The Intrusive Rocks.

The Dolerite.—Although the dolerite of Mynydd-y-Gader varies much in coarseness, it is singularly uniform in mineralogical character and contains very few accessory minerals. The prevailing type is a fine-grained, rather pale, greenish-black rock, uniform in texture, and containing neither vesicles nor phenocrysts. In rare cases it becomes strongly vesicular, as at certain points on the northern margin of the mass (82) [1] or in narrow sills such as occur to the south of Mynydd-y-Gader. In many places the rock becomes very coarse; but on the whole it is remarkably uniform and fine-grained. At 212 it has a silica percentage of 56·28, and a specific gravity of 2·81.[2] It is often strongly columnar, especially in the area lying south of the sources of the Tan-y-gader and Bryn-rhug streams, and towards the eastern end of the mass. The columns are often roughly hexagonal, and 2 to 3 feet or even more in diameter. The intrusive character of the junction between the dolerite and the Rhyolitic Series is often very clear, as along the southern border between the south-westerly-projecting tongue (180) and the little pond on the southern margin, where blocks of rhyolite are often included in the dolerite (Pl. XXXVI, fig. 2).

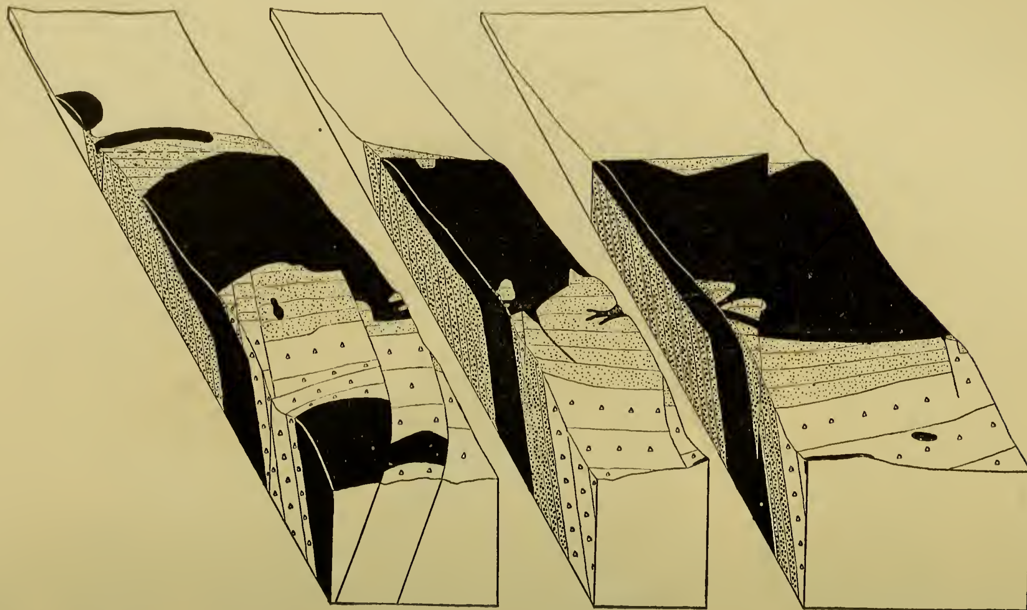
At the spot (254) north-west of the south-westerly-projecting tongue of dolerite (180) the rhyolite has been partly re-fused by the dolerite,[3] the resulting rock having a somewhat foliated appearance. Near (180) also veins of a fine-grained pale dolerite (Pl. XXXVI, fig. 1) penetrate both the neighbouring rhyolitic

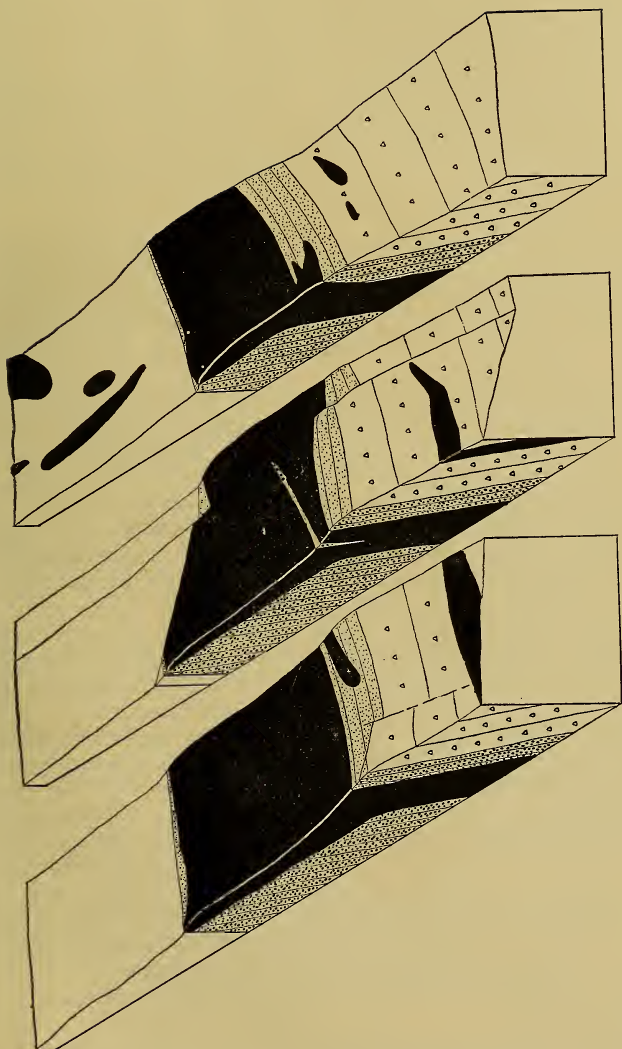
[1] These numerals in parentheses refer to the numbers marked upon the specimens, and the points at which they were collected are shown by corresponding numbers on the map.

[2] All silica-percentages and specific gravities quoted, excepting those on p. 360, were determined in the Chemical Laboratory of University College, Bristol, by Mr. E. M. Lane.

[3] This was pointed out by Mr. Harker, to whom we are much indebted for help in the examination of these rocks.

Fig. 4.—*Diagram illustrating the structure of Mynydd-y-Gader.*
(Scale of base-lines and vertical lines : 3 inches = 1 mile.)





VI.

V.

IV.

[Symbols as in fig. 1.]

rocks and the dolerite of the tongue. These are probably contemporaneous veins—residual portions of the magma analogous to the pegmatite veins in granite; they, however, depart from the usual rule in being finer-grained than the rocks with which they are associated. The veins have a specific gravity of 2·86 and a silica-percentage of 50·40. The rock which they penetrate has a specific gravity of 2·87 and a silica-percentage of 50·0. The coarsest dolerite is met with in the south central portion of the mass, to the east of the little pond. South and west of the main mass of Mynydd-y-Gader are many small patches of dolerite, lying in the midst of the rhyolitic and ashy beds. The most important of these are marked upon the map (Pl. XXXV), but many are too small to be indicated.

Essential constituents of the dolerite.—In the coarser dolerites augite occurs as a rule in fresh, pale-brown, brightly polarizing, highly ophitic plates. It is frequently not pleochroic, but occasionally (163) shows faint pale-green and brown tints. Neither diallagic modifications nor hourglass structure were met with, and twinning is not common.

In many of the fine-grained dolerites the augite is replaced by fibrous amphibole, in others by a chloritic mineral. In some cases the augite is replaced by calcite. No original hornblende has been found in any of the Dolgelly dolerites; nor has any rhombic pyroxene or olivine been met with in any of the Dolgelly rocks.

Felspars.—These are always of earlier origin than the augite. The prevalent felspar, labradorite, is often more or less completely replaced by epidote or by calcite. The altered felspars are sometimes bordered by fresh secondary material.

Iron-ores always play a very prominent part, and are sometimes original, sometimes secondary constituents. Ilmenite is the prevailing mineral, and may occur in large skeleton crystals or in irregular patches. It invariably shows the usual alteration into leucoxene. Occasionally it is intergrown with magnetite, which has been met with at a considerable number of points, but is far less common than ilmenite.

Accessory minerals and alteration-products.—The characteristic alteration-product of the dolerites is epidote, as was noted by Cole & Jennings.[1] But rarely is a rock met with in which epidote is not conspicuous in microscopic sections; and in some rocks (216) it is perhaps the most prominent constituent. It occurs, as a rule, in brilliantly-polarizing, often well-cleaved prisms, which are sometimes (163) arranged in a radiating fashion.

Apatite is decidedly uncommon, having been met with in only a few sections (297).

Although leucoxene is almost universally present, sphene has been noticed only at one spot (214).

Pyrite is met with at various points (215, 235, 180), but is not a very common accessory mineral.

[1] Q. J. G. S. vol. xlv (1889) p. 432.

(b) The Contemporaneous Rocks.

(i) The Rhyolitic and Ashy Series.—To the south-east of the Mynydd-y-Gader dolerite occurs perhaps the most varied and interesting series of exposures in the district:—dolerites, nodular, banded and compact rhyolites, tuffs coarse and fine, and slaty beds rapidly succeeding one another. Most of these bands are, however, lenticular; and, when followed along the strike to the north-east and south-west, they die out.

In a traverse following approximately the line CD shown in the south-eastern portion of our map (Pl. XXXV), the rocks passed over are as follows:—

(1) Andesite, a broad and prominent band; the felspars tend to weather out, giving the rocks a pseudo-vesicular appearance.
(2) Narrow band of tuff dipping at one point south 10° west at 42°.
(3) Dolerite enclosing patches of tuff.
(4) Black ashy shale, becoming more distinctly ashy up the hillside.
(5) Nodular rhyolite, a narrow band.
(6) Tuff.
(7) Main nodular rhyolite band.
(8) Tuff.
(9) Banded rhyolite.
(10) Rhyolite, compact on the south, banded on the north with an intrusive tongue of dolerite (180).
(11) Massive dolerite of Mynydd-y-Gader.

When this series is followed westwards, first the nodular rhyolite band 5 dies out, so that bands 4 and 6 join. Farther on the main nodular band (7) disappears, so that the ashy band (8) joins 6, and the series consists of a great mass of banded and compact rhyolite on the north, succeeded on the south by a great series of tuffs. After the dying-out of the nodular rhyolite the ashy series, which dips southwards at high angles, becomes very coarse and devoid of the shaly matrix which characterizes it farther east. The fragments in it are mainly rhyolite, but there are some of slate. Although the banded character extends much farther westwards than the nodular, it eventually dies out, and in the area to the south-east of the little pond only compact rhyolite occurs.

Towards the north-east also the nodular and banded structures disappear, and the rhyolite becomes compact, retaining this character as far as the Afon Aran.

The Rhyolites.—For purposes of detailed description the rhyolites may be divided into:—

1. Rhyolites showing neither nodules nor banding.
2. Nodular rhyolites.
3. Banded rhyolites.

Nodular and banded rhyolites are confined to the south-eastern part of the Mynydd-y-Gader area.

Rhyolites showing neither nodules nor banding.—These rocks generally have a more or less flinty character, and a fracture which becomes more conchoidal as the flintiness increases. The colour of the weathered surface in the field is variable, sometimes dark, often very pale. On a freshly-broken surface the colour is generally grey or greenish grey, becoming in some cases nearly black, and in others, especially when somewhat weathered, pale pink or white (272).

The texture is sometimes extremely uniform; sometimes the development of patches and strings of a chloritic mineral imparts to the rock a variegated appearance. Flow-structure is occasionally well seen in a hand-specimen (179), but the rocks are never vesicular. Little phenocrysts of quartz and felspar are nearly always apparent in the freshly-broken surface. Small grains and crystals of pyrite are often conspicuous in a hand-specimen.

Microscopic characters.—The rhyolites are, in general, remarkable for their uniformity of character and the small number of minerals represented. The correspondence with those described by Mr. Harker from Carnarvonshire is, in most cases, very close.

The ground-mass is, as a rule, cryptocrystalline, frequently with strings and patches of microcrystalline material, which are not sharply marked off from the cryptocrystalline. Flow-structure is frequently seen when the section is viewed in ordinary light, but ceases to be apparent in polarized light. It is often brought out by the wisps or bands of chloritic material which has collected in the loops of the bends.

No examples of perlitic structure have been met with. Occasionally the ground-mass breaks up under polarized light into a mosaic of irregularly-interlocking blurred patches (micropoikilitic) (189). This structure sometimes extends uniformly over the whole section, sometimes occurs locally in bands. One section (176) shows curious little micropegmatitic groups, exactly similar to those described by Mr. F. R. Cowper Reed [1] from Fishguard. They clearly represent felspar crystals, and in one case the felspar of the micropegmatite shows Carlsbad twinning.

In almost every slide there are numerous crystals or grains of felspar and quartz, the latter being often corroded by the ground-mass. The felspars nearly always occur as small crystals, having various lengths up to about 5 mm. Although the crystals occasionally show only Carlsbad twinning, they are more often twinned on the albite type, and, from their low extinction-angles, belong to the albite-oligoclase series, as in the case of the Carnarvonshire rhyolites.[2] No ferromagnesian minerals have been met with. Most of the slides show small irregular patches of iron-ore, which, from the leucoxenic alteration, are no doubt ilmenite. A chloritic decomposition-product, in the form of patches and strings of a pale-green feebly polarizing substance, is very common. In some cases (179) much finely-disseminated pyrite occurs.

[1] Q. J. G. S. vol. li (1895) p. 162.

[2] The 'Bala Volcanic Series of Caernarvonshire' 1889, p. 20.

Nodular rhyolites.—The great development of these rocks (Pl. XXXIX, fig. 1) on parts of the southern slopes of Mynydd-y-Gader forms one of the most remarkable features of the geology of the district. The nodular structure does not occur in a patchy manner, but is limited to one or two well-marked bands running parallel to the general strike of the rocks. These bands lie within the Ashy Series.

Two kinds of nodules may be distinguished :—

(*a*) Regularly spherical or spheroidal nodules, rarely more than an inch in diameter. They are often hollow, and show a marked concentric structure when weathered. They occur chiefly in the western part of the outcrop. (See Pl. XXXIX, fig. 2.)

(*b*) Larger ovoid lumps, sometimes reaching a length of from 4 to 5 inches. These are not hollow, and do not show a concentric structure. They come from the eastern part of the outcrop. (See Pl. XXXIX, fig. 4.)

The nodules of the first of these types stand out on the weathered surface, and cause the rock superficially to resemble a conglomerate. Sometimes a number of nodules of approximately equal size are compacted together, but generally the spaces between the larger nodules are occupied by smaller.

In many places, instead of nodules, the weathered rock-surface shows a network of sinuous ridges of flinty material (Pl. XXXVII, fig. 1) standing out boldly. The spaces between the ribs of the network vary from a quarter of an inch to over 2 inches. Patches of nodular rock may be mingled with patches without nodules, or the nodules may be enclosed in a network of flinty ridges. It is possible that the flinty network may be in part the result of flow-brecciation.

Sometimes the nodule is evidently composed of three or four concentric layers (Pl. XXXIX, fig. 2), in other instances it is uniform. Frequently the nodules are hollow, and sometimes, in addition to the central hole, a space occurs between the concentric layers, or, instead of there being one central hole, several irregular spaces may occur. There seems every reason to suppose that all these cavities are of secondary origin, are due to weathering, and that all the nodules were originally spherulites. This is the view adopted by Prof. Cole[1] and Mr. Harker[2] in the case of the Carnarvonshire rocks, and by Mr. Thomas[3] for those of Skomer. No examples of nodules were found in which the cavities were filled by or lined with quartz. None of the solid unweathered nodules show a radial arrangement when broken across; but this structure is sometimes strongly marked in certain of the nodules, in which weathering has etched out the several concentric layers.

Phenocrysts, whether of quartz or felspar, are very much less common in the nodular rhyolites than in either the compact or the banded varieties.

In thin sections the nodules are sometimes seen to pass gradually

[1] Q. J. G. S. vol. xli (1885) pp. 162–68; & *ibid.* vol. xlii (1886) pp. 183–90.
[2] 'The Bala Volcanic Series of Caernarvonshire' 1889, pp. 28–40.
[3] Q. J. G. S. vol. lxvii (1911) pp. 185–90.

into the surrounding matrix, sometimes are sharply marked off from it either by the aggregation of particles of a dark, probably chloritic mineral along the border of the nodule, or by a minute band of quartz. Micropoikilitic structure is extremely characteristic of these rocks; and, although it occurs in both the nodules and the surrounding matrix, it is especially characteristic of the nodules.

Banded rhyolites.—These resemble the nodular rhyolites in being practically confined to the eastern half of Mynydd-y-Gader. They occupy a larger area in the field than the nodular rhyolites, and occur in a broad band into which projects the tongue of dolerite (180). Some 400 yards to the west of this tongue they gradually lose their banded character, and pass into ordinary rhyolite. The weathered surface presents a very striking appearance, showing a series of white flinty bands ranging from one-half to 2 inches in thickness and standing out very prominently. (See Pl. XXXVIII, fig. 1.)

The banding is parallel to the general strike of the rocks, that is, west-south-westerly, and the individual bands, although they sometimes curve, run approximately parallel one to the other. The bands sometimes retain a uniform thickness for a foot or more, but frequently anastomose with one another and swell out into lenticular forms.

This coarse banding, seen on the weathered surface, is, as a rule, accompanied by a very fine banding, seen on the freshly-broken surface, and often brought into prominence by the development of strings of a chloritic material. Small phenocrysts, chiefly of quartz, often show up well on the broken surface in the banded rhyolites.

In polarized light the rocks show cryptocrystalline alternating with microcrystalline or micropoikilitic bands. Phenocrysts, chiefly of quartz, more rarely of felspar, are decidedly commoner than in the nodular rhyolites, but are not so abundant as in the rhyolites that show neither nodules nor banding.

Chemical characters of the rhyolites.—Two of the rhyolites were analysed for alkalies as well as silica, and proved to contain a high percentage of soda. The resemblance between these Dolgelly rhyolites and those from Skomer described by Mr. Herbert H. Thomas is great, as is shown by the following analyses:—

No. 179. *Rhyolite, southern side of Mynydd-y-Gader, Dolgelly.*	No. 28. *Nodular rhyolite, near the eastern end of Mynydd-y-Gader.*	*Soda-rhyolite, near the Table, top of cliff, east of the Spit (Skomer). (Anal. 345, slide E 7768.)*
SiO_2 ...... 78·87	SiO_2 ...... 72·79	SiO_2 ...... 79·64
K_2O ...... 0·54	K_2O ...... 3·37	K_2O ...... 0·38
Na_2O ... 4·28	Na_2O ... 5·33	Na_2O ... 6·40

All these analyses were made by Mr. E. G. Radley.

The tuffs or ashes.—Tuffs are splendidly developed to the south of Mynydd-y-Gader, and for hundreds of yards present a succession of bare weathered faces, on which the included fragments stand out with great prominence: these are of all sizes, up to a length of 18 inches. The large blocks are not associated together so as to form a coarse agglomerate, but occur sporadically. The material of the blocks is, in the main, rhyolite, but pieces of slate and grit also occur. (See Pl. XXXVII, fig. 2.)

IV. Comparison with other Areas. (P. L. & S. H. R.)

Although it has long been known that in North Wales a great volcanic series lies either in the Arenig or in the Llandeilo Series, or in both, there are few places where its precise relations to the graptolite zones have been determined. The most important district for comparison with that which we have been describing is the district of Arenig itself, which is situated only 15 or 16 miles to the north-east, and has been described in detail by Mr. W. G. Fearnsides.[1]

The main Volcanic Series of Arenig lies above the *Didymograptus-bifidus* Shales, and seems to belong to the Llandeilian. Apparently it corresponds approximately with our Ashy Series, and, like it, consists chiefly of ashes and agglomerates. These are generally andesitic in character, and it is only towards the top that rhyolitic beds predominate. Associated with the ashes and agglomerates are numerous sills and sheets of intrusive rock, but these are more varied in character than at Dolgelly. Among them, for example, is a group of hypersthene-andesites, but no rhombic pyroxenes have been found in any of the rocks of the district here described. There is, however, another group of andesitic dolerites which approaches more nearly in character to the dolerites of Dolgelly.

No lava-flows of older date than the *Didymograptus-bifidus* Zone have been described at Arenig. But ashy fragments occur in the *D.-bifidus* Zone itself, and the *Calymene* Ashes, which lie between the *D.-hirundo* and the *D.-extensus* Zones, may be contemporaneous with our Rhyolitic Series. In any case, they show that volcanic eruptions took place in North Wales during the Arenig epoch, and Dolgelly may well have been closer to the seat of activity.

Near Portmadoc, another area examined by Mr. Fearnsides,[2] the evidence is not sufficient to determine the exact horizon of the volcanic rocks.

A group of volcanic rocks which lithologically presents some resemblance to the Rhyolitic Series has been described by Miss Elles[3] in the neighbourhood of Conway. But the base is not seen, and the palæontological evidence indicates that the part examined belongs to a considerably higher horizon than any of the rocks in the area here described.

It is to South Wales that we must turn, in order to find a volcanic group which both in age and in character approaches the Rhyolitic Series of Dolgelly. On Skomer Island and the adjacent mainland

[1] Q. J. G. S. vol. lxi (1905) p. 608.
[2] *Ibid.* vol. lxvi (1910) p. 142.
[3] *Ibid.* vol. lxv (1909) p. 169.

an interesting series of volcanic rocks has been described by Mr. Herbert H. Thomas.[1] The evidence of its age is not conclusive, but from a comparison with neighbouring areas Mr. Thomas is inclined to place it in the *D.-extensus* Zone. The group consists in part of rhyolitic lavas, and these are very similar in character and constitution to those of Dolgelly. In both cases the flows are sometimes banded and sometimes nodular. The general resemblance in character and probable age led us to have analyses made of two of our specimens (see p. 360), and these analyses show that there is an equally close resemblance in chemical composition. Both at Skomer and at Dolgelly the rhyolites contain a high percentage of soda.

But here the resemblance ends. The rhyolites do not form by any means the largest part of the Skomer Series, and the Dolgelly rocks are petrologically far less varied than those of Skomer. If, however, the two series should really prove to be of the same age, the similarity of the rhyolitic lavas will be of considerable interest.

EXPLANATION OF PLATES XXXV–XXXIX.

Plate XXXV.

Geological map of the neighbourhood of Mynydd-y-Gader, on the scale of 3 inches to the mile, or 1 : 21,120.

Plate XXXVI.

Fig. 1. Fine-grained dolerite penetrating the coarser variety. The hammer rests on one vein about $2\frac{1}{2}$ feet wide; and a second vein, separated from the first by a narrow band of coarser dolerite, is seen on the right. (See p. 353.)

2. Blocks of rhyolite caught up by, and enclosed in, the dolerite. (See p. 353.)

Plate XXXVII.

Fig. 1. Nodular rhyolite, Mynydd-y-Gader. In the upper part of the figure the sinuous flinty ridges characteristic of some parts of the nodular rhyolite are seen. (See p. 359.)

2. Tuffs, Mynydd-y-Gader. (See pp. 360–61.)

Plate XXXVIII.

Figs. 1 & 2. Banded rhyolite, Mynydd-y-Gader. (See p. 360.)

Plate XXXIX.

Figs. 1–4. Nodular rhyolite, Mynydd-y-Gader. (See p. 359.)
In fig. 2 one of the nodules shows a concentric structure and central hollow.

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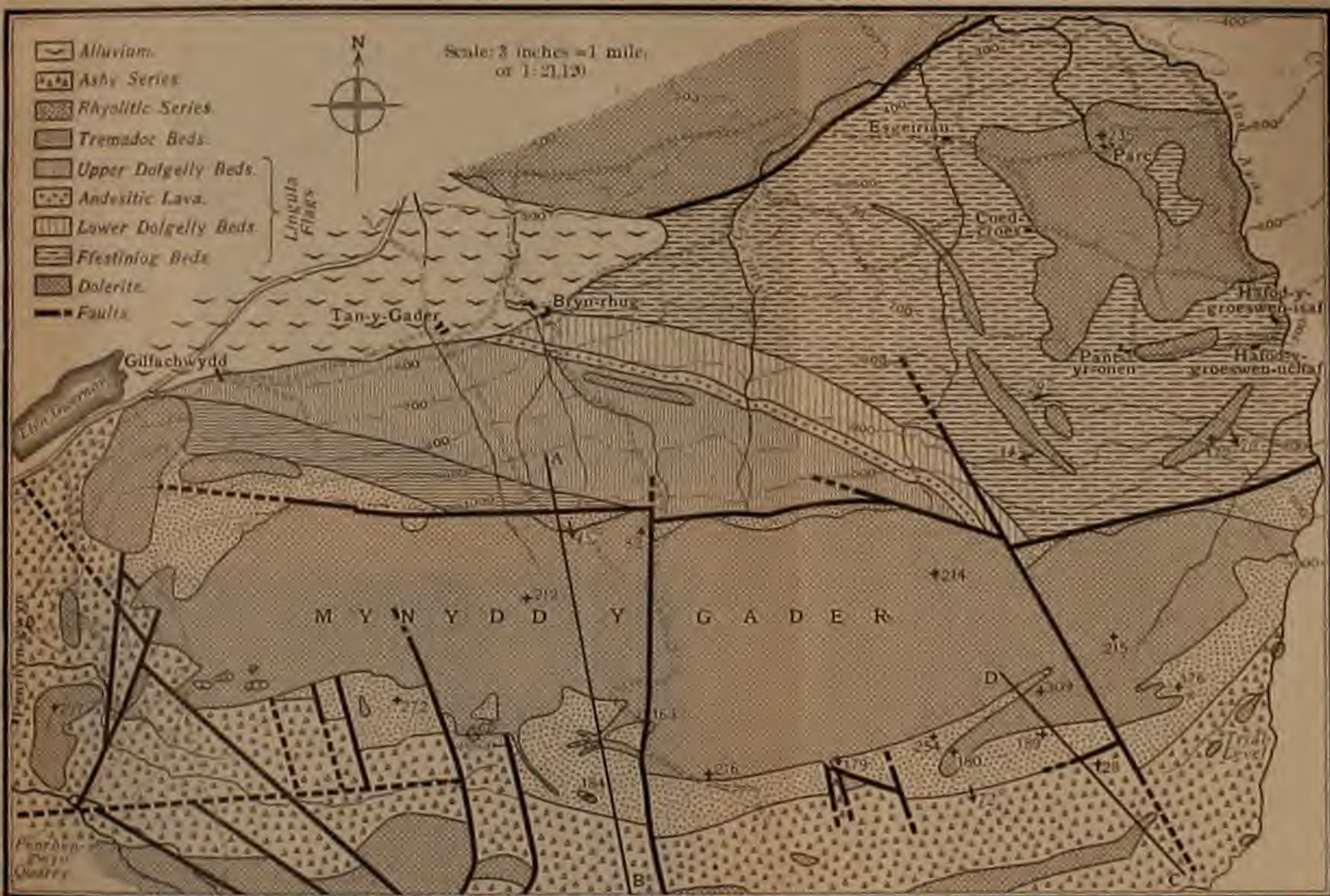
[1] Q. J. G. S. vol. lxvii (1911) p. 175.

Alluvium.
Ashy Series.
Rhyolitic Series.
Tremadoc Beds.
Upper Dolgelly Beds.
Andesitic Lava.
Lower Dolgelly Beds.
Ffestiniog Beds.
Dolerite.
Faults.
Gilfachwydd
Llyn Gwernan
Penrhyn-gwyn
297
Penrhyn-gwyn Quarry



GEOLOGICAL MAP OF THE NEIGHBOURHOOD OF MYNYDD-Y-GADER.

[The letters A B, C D refer to text-fig. 1, p. 350, and to the section described on p. 357.]

S. H. R. photo.

Fig. 1.—*Fine-grained dolerite penetrating the coarser variety.*

S. H. R. photo.

Fig. 2.—*Blocks of rhyolite caught up by, and enclosed in, the dolerite.*

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S. H. R. photo.

Fig. 1.—*Nodular rhyolite, Mynydd-y-Gader*

S. H. R. photo.

Fig. 2.—*Tuffs, Mynydd-y-Gader.*

Fig. 1.—*Banded rhyolite, Mynydd-y-Gader.*

S. H. R. photo.

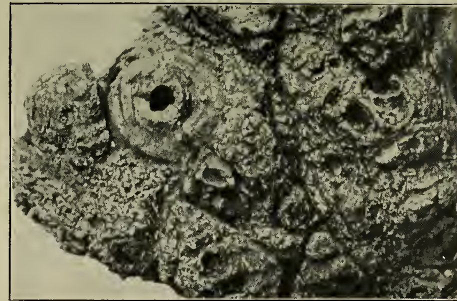
Fig. 2.—*Banded rhyolite, Mynydd-y-Gader.*

S. H. R. photo.

Fig. 1 $\times \frac{1}{4}$.

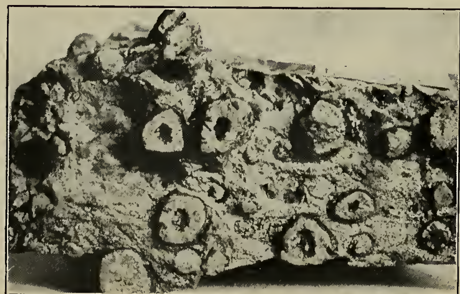
S. H. R. photo.

Fig. 2 $\times \frac{1}{2}$.



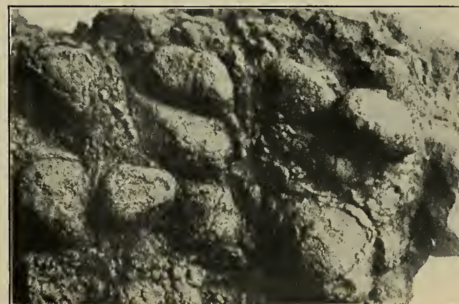
S. H. R. photo.

Fig. 3 $\times \frac{1}{2}$.



S. H. R. photo.

Fig. 4 $\times \frac{1}{2}$.



S. H. R. photo.

Nodular rhyolite, Mynydd-y-Gader.

Discussion.

Mr. H. H. Thomas congratulated the Authors on the results of their detailed mapping in a complicated region, and he was glad that another series of Welsh igneous rocks had been relegated to their proper position in the Ordovician sequence. In this district the Authors had traced fossiliferous Tremadoc and Lower Llanvirn rocks, but between these there was only a relatively thin series of rhyolites. Did the Authors consider the Rhyolitic Series to form part of the true Arenig, or did they think that it possibly occurred as part of the Lower Llanvirn?

He was interested in the extremely close resemblance, both lithological and chemical, which these rhyolites bore to those of Skomer Island, and was glad that the Authors had come to the conclusion that the cavities in the larger spherulites were of secondary origin and were not lithophysal in character.

Prof. W. W. Watts considered the existence of a volcanic horizon between the Lower and the Upper Dolgelly Beds to be of such importance, that he would be glad to hear whether the Authors had any additional evidence in support of the extrusive character of the igneous rocks.

Mr. P. Lake, in reply to Mr. Thomas, said that the Rhyolitic Series probably belonged to the *Didymograptus-extensus* Zone; but all that was definitely proved was, that it lay between the *Dictyonema* Zone on the one hand and beds with *Didymograptus bifidus* on the other. With regard to the question raised by Prof. Watts, the relations of the andesite to the *Lingula* Flags were dealt with in the Authors' previous paper, and they had no further evidence to offer. The andesite appeared to lie at a constant horizon, and showed no signs of intrusion.

20. *On an* Inlier *of* Longmyndian *and* Cambrian Rocks *at* Pedwardine (Herefordshire). By Arthur Hubert Cox, M.Sc., Ph.D., F.G.S. (Read February 7th, 1912.)

Contents.

I. Introduction.

The inlier under consideration occupies a small strip of country, about a mile in length, around the hamlet of Pedwardine, near Brampton Bryan, a village situated on the Ludlow–Knighton road, 11 miles west of Ludlow and 6 miles east of Knighton.

Through the district in question passes the great north-east and south-west line of disturbance which, extending through Lilleshall, Church Stretton, and Old Radnor, brings up the older formations at so many points along its course.

The presence at Pedwardine of Cambrian shales with *Dictyonema* was first mentioned by Lightbody,[1] who observed that at one point these shales are covered unconformably by 'Llandovery.' Their occurrence at this locality is also noticed by Murchison,[2] Callaway,[3] and La Touche,[4] the last-named observer referring in addition to the 'Cambrian grits and pre-Cambrian rocks' seen in Brampton Bryan Park (*op. cit.* p. 25).

Despite these early records, no attempt appears to have been made to fix the boundaries of the Cambrian beds, or to ascertain their relations to the surrounding formations. Further, the name 'Cambrian' does not appear on the old 1-inch map of the Geological Survey.[5] In that map the whole strip is coloured as 'Llandovery,' succeeded conformably by Wenlock Shales on the east, and faulted against Ludlow beds on the west; but the word 'Fossils,' which is written across the strip, would appear to refer to the *Dictyonema*, which is abundant in the Cambrian shales.

The district is dominated on the western side by the eastward-facing Ludlow escarpment, which ranges north and south through Brampton Bryan Park and Pedwardine Wood, where it rises to an

[1] 'The Geologist' vol. iii (1860) p. 462.
[2] 'Siluria' 5th ed. (1872) p. 45.
[3] Q. J. G. S. vol. xxxiii (1877) p. 659.
[4] 'Handbook to the Geology of Shropshire' 1884, p. 14.
[5] Old Series, Sheet 56, N.E.

altitude of over 1000 feet O.D. The combined outcrops of the *Dictyonema* Shales, and of the Brampton and Letton Beds to be presently described, occupies approximately the ground between the 500- and 700-foot contour-lines on the eastern side of this escarpment, forming a strip a little over a mile long and having a breadth at the widest part of rather more than half a mile. This outcrop naturally breaks the symmetry of the Ludlow escarpment, replacing the normal steep scarp-slope by a more gentle convex and terraced slope. This merges eastwards into the wide, level, gravel-covered plain occupied by the Wenlock Beds.

II. The Brampton Grits and Conglomerates.

The most conspicuous rocks within this strip consist of massive conglomerates and greenish grits showing no clear stratification, which are exposed at several localities. The best exposure is found in a disused quarry, in the small plantation near the entrance to Brampton Bryan Park. These are the beds referred to by La Touche as 'Cambrian grits and pre-Cambrian rocks.'[1] Another exposure lies on the Brampton Bryan–Lingen road, a third of a mile south of the first-named village.

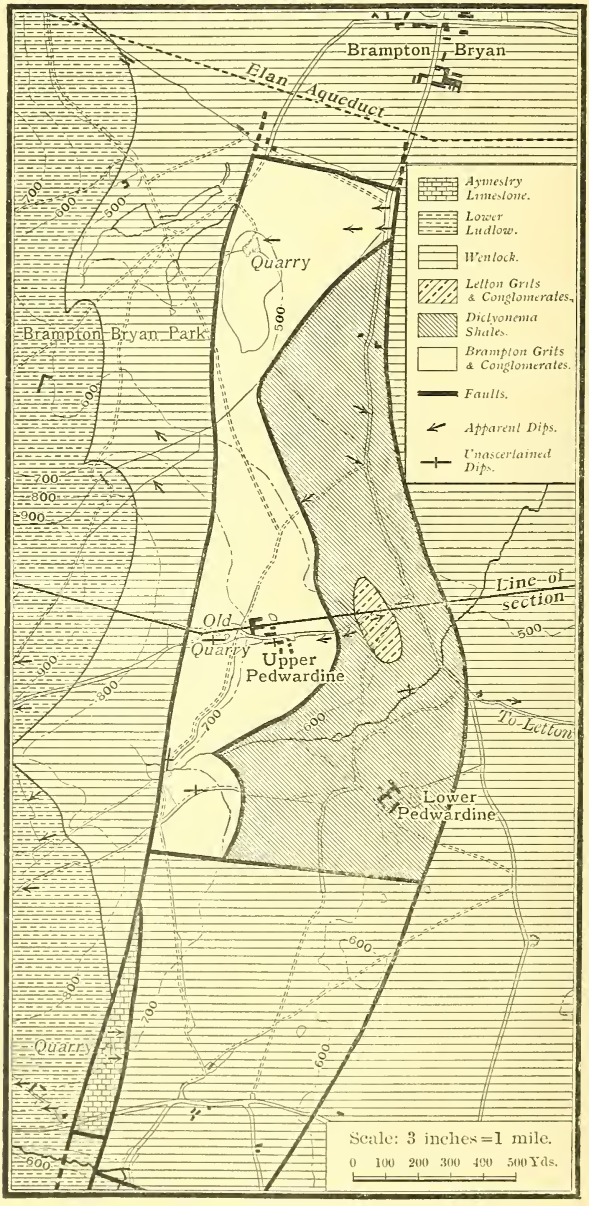
In the park quarry the beds are seen to consist for the most part of purple-green and reddish grits, which show a general tendency to become conglomeratic, the pebbles being chiefly quartz with less abundant felsite-fragments. These grits are not well stratified; but the bedding is shown by a few green shaly bands, which prove the series to dip steeply (60° or 70°) a little north of west. There is much irregular jointing, accompanied by overthrusting from the west.

The roadside exposure mentioned above is situated some 400 yards east of this quarry, the two points being connected by an obvious ridge. Here the dip is still less clear—owing to irregular jointing, but it appears to be in the same direction as in the park. The beds at this point are distinctly more conglomeratic, containing pebbles up to an inch or more in diameter. Here, again, the most abundant pebbles are vein-quartz of various colours, accompanied by numerous 'felsite' pebbles. The majority of the pebbles are fairly well rounded, a minority being distinctly angular.

Under the microscope a specimen of the conglomeratic grit from this roadside exposure shows the felsitic fragments to include numerous different types of rhyolitic tuffs and rhyolites. Among the last-named may be mentioned a variety with fine spherulitic outgrowths from quartz-phenocrysts. Other fragments present are quartz-schists, and vein-quartz pebbles which have been completely crushed into a mosaic before entering into the conglomerate. All these are, however, quite outnumbered by the normal quartz-pebbles and quartz-grains, some well rounded, others quite angular, the whole being cemented by a small amount of muddy matrix deeply stained by limonite.

[1] 'Handbook to the Geology of Shropshire' 1884, p. 25.

Fig. 1.—*Geological map of the Pedwardine inlier (1 : 21,120).*



[The heavy black lines represent faults.]

Similar conglomerates and grits are seen at various other small exposures over an area extending for about a mile in a southerly direction. At some of these exposures there is a tendency for the grits to become more quartzose; microscope-slides show a considerable outgrowth of secondary quartz from the quartz-grains, but the rock can never be termed a true quartzite.

The ground occupied by the outcrop of these grits tends to be very hummocky in character, and the site is often covered by trees. The grits have at one time been quarried in Brampton Bryan Park and around Upper Pedwardine for use in the neighbouring walls and buildings, but the workings, long abandoned, are now almost completely overgrown.

These Brampton Grits and Conglomerates appear to be quite unfossiliferous, no trace of an organism having been discovered at any of the exposures. Stratigraphical evidence as to the age of these beds is also unfortunately absent, as their outcrop is bounded on all sides by faults. On one side, as will appear later, they seem to be thrust horizontally over *Dictyonema* Shales.

Field evidence and direct palæontological evidence both being absent, there remains only the lithology to afford any clue as to the age of these Brampton Beds.

As previously noted, La Touche[1] speaks of the 'Cambrian grits and pre-Cambrian rocks of Brampton Brian Park.' Now, all the Brampton Beds belong evidently to a single series, it being quite impossible to make any line of division, based either on the lithology or on any other of the field-characters.

Lithologically these beds do not resemble any of the Cambrian grits and sandstones (Comley Sandstones) that I have seen in Shropshire. They find their nearest lithological equivalents in some of the beds of the Longmyndian outcrop at Hopesay, which lies some 7 miles north of Pedwardine. Moreover, in the main Longmynd area almost exactly similar beds are seen in the conglomerates of Stanbach.[2] The Stanbach conglomerates form a part of the Bayston Group, which is the lowest member of the Upper (or Red) division of the Longmyndian.[3]

The possibility of the strata of this Brampton series being of Bala age is at once excluded by the fact that, within a few yards of them we find rocks which, as will be shown later on, I consider to be of Bala age, differing markedly from the Brampton Beds in field characters as well as in direction of dip.

From their position between Cambrian and Wenlock and from the sinuous outcrop of their junction with the underlying Cambrian, it might be supposed that these Brampton Grits are Llandovery Beds resting unconformably upon the *Dictyonema* Shales.[4] This, however,

[1] 'Handbook to the Geology of Shropshire' 1884, p. 25.

[2] I am indebted to Prof. C. Lapworth, to whom I submitted hand-specimens from Pedwardine, for calling my attention to their resemblance to these Stanbach conglomerates.

[3] C. Lapworth & W. W. Watts, 'Shropshire,' in 'Geology in the Field' (Geol. Assoc. Jubilee vol.) 1909–10, p. 748.

[4] The whole area is coloured as Llandovery on the 1-inch map.

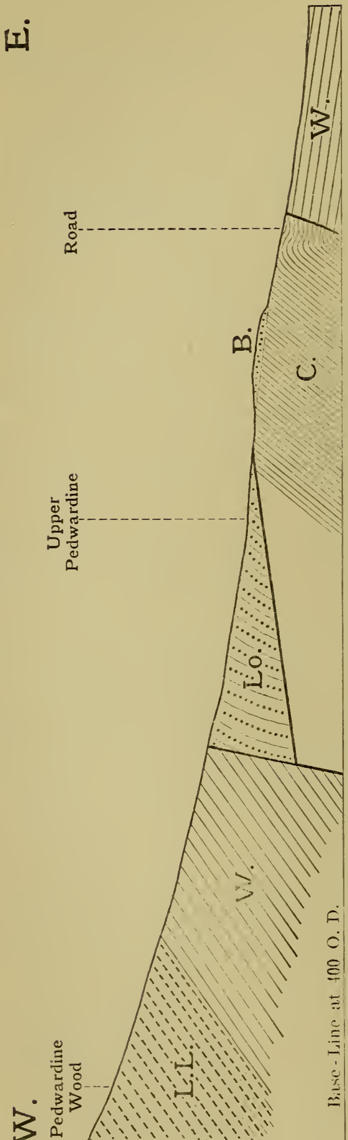


Fig. 2.—*Section across the Pedwardine inlier. (Horizontal scale: 6 inches = 1 mile; vertical scale = twice the horizontal.)*

[Lo = Brampton Grits and Conglomerates; C = *Dictyonema* Shales; B = Letton Grits and Conglomerates; W = Wenlock Beds; LL = Ludlow Beds. The thicker black lines represent faults.]

is highly improbable, in the light of the following combination of facts:—

(1) The Brampton Grits have a high westerly dip, as previously mentioned.
(2) Less than 200 yards to the east are Letton Grits and Conglomerates [Bala ?],[1] which dip gently eastwards and rest unconformably upon the Cambrian.
(3) No Bala Beds actually intervene between the Brampton Grits and the Cambrian.

Thus, taking these facts into consideration, it would seem that the Brampton Grits and Conglomerates cannot lie unconformably upon the Cambrian and Bala: nor is the junction to be explained by normal faulting. Further, although this Brampton-Grit series bears a lithological resemblance to the lowest Upper Llandovery Beds as seen in the nearest outcrop at Corton, near Nash Scar and Presteign, 6 miles south-west of Pedwardine, the bedding in these lowest Upper Llandovery Beds is always quite apparent and fossils occur in abundance; while the coarse gritty beds there soon pass into a finer-grained sandstone, a type which is nowhere represented among the Brampton Grits and Conglomerates. Moreover, this Brampton-Grit series shows abundant signs of having been affected

[1] See p. 370 *postea*.

to a much greater extent by earth-movements than have the immediately adjacent Bala Beds.

Thus, in the entire absence of fossils and taking account of the close resemblance to some of the typical Longmyndian beds, in conjunction with other field evidence, I have no hesitation in assigning these Brampton Grits and Conglomerates to the Longmyndian.

In this connexion it may be noted that the Brampton Grits differ in appearance, although not in composition, from the series found along the same line of dislocation 9 miles to the south-west at Old Radnor, a series claimed as Longmyndian by Dr. Callaway.[1] These Old Radnor rocks have, however, evidently been subjected to much greater disturbance, as shown by the prevalence of slickensiding and brecciation, resulting in the complete obliteration of all bedding-planes.

III. The *Dictyonema* Shales.

The *Dictyonema* (Upper Cambrian) Shales occupy the ground on the eastern side of the outcrop of the Brampton Grits and Conglomerates. They are best exposed in the deeply-cut course of a small stream, alongside the field-path running from the Brampton Bryan–Lingen road to Upper Pedwardine. Here they are seen to dip steeply (up to 50°) westwards, that is towards the Brampton Grits.

These *Dictyonema* Beds are thinly-bedded greenish shales, precisely similar to the typical *Dictyonema* Shales of Shineton.[2] *Dictyonema sociale* is fairly abundant, and *Lingulella nicholsoni* also occurs; but no other fossils have been recorded.

Other smaller exposures show the dip of these beds to be rather inconstant. For example, there is a small fold near the road, perhaps due to the close proximity of the boundary-fault; while, in an exposure on the south side of the same field, the beds appear to be horizontal.

IV. The Letton[3] Grits and Conglomerates.

The Letton Grits and Conglomerates are seen resting on a planed-off surface of the *Dictyonema* Shales at the first-mentioned exposure of the latter. These are the beds referred to as 'Llandovery' by Lightbody,[4] Callaway,[5] and La Touche.[6] Only a few feet of these beds are exposed. They are conglomerates and coarse grits, the conglomerate consisting essentially of well-rounded quartz-pebbles, with an occasional rather greenish quartzite-pebble evidently derived from the Cambrian quartzite, although this latter is not exposed anywhere within 10 miles of Pedwardine. These Letton Conglomerates yield numerous casts of *Orthis calligramma*, which are for the

[1] Q. J. G. S. vol. lvi (1900) p. 511.

[2] C. Callaway, *ibid.* vol. xxxiii (1877) pp. 659–60.

[3] Letton is a hamlet situated about three-quarters of a mile east of Upper Pedwardine.

[4] 'The Geologist' vol. iii (1860) p. 462.

[5] Q. J. G. S. vol. xxxiii (1877) p. 659.

[6] 'Handbook to the Geology of Shropshire' 1884, pp. 14, 25.

most part badly preserved, as is only to be expected in such coarse-grained rocks. The beds dip at about 5° eastwards, whereas the underlying *Dictyonema* Shales dip steeply westwards. The Letton Grits are lithologically very similar to the Hoar Edge Grits of Caradoc, and are probably to be referred to the Bala Series.

These fossiliferous Letton Grits and Conglomerates differ from the unfossiliferous Brampton Grits and Conglomerates, which are seen a few yards farther up the path, in being less compact and also in the following characters :—Felsite-pebbles are practically absent, whereas pebbles undoubtedly derived from Cambrian quartzite occur. Such quartzite-pebbles have nowhere been found in the unfossiliferous series. Further, the jointing and bedding of the Letton Grits and Conglomerates are quite regular, and the beds have a gentle easterly dip; while, on the other hand, the unfossiliferous series, as already mentioned, shows irregular jointing and imperfect bedding with a steep westerly dip.

The Letton Beds are not exposed at any other point, and so their outcrop can only extend over a few square yards: it is particularly fortunate that there should be an exposure within so limited an area.

V. The Structure.

The members of these three series, Brampton Grits and Conglomerates, *Dictyonema* Shales, and Letton Grits, together occupy the whole extent of the inlier, Llandovery Beds being entirely absent.

The structure of the whole district is that of a broken anticline with an axis running north and south, all the beds on the east of the inlier dipping gently eastwards, and those on the western side dipping up to 40° westwards.

The inlier itself is bounded on both eastern and western sides by two of the main north-east and south-west faults which are so prominent in Shropshire, although here the direction of the faults is more nearly due north and south.

The eastern boundary-fault brings against the older rocks Wenlock Shale of typical Shropshire facies, and having everywhere a gentle easterly dip. From its outcrop this would appear to be a reversed fault.

The western boundary-fault brings on Wenlock Shales and Lower Ludlow Beds. This fault gives rise to a small scarp at one locality, where the Brampton Grits and Conglomerates are brought against the softer Wenlock Shales; but the direction of its hade is nowhere to be seen.

The northern and southern boundaries of the inlier must in each case be due to cross-faults, but their position and their direction can only be stated approximately. At the northern end the Brampton Grits and Conglomerates disappear beneath drift along the northern border of Brampton Bryan Park, and the fault in all probability coincides with the drift boundary. On the southern side of the inlier there is no reliable evidence of the direction taken by the fault, owing to lack of exposures and to the fact that the *Dictyonema* Shales and the Wenlock Shales, which are there brought into contact one with the other, give rise to such similar ground.

Within the inlier the relation of the *Dictyonema* Shales to the Brampton Grits and Conglomerates is nowhere displayed in section. As previously remarked, the strata of both these series are highly inclined to the west, so that the *Dictyonema* Shales dip towards the Brampton Beds. The boundary between the two formations follows a very sinuous course, too complex to explain by normal faulting. This sinuous boundary would represent exactly the outcrop of a very gently inclined thrust-plane dipping about north-north-westwards. This leads to the conclusion that the Brampton Grits and Conglomerates have been thrust from the north-west on to the Cambrian. The thrust is obviously earlier than the north and south post-Silurian faults which bound the inlier; and, since the neighbouring Letton Beds rest almost horizontally and show no signs of disturbance, it is possible that the thrust is of pre-Bala date. If this be the case, then the movement which tilted the Letton Beds eastwards would have the effect of making the thrust-plane appear more nearly horizontal than it was originally.

It is noteworthy that, whereas no sign of any great disturbance is seen among the Wenlock Shales on the east of the inlier, the Ludlow Beds on the western side are everywhere much folded and show signs of a considerable amount of overthrusting. It would thus appear that this inlier is only the faulted remnant of a much larger mass, which served to protect the country on the east from the effects of the post-Silurian pressures arising in the west.

Occurrence of Aymestry Limestone.

Owing to a branching of the western boundary-fault at the southern end of the inlier, a small strip of Aymestry Limestone is let in between Wenlock Shales and Lower Ludlow. It is to these beds that the words 'Nodular Limestone, Corals,' printed on the 1-inch Geological Survey map, doubtless refer.

This occurrence is interesting, as affording a last glimpse of the Limestone before its complete disappearance in the west. It is seen in two small disused quarries to be only a few feet thick, and nodular and very impure in character owing to the abundance of shaly partings. It yields *Conchidium knightii*, *Rhynchonella nucula*, numerous corals (*Favosites, Heliolites*, etc.), and is underlain by shales with ill-preserved graptolites, the whole series dipping eastwards at an angle of 10°.

VI. Summary.

1. The inlier of Pedwardine consists mainly of Brampton Grits and Conglomerates and *Dictyonema* (Upper Cambrian) Shales.
2. The Brampton Grits and Conglomerates are referred to the Longmyndian.

3. There is also a small patch of Letton Grits and Conglomerates which rest with strong unconformity upon the Cambrian rocks, and appear to be of Bala age.
4. No Llandovery Beds are present.
5. The Brampton Grits and Conglomerates have been thrust from the north-west on to the Cambrian rocks.
6. Later faulting has brought these beds against Wenlock and Ludlow deposits.
7. The inlier is part of a barrier which has preserved the district on the east from the effects of the post-Silurian stresses.
8. A remnant of Aymestry Limestone is let in between two faults at the southern end of the inlier.

Finally, I wish to take this opportunity of expressing my thanks to Prof. W. W. Watts, for calling my attention to this district, and to Prof. C. Lapworth and Dr. T. F. Sibly for numerous valuable suggestions.

Discussion.

The President (Prof. W. W. Watts) pointed out that the section showing the relation of the rocks was rather a complicated one, and it was not easy to imagine the exact succession of movements to which it was due. If the discovery of an outlier of Bala rocks resting unconformably on the Shineton Shales were confirmed, it would be an interesting continuation of the conditions observable many miles to the north-east at Hoar Edge, along the prolongation of the great Lilleshall-Radnor fault. He congratulated the Author on the evidence that he had advanced as to the identification of Longmyndian rocks in the Pedwardine area.

Mr. W. G. Fearnsides also congratulated the Author upon his choice of so interesting a district, but was of opinion that further evidence was needed upon several of the points raised. When visiting Callaway's locality of Pedwardine with the President last summer, he had had the opportunity of collecting many specimens showing the various stages in the development of *Dictyonema*, and in examining these he had been much impressed by the unaltered character of the matrix. The specimens of *Dictyonema* are contained in soft, papery, olive-grey shales, and to the speaker it seemed a far-fetched notion to suppose that the adjoining coarse purple and red rocks had been carried to their present position by so drastic a process as the postulated horizontal thrust-plane would demand. A few well-planned excavations might easily decide this question. With regard also to the rocks referred to the Bala Series, he was not quite satisfied. Their local appearance and a strange absence of fine sediment between the pebbles seemed to suggest close affinity to the Llandovery rocks of the Welsh Borders; but of course, though resemblances count for much, the evidence afforded by the contained fossils should be decisive.

The Author, in reply, stated that he had closely investigated the Llandovery outcrop near Presteign, and had found considerable lithological differences from the Pedwardine grits and conglomerates. He did not regard the unaltered condition of the *Dictyonema* Shales as affording any evidence against the occurrence of a large thrust above them, since it has often been noticed in other areas that the rocks below a thrust-plane may not be affected to any great extent. With regard to the eastward displacement caused by such a thrust, it should be noted that the Longmyndian beds of Pedwardine lie considerably to the east of the strike-line of the corresponding beds of the main Longmynd area. He did not consider the absence of matrix from the Bala grits to be a character of any importance in correlation, since the thickness of such beds was so small and the rocks lay so near the surface. He agreed that excavations were needed to clear up certain points, but he had no opportunity of undertaking them at the time of his investigation of the district. In conclusion, he thanked the President and Fellows for the kind reception given to his paper.

21. *On the* Pre-Cambrian *and* Cambrian Rocks *of* Brawdy, Hayscastle, *and* Brimaston (Pembrokeshire). By Herbert Henry Thomas, M.A., B.Sc., Sec.G.S., *and* Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S. (Read April 17th, 1912.)

[Plate XL—Geological Map.]

Contents.

I. Introduction.

During the recent revision of the geology of the Pembrokeshire coalfield by the Geological Survey, a portion of the area dealt with in this paper had to be surveyed by one of us on the scale of 6 inches to the mile. The work had not progressed far before it was recognized that this area was one of exceptional interest, and one in which the relations of the Lower Cambrian to the pre-Cambrian rocks could be made out with little difficulty. We therefore decided to make an unofficial survey, on the same scale, of that portion of the district, containing Lower Cambrian and older rocks, which lay beyond the limits of the proposed publications of the revised geological survey.

The area surveyed and represented by the appended map (Pl. XL) is that portion of Pembrokeshire which stretches from the River Cleddau at St. Lawrence to St. Bride's Bay at Newgale, and includes the villages of St. Lawrence, Hayscastle, and Brawdy. Its total length from east to west is about 9 miles, and it has a maximum breadth of about 2 miles.

The country is of low relief, seldom rising to more than 400 feet above sea-level, and forms a somewhat elevated part of the West Pembrokeshire plain. The surface-configuration has but little relation to the nature or texture of the rocks beneath, and natural exposures are of rare occurrence, except on the sides of the deeper valleys and in the sea-cliffs.

Before proceeding to a description of the results of our survey, reference may be made to the principal works bearing on the district and to the chief points established by previous writers.

(*a*) Historical Review.

The first reference to the geology of this district is in the 'Silurian System' (1),[1] published in 1839, in which Sir Roderick Murchison mentions the Cambrian rocks at Cwm Mawr, Newgale. He does not refer to the igneous rocks of the neighbourhood; but he detected the faulted nature of the junction between the Cambrian and the Carboniferous (Millstone Grit), at Newgale, although (p. 374) he says that

> 'Near Brawdy the culm field rests upon, and has the appearance of graduating into the Cambrian System.'

The first mention of the igneous rocks of this old ridge was not made until some years later (in 1842), when Sir Andrew Ramsay drew up a manuscript report on the geology of Pembrokeshire (2). He had noted the variation in texture of the granitic rocks, but regarded the rhyolitic rocks of Rhindaston and Pointz Castle as fine-grained modifications of the same. With regard to the granite, he says that

> 'the ground is so much obscured that it is impossible to see the manner in which the granite affects the strata through which it is intruded, but from various evidences I consider it probable that it shoots into veins into the stratified rocks in a manner similar to the granite of Arran.'

In 1845 when the results of the first official geological survey (3) were published in Sheet 40 of the map, the main outlines of the pre-Cambrian rocks were indicated; the rocks of Brimaston, Brawdy, and Pointz Castle were coloured as 'granite,' and those of Rhindaston as 'greenstone.' The Cambrian beds were not differentiated by colour, but the words 'Purple Beds' indicated their presence near Trefgarn Owen and Roch Bridge, respectively on the northern and southern sides of the pre-Cambrian axis. In the following year (1846), Sir Henry De la Beche (5) gave a brief description of the granite between St. Lawrence and Brawdy, and remarked that towards its margin it passes into a rock similar to a Cornish elvan. He states that

> 'this granite . . . seems to have altered the stratified rocks in contact with it in many places, but the date of its protrusion is uncertain.'

Soon after this W. T. Aveline spent some time in the district revising the geological map, preparatory to the issue of a new edition (7); and one of his notebooks (6), preserved at the Geological Survey Office, contains much valuable information. His chief work was among the Lower Cambrian rocks which were subsequently coloured on the map, and of which the most important

[1] These numerals refer to the Bibliography on p. 377.

exposures are mentioned in his notes; he had, however, included in the Cambrian a good many pyroclastic rocks of greater antiquity (p. 379). He gave a description of the granite at several localities, but erroneously considered, on macroscopic evidence, that it contained hornblende.

On the later edition of the Geological Survey Map (7) the rhyolitic rocks of Rhindaston are indicated as intrusive porphyry, but the mass at Pointz Castle is still coloured as granite.

This region has not been revised since 1857 by the Geological Survey.

After an interval of twenty years, we enter upon a period which was marked by a great advance in South Welsh stratigraphy, namely that period over which were spread the researches of the late Dr. Hicks and J. W. Salter; for, with the recognition of a base to the Cambrian System and the establishment of a faunal succession within the Cambrian itself, modification of the pioneer work of the Survey was not only necessary but expected. Hicks had already suggested the names 'Dimetian' and 'Pebidian' for two pre-Cambrian rock-groups at St. David's, and in 1878 (9) he recognized their extension into the Hayscastle area. He remarked that, in the latter district, the Dimetian rocks

'form an axis to the newer rocks... similar in many respects to the one at St. Davids; and they are flanked in part by metamorphic Pebidian, and along both sides by unaltered Cambrian rocks.'

In 1879 (10) he suggested the name 'Arvonian' for a group of pre-Cambrian bedded felsitic rocks, and as such rightly claimed the rocks of Pointz Castle and Rhindaston. The Arvonian, however, included rocks of post-Cambrian age, and the remainder has proved to be inseparable from the Pebidian.

Sir Archibald Geikie in 1883 (12) questioned the pre-Cambrian age of the older rocks at St. David's and incidentally those of this region, so that Dr. Hicks (14) in the following year found it necessary, with additional evidence, to reiterate his statement that the igneous masses of Pointz Castle, Brawdy, and Hayscastle were older than any of the Cambrian deposits. His last paper bearing on this district was published in 1886 (15), and in an appendix by T. Davies were given several descriptions of Dimetian and Pebidian types.

Since this date nothing had been written on this particular area, until one of us gave a brief mention of the rock-types and a few of the chief exposures in the Summary of Progress of the Geological Survey for 1908 (16). In the summer of last year one of us conducted certain Members of the Geologists' Association over a portion of the ground that we had surveyed, and Mr. J. F. N. Green published a report on this excursion in the 'Proceedings of the Geologists' Association' (17), based on notes supplied by us.

(*b*) Bibliography.

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(3) One-Inch Map, Sheet 40, Old Series, 1st edit. published by H.M. Geological Survey, 1845.
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(9) Hicks, H.—'Additional Notes on the Dimetian & Pebidian Rocks of Pembrokeshire, with an Appendix by T. Davies' Quart. Journ. Geol. Soc. vol. xxxiv (1878) p. 153.
(10) Hicks, H.—'On a New Group of Pre-Cambrian Rocks (the Arvonian) in Pembrokeshire, with an Appendix by T. Davies' Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 285.
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(15) Hicks, H.—'The Pre-Cambrian Age of certain Granitoid, Felsitic, & other Rocks in North-West Pembrokeshire' Quart. Journ. Geol. Soc. vol. xlii (1886) p. 351.
(16) Thomas, H. H., in the Summary of Progress of the Geological Survey for 1908, Mem. Geol. Surv. 1909, p. 30.
(17) Green, J. F. N., in Proc. Geol. Assoc. vol. xxii (1911) p. 215.

II. The Pre-Cambrian Rocks.

The pre-Cambrian rocks of this district, as at St. David's, may be separated into two main divisions:—an older division consisting largely of fragmental and extrusive rocks, and a younger division of which the rocks are essentially intrusive. For these two groups we retain the respective names Pebidian and Dimetian, which were applied by Henry Hicks to similar rocks in the district of St. David's, and also suggested for some of the rocks within the district under description.

(*a*) The Pebidian.

Rocks of this division make up a large proportion of the area occupied by the pre-Cambrian formations; but, although various types can easily be distinguished in different parts of the district, no detailed subdivision of the rocks classed by us as Pebidian was attempted.

The Pebidian of this region is apparently not so well developed as in the district of St. Davids, nor is it separable into so many subdivisions. It is, however, possible to detect several different stages which may be correlated, in a general way, with the upper portion of the St. David's Pebidian as described by Mr. Green under the names of the Treginnis, Caerbwdy, and possibly Ramsey Sound Series.

Broadly speaking, the Pebidian of the Hayscastle region may be divided into two groups of rocks: one best-exposed in the neighbourhood of Pont-yr-hafod, and the other around Rhindaston and Gignog.

(i) The Pont-yr-hafod Group. (P^1—P^3 of the Map, Pl. XL.)

Between Hayscastle and Tre-rhôs there seems to be a definite sequence of rock-types appearing in the same order on both sides of the stream which crosses the road at Pont-yr-hafod; the distribution of beds suggests either a synclinal, or an anticlinal, axis ranging nearly along the valley. The beds on the north side of the valley are exposed on the same line of strike at Hayscastle, where they have a dip of 45° to the north-north-west; this renders it probable, apart from other considerations, that the beds lie in the form of an anticline.

Assuming that this inference is correct, the oldest strata exposed in the district are highly felspathic tuffs, some beds of which are coarse and even conglomeratic. Other bands are fine-grained, frequently laminated, and present a striped appearance on a fractured surface. The rocks of coarsest texture occur in the lowest exposed part of the group.

The lower and coarser tuffs are prevailingly pink and green; and, as the differently coloured fragments in the finer varieties are fairly evenly distributed throughout the rock, the result is a mottled or speckled appearance.

In the coarser tuffs, such as those cropping out along the northern side of the valley below Ffynnon-gron, the fragments are rounded and reach an inch in diameter. These fragments are variously coloured, and consist of quartzite, rhyolite, quartz-bearing fine-grained tuffs, and large fragments of keratophyres and rocks of intermediate composition: an assemblage which points to the existence of an older group of bedded deposits unexposed within the district under description. Most of the rock-types, however, are represented in the later Pebidian deposits. With these coarse pink and green tuffs are associated some apparently thin bands of purple or maroon-coloured fine-grained tuff which furnish highly characteristic débris.

The coarser rocks are succeeded by a thin series of blue and variously-coloured pale speckled tuffs of acid composition, which are in turn followed by buff-weathering rhyolitic tuffs containing bands of purple, less-acid, speckled tuffs that link them with the older rocks of the group.

Upwards the series seems to become still more felspathic and siliceous, and the purple, pink, and green tuffs give place to fine-grained felspathic rocks which form part of the upper group, and on weathering are difficult to distinguish from some of the sandstones occurring low down in the Cambrian System.

It was probably the confusion of these tuffs with the Cambrian sandstones that impelled several observers to consider the Dimetian rocks to be post-Cambrian intrusions.

(ii) The Rhindaston and Gignog Group.
(P^4 of the Map, Pl. XL.)

What appears to be the highest subdivision of the Pebidian present within the district is essentially rhyolitic and keratophyric in character, and comprises rhyolitic ashes, quartz-keratophyres, and occasional rhyolitic breccias. It is into the various members of this group that most of the Dimetian rocks have been intruded.

The most prevalent type is the rhyolitic ash which forms much of the ground around Gignog and to the south of Hayscastle. The rocks are well-bedded in character, but are in a highly altered condition. They are usually pale-grey, blue, greenish-grey, white or pink. They are of fairly fine texture, but in most cases show abundant small quartz-crystals and grains, similar to the quartz of the quartz-keratophyres, to be subsequently described (p. 385), with which they are associated.

These rocks break down readily, and are seldom exposed; but they are best seen in some old quarries to the west of Gignog and in the slopes of the valley (Brandy Brook) east of Asheston.

They are well represented by débris all over their outcrop, and a careful study reveals the fact that with them are associated bands of harder siliceous rock of felspathic character, in which minute quartz-phenocrysts are visible to the unaided eye. It is possible that some of these rocks may be of the nature of sills; but their identity with fragments in the tuffs, and the evidence obtainable from sections on Rhindaston Mountain and in the cliffs to the south of Pointz Castle proves that a great number, at any rate, are lava-flows.

Generally speaking, these quartz-keratophyres or quartz-bearing soda-rhyolites are pale-grey, opaque, fine-grained rocks with minute ill-formed quartz-phenocrysts. Occasionally, when fresh, they may have a blue-grey colour and flinty texture, and may be translucent in thin splinters. Such rocks form the greater part of the hill behind Rhindaston-fawr, and are especially well represented near the summit of that hill. The same blue, flinty, rocks occur on the northern flank of Rhindaston Mountain, near Barch.

A good section of quartz-keratophyres, with vesicular surfaces and fluxion-structure, interbedded tuffs and rhyolitic breccia, is exposed in some crags overlooking the valley of Brandy Brook, half a mile south of Gignog Ford, at a point marked by a dip-arrow on the map (Pl. XL). These rocks, it may be remarked, strike approximately at right-angles to the Cambrian basal conglomerate, which, therefore, probably overlies them with strong discordance.

Another mass of rhyolitic rocks which can be studied in detail is exposed along the coast between Newgale and Porth Mynawyd on the west. The rocks forming this mass have been the subject of conflicting statements; but their true nature was first detected by Hicks (15, pp. 353, 354), who described them as a group of rhyolites and breccias. He recognized that some of the rocks were spherulitic, and that others showed fluxion-structure, while among them were beds of breccia and fine ash. The greater number of the rocks are white and opaque, like most of the weathered rocks of this class; but a quarry on the cliff above Cwm Bâch has exposed a blue flinty rock similar to that of Rhindaston. Curiously vesicular rocks, in which the cavities have been filled with secondary quartz, are exposed in Cwm Bâch. Breccias are prevalent along the coast, and fluxion-structures may be observed in the rocks forming many of the crags of the upper portions of the cliffs.

Rhyolitic breccias, presumably belonging to this group, have also been detected in other parts of the district, one beautiful purple rock occurring on the path 300 yards south-west of Hayscastle Farm.

(*b*) The Dimetian. (D_1–D_3 of the map, Pl. XL.)

Considering that almost the whole of the pre-Cambrian complex of Brawdy and Hayscastle was coloured as granite on the older maps, it was somewhat surprising to find that granitic rocks form so small a portion. A variety of intrusive rock-types, however, is represented and they may be grouped under the names quartz-porphyry, biotite-soda-granite, and albite-diorite. The relations of one type to another are rendered rather obscure through the lack of sections, but the detailed mapping makes it apparent that the granite represents the earliest plutonic phase of the Dimetian in this district, and that it has been intruded into the Pebidian.

The quartz-porphyry was regarded by De la Beche and Ramsay as a marginal variety of the granite; but, although we agree in its being a variety of the granite, we are not convinced that it is marginal in character.

At Brimaston Hall there appears to be a complete passage from one type to another, the change being gradual and taking place over a somewhat wide zone; but in other parts of the district, as at Brawdy and Silver Hill, the change of type is sudden—as if there had been a slight time-interval between the intrusion of the granite and that of the quartz-porphyry.

The relation of the diorite to the other intrusive rocks is difficult to establish, but it will be discussed below (p. 382).

The hypabyssal and probably the latest pre-Cambrian intrusions are, in our opinion, represented by a series of doleritic dykes which we have observed to cut the Pebidian and various members of the Dimetian. All the same, we have no clear evidence that these dykes are not of later date, for similar dykes of post-Cambrian age occur in the district, and most of the basic dykes near St. David's are later than the faulting which has affected the Cambrian deposits of that area.

It is perhaps rash, therefore, to assign any of these rocks to the pre-Cambrian without definite proof of their age; on the other hand, a dyke-phase forming the latest episode of the intrusions agrees with what is observable in many other areas such as the Lizard Peninsula, South Pembrokeshire, etc.

These dykes are not often exposed, but we have seen a sufficient number of them to make it probable that their importance has been underestimated.

The areas occupied by the various Dimetian types are clearly indicated on the Map (Pl. XL), so that little need be said concerning their distribution—except that the quartz-porphyry covers by far the largest area, and is the most persistent type. The diorite, on the contrary, occupies but a small area, and only one mass has been detected.

In a later portion of this paper we have discussed the relation of the Cambrian rocks to the older deposits, and assuming that we have good evidence of the pre-Cambrian age of all the intrusive rock-types mentioned above, it remains here to demonstrate if possible the relation of these types to each other and to the Pebidian. Let us first consider the granite and the quartz-porphyry.

It is unfortunate that there are, so far as we can ascertain, no natural junctions between the various masses of granite and the Pebidian; but, as the granite and the quartz-porphyry are without doubt merely different phases of the same rock, and locally pass one into the other, it will suffice to deal with that which occupies the larger area and stands in clearer relationship to the Pebidian.

Where possible, the boundaries of the quartz-porphyry-masses were traced with some care; and, although there are no clear junctions exposed between these masses and the older masses of the pre-Cambrian, the mapping brings out the fact that their outlines are far from regular and that their boundaries often cross the strike of the Pebidian rocks in a manner inexplicable on the supposition of any reasonable system of faulting. As an instance of this, we may cite the mass of quartz-porphyry to the north of Barnard's Hill, and those of Tre-rhôs, Brawdy, Hayscastle, and Rhindaston.

We were fortunate enough to be able to follow the boundaries of several of the masses, especially of the first-mentioned mass, with considerable exactitude; it was made quite clear to us that the quartz-porphyry was intrusive into the Pebidian, and partook probably of the nature of a boss rather than of that of a sill. The small elliptical mass occurring in the valley between Tre-rhôs and Ffynnon-gron added evidence in favour of this view.

It is certain that neither the granite nor the quartz-porphyry cuts or alters in any way any member of the Cambrian System.

Passing now to a consideration of the diorite of Knaveston, the determination of its relative age is a matter of considerable difficulty; for, although it appears to be in natural contact with granitic rocks on its western side, no junction is visible; it is faulted on the north against granite, while on the east and in the immediate south the ground is so obscure and drift-covered that it is unsafe to base any far-reaching conclusions on the evidence available. It is possible that the diorite is quite a small intrusion, smaller than is indicated on the map, and may be of later date than the granite with which it is in contact. This, however, would be contrary to the order usually observed in the sequence of plutonic intrusions, although it would be analogous to that presented by the dioritic dyke-phase in the supposed pre-Cambrian of South Pembrokeshire.[1]

Doubt may be thrown on the presence of a dyke-phase of the Dimetian in this district, but appearances are in favour of its existence. Several basic dykes have been detected in the Dimetian and Pebidian; and although, as at Brawdy and Silver Hill, they strike obliquely to the outcrop of the Cambrian rocks, they cannot be traced from the older into the younger system. We have no reason to believe that in these cases the base of the Cambrian is faulted against the older rocks—in fact, the field evidence is against such an explanation of the sudden ending-off of the dyke-rocks.

(i) The Granite. (D^1.)

The granite of this region has been mentioned at various times and brief descriptions given by several writers, but its correct limits were not defined on any geological map.

It occurs in several isolated patches, and forms a relatively small portion of the pre-Cambrian complex. The areas in which it comes to the surface are Brimaston and Brawdy, but in neither of these districts is it well-exposed. It has weathered to a soft sand, and in many places, as near Brawdy Vicarage, has been dug to a depth of several feet.

Sir Andrew Ramsay (2) noted that

> 'owing to the readiness with which it decomposes, particularly when large-grained, it is rare to find it in solid masses in place. The large-grained variety decomposes most easily, and in some places where sand-pits have been dug at the depth of six or eight feet from the surface, it is still easily dug out with a shovel.'

In the neighbourhood of Brimaston the granite is best observed on the somewhat steep bank that flanks the northern side of Nant-y-coy Brook. The easternmost patch, which is faulted off from the main mass, is exposed in a small quarry overlooking the stream, and consists of a fine-grained non-porphyritic rock of a yellow to buff colour, speckled with flakes of decomposed biotite. A darker,

[1] O. T. Jones, in 'The Geology of the Country around Haverfordwest' Mem. Geol. Surv. Explan. Sheet 228; in the press.

finer-grained, and slightly more basic rock is included, in the form of abundant patches which reach several inches across.

The main Brimaston mass is exposed in a small quarry about half a mile east of Brimaston, and in the road near Broadway. It presents characters similar to that already described and, like it, includes many basic patches. Along the remainder of the outcrop only débris is observable, but this is everywhere abundant.

At Brimaston, especially in the farmyard of the Hall, the granite appears to pass gradually into the quartz-porphyry described below.

The Brawdy mass, which is cut up by faults, may be seen at the surface in the farmyard of Brawdy Farm, on both sides of the valley near Silver Hill, and flanking the fault-valley between Troed-y-rhiw and Knaveston. It has been dug for sand by the roadside to the west of Knaveston, near a faulted patch of Lower Cambrian sandstone. It is somewhat variable in type, but agrees with the Brimaston mass in all essential characteristics.

(ii) The Quartz-Porphyry. (D^2.)

The quartz-porphyry forming the various masses shown upon the map has a slightly variable texture, and exhibits slight variations in colour; but all these varieties are linked together by the large size and abundance of the quartz-phenocrysts and the relatively fine-grained nature of the matrix in which these phenocrysts are set.

The main mass of the quartz-porphyry, which occupies the country around Brimaston and Hayscastle Cross, is a much-weathered rock of a pale yellow to buff colour, having abundant rounded quartz-crystals which measure up to a quarter of an inch in diameter. The outcrop of this rock is covered with its débris, but exposures in the solid are rare, as the rock has weathered to a great depth. The flat character of the ground has perhaps prevented in a great measure the natural removal of the weathered rock.

Shallow pits have been dug in this mass at various localities, as at Barnard's Hill behind the farm, and the hollow 400 yards to the west. A variety with extremely large quartz-crystals also occupies the ground close to Broadway Farm, and rises from the drift-covered moor to the west of Mountain Water. Portions of the rock occasionally show a distinct purplish or pinkish tinge, and contain amethystine quartz; but in the greater portion the quartz is either colourless, or opaque-white.

Small masses of a similar rock occur to the north of Barnard's Hill, near St. Lawrence, at Hayscastle, and at Brawdy; and a small elliptical outcrop was detected among the Pebidian purple tuffs on the north side of the hollow, half way between Tre-rhôs and Ffynnon-gron.

(iii) The Diorite. (D^3.)

The Knaveston diorite is a fairly compact, dark-grey, fresh rock, speckled and sometimes stained green. It is of moderate grain, and has been quarried for local building-stone at a point 400 yards to the north-west of Knaveston Cottage. This rock occupies quite a small area, and only one outcrop has been detected. It differs in character from the other basic intrusions which cut the granitic rocks of the surrounding country, and has no parallel in the St. David's region. Dioritic rocks, however, occur among the supposed pre-Cambrian of South Pembrokeshire, as at Johnston, Talbenny, etc.

(iv) The Basic Dykes.

A certain number of basic dykes, which we are inclined to regard as a phase of the Dimetian, cut the Pebidian and also the older members of the Dimetian. Such dykes occur in the granite of Brawdy, where one is seen in the farmyard cutting the granite and abutting against the Cambrian conglomerate; another cuts the granite in the road near Brawdy Vicarage, and yet another in the granite has been cut into by a small quarry in the valley south of Silver Hill.

Another basic dyke, measuring about 45 feet across its outcrop, cuts the older Pebidian, and is exposed in the road at Pont-yr-hafod, east of Hayscastle. It is similar in all respects to those mentioned above. These dykes are certainly numerous; but they are not conspicuous, on account of the covered nature of the ground.

Generally speaking, they are fairly dark-grey to dark bluish-green rocks of moderately fine texture.

(*c*) Petrography.

(i) The Pebidian.

The Pont-yr-hafod Group.—Specimens for microscopic examination were taken from the lowest exposed purple-and-green tuffs at Pont-yr-hafod: the best specimens being collected from a small pit behind the schoolhouse (E 8993, 8994).[1]

These tuffs are composed of somewhat angular fragments, which represent a variety of rocks of volcanic and sedimentary character, but no rocks of a plutonic nature have been met with. The larger fragments consist of fine-grained quartz-albite rocks which may be classed with the keratophyres, but much of their original structure has been destroyed. Other fragments are of the nature of quartzose keratophyric tuffs, and are made up of broken and angular quartz- and albite-crystals in a fine sericitic matrix. Fragments of what were presumably andesitic or basaltic rocks are represented by chloritized and iron-stained masses, in which occasionally a microlitic structure is still observable.

Among the smaller fragments of the above-mentioned materials occur abundant grains and broken crystals of quartz, which have

[1] These numerals refer to the numbers of the slides in the collection of the Geological Survey.

seemingly been furnished by quartz-keratophyres, and pebbles of felspathic quartzose sedimentary rocks.

The matrix of the Pont-yr-hafod rocks is extremely fine-grained, and under the microscope has almost a glassy aspect, owing to the little action that it has on polarized light. It appears to be highly siliceous, and is slightly iron-stained. In the finer tuffs the matrix is not so siliceous, neither does it consist of so finely comminuted material.

One other mass referable to this group of rocks occurs as a faulted lenticle, and is presumably surrounded by younger beds. It forms a striking mound in the bottom of the fault-valley which ranges from Gignog to Knaveston. The rocks are extremely rotten, and have lost most of their original structure; but it is possible to make out (E 7244, 7245) that the fragments were of andesitic character, and consisted of plagioclase felspar-crystals set in a fine-grained and vesicular ground-mass. The whole rock now consists of a mass of chlorite, secondary quartz, and iron-ores. The felspar-phenocrysts are replaced by a mosaic of secondary quartz, and thus stand out in contrast with the matrix, which is chloritic and iron-stained. Considering the mass as a whole, it probably was slightly more basic in composition than most of the tuffs of the Pont-yr-hafod Group exposed around Pont-yr-hafod.

The Rhindaston and Gignog Group.—Unlike the rocks of the Pont-yr-hafod Group, the acid group of Rhindaston and Gignog had been detected in places by previous observers, who have from time to time furnished descriptions of certain of its types.

The majority of the rocks of this group may be classed as quartz-bearing soda-rhyolites or quartz-keratophyres, and their attendant tuffs.

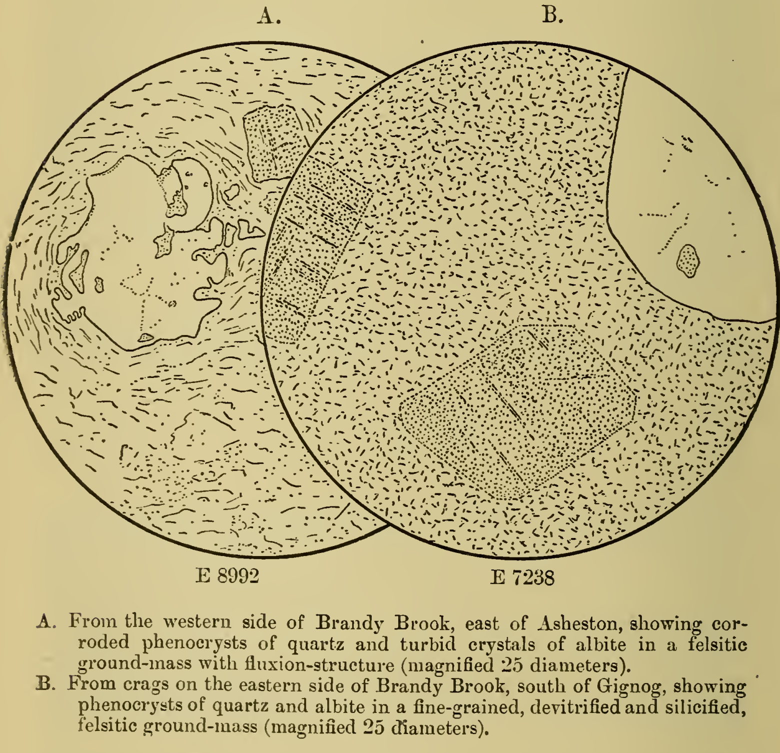
Specimens for examination have been collected from a variety of localities, but chiefly from the good exposures near Gignog, from the crags on the east side of Brandy Brook, and from the cliffs between Pointz Castle and Porth Mynawyd. The Gignog rocks are typical of the group. A specimen collected from the western side of the Brandy Brook valley, to the east of Asheston, proved to be a quartz-keratophyre (8992), and is shown in fig. 1 A (p. 386). It consists of corroded quartz-phenocrysts, measuring some few millimetres across, and well-shaped phenocrysts of albite, set in a fine-grained devitrified and silicified ground-mass in which the original fluxion-structure can be distinctly made out.

The associated tuffs are composed of exactly similar materials, and only differ from the above in their obviously fragmental character (E 7246, 7258). Usually the larger fragments in these tuffs are not rock-fragments, but broken crystals. Occasionally, however, the tuffs become coarser and well-banded (E 7247, 7248) with the introduction of more finely clastic material in the form of fine-grained sedimentary rocks of quartzose and argillaceous character, while chloritized fragments of andesitic rocks may be present in some quantity.

A breccia from Hayscastle (E 7770) belonging to this series has a beautiful purple colour and, under the microscope, shows itself to be composed of fragments of devitrified quartz-keratophyres. The felspar-phenocrysts are, as usual, all albite, and in the ground-mass it is possible to detect traces of the original banding of the rock and to make out fluxion and even perlitic structures.

Specimens taken from the Rhindaston mass, on the eastern side

Fig. 1.—*Quartz-keratophyres from the Rhindaston and Gignog Group.*



A. From the western side of Brandy Brook, east of Asheston, showing corroded phenocrysts of quartz and turbid crystals of albite in a felsitic ground-mass with fluxion-structure (magnified 25 diameters).

B. From crags on the eastern side of Brandy Brook, south of Gignog, showing phenocrysts of quartz and albite in a fine-grained, devitrified and silicified, felsitic ground-mass (magnified 25 diameters).

of Brandy Brook, show the rocks to be lavas and associated tuffs (E 7230, 7237–7241). The lavas contain a few small corroded quartz-phenocrysts, but have a preponderance of albite-felspar (E 7238, fig. 1 B). The ground-mass is composed of microcrystalline quartz and albite, but it contains locally a considerable quantity of epidote, the presence of which suggests the possibility of the felspars being at one time richer in lime than they are at present. This is the only indication, however, of albitization observable in these rocks, and it is probably not wholly trustworthy.

The rocks of the Pointz-Castle mass are those which in the past were classed by Hicks as part of his Arvonian. A petrographical description of a rock of this group was given by Dr. Bonney, who compared it with the rhyolitic ash of Clegyr Bridge in the St. David's district. The bulk of the Pointz-Castle mass consists of fragmental material, either in the form of breccia or in that of ash; but quartz-keratophyres occur, and, as pointed out by Hicks, some of them appear to have been vesicular (E 7226).

In a rock collected from the upper end of Porth Mynawyd near the lime-kiln, the quartz-phenocrysts reach a fair size (E 7252), and are much more abundant than the albite-phenocrysts. The ground-mass is a microcrystalline mass of quartz and albite, with a little sericitic material.

One of the vesicular rocks in which the vesicles are filled with a mosaic of secondary quartz occurs at the base of the cliff on the northern side of Cwm Bâch, Newgale. This rock has also a tendency to show spherulitic structure in the ground-mass.

(ii) The Dimetian.

The granite.—The normal granite of Brawdy and Brimaston is a fairly fine-grained, yellowish-grey rock, which contains a variable amount of quartz, felspars, and ferromagnesian minerals. There is a complete absence of porphyritic structure; but, occasionally, the quartz may show a tendency towards idiomorphism. The presence of mica was recorded by De la Beche in 1846 (5, p. 230).

Under the microscope the rock of Silver Hill and Knaveston (E 7249, 7251) seems to be of uniformly medium grain, and consists of quartz, felspar, and a green pleochroic mineral pseudomorphous after biotite. The most interesting feature of this rock is the nature of the felspars, and their relation one to the other and to the quartz.

The greater portion of the felspar is much-twinned albite, the crystals of which are often surrounded by perthite, and are in optical continuity with the albite of the perthite. The relative proportions of perthite and albite are variable in different parts of the mass, specimens from Knaveston containing a greater proportion of albite than those from Silver Hill.

The quartz of much of the rock shows the usual granitic characters; but occasionally it has a tendency to form pegmatitic or granophyric intergrowths with the alkaline felspars—a tendency which becomes more marked as the texture of the rock becomes less coarse, as at the extreme end of the mass to the east of Brimaston (E 6572).

None of the specimens examined contained microcline, and accessory minerals such as primary sphene, apatite, or iron-ores are not abundant.

Compared with the Dimetian granite of St. David's there are a great many points of similarity, especially in the structure and the composition of the felspars, for the St. David's rock consists chiefly of albite and perthite, with possibly some anorthoclase. The St. David's granite, as shown by the analysis made by Persifor Frazer and quoted by Hicks (14, p. 528), is, like the one under description, particularly rich in soda; in fact, the analysis of the St. David's rock shows 45 per cent. of albite, 4 per cent. of orthoclase, and not more than 2·7 per cent. of anorthite.

In the St. David's Dimetian, specimens taken from Bryn-y-garn show albite to be the only plagioclase-felspar present, and they contain perthite like the specimens from Silver Hill.

The mica of the St. David's Dimetian is slightly more decomposed than that of the Brawdy and Brimaston masses, for it seldom shows the pleochroic halos characteristic of this mineral in its fresh state; also it appears to have been more highly titaniferous, for its decomposition has resulted in the separation of a considerable quantity of secondary sphene.

The St. David's mass, like those of Brawdy and Brimaston, has pegmatitic modifications.

The quartz-porphyry.—The macroscopic characters of this rock have already been mentioned (p. 383). Microscopically it exhibits corroded quartz-phenocrysts, alkaline felspars, and a little decomposed biotite, set in a beautifully micrographic ground-mass (E 9022). It is obviously related petrographically to the granite, and is almost certainly a product of the same magma.

The felspar of the phenocrysts is chiefly albite; the crystals are ragged in outline, much twinned, and of smaller dimensions than the quartz-crystals. They are for the most part rendered turbid by micaceous products of decomposition.

Around the quartz-crystals is a fairly wide resorption-halo of micrographic material, in which the quartz extinguishes simultaneously with that of the phenocryst. Similar halos surround the albite-crystals; but, in this case, the felspars of the granophyre and crystal are in optical continuity. In the remaining portion of the ground-mass quartz is predominant, and extinguishes in irregular patches after the manner of the ground-mass of many devitrified rhyolites; but the structure of each patch is minutely granophyric.

The rock is evidently rich in silica, and the soda-content must be high, on account of the prevalence of albite. It would compare closely with the elvans of Cornwall, but would probably show a difference in having an excess of soda over potash. In the elvans there is a greater percentage of potash, and generally an absence of granophyric structure in the ground-mass.

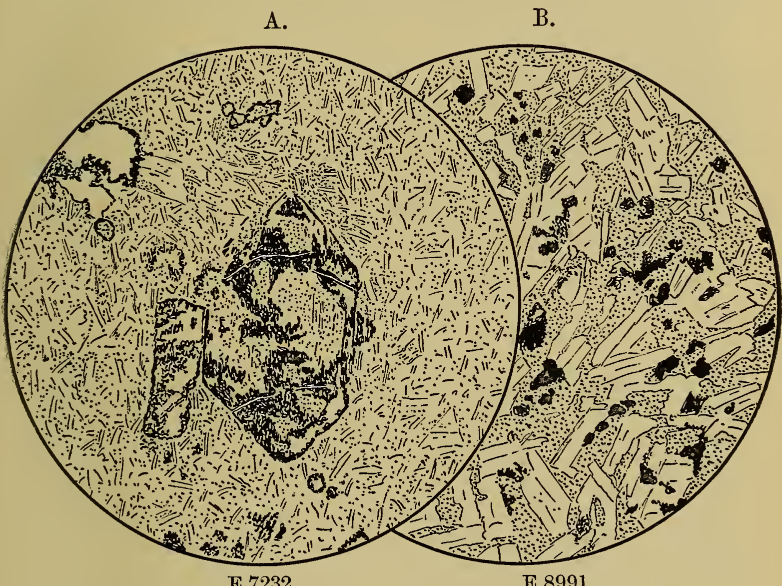
The Knaveston diorite.—The diorite is a dark-grey medium-grained speckled rock, in which hornblende-crystals are obvious to the unaided eye. Under the microscope it is seen to consist chiefly of pale bluish-green hornblende, albite-oligoclase felspar, a little augite, and much sphene. The hornblende sometimes behaves ophitically towards the felspars, and contains small patches of augite.

The general characters of the rock lead us to the conclusion that it should take its place among the augite-diorites rather than with the epidiorites, for we believe the hornblende to be in the main primary.

The felspars are nearly all albite, but they are frequently decomposed, chiefly to micaceous aggregates. The presence of a little epidote, however, may point to the presence of a more basic soda-lime-felspar in the undecomposed rock.

A striking feature of this diorite is the abundance of sphene

Fig. 2.—*Dyke-rocks from the pre-Cambrian and Cambrian.*



A. Albitized and silicified olivine-dolerite cutting the upper sandstones of the Welsh Hook Beds of Cwm Mawr, Newgale. The figure shows a well-shaped pseudomorph after olivine in a fine-grained ground-mass (magnified 25 diameters).

B. Albitized and chloritized ophitic dolerite cutting the tuffs of the Pont-yr-hafod Group. The figure shows laths of albite in a mass of chlorite and iron-ores (magnified 25 diameters).

which occurs in large ophitic plates moulded on both felspars and hornblende. It is almost colourless, and appears to be an original constituent of the rock. The presence of abundant sphene in soda-rich plutonic rocks is not an unusual feature, and seems to point to some intimate relation between the titanic acid and the soda-content of the original magma. Ilmenite is present in some quantity, and on decomposition has given rise to granular sphene. Apatite occurs in fairly large prisms, but is an uncommon accessory.

Augite-diorites of this type have not been met with in the St. David's region, but this occurrence is of interest in view of the great mass of dioritic rocks of supposed pre-Cambrian age, which occupy the ridge between Johnston and Talbenny in South Pembrokeshire.

The basic dykes.—The distribution of the basic dykes which have been observed to cut the older rock-groups has been already discussed.

Usually they are fairly fine-grained rocks of uniform texture and dark grey to dark bluish-green colour. They become still finer towards their edges, for their margins have been chilled against the rocks into which the dykes were intruded.

Specimens for microscopic examination were collected from a small opening in one of these dykes, to the south of Silver Hill (E 7250), and from the roadway at Pont-yr-hafod (E 8991). They prove to be completely albitized, and to consist of lath-shaped crystals of albite arranged in no particular manner, set in a matrix of chlorite and iron-ore.

The general structure of these rocks may be judged from fig. 2 B (p. 389), which represents the rock exposed at Pont-yr-hafod.

III. The Cambrian Rocks.

(*a*) Their Succession and Distribution.

The Cambrian rocks form a much-torn fringe to the pre-Cambrian massif, although doubtless they were once continuous over the whole district. They occupy the greatest area near the two ends of the elongated mass, the most complete sections being found at the north-eastern extremity in the neighbourhood of the Cleddau Valley. The succession there obtained is confirmed by sections in the south-western area, which extends from Rhindaston to Pointz Castle; the highest group, however, has not been recognized in that district, except perhaps on the southern flank of Rhindaston Mountain, near the Kite. The smaller areas of Lower Cambrian rocks which occur along the north-western margin of the complex (north of Tre-rhôs, north-west of Hayscastle, and Trefgarn-Owen) are of the nature of lenticles, faulted in between the rocks of the massif and the younger rocks which surround it. Similar faulted lenticles also occur within the massif, as to the north-east of Tre-rhôs and to the south and east of Troed-y-rhiw.

The succession in the Welsh Hook and St. Lawrence district is well displayed down the hill from St. Lawrence Church to Welsh Hook Bridge, and thence north-eastwards along the main road through Welsh Hook, or northwards along the eastern and western banks of the Cleddau.

The highest beds are developed principally in the neighbourhood of Ford, the best sections being found in the railway-cuttings south and north-west of that hamlet.

The rocks are described under the following headings:—

		Thickness in feet.
Ford Beds ...	7. Banded shales	Unknown.
	6. Musland Grit..	About 100
Welsh Hook Beds.	5. Green quartzitic sandstones...............	More than 100
	4. Purple sandstones..	About 250
	3. Red shales	50
	2. Green felspathic sandstones	450
	1. Conglomerate, pebbly grit, and quartzite	0 to 150

The lower beds only, corresponding to the numbers 1–4, are found in the south-western area; but, unless otherwise stated, the observations on the Welsh Hook sequence may be assumed to apply to the remaining areas.

The Welsh Hook Beds.

(1) The basal beds vary in character from conglomerate to pebbly grit or coarse quartzite in a comparatively short distance.

At Stone Hall Mill a coarse conglomerate, with pebbles of liver-coloured quartzite, rests upon highly-sheared rhyolitic ashes; while to the east of Stone Hall the basal beds are saccharoidal pebbly grits containing pale pink quartz-pebbles, probably derived from certain types of the quartz-porphyry which contain amethystine quartz: in this locality the grit appears to overlie a mass of quartz-porphyry.

The most remarkable development of the conglomerate is that in the south-western area, to the east of Silver Hill. Unfortunately there is no exposure; but, during our visits, some of the fields, intervening between the outcrop of the green sandstone (2) and the granite, were covered with big blocks of coarse conglomerate derived from the immediate subsoil. The large lumps contain pebbles of vein-quartz, granite, and diorite; while numerous well-rounded pieces of vein-quartz, diorite, granite, porphyry, and quartzite, occurring in association with them, are almost certainly pebbles weathered out from the conglomerate. The presence of the Knaveston dioritic mass about 400 yards away might account for the diorite-pebbles. This conglomerate was assayed for gold by Dr. W. Pollard, of H.M. Geological Survey, but it yielded no values.

There is a small quarry in conglomerate, with pebbles up to 4 inches in diameter, on the western side of Brandy Brook, half a mile north of Gignog; all the pebbles observed there were of quartzite and vein-quartz.

On Tre-rhôs Moor, and to the south, the basal beds have disintegrated to some depth; at the former locality they have been dug for sand, and in other places the fields are covered with well-rounded pebbles.

(2) The succeeding group is made up of greenish-blue, felspathic, somewhat micaceous or chloritic sandstones in their fresh state; but they usually weather to soft, buff-coloured or pale yellowish

sandstones which are at times difficult to distinguish from some of the Pebidian tuffs. Bedding-planes are usually not well-developed; near Welsh Hook some of the coarser varieties exhibit false-bedding.

In the area to the west of Brimaston the rocks of this group are somewhat coarser in texture, and weather light or dark brown with dark small spots.

(3) The red shales, although only a thin band, are remarkably persistent and uniform in character, and they formed a useful horizon in mapping the ground. In the middle of the band they are soft smooth shales of a rather vivid dark red or maroon colour; but they take on a dull purple tint in the upper and lower portions.

They are well-exposed to the north-west of Welsh-Hook Bridge, and in a hollow overlooking Cwm-bâch, south-west of Pen-y-cwm.

At the last-named place they yielded fossils to one of us and to Mr. J. Pringle, notably a large species of *Leperditia*; similar shales in Crow-cwm Wood, to the south-east of Llethr, yielded the same form.

A thin band of pale tuff traverses these red shales, and is exposed in the little hollow above Cwm-bâch. It consists almost entirely of well-shaped crystals of plagioclase-felspar, and represents the only trace of volcanic activity discovered within the Cambrian System.

(4) The purple sandstone group consists of well-bedded, fine-grained, micaceous sandstones, which are generally felspathic and of a dull purple-red or purple-grey colour.

Occasional bands of green chloritic sandstone are present in the series, especially on the coast to the south-west of Pen-y-cwm.

The best exposures are near Welsh Hook, near Trefgarn-Owen, on the coast north of Cwm-mawr, and at Roch Bridge.

These sandstones have been quarried extensively for building purposes.

(5) Succeeding the purple sandstones, in the neighbourhood of Welsh Hook, is a thin group of green micaceous and quartzitic sandstones, some bands of which are somewhat coarsely grained. Similar beds succeed purple sandstones on the south side of the Cleddau, south-east of Musland; and also on the east side of Brandy Brook, near Rhindaston Mountain.

They appear to form a normal upward continuation of the underlying group, although they have not been observed elsewhere, the reason being that the upper portion of the purple sandstone group is faulted out in all the other localities.

On the eastern side of the valley, near Welsh Hook, they are invaded by a dark-green spotted doleritic rock which appears to follow the dip and strike of the surrounding beds.

The Ford Beds.

The position of the Ford Beds in the Cambrian sequence is by no means clear.

(6) The lowest beds are exposed in the railway-cuttings to the south-east of Musland, and consist of about 50 feet of greenish-yellow felspathic grit which forms rather thick beds. The central portion is somewhat coarse and pebbly, while at its upper limit it passes up into the overlying shaly and flaggy series. To the same grit may be assigned the numerous blocks of pebbly grit on each side of the road, half a mile west of Ford; it is there followed by the shaly group.

(7) As exposed in the deep railway-cuttings, the upper group consists of greenish-blue or dark-blue shales, with numerous thin pale bands which resemble ashy layers; iron-pyrites is of frequent occurrence in some of the beds.

The group is traversed by a persistent cleavage, which makes a small angle with the bedding. On weathering, the beds appear as soft buff-coloured or whitish shales: they are usually somewhat striped, their joint-faces are often stained yellow with iron, and are sometimes iridescent.

Curious tube-like markings occur on some of the surfaces, and are suggestive of annelid borings. But, despite assiduous search, no fossils have been found in this group.

Pale greenish highly-cleaved shales also succeed the green quartzitic sandstones (5) in an old mill-leat north of Welsh Hook; they resemble the Ford Beds very closely. In this section they appear to pass up conformably into very dark shales of the Menevian type, but these rocks are so inaccessible that they cannot properly be searched for fossils.

It is not known upon what the base of the Musland Grit rests in the railway-cutting; but, if no fault occurs along the bed of the river in that locality, it would appear that a small thickness of the upper green sandstones intervenes between the purple sandstones and the Musland Grit.

Beds Nos. 1–4 can be paralleled readily with various subdivisions of the Caerfai Group of Hicks: the correspondence is closer than would appear from published accounts of the St. David's sequence, for the thickness of some of the subdivisions, notably the purple Caerbwdy Sandstones, was overestimated by Hicks. The red shales (No. 3) correspond to those which yielded fossils near St. David's, and, like them, contain a thin bed of felspathic tuff.

Succeeding the purple Caerbwdy Sandstones in the St. David's district are the basal beds of the Solva Group; it is difficult to determine, however, where the dividing-line was supposed to be drawn. The group which conformably succeeds the purple sandstones to the west of Caerbwdy Bay closely resembles the green sandstones of No. 6, and if the Solva Beds immediately succeed the purple sandstones of Caerbwdy, it is possible that No. 5 represents the basal beds of the Solva Series. On the other hand, as far as their lithological characters are concerned, they might equally well represent the upper portion of Hicks's Caerfai Group, the difference in colour of the sediments being comparatively unimportant.

With regard to the position of the Ford Beds, it might be suggested that they belong to the *Lingula* Flags or to the Arenig, both of which formations occur in the vicinity; but they are quite distinct lithologically from both, and it is considered likely that they are older than either.

They can hardly be compared with the Lower or Middle Solva Beds, as developed in the St. David's district; but they bear considerable resemblance to the Upper Solva Beds, more especially those of Penpleidiau, which also contain much iron-pyrites and have the same tubular markings, like annelid borings.

Of all the Lower Palæozoic formations with which we are acquainted, the Upper Solva Beds, near their junction with the Menevian, offer the greatest similarity to the Ford Beds, and they are provisionally assigned to that horizon. It is worth noting in this connexion that the pre-Cambrian mass of Pointz Castle is faulted against fossiliferous Menevian deposits to the south of Loch-faen. Fossiliferous Menevian beds also occur on the southern flank of Rhindaston Mountain, near Ferny Glen.

The objection to this view is the apparently unfossiliferous nature of the Ford Beds, which somewhat sharply contrasts them with the Upper Solva Beds of the St. David's district.

Whatever view is ultimately adopted as to their horizon, it seems clear that a stratigraphical break must occur in the district that we have surveyed, for there is little, if any, trace of the Lower and Middle Solva Groups, which are of great thickness near St. David's. If the Ford Beds be assigned to a higher horizon, the break becomes correspondingly greater.

From the behaviour of the outcrops it is considered that any rational system of faulting is inadequate to account for the stratigraphical relationship of the Ford Beds to the lower horizons.

(*b*) Their Relation to the Pebidian and Dimetian.

On account of the nature of the country which we are describing, the mapping had to be carried on very largely by utilizing the indications as to the nature of the subsoil furnished by débris in hedges and on fields; and a few words may be added on the probable correctness and value of a map of a complicated district constructed in this manner.

Experience has shown us that in this part of the country, as well as in other parts of Pembrokeshire where the rocks are scantily exposed, a map can be constructed by this method which attains almost as high a degree of accuracy as if exposures were much more frequent, and is of far greater accuracy than if the solid exposures alone were examined, and the map completed on this basis without reference to the débris.

It was demonstrated over and over again that when, in any part of the district which was being surveyed by means of débris-indications, exposures of the solid rock were encountered so that the nature and inclination of the rocks underlying the subsoil could be examined directly, such exposures rarely necessitated any change in the position of the lines drawn up to that point. The solid exposures merely confirmed the position of lines which had been drawn by reference to débris alone or, in some cases, aided by such slight features as exist in that part of the country. These remarks appear to be necessary, in order to explain how a map showing so many subdivisions of rocks and such complicated structures can be constructed in a country which is singularly devoid of natural sections.

Only one clean exposure showing the base of the Cambrian actually resting on older rocks occurs in the district, namely, in the lane leading to Stone Hall Mill, where the conglomeratic quartzite rests upon highly-cleaved or schistose rhyolitic ashes, which probably belong to a high part of the Pebidian.

In Brawdy farmyard, however, the line of contact of the Cambrian pebbly grit with the Brawdy granite can be located with precision.

The mapping brings out the fact that the base of the Cambrian adjoins widely different rocks in different localities. In most cases the junction is presumably normal, for its trend is usually not parallel to the main lines of faulting. If we suppose the base of the Cambrian in the district between St. Lawrence and Brimaston to be faulted against the older rocks, the faults would have to pursue an extraordinarily undulating course in a direction contrary to most of the faults of the district; and, moreover, would have to leave the Cambrian rocks unaffected, while producing considerable dislocation in those adjoining. It seems more natural to assume, therefore, that in this district, at any rate, the junction of the Lower Cambrian with the underlying rocks is one of normal superposition.

Near Stone Hall, as has been stated, the basal Cambrian rests upon the Pebidian, and to the east of Newton East can be seen in close proximity to similar rocks. North of Brimaston the lowest Cambrian adjoins a coarse quartz-porphyry, while in two separate outcrops, east of Brimaston, it stands in the same relation to the Brimaston granite.

South-east of Tre-rhôs the rock which is in contact with the basal Cambrian is a coarse quartz-porphyry; while a little farther south-west this rock is replaced by striped pink-and-white rhyolitic tuffs, which belong to the upper part of the Pont-yr-hafod Group of the Pebidian.

On Rhindaston Mountain, and to the north of Pen-y-cwm, Pebidian tuffs adjoin the Cambrian conglomerate; but, in the long stretch from Knaveston to Brawdy, Dimetian granitic rocks are once more in contact with it: near Brawdy it is fairly certain that if any fault occurs at the junction of the Cambrian with the older rocks it is of trifling amount.

It has been mentioned that pink amethystine quartz-pebbles occur in the conglomerate, and are similar to those in the neighbouring quartz-porphyry: also we have commented on the nature and abundance of the igneous boulders in the conglomerate of Silver Hill (p. 391).

The foregoing facts and considerations render it most probable that in the district described the base of the Cambrian rests unconformably upon a complex series of tuffs and lavas, and of plutonic masses intruded into these volcanic rocks.

Subsequent to the period of the formation of the tuffs referred to the Pebidian, there must have been one or more periods of intrusion which were followed by extensive denudation of the rocks that formed the cover of the plutonic masses. These facts point to the lapse of a considerable interval of time between the formation of the Pebidian and the deposition of the earliest Cambrian rocks.

(*c*) Post-Cambrian Basic Dykes.

Basic dykes which cut the Cambrian deposits are exposed at several localities. Two dykes, one much thicker than the other, cut the purple sandstones of the Welsh Hook Beds in the little bay known as Cwm-mawr, at Newgale, and may be seen on the foreshore. They are both albitized diabases: the thinner dyke (E 7232), the southernmost of the two, contains good pseudomorphs after olivine (fig. 2 A, p. 389).

The thicker dyke (E 7235) presents chilled margins, now much faulted and sheared, to the Cambrian rocks into which it is intruded. This rock was noted by Murchison,[1] who indicated it in his sections; he was wrong, however, in showing it as coming up along the fault which separates the Cambrian from the Carboniferous; it lies entirely within the Cambrian formation, and is certainly pre-Carboniferous in age.

Other dykes which cut the same division of the Welsh Hook Beds may be seen on the eastern side of the Cleddau, north of Welsh-Hook Bridge; they are much sheared, and completely decomposed. Originally, they were in all probability diabases similar to those of Newgale.

IV. Tectonics.

The pre-Cambrian and early Cambrian rocks of the Hayscastle area seem to stand in the relation of a horst to the higher beds which adjoin them. The boundaries of the area are faults except in the south-west, where the rocks are truncated by the coast. These faults have in all cases let down younger rocks on the outside of the area, but there is no decisive evidence as to whether they are normal or reversed.

[1] 'Silurian System' 1839, pl. xxxv, figs. 7 & 9.

While maintaining an average west-south-westerly direction they pursue a somewhat sinuous course. The main faults tend to give off frequent branches, many of which have been traced in the older rocks; others probably exist in the surrounding younger rocks, but these we have not attempted to follow.

These offshoots in many cases, especially along the northern margin, rejoin the main boundary-faults, and so include lenticles which are faulted on every side. The boundary-faults are therefore not simple fractures, but form part of a complicated and anastomosing system.

It is probable that, in certain instances, the boundary of the area surveyed does not coincide with the line of greatest displacement, but with an offshoot from it. South of Rhindaston Mountain, for instance, the rocks which adjoin the Lower Cambrian deposits are black shales with abundant *Agnostus*, and are to be referred to the Menevian ; while a little farther south are Arenig rocks separated from the latter by another fault, the downthrow of which must be far greater than that separating the Menevian from the Lower Cambrian. The displacement between the Menevian and the Lower Cambrian may be still smaller if, as is possible, the thick Solva Series is not represented in this district. The main fracture is therefore located some distance to the south of the Lower Cambrian.

Similarly, on the north side of the area, the rocks which adjoin the boundary appear to be Middle or Upper Cambrian, whereas a short distance to the north are Arenig deposits. It must be remembered, however, that in this region it is possible that members of the Arenig Series transgress rocks of the older formations.

The westerly extension of the northern boundary beyond the area surveyed is indicated on the Old Series Geological Survey Map (Sheet 40) by the 'Purple Sandstones and Slates' of Dinas Mawr, south of St. Elvis, and the 'Purple Beds' of the islet Green Scar, or Sger Lâs, about a mile farther west. The country to the north of these localities is occupied by Upper Cambrian rocks with possibly some Middle Cambrian. It will be noticed that in a westerly direction the boundary of the Hayscastle area approaches the St. David's area, so that the downthrow of the northern boundary-fault appears to diminish westwards.

Structures of the older rocks.—The older rocks of the area under description are traversed by several faults which have the same general direction as the boundary-faults and, like them, give off branches which enclose faulted lenticles. The principal fault ranges through Hayscastle, Gignog, and Knaveston, and determines a highly conspicuous valley between the two first-named places. At Gignog the fault appears to split up in a complicated manner, and throws down the Carboniferous rocks between two of its branches.

At the north-eastern extremity of the district near the Cleddau

Valley there is evidence of folding of the Cambrian rocks along axes roughly parallel to the main direction of faulting; the folds have a general easterly pitch, and therefore the outcrops meander widely in a north-and-south direction. An anticlinal axis passes near Stone Hall, and another to the south of Newton East. A faulted syncline occurs to the south of Stone Hall, and a wide syncline can be traced to the east of Brimaston.

Insomuch as the trend of the outcrops in this region departs widely from the direction of the main faults, the original relation of the Cambrian to the underlying rocks is likely to be unchanged; it is in such a district, therefore, that one might hope to discover unfaulted junctions of the base of the Cambrian.

The assumption previously made that the rocks of Pont-yr-hafod are brought to the surface by an anticlinal fold is in accordance with the structure revealed farther north-east, for the well-marked anticline near Stone Hall appears to range directly for Pont-yr-hafod.

The age of the faults.—It is clear that some of the faults which traverse the horst are post-Carboniferous in age, as the Coal Measures and the Millstone Grit are involved in the movements. It is probable, however, that the greater part of the faulting is due to movements which took place in pre-Carboniferous times: the southern boundary-fault, for instance, which must be of considerable throw in the older rocks, abuts near Roch Bridge against a post-Carboniferous north-and-south fault, but no fault of corresponding importance can be traced in the Coal Measures along the same line.

The existence of great pre-Carboniferous movements, and the consequent overstep of the Carboniferous rocks on to the older formations, seems the most reasonable way of accounting for the association in this district of Carboniferous strata with rocks of much greater antiquity. Any other view involves the existence of faulting on a prodigious scale, and is contrary to the evidence obtainable in other parts of Pembrokeshire.

V. Summary and Conclusions.

About 8 or 10 miles to the east of St. David's lies an extensive area of plutonic and volcanic rocks surrounded by and intimately associated with sedimentary rocks of the Cambrian System.

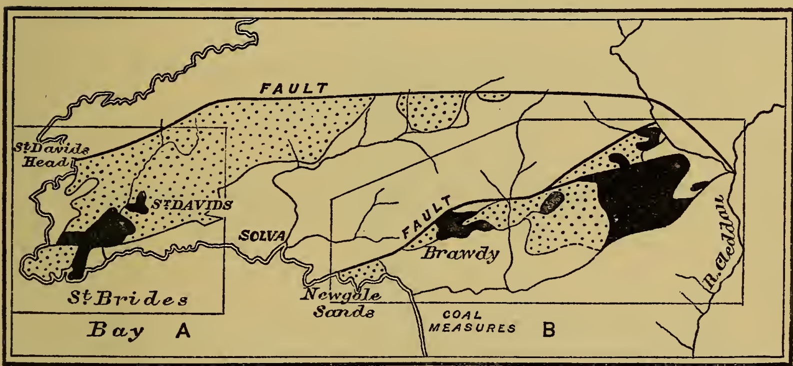
The igneous and pyroclastic rocks are brought to the surface along an axis, ranging in an east-north-easterly and west-south-westerly direction, which is approximately parallel to that of the ancient ridge of St. David's. They are divisible into two classes: an older volcanic series and a newer plutonic and hypabyssal series, for which Hicks's names of Pebidian and Dimetian are respectively retained.

The Pebidian is separable into several types, the lower exposed portion being, in general, andesitic in character, the upper rhyolitic and keratophyric.

The Dimetian, which is intruded into the Pebidian, and is therefore younger, includes granite and quartz-porphyry, diorite, and probably a set of basic dykes which are later than the other rock-types. The granite and quartz-porphyry appear to be variants of the same rock, and, together with the diorite, are rich in soda and relatively poor in lime.

The Cambrian deposits form a much-torn fringe to the pre-Cambrian massif, and for descriptive purposes have been divided into two, a lower division to which we have applied the appellation Welsh Hook Beds and a higher termed Ford Beds.

Fig. 3.—*Index-map of North-West Pembrokeshire, showing the areas occupied by pre-Cambrian rocks. (Scale : 1 inch=4 miles.)*



[Full black=Dimetian rocks; dotted areas=Pebidian rocks. A=Mr. J. F. N. Green's map, Q. J. G. S. vol. lxiv (1908) pl. xliv; B=Pl. XL accompanying this paper.]

The Welsh Hook Beds can be correlated closely with Hicks's Caerfai Series, and, like the similar beds at St. David's, consist of a basal conglomerate, pebbly grit and quartzite, green sandstones, red shales, and purple sandstones.

The Ford Beds, which are chiefly dark shales, are less easy to place; but they appear to be referable to that portion of the Upper Solva Group which is not far removed from the Menevian. There is, consequently, a stratigraphical break between the Ford Beds and the highest members of the Welsh Hook Group. A large part of the Lower Cambrian sequence, as established by Hicks near St. David's, is absent in this district; the greater portion of the Solva Series is not represented, being in all probability transgressed by the higher beds between Solva and Hayscastle.

The basal bed of the Cambrian rests upon a variety of rocks which belong to both the Pebidian and the Dimetian, and it often has a strike which is wholly discordant with the rocks beneath. It also contains an assortment of pebbles which in some instances are identical with, and were probably furnished by, the underlying rocks.

It is, therefore, considered that in the district described the base of the Cambrian Formation rests unconformably on a complex series of tuffs, lavas, and plutonic rocks.

Subsequent to the formation of the Pebidian, there were one or more periods of intrusion followed by extensive denudation of the rocks which covered the plutonic masses. There was, consequently, a lapse of a considerable interval of time between the laying down of the Pebidian tuffs and the deposition of the earliest Cambrian rocks.

The pre-Cambrian and early Cambrian rocks of the Hayscastle area form a horst surrounded by younger beds. They are faulted on all sides, and the greater number of the faults are probably due to movements which took place in pre-Carboniferous times, and caused a gradual overstep of the Carboniferous rocks on to the older formations.

Post-Carboniferous movements have also been active in the district, producing faults of some magnitude.

EXPLANATION OF PLATE XL.

Geological map of the Brawdy and Hayscastle District (Pembrokeshire), on the scale of 2 inches to the mile, or 1 : 31,680.

Discussion.

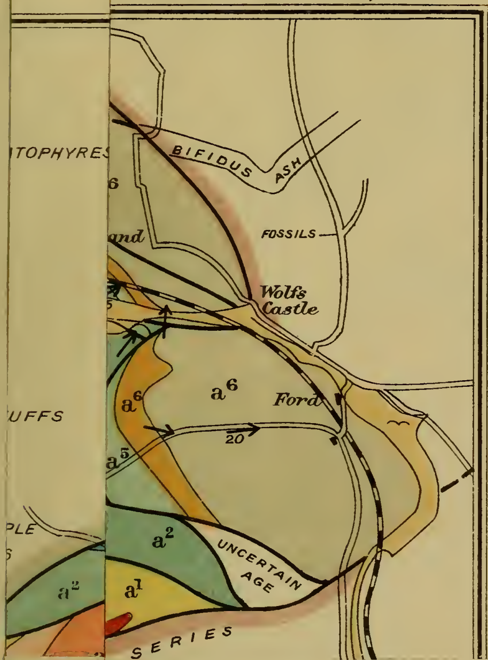
Mr. J. F. N. Green said that he had listened with the greatest pleasure to this important paper. The country was most difficult, and the complex structure could only be elucidated by the refined methods of mapping adopted by the Authors. The general equivalence of the tuffs to those of St. David's was of interest, especially the persistence of the acid Clegyr Conglomerate, which also occurred in the Solva Valley and retained its characters and stratigraphical position for at least 9 miles.

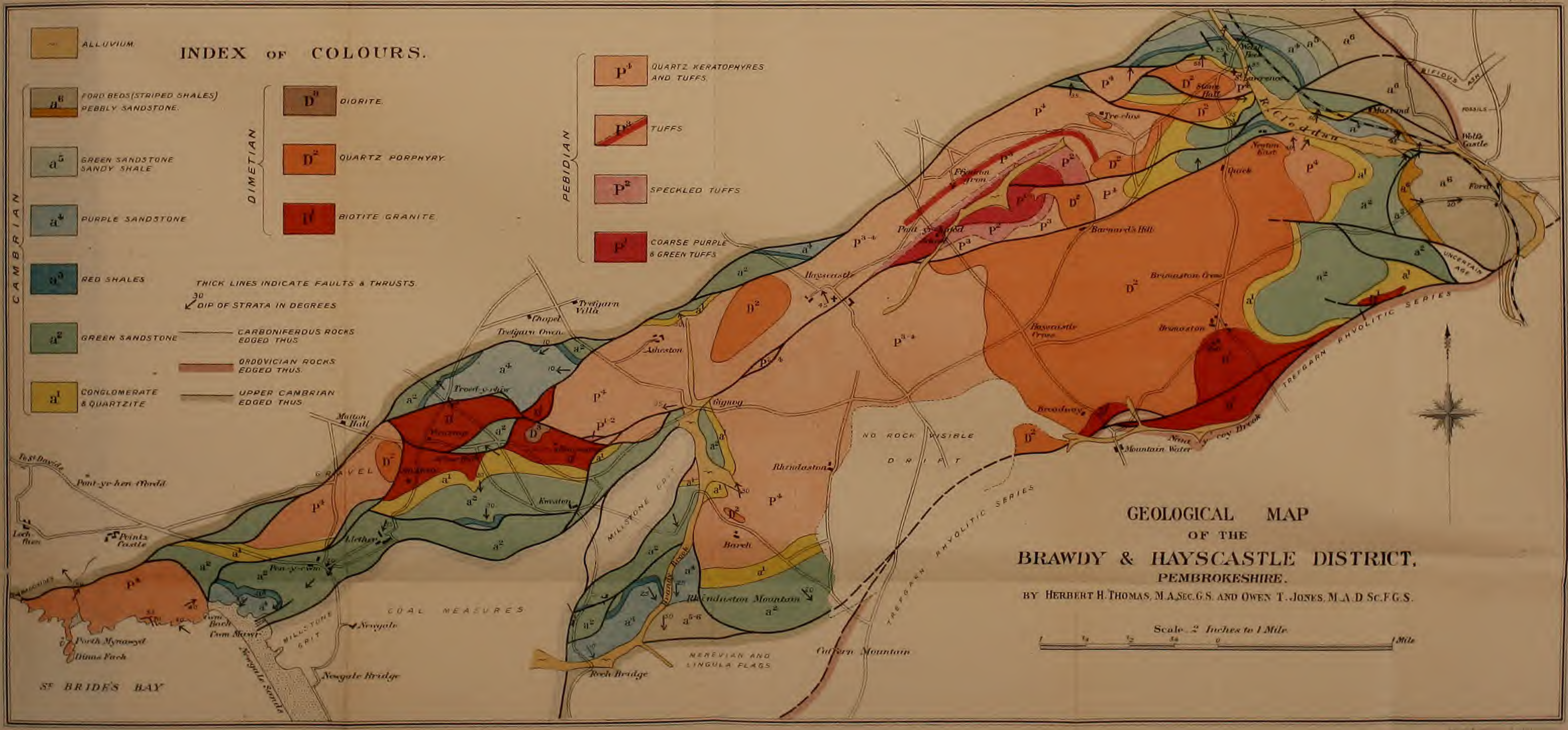
He thought that more evidence was required before the pre-Carboniferous age of the main movements could be accepted as definitely proved.

The conclusion that basic dykes of pre-Cambrian age probably occurred was interesting. At St. David's the predilection of the basic dykes for the Dimetian was well-known; and, near the cathedral, dykes, which seemed to differ from the common post-Cambrian types, were found in both Pebidian and Dimetian: but their pre-Cambrian age, though probable, was not yet demonstrated.

In conclusion, he wished to express his pleasure in that some of the older rocks of the region had been investigated by modern petrographical methods.

Mr. G. Barrow was pleased to see that the main results of


TOPHYRES
BIFIDUS ASH
FOSSILS
Wolfs Castle
a6
Ford
20
a6
a5
UFFS
a2
UNCERTAIN AGE
a2
a1
SERIES



Quart. Journ. Geol. Soc. Vol. LXVIII, Pl. XI.

Hicks's work in South Wales had been finally verified, and that the terms Pebidian and Dimetian were to be restored.

Hicks at first regarded the Dimetian as an intensely altered sediment which showed only the last traces of the original bedding, a view held at that time by many geologists. It has since proved to be a granitic rock, the apparent bedding being due to a foliation which was produced either during or after consolidation.

After working for some years in South Wales, Hicks visited the Highlands and reopened the question of the upward succession. Here he again recognized his Dimetian, both at Loch Maree in the Lewisian Gneiss, and to the south-east of the Moine Thrust. He also noted here the peculiar type of flinty rock associated with the Dimetian, which we now know to be due to the contact-action of the igneous rock. The speaker, twenty-five years ago, recognized a similar rock, also in association with the flinty material, at the southern end of the Highlands (the Ben Vuroch augen-gneiss in Perthshire). This intrusion cuts both the Central Highland Quartzite and the Limestone, which thus are older than part at least of the Lewisian Gneiss.

Prof. O. T. Jones, replying on behalf of the Authors, thanked the President and Fellows for the reception given to their paper.

In answer to Mr. Green, he stated that there could be no question as to the magnitude of the pre-Carboniferous movements in the district. The base of the Carboniferous rocks had been proved by the officers of the Geological Survey to overstep successively Old Red Sandstone, Silurian, and Ordovician rocks; also big faults, which occurred at and near the southern margin of the area described, were not continued into the Carboniferous rocks.

22. *The* Glaciation *of the* Black Combe District (Cumberland).

By Bernard Smith, M.A., F.G.S. (Read March 17th, 1912.)

[Plates XLI–XLIII.]

Contents.

I. Introduction.

Black Combe—a long whale-backed ridge of slate rising to a height of 1969 feet—is situated a few miles south of the mouth of Eskdale, and dominates the southward-trending extremity of Cumberland, which is separated from Lancashire by the Duddon valley and estuary. The coast-line of Cumberland, from St. Bees Head to Furness, is in the same latitude, and occupies a somewhat similar position—with the exception of its trend—, as the Cleveland shoulder of Yorkshire.

While working upon the solid formations of this area four or five years ago, my attention was diverted to the study of the superficial deposits, dry rock-valleys, and other signs of glacial activity, which presented many problems of great interest. The relations, for example, between the Lake-District Ice and the Irish-Sea Ice are well exhibited, and many of the glacial phenomena of the Isle of Man are here repeated.

My thanks are due to Mr. Herbert H. Thomas, Dr. J. E. Marr, Mr. G. Barrow, and Mr. G. W. Lamplugh for valuable suggestions and encouragement; also to Mr. E. L. Guilford, who accompanied me in the field, and placed many of his photographs at my disposal.

Between 1869 and 1878 several valuable papers[1] dealing with the drifts of North-West Lancashire and parts of Cumberland were contributed by D. Mackintosh to the Geological Society and the 'Geological Magazine.' Most of his remarks on the Black Combe district are confined to the distribution of the granitic drift, but he also describes a traverse through the Whicham Valley and one ascent of Black Combe. In general, he infers that the drifts were deposited by the sea and floating ice, though more or less of the clay and loam composing them may have originated as subglacial mud.

C. E. De Rance,[2] while believing more thoroughly in the land-ice glaciation, thought that the lower parts of the Lake District were at first under water, and that the Middle Drift Sand required a subsidence of 1400 feet for its formation. The Upper Boulder Clay he considered to be due to ice-foot. On re-emergence of the land, valley-glaciers once more appeared. He makes no particular reference to the Black Combe area.

Clifton Ward,[3] in his paper on 'The Glaciation of the Southern Part of the Lake District,' showed that huge glaciers passed down Eskdale, Wastdale, the head of Duddondale, and southwards over Coniston; but he carried his observations no farther west or south. He postulated a later submergence of 2000 to 3000 feet, but allowed a re-elevation of the land for a late set of glaciers.

A manuscript report (*circa* 1877, preserved in the Office of H.M. Geological Survey) by W. T. Aveline, C. E. De Rance, and Hebert, on Sheets 98 N.W. and 99 N.E. (O.S.), throws a certain amount of light on the distribution of the glacial deposits in the St. Bees, Scafell, and Coniston directions.

In a paper on 'Boulder Clay,' published in the 'Transactions of the Cumberland Association' for 1877–78 (pt. iii, pp. 91–108), C. Smith discusses the origin of the Cumberland drifts.

Two papers[4] by Mr. J. D. Kendall, on the boulders and glacial deposits of West Cumberland, were published shortly afterwards. Like Mackintosh (to whose work he makes no reference), he attri-

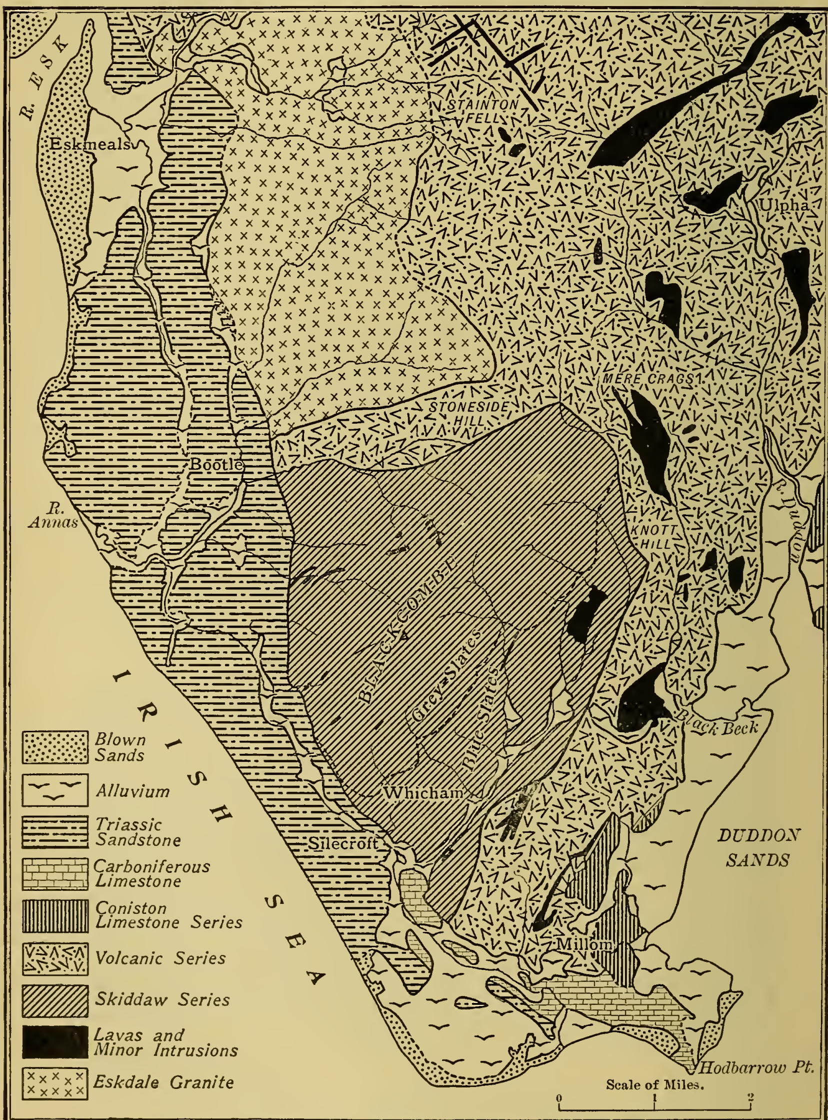
[1] 1. 'On the Correlation, Nature, & Origin of the Drifts of North-West Lancashire & Part of Cumberland, with Remarks on Denudation' Q. J. G. S. vol. xxv (1869) pp. 407–31; 2. 'On the Dispersion of Criffell Granite & Caldbeck Porphyry over the Plain of Cumberland' Geol. Mag. vol. vii (1870) pp. 564–68; 3. 'On the Drifts of the West & South Borders of the Lake District, & on the Three Great Granitic Dispersions' *Ibid.* vol. viii (1871) pp. 250–56, 303–12; 4. 'Observations on the More Remarkable Boulders of the North-West of England & the Welsh Borders' Q. J. G. S. vol. xxix (1873) pp. 351–59; 5. 'On the Traces of a Great Ice-Sheet in the Southern Part of the Lake District & in North Wales' *Ibid.* vol. xxx (1874) pp. 174–79; 6. 'Results of a Systematic Survey, in 1878, of the Directions & Limits of Dispersion, Mode of Occurrence, & Relation to Drift-Deposits of the Erratic Blocks or Boulders of the West of England & East of Wales, including a Revision of many years' Previous Observations' *Ibid.* vol. xxxv (1879) pp. 425–53.

[2] 'On the Two Glaciations of the Lake District' Geol. Mag. vol. viii (1871) p. 116.

[3] Q. J. G. S. vol. xxxi (1875) pp. 152–65.

[4] 'Distribution of Boulders in West Cumberland' Trans. Cumb. Assoc. pt. v (1879–80) pp. 151–57, and 'The Glacial Deposits of West Cumberland' *Ibid.* pt. vii (1881–82) pp. 61–78.

Fig. 1.—*Geological map of the Black Combe district, based on the 1-inch Survey Map. (Scale: 1 inch = 2 miles, or 1 : 126,720.)*



buted the distribution of Scottish rocks to boulder-bearing icebergs swept along by marine currents. He also required two separate submergences of the land to account for his facts, although he recognized the active part played by land glaciers in the formation of the boulder-clays.

Among the writings of T. Mellard Reade, that upon the Eskdale Drift and its bearing upon glacial geology,[1] published in 1893, is of great interest in its relation to the subjects discussed below. In a later (1896) Address [2] he deals with the Low-Level Marine Boulder Clays and Sands between St. Bees Head and Ravenglass.

Since that time little seems to have been written about the Black Combe area, although Mr. G. W. Lamplugh drew a comparison between the drift-plain west of Black Combe and the northern drift-plain of the Isle of Man.[3]

II. Geological Structure.

The district examined may be divided in a broad way into three main physiographical divisions, from east to west, as follows:—(1) The Duddon Valley and Estuary, (2) the mountainous tract between the Duddon Valley and the plain, (3) the low plain at the foot of the mountains, and bordering the sea between Millom and Ravenglass.

In the greater part of the Duddon Valley, and over the mountain tract, the glacial drifts have merely modified the pre-existing topography, but the third district—the plain—is almost entirely composed of drift deposits of considerable thickness, which descend below sea-level beneath a large part of the plain's surface extent.

Near Kirksanton and Millom in the south, some low ground is occupied by Carboniferous Limestone. North of Silecroft the formations beneath the plain are considered to be of Triassic age; but, with the exception of one exposure mapped by Aveline near Corney Hall, north of Bootle, there is no visible outcrop of these rocks.

The mountain country consists chiefly of three distinct types of rock: namely, slate, volcanic rocks, and granite. An inlier of so-called 'Skiddaw Slate,' roughly triangular in shape, and 12 or more square miles in extent, forms a group of fells reaching a height of 1969 feet at Black-Combe summit. The bulk of this mountain consists of blue-grey slates of felspathic appearance, tremendously compressed and very highly cleaved, the cleavage-planes dipping generally in a north-westerly direction. In some cases secondary cleavage and pressure has resulted in the production of slates with frilled surfaces and presenting a glossy appearance. Chevron folds and belts of rock riddled with vein-quartz, which coincide roughly with the direction of cleavage, testify also to the tremendous pressure brought to bear upon these rocks.

[1] Geol. Mag. dec. 3, vol. x (1893) pp. 9–20.

[2] 'The Present Aspects of Glacial Geology' Proc. Liverp. Geol. Soc. vol. viii (1897–1900) pp. 13–31.

[3] 'The Geology of the Isle of Man' Mem. Geol. Surv. 1903, p. 366.

Some of the slates are banded. In such cases it can be shown that the directions of true dip and cleavage-dip are, as a rule, non-coincident and sometimes entirely opposed one to the other.

The age of these rocks, the nearest equivalents of which are, perhaps, the pale Manx (Barrule) slates, is at present unknown. The slates on the south-eastern side of the tract, which form the floor of the Whicham Valley and the lower slopes on both sides, are of a different type, and should, before long, yield definite palæontological evidence as to their age. They appear to be separated from the pale slates on the west by a plane (perhaps a thrust) which dips in a north-westerly direction at about 15°. They are soft blue shales, ashy-looking slates, fine black mudstones, and grits. Near Whicham Mill Ford I have found *Caryocaris wrightii* and an obscure fragment of a graptolite [1] at the quarry west of the mill.

South-east of the mill the cleavage is disturbed by faults crossing the valley in a north-easterly direction, and on the south side of the valley both dip and cleavage are frequently reversed.

Upon the north, east, and south-east the slates are bounded by rocks of the Borrowdale Series, from which they are separated either by faults or by thrust-planes. The rocks are chiefly andesitic (and sometimes vesicular) lavas and ashes, many of the latter being coarsely banded. On the north, a well-recognized type is a porphyritic andesite occurring, with associated ashes and vesicular lavas, between Bootle and Stoneside Hill. On the north-east are the andesite and ashes of Mere Crags, and the banded ashes of Lath Rigg, some of which contain fragments of rhyolite; and on the southern slope of Wrayslack Hill, about half a mile east of Knott Hill, occurs a coarse breccia, with blocks of spherulitic rhyolite measuring up to 2 feet in length.

Cleaved and banded ashes also occur between Millom and The Green.

In addition to the above, there are numerous small intrusions in both Borrowdale rocks and Skiddaw Slates.

The volcanic rocks are flanked on the south-east, near Millom, by rocks of the Coniston Limestone Series and Carboniferous Limestone.

About 2 miles north of Black Combe summit the southern part of the Eskdale Granite is in contact with a narrow strip of volcanic rocks averaging only half a mile in width. The northern margin of the Skiddaw Slates is, indeed, within the metamorphic aureole of the granite, which makes it difficult to determine accurately the position and character of the junction between slates and volcanic rocks. The granite averages 2 miles in width as far north as the mouth of Eskdale, after which its outcrop expands considerably. Its eastern boundary forms fairly high ground, but on the west there is a descent to a low plateau dissected by the marginal drainage of the ice-sheet.

[1] Harkness records *Graptolites sagittarius* from the débris of quarries in the southern escarpments of the mountain; see 'On the Skiddaw Slate Series' Q. J. G. S. vol. xix (1863) pp. 131, 132.

III. Pre-Glacial Condition of the District.

With the exception of the drift plain, the main features of the district had been developed before the advent of the Ice Age. As a result of the glaciation, some of these features were accentuated, others were subdued, and some new ones were introduced.

The cleavage-dip of the slate accounts in part for the smooth northward-facing slopes of Black Combe, and the more craggy south-eastern and south-western slopes. These features, however, were certainly accentuated by glaciation. Over-steepening of the seaward slope of the mountain accounts for the precipitous descents upon that side. The sides of the Whicham Valley are similarly affected, and the valley-bottom has been somewhat over-deepened. In the volcanic tracts the rugged features, which now appear to be so prominent when one is looking in a direction opposed to that of the ice-movement, would, in pre-Glacial times, have been prevalent everywhere. The chief alterations in feature of the granite tract would consist in the destruction of 'tors' and the removal of a great quantity of rotten rock from the lower ground. Some of the drift-deposits of the plain descend below sea-level: hence it is quite possible that the pre-Glacial sea may have touched the foot of Black Combe; but, even if this were the case, it would not account for the smoothed and oversteepened slopes, cut-away spurs, and hanging valleys which occur at higher elevations.

In the mountain districts the main pre-Glacial drainage-lines were similar to what they are to-day. Upon the advance of the ice some of the smaller channels were choked with drift; but in most of these the post-Glacial streams follow the old lines, and are removing the extraneous material from their valleys.

IV. The Maximum Glaciation.

Evidence as to the direction of movement of the streams of ice which invaded the district during the maximum [1] glaciation is furnished chiefly by (*a*) the composition and distribution of the drifts, (*b*) the erratics, and (*c*) the grooved, smoothed, and moutonné surfaces, seen to perfection in the volcanic tract. Minor evidence is yielded by striæ and by scoured or steepened valley-sides, cut-away spurs, and hanging valleys, and, during the stages of retreat, by the trend of moraines and of marginal drainage-channels.

My observations tend to show that, during the flood-tide of glaciation, the whole district was completely overridden by an ice-sheet formed by the confluence of the edge of the Lake-District ice-cap with the great Irish-Sea Glacier, one of the points of contact between the two lying about a mile west of Black-Combe summit.

[1] The anomalous distribution of some of the Lake-District boulders may have been due to valley-glaciers reaching the sea before its invasion by the Scottish ice, and launching bergs which scattered in various directions and strewed rock-fragments over the sea-bed.

The top of Black Combe (1969 feet) was overridden by comparatively clean ice, which ascended the gentle northern slopes, signs of its passage being furnished by a few scattered boulders near the Cairn. There is plenty of evidence of the ice-movement over the lower shoulders of the mountain.

V. (1) The Lake-District Ice.

The Lake-District ice moved from three main directions: (i) the Broughton Valley; (ii) the Duddon Valley and the high ground on the west; and (iii) Eskdale.

(i) The Broughton Valley.—W. T. Aveline[1] states that in the first of these districts the Broughton drift chiefly consists of scattered angular or partly waterworn stones, and large 'perched blocks.' In places it has filled up some of the deep valleys, which generally have been again excavated by the existing streams, showing a rocky bottom. Where the drift assumes any thickness, as on the side of some of the valleys, it is found to consist of travelled stones or boulders scattered in a finer matrix derived from the disintegration of the surrounding rocks. He records huge erratics of volcanic breccia on Broughton Moor, and one (the 'Red Gall Stone') on Tower High Common, but none of them seem to have travelled far. Some huge boulders of Coniston Limestone on Broughton Moor, and the fragments of dark graptolitic mudstones in the drift near the Coniston Copper Mines, have apparently come from the north-east.

(ii) The Duddon Valley and the high ground on the west.—The Duddon Valley, cut entirely in volcanic rocks, is beautifully glaciated. On looking up the valley we see the craggy faces of the cliffs and rocky knobs; but, on looking down, we notice that the smoothed backs of the knobs, partly covered by grass and with their bases often plastered about with boulder-clay, give to the scene a remarkably smooth and tame appearance.

In the lower part of the valley, between Ulpha and the Duddon Bridge, are splendid examples of *roches moutonnées*. The ice-movement was here from north 30° east.

Of the upper part of the valley Mackintosh[2] writes:—

> 'The eastern slope . . . . of the Duddon is covered with a succession of gently-swelling knolls (with rocky nuclei) of pinel, and overlying loam, both containing large boulders. In many places there are *roches moutonnées*, with parallel undulations or wide ◡-shaped grooves (as well as minute striæ) pointing north-north-east, or nearly in the direction of the valley.'

Thus the general direction of ice-movement between the Broughton-Coniston and Duddon Valleys was south-westward from the direction of the Coniston Fells, crossing the Duddon Valley between Ulpha and Duddon Bridge obliquely. West of this part of the valley ice-moulded surfaces, occasional striæ, and rock-grooves,

[1] MS. report. [2] Geol. Mag. vol. viii (1871) p. 306.

on the highest ground, prove that the direction of flow was maintained for about a mile, after which it turned southwards owing to pressure of ice moving in that direction. The hill-slope, between the 400- and 700-foot contours, north-west of Duddon Bridge, consists of a series of scarps which have been polished and striated so that the hillside is now practically one gigantic roche moutonnée, the movement having been obliquely upwards.

Trails of boulders descend the eastern slope of the Black Beck Valley about 2 miles north of The Green, and in some cases cross to the other side. A boulder of the coarse rhyolitic breccia which occurs *in situ* at 600 feet was found half a mile away, on the west side of the valley, below the 500-foot contour, the direction of transport being in direct alignment with the striation on the parent rock.

The Coniston-Broughton ice crossed the Duddon Estuary, overrode the high ground near Lady Hall, and choked the Black Beck Valley near The Green with several large drumlins.

From Duddon Bridge to Lady Hall the lower slopes on the west of the estuary have been over-steepened and all spurs cut away. On the higher ground the rock is scored by glacial grooves, and many perched blocks, ranging up to 12 feet or more in greatest diameter, are scattered about. A boulder of banded ash, measuring $8 \times 6 \times 5$ feet, resting on a smoothed surface of cleaved ash, occurs by the roadside a few yards north-west of Haws near The Green.

South of The Green, glacial grooves and splendid roches moutonnées clearly indicate that the direction of movement of the higher parts of the Duddon ice was south-westward, until contact with the Whicham-Valley ice caused it to take a more southerly course along the eastern slope of Millom Park. Farther south it was affected by the Irish-Sea ice.

Boulder-clay is frequently exposed at low levels between Duddon Bridge and Lady Hall: it also occupies the hollows on the higher ground to the west, and is plastered round the smoothed rock-surfaces.

About 400 yards south of the Inn, at The Green, is a 20-foot (artificial) section in one of the above-mentioned drumlins. The deposit consists of a more or less homogeneous brown clay or loam, sometimes slightly reddish, and contains streaks of reddish-brown sand or fine gravel, which dip gently in both directions along the line of section, that is, transverse to the long direction of the drumlin. The larger boulders are 3 or 4 feet long, and consist chiefly of Borrowdale lavas and ashes or pinkish quartz-porphyries. Some of the smaller boulders of sedimentary rock, such as greenish-blue shales, micaceous slates, and micaceous banded grits, are frequently striated. These rocks, and a few small boulders of rotten Coniston Limestone, suggest the Coniston-Broughton district as their seat of origin.

A second pit in the same drumlin shows a similar section of brown, slightly loamy clay—a true till—overlain by tawny sand with boulders on the hill-slope. Boulders of Coniston Limestone were also found in a gravel-pit north-west of Hallthwaite Church, and on Millom Park.

At the flood-tide of glaciation the Whicham Valley was filled chiefly by ice moving southwards from the high ground west of the Duddon. Some of this ice overrode the northern slopes of Black Combe, and helped to fill the valleys tributary to the Whicham Valley. Between Ulpha Park, Thwaites Fell, and Prior Park, about the head of Black Beck, a large tract of undulating ground, rising over 1000 feet, is covered by reddish-brown boulder-clay derived almost entirely from volcanic rocks, upon which it also lies.

Craggy ground on the north-east side of Black Beck, opposite Swinside Fell, furnishes proof, in its moulded surfaces, of the southward movement of the ice. Boulder-clay is plastered on the northern slopes of Knott Hill, which split the ice-stream until it was swamped beneath it. Just below the 900-foot contour the eastern face of the hill is beautifully smoothed, while trails of boulders are directed in a southerly direction along the southern slopes. The line of confluence between this ice and that from the Duddon Valley is marked by a boulder-covered ridge, about half a mile long, which terminates east of Baystone Reservoir.

In the western half of Millom Park the southerly direction was maintained, and slate-débris was dragged up on to the volcanic rocks above Sandholes Wood. A boulder of ash, measuring 15×8 feet, lies near the same spot; but over the whole of the above-mentioned area the most conspicuous, though not necessarily prevalent, type of boulder is a reddish quartz-porphyry, similar to those which occur (among other places) *in situ* near Seathwaite, in the Duddon Valley.

Ice pressed through the gap (300 to 400 feet above O.D.) between Millom Park and Lowscales Bank, filling the hollow south of the latter with boulder-clay containing well-glaciated fragments of Skiddaw Slate. On Pohouse Bank a boulder of banded ash, measuring $11 \times 8\frac{1}{2} \times 6\frac{1}{2}$ feet, which rests at 550 feet, may have been quarried from a lower position on Lowscales Bank, but its glaciated appearance suggests that it came from a greater distance. Moutonné surfaces show that the Whicham-Valley ice was there, turning to the south-east in obedience to the thrust of the Irish-Sea ice, which pressed into the mouth of the valley. Boulder-clay is chiefly confined to the lower parts of the valley and to the gentler slopes upon its sides; it is said to be very thick at Baystone Reservoir.

There are three well-marked valleys opening on the Whicham Valley north-east of Black Combe summit. Ice crossed the watershed in a south-easterly direction into the first of these—that of Whicham Beck, the northern side of which is still filled with drift.

In the valley of Stoupdale Beck a number of boulders of pale quartz-porphyry and of Stoneside Andesite (p. 406) occur at 1250 feet immediately south of Stoupdale Crags. The andesites have been carried directly over the watershed from their position *in situ*.

Below the falls, about a third of a mile down stream, the cliff on the south-east side of a southward-entering tributary has been polished by ice moving in a south-easterly direction. A similar example occurs about 400 yards from the head of Whicham Beck.

During the maximum glaciation the ice apparently filled Whitecombe and its tributary, Blackcombe Valley. The watershed at Whitecombe Head (1429 feet) is covered with peat, but the passage of ice over it is revealed by the presence of a few small boulders of quartz-porphyry and volcanic rocks in slaty rubble beneath the peat. Near the head of the combe the ice appears to have overridden a mass of weathered and unstriated slate, in which the stream has now cut a gorge. Farther down, a true slaty boulder-clay with striated stones sets in, and in the lower parts of the valley becomes almost continuous with that spread over the floor of Blackcombe.[1] A few yards below Whicham Mill Ford the slate is turned over to the south by the downstream ice-movement.

North of Black Combe a few boulders of Eskdale Granite lie upon the drift-covered slopes south of the Fell road from Bootle to Broughton, and about 550 yards south-east of the eastern boundary of the granite. Stoneside Hill and the ground more than half a mile to the west of it, south of the granite outcrop, are free from drift, the only erratics noted being volcanics. Moutonné surfaces on Stoneside Hill point to an ice-movement slightly east of south; but the chief streams of boulders from the granite passed to the north-west of the hill in the direction of Bootle Fell, where they occur in considerable numbers.

On the gentle slope north of Black-Combe summit there are a few scattered boulders of coarse ash, and of pale quartz-porphyry with white mica, like that of the dykes exposed in Grainsgill Beck (between the 1000-foot and 1250-foot levels) about a mile to the north. Their occurrence seems to prove that the mountain-top was buried beneath ice laden with very little débris.

(iii) Eskdale.—It is important to decide how much of the ice moving along the coast should be considered as Irish-Sea ice, and how much as of local origin. When a tributary glacier has added its quota to the edge of a main glacier, it may for a time retain its individuality as a distinct stream, yet it eventually becomes incorporated in the main stream and takes its name. So, in this case, ice-streams descending from Eskdale, and the valleys of the Mite, Bleng, Irt, Esk, and Ehen, farther north, added their share to the fringe of the Irish-Sea ice-sheet and travelled down the coast alongside it and one another, each for some time preserving its identity. After travelling a few miles, however, these streams, and the different types of drift carried along by them, to a great extent intermingled. The edge of the ice was also crowded inland, and so the drift from one formation was moved inland across other formations to the east. It seems well, therefore, to regard the local additions to the Irish-Sea ice as part of that body.

[1] This was possibly the result of later cirque-glaciation.

(2) The Irish-Sea Ice.

In the neighbourhood of Bootle the Ennerdale ice had become to all intents a part of the Irish-Sea ice, while the Eskdale ice still maintained its identity in some degree, yet by the time Whitbeck was reached it, in turn, was almost inseparable from the Irish-Sea ice. After passing Whitbeck the edge of the ice was forced first into the mouth of the Whicham Valley near Silecroft, diverting the flow of the ice down that valley, as above explained (p. 410), and then some distance up the broad estuary of the Duddon, where it also affected the flow of the local ice. Having incorporated the Whicham-Valley and Duddon ice it passed across parts of Furness and Morecambe Bay, and impinged upon the Fleetwood and Blackpool coastline.

The evidence for these movements will be found below in the description of the drifts left by the Irish-Sea ice, which it is now proposed to set forth in some detail, and at the risk of subsequent repetition.

VI. The Drift-Deposits of the Plain and the Adjacent Hill-Slopes.

In describing the drifts of the plain[1] between St. Bees and the Duddon, Mackintosh recognized three divisions in upward succession :—

(a) A Lower reddish, yellowish, or yellowish-brown Boulder Clay or 'pinel,' often varied by a light bluish or greenish tint, and containing the greatest number of large boulders. This, he considers, was mainly derived from the waste of the volcanic rocks and Coal-Measure shales of Cumberland.

(b) The sand and gravel formation of the plain, containing pebbles and a few boulders of most of the rocks found in the clay above and below it.

(c) An Upper red loamy clay (partly derived from the waste of Permian [Triassic] strata), containing few boulders.

In his discussion of the general results of his studies[2]—embodied in eight papers—he considers that the rounded, smoothed, and polished boulders must have been chiefly shaped by floating ice and sea-waves. He infers that floating or ground-ice glaciated a great part of the Lake District; that the drifts were deposited by the sea and floating ice; that more or less of the clay and loam comprising them may have originated as subglacial mud; that the Middle Sand and Gravel were accumulated during the gradual rise, and not during the fall of the land, as C. E. De Rance believed; and that the Upper Boulder Clay of the plains was deposited during a succeeding submergence, the vertical extent of which was at the very least 1300 feet.

[1] 'On the Dispersion of Criffell Granite & Caldbeck Porphyry over the Plain of Cumberland' Geol. Mag. vol. vii (1870) pp. 567–68.

[2] 'On the Drifts of the West & South Borders of the Lake District, & on the Three Great Granitic Dispersions' Geol. Mag. vol. viii (1871) pp. 310–12.

The section[1] which he drew of the drifts between Black Combe and the sea gives a fairly correct impression of their general relations; but these general relations seem to be best explained on the assumption that the drifts are all the product of an ice-sheet which was resting upon the shelving shore of the Irish Sea Basin.

(i) Thickness of the drifts.—There seems to be, on the whole, little available evidence as to the thickness of the drifts near the sea-border, yet the records obtained show that, in general, they descend far below sea-level. At Thornflat, Drigg, about 50 feet above sea-level, a boring passed through 160 feet of Boulder Clay, with seams of running sand, without reaching its base; but near Bootle, Aveline mapped sandstone *in situ* (p. 405) at nearly 150 feet above sea-level. In many places between Bootle and Silecroft it seems likely that the inland drifts may descend below sea-level, as they do in the coast-sections. If this be so, the sea, in pre-Glacial times, assuming the present level to be the same, may have washed the western slope of Black Combe, forming a sea-cliff now concealed.

A boring, recorded by Mackintosh,[2] at the south-western end of the Whicham Valley, was stopped in 300 feet of sand, but we are not informed whether this sand is Glacial or not; the lower part of the boring may well have been in Trias. I have been informed that many borings through the alluvium, close to and east of, Silecroft, in search of hæmatite, have failed, sand only being encountered. Off Hodbarrow Point,[3] south-east of Millom, a boring proved 132 feet of clay, and others, farther in the estuary, passed through a great thickness of sand (? estuarine), sometimes resting on clay. Near Burnfield, about a mile and a quarter north of Millom, gravel extends to 70 feet below sea-level, when slate is encountered.

East of the Duddon, at Irleth, near Askham in Furness, the total thickness of the three drifts was 291 feet, resting upon limestone some distance below sea-level.

(ii) St. Bees Head to Hycemoor.—Aveline says of the St. Bees Sandstone area:—

'Much of the ground under which the sandstone lies is covered with superficial matter, this matter being foreign-derived stones and boulders mixed up with sand and fragments disintegrated from the red sandstone itself. In many cases it may be said to be buried in its own waste. In many quarries the breaking up of the higher beds may be observed.' (MS. Report.)

Hebert states[4] that on the sandstone there are large tracts of

[1] 'On the Drifts of the West & South Borders of the Lake District, and on the Three Great Granitic Dispersions' Geol. Mag. vol. viii (1871) p. 255.

[2] Q. J. G. S. vol. xxv (1869) p. 428.

[3] Geological Survey 6-inch map.

[4] MS. Report.

peaty land—probably not filled-in tarns, but due to growth of peat on swampy land formed on the sandy drift covering the sandstone.

On Cleator Moor[1] reddish-brown Boulder Clay, with boulders chiefly of Ennerdale Syenite and trap, rested on a striated surface of Carboniferous Limestone, the striæ being between north-east and north-north-east. The sandstone of St. Bees Head also is finely striated at 300 feet from north 30° east.[2] Between St. Bees and Gosforth there is a succession of knolls and plateaux of sand and gravel, the whole being underlain by boulder-clay near sea-level.

Immediately south of Seascale the drifts consist of alternations of sandy boulder-beds and streaks of stony-clay loam. Boulders on the beach reach 3 feet or more in diameter, and pieces of St. Bees Sandstone were found measuring up to 2 feet in greatest diameter.

Criffel Granite occurs as far inland as Gosforth, immediately north of which place boulder-loam and sand, beneath fine sand and gravel, rest directly upon New Red Sandstone. Lower Boulder Clay[3] makes its appearance at the railway-station and on the sea-beach at Ravenglass.

(iii) Hycemoor to Haverigg.—Red boulder-clay was at one time dug at the Bootle tile-works, about a mile north-west of Hycemoor. On Hycemoor (Bootle) beach boulders of various types of volcanic rock and of Eskdale Granite, up to 2 feet in length (near low-water mark—9 feet), were collected. Smaller granites and porphyrites resemble those of Dumfries and the north-west of Scotland. Ennerdale Granophyre was also found. Among the sedimentary rocks were boulders of St. Bees Sandstone, up to 8 inches in length, and yellow and purple micaceous sandstones, enclosing small flakes of red marl. Coarse grits, grauwackes, purple and green-banded grits and mudstones, and greenish hornfels, with glacial striæ, were also represented.

About a mile farther south the low cliff consists of 12 feet or more of tough red sandy clay, sometimes with a sandy top. It contained boulders throughout, one of St. Bees Sandstone being 18 inches long. South of the River Annas, near Annaside, the cliff, which is there 82 feet high, consists chiefly of red loamy clay capped by yellowish sand. About 20 or 30 feet above the beach there is a coarse conglomeratic boulder-bed 4 feet thick. Some 80 yards farther south the cliff is capped by a grey clay; while the beach is strewn with large fallen calcreted blocks of the conglomerate, which is continuous in the clay for quite a mile farther. A boulder of Eskdale Granite measured $12 \times 12 \times 8$ feet.

[1] D. Mackintosh, 'On the Origin of the Drifts, so-called Moraines, & Glaciated Rock-Surfaces of the Lake District' Geol. Mag. vol. vii (1870) p. 459.

[2] *Id.* 'On the Drifts of the West & South Borders of the Lake District, & on the Three Great Granitic Dispersions' *Ibid.* vol. viii (1871) p. 250.

[3] *Ibid.* p. 254.

At Gutterby Lane End (near Gutterby Spa), where the cliff is 80 to 90 feet high, the following section was exposed:—

	Thickness in feet.	
Red loamy clay, often stony, with seams of sand	20	
Sand and gravel, with fine sand at the base	30	
Thin bed of marly and loamy clay	1	30
Sandy boulder-bed with shell-fragments [1]	6–8	
Sand	8	
Sandy boulder-bed with shell-fragments [1]	3	
Sand	10	

Stiff brown stony clay seen in the base of the cliff.

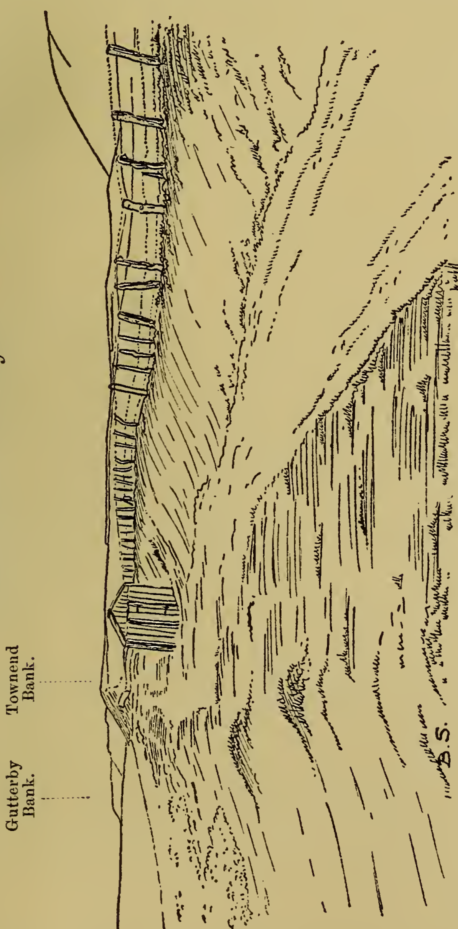


Fig. 2.—*The drift-plain seen from Silecroft beach, looking northwards. Black Combe is on the right.*

The Upper Boulder Clay is in places very similar in appearance to the Lower, which is loamy and pale red about 160 yards to the south-east of this exposure, and 150 yards farther south rises in the cliff and becomes reddish brown.

In the boulder-bed there are thin seams with pebbles and fragments of coal up to 6 inches in length. Small pebbles of banded Criffel Granite occur occasionally, and St. Bees and yellow marly sandstones are quite common. Quite three-fourths of the large boulders on the beach are volcanic: others are chiefly Eskdale Granite and St. Bees Sandstone (the latter up to 2 feet in size).

Continuing south-eastwards, stratified sands and boulder-beds occupy the

[1] *Turritella communis* Risso, *Buccinum undatum* Linn., *Anomia ephippium* Linn., *Ostrea*, and *Mytilis edulis* Linn. Determined by Mr. H. A. Allen.

middle of the cliff, and occasional boulders of Criffel Granite occur as far south as Townend Bank. The red loamy Upper Boulder Clay ends at the southern extremity of Townend Bank; while red sands and gravels appear at the top of the cliff, and extend nearly to its base, which consists of reddish boulder-clay. The stratified false-bedded sands are of various degrees of fineness and colour, and have variegated sandy loams and clays interbedded with them.

In Silecroft brickyard there is an exposure of about 12 feet of salmon-tinted loamy Lower Boulder Clay, containing very few stones. In addition to a few volcanic boulders, there were slate and coal fragments, some well-striated fine grits, and a small boulder of Criffel Granite. At the clay-pits east of Whitriggs Close, Haverigg, the section consists, in the lower part, of a red loamy clay with small stones and boulders and a few sandy laminæ. The upper 12 feet is chiefly yellow sand, with streaks of clay, beneath a capping of dull chocolate-coloured clay with a few stones.

VII. The Lower Boulder Clay.

(1) The Coast-Sections.

It thus appears that Mackintosh's three divisions of Lower Clay, Middle Sands, and Upper Clay, although one member or another may be missing, hold good in the main; but the lateral and vertical variations in character, and the changes in level of the drifts, are probably much greater than he imagined, and the facts are not compatible with his theories concerning their mode of formation. The passage, for example, of a lower brown till, which rises above high-water mark at Gutterby Banks, into a reddish loamy clay within a space of a few yards is more suggestive of the action of an ice-sheet that has picked up materials of diverse character and incorporated them in its ground-moraine, than of deposition in water. The whole series, as Mr. Lamplugh has pointed out,[1] is strikingly similar to that of the Extra-Insular Drift of the Isle of Man described by him in these terms:

> 'the whole [that is, the three divisions] are so intermingled and so interchangeable that, so far as the beds above sea-level are concerned, we can scarcely escape from Mr. [P. F.] Kendall's conclusion that the Manx drift forms one great irregular series.'

After expressing the view that both the Extra-Insular drift and the Local drift of the Island were practically contemporaneous, and both the product of land-ice, he concludes that (*op. cit.* p. 356)

> 'Whatever explanation is adequate for the Isle of Man will be capable of wide application'

to this and other areas.

The Middle Sands and Gravels I consider to have been formed during the waning of the ice-sheet, preceding a slight advance

[1] 'The Geology of the Isle of Man' Mem. Geol. Surv. 1903, p. 335.

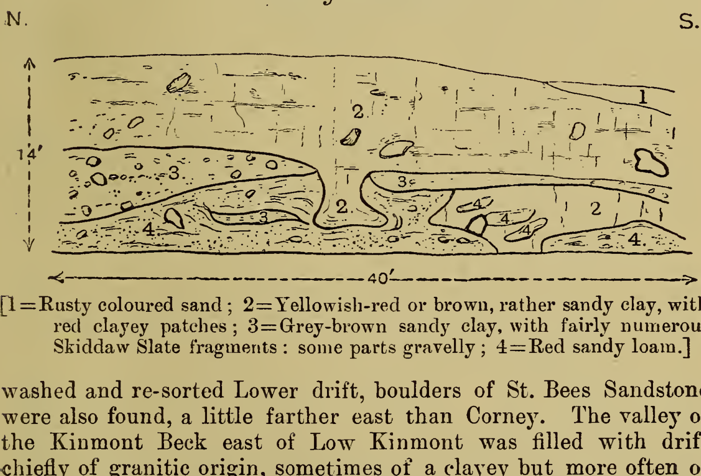
which introduced the Upper Boulder Clay. These events will be discussed more fully at a later stage.

Some of the inland sections where the Lower Boulder Clay rises up the flanks of the hills, and rests upon granite, volcanic rocks, or slate, will now be described. These sections show the dovetailing of drifts of distant and of strictly local origin [1]; but this, as I have shown above (p. 411), does not in all cases imply an intermixture of Irish-Sea and Lake-District drift.

(2) The Inland Sections.

(i) North of Bootle.—Upon the granitic tract north-east of Bootle the drift which passes for Boulder Clay is largely composed of granitic débris, and is difficult to separate from the later fluvioglacial sands and gravels. It contains included streaks of red loamy clay in a few places, with, among others, small boulders of St. Bees Sandstone (Park Nook, near Bridge End). In the later fluvioglacial gravels of this area, formed chiefly from

Fig. 3.—*Section of Boulder Clay near Fell Green, Bootle, looking eastwards.*



[1 = Rusty coloured sand; 2 = Yellowish-red or brown, rather sandy clay, with red clayey patches; 3 = Grey-brown sandy clay, with fairly numerous Skiddaw Slate fragments: some parts gravelly; 4 = Red sandy loam.]

washed and re-sorted Lower drift, boulders of St. Bees Sandstone were also found, a little farther east than Corney. The valley of the Kinmont Beck east of Low Kinmont was filled with drift chiefly of granitic origin, sometimes of a clayey but more often of a loose texture. The head of Damkirk Beck, a mile east-north-east of Bootle, is cut partly in a rich red Triassic boulder-clay with greyish patches of granitic débris.

Dovetailing of the drifts is well shown in a section at the head of the Fell Road to Broughton, about 150 yards south-east of Fell Green, east of Bootle (fig. 3). Granites are common in this section, and there is the usual suite of volcanic rocks, among them an

[1] For a comparison, see the description of the lateral moraine of the Von Post Glacier, Spitsbergen, by Mr. G. W. Lamplugh in 'The Shelly Moraine of the Sefström Glacier, &c.' Proc. Yorks. Geol. Soc. vol. xvii, pt. iii (1911–12) pp. 237–38.

agglomerate with included fragments 6 inches in length. There are a few boulders of soft red sandstone, and many well-striated Skiddaw Slates from the neighbourhood of Cleator and Ennerdale.

(ii) Western slope of Black Combe.—The Lower drift rises from a level of about 250 feet near Fellside (half a mile east of Bootle) to a height of over 400 feet near Whitbeck, falls to 200 feet near Sledbank, but rises again to 300 feet at the mouth of the Whicham Valley. Skiddaw Slate débris becomes an increasingly important constituent in a southerly direction, but there is a great amount of Triassic débris throughout, as well as granitic and andesitic material of all sizes.

Between Fellside and Hall Foss (a mile south-east of Bootle) the Boulder Clay is very sandy, and the hillside above its level has been scraped and polished by southward-moving ice which left erratics and perched boulders upon the slopes above (p. 422). Between Hall Foss and Hole Gill the lower slopes are also scraped and steepened, and boulders occur in the lower part of Hall Foss above the level of the clay. A section near the footpath on the northern side of Hole Gill Beck shows the interweaving of drifts—chiefly brown and sandy at the western end, with slate-grey material in the middle, and clayey drift with very little slate at the eastern end. A pit on the south side shows variegated drift with much slate-débris.

A platform, the scarped face of which (pp. 434–35) is situated from 50 to 100 yards west of the footpath, consists of unstratified drift of a sandy texture, containing a considerable amount of slate. Boulders of slate also lie on its surface. Near Monkfoss Farm, 300 yards from the bare hillside, the drift is brown and sandy, but unstratified.

The lower of two pits by the road south of Whitbeck Mill showed 12 feet of brown gritty boulder-clay, with much slate-débris, resting on a foot or more of red sandy drift containing lumps of red sticky loam and fragments of red sandstone and shale. The bottom of the further pit was almost on a level with the top of the last. It exposed 12 feet of more homogeneous brown sandy drift full of stones, mostly of slate, but there were also boulders of granite, etc. A tawny-yellow sand (probably rainwash) following the slope of the hill crossed the edges of the deposits, in both sections, obliquely. The slaty fragments in the drift north of this point were mainly of the pale unbanded felspathic type; in these sections, however, the blue banded slates begin to appear, and are quite common farther south.

In Miller Gill, behind Whitbeck Mill, there is a beautifully glaciated surface of slate, from which the boulder-clay has been stripped away; and 150 yards upstream is a second, the direction of ice-movement in both cases having been to the south-east.

A pit about 440 yards south-south-east of Whitbeck Church shows 10 feet of slaty drift, with patches or streaks of loam and red clay. Another section about a third of a mile to the south shows a similar admixture, and contains a few boulders of Triassic sandstone.

There is an interesting section near a quarry in a dyke on the hillside above Wood House. The Boulder Clay, which rests upon a smoothed and striated surface of Skiddaw Slate, is a composite mixture of variegated drift, as shown in the appended section (fig. 4). Boulders of slate are beautifully striated.

Fig. 4.—*Section in Boulder Clay near Wood House, Whitbeck, looking southwards.*

[1 = Roughly-stratified slaty drift, with boulders: matrix brown and gritty, sometimes approximating to a gravel; 2 = Yellowish loam, with fewer stones, but more of large size and distant origin than in 1; 3 = Strip of brick-red sand with stones; 4 = Tawny-coloured sand with stones resting upon 1 & 2 in a 'pockety manner.' At the bottom (left) of the section, the clay (1) rests upon a glaciated surface of Skiddaw Slate.]

Near Sledbank there is an admixture of slaty and red-clay drift, with sandy and gravelly layers streaked out in a south-easterly direction. It is overlain by 2 feet of tawny-yellow sand, and underlain by a similar thickness of warm red sand, both containing stones. The boulders are chiefly slates, lavas, tuffs, ashes, and Eskdale Granite, some of the latter being very rotten. Boulders of Ennerdale Granophyre and St. Bees Sandstone were also noted.

(iii) Whicham to Duddon Estuary.—The Boulder Clay, swinging round the shoulder of Black Combe, is traceable to the back (west) of Whicham Rectory, and next appears upon the opposite side of the valley south of Pohouse, about a mile from the valley-mouth. Under Nicle Wood and Lacra Bank it is rather sandy, and contains slates, red sandstone, granites, granophyres, and volcanic rocks. On the western slope of Lacra Bank it is largely composed of the underlying slates, and rises to over 300 feet; it sinks to below 200 feet under Kirksanton Bank, but granite boulders are found as high as 400 feet. On the south-eastern slopes of Harrath Hill (west of Millom) the drift is reddish, and granite boulders rise no higher than 200 feet.

At King's Quarry, Millom, more than 4 feet of red clay rests upon the Coniston Flags, and Mackintosh [1] records red clay with boulders of Eskdale Granite, resting upon a beautifully striated surface of Carboniferous Limestone (about half a mile south of the station), in which most of the striations point north-eastwards. He concludes that the glaciating agent and the carrying agent were not the same, assuming that the glaciating agent moved in a south-westerly direction out of the Duddon Estuary. On the contrary, however, the granitic drift of the maximum glaciation was carried some distance up the centre of the Duddon Estuary,[2] and appears again at 70 feet above sea-level on Dunnerholme, upon the east side of the estuary. Mackintosh [3] however, describes it as being Upper Boulder Clay 2 to 5 feet thick—a red loamy clay,[4] well charged with rounded and half-rounded stones, slate, porphyry, and granite, many much more rounded than those at the base of the cliff. Granites also occur over the ground stretching a mile north-east of Dunnerholme; and at a small quarry near Gargreave, about 250 feet above the sea, the slates were planed down and slightly grooved 10° west of north.

VIII. Distribution of Scottish Boulders.

The distribution of boulders of Criffel Granite in the drifts of the coast, as a whole, has been so fully described by Mackintosh and others [5] that I need say no more than that my own observations confirm or strengthen those of previous investigators. North of the district here described the eastern boundary of the Criffel Drift

[1] 'On the Drifts of the West & South Borders of the Lake District, &c.' Geol. Mag. vol. viii (1871) pp. 304–305. This may be the exposure at Redhill Quarry shown on the 6-inch Geological Survey map, about three-quarters of a mile south-south-east of the station.

[2] The Irish-Sea ice seems to have received its tributaries on the outer sides of convex bands, in much the same way as some rivers do. Mr. J. D. Kendall recognized that the boulder-current was deflected up to the Vale of Duddon near Millom.

[3] 'On the Correlation, Nature, & Origin of the Drifts of North-West Lancashire & a Part of Cumberland, &c.' Q. J. G. S. vol. xxv (1869) p. 425.

[4] The kind of Lower Boulder Clay that we might expect to find in such a position.

[5] See references on p. 403.

coincides with the main road between Egremont and Ravenglass, after which it follows the railway to near Silecroft. I have seen boulders of the granite as far south as Silecroft, and they have been recorded by Mr. J. D. Kendall[1] near Whicham Hall, and by Charles Smith[2] near Millom (see also p. 444). With the exceptions stated below, most of the other boulders in the drifts south of Bootle were derived from Cumberland, or from the sea-bed off the Cumberland coast. On the beach at Hycemoor (near Bootle Station) grits and grauwackes, like those of the South-West of Scotland, are of common occurrence, and so too are porphyrites similar to those of Dumfries. Grauwackes also occur on Silecroft beach, and seem to extend as far eastwards as the Criffel Granite. I found several east of Nicle Wood on the eastern side of the Whicham Valley, near its mouth, and boulders also of Scottish porphyrites, both here, and near Whicham (compare the Castle-Douglas porphyrites). On Bootle Fell there was a hornblende-granite similar to a Galloway granite, and near Whitbeck some of the boulders are of the Dalbeattie or Cairngall Granite types.

No boulders of Ailsa Craig microgranite were seen.

IX. Phenomena occurring during the Retreat of the Ice.

(1) Moraines and Trails of Boulders.

Between the 500- and 800-foot contours, on the slopes of Stainton Fell, south of the mouth of Eskdale, there is a series of low morainic ridges, about a mile in length, trending south-south-westwards, and breached near the centre by Stainton Beck. Farther south a splendid moraine, with the same direction, descends to, and follows, the 700-foot contour for more than a mile, to a point about half a mile east-south-east of High Corney. Another, south-east of High Corney, lies between 500 and 600 feet.

The slopes of Waberthwaite and Corney Fells, between 700 and 1000 feet, are covered by a series of less perfect, but quite distinct, moraines, or morainic terraces, trending north and south, formed as the ice slowly withdrew by lateral shrinkage. Thicker deposits of Boulder Clay lie at a lower level between the steeper hill-slope with moraines above, and the channelled granite-plateau below, which, with its gravelly covering, reaches a height of between 400 and 500 feet. These moraines were left by Lake-District ice, confluent with the Irish-Sea ice.

West of Buckbarrow Beck, near its junction with Kinmont Beck, the moraines take a south-westerly trend, crossing the contours nearly at right angles. The valley of the Kinmont Beck was choked by drift, and is now being re-excavated, the relics of in-filling material being re-arranged and redistributed by the stream as a series of terraces (Pl. XLI, fig. 1). On Bootle Fell ridge-

[1] 'Distribution of Boulders in West Cumberland' Trans. Cumberland Assoc. pt. v (1879–80) p. 155.

[2] 'Boulder Clay' Trans. Cumberland Assoc. pt. iii (1877–78) p. 103.

shaped lateral moraines occur on and above the 700-foot contour, with a north-and-south trend, but swing round to the south-west and west, and cross the contours immediately south of the Fell road from Bootle to Broughton.

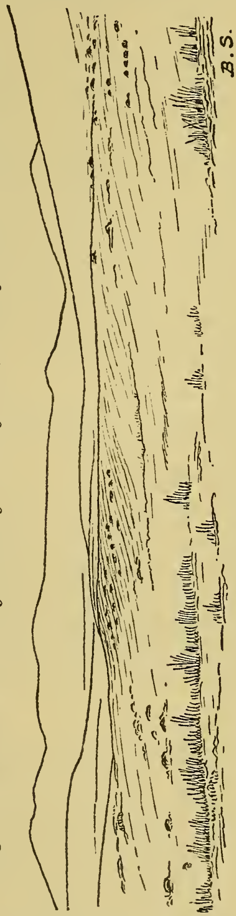


Fig. 5.—*Moraine near High Corney, Corney Fell, looking north-north-eastwards.*

[This moraine has a ridge-like top, and is more than a mile long.]

No true moraines were seen upon the western slopes of Black Combe, for the steep descent and the general absence of ice-free ledges would probably forbid any great accumulation of morainic matter. On Butcher's Breast, however, Eskdale Granite and Borrowdale erratics are clustered between the 600- and 700-foot contours, and there is another patch above the 1000-foot level north of the head of Hallfoss Beck.

South of Monkfoss Beck,[1] also, is an interesting trail of boulders, of the nature of a moraine, between the 800- and 1000-foot contours. The erratics consist chiefly of boulders of Eskdale Granite,[2] the largest of which, the 'Broughton Stone,' measures $8 \times 9 \times 5$ feet, while another measures $6 \times 5 \times 3$ feet. There are also boulders of andesite, volcanic breccia (7 feet long: probably from Caldbeck, containing fragments averaging 4 to 6 inches in length, but up to 2 feet maximum), banded ashes, and pale quartz-porphyry like that exposed at the foot of Holegill Beck.

Small moraines occur in the Combes upon the south-east side of Black Combe; but, since they belong to a late stage of the glaciation, they will be referred to in another section (p. 446).

The Whicham and Duddon Valleys are, on the whole, free from moraines, but in the latter there is (about 8 miles due east of the mouth of Eskdale) a splendid example of a lateral moraine under Walna Scar near Seathwaite. Mackintosh[3] describes this 'great wonder of the Duddon Valley' as a post-marine lateral moraine, probably formed by a shallow glacier.

[1] Mackintosh refers to an 'ice-floe load' of boulders on a plateau, on the south side of the upper part of Foss Beck, at a height of about 1000 feet, discovered by Mr. Eccleston of Carlisle: he probably alludes to this group. See Geol. Mag. vol. viii (1871) pp. 255, 256.

[2] Mr. J. D. Kendall also records boulders of Eskdale Granite at 1000 feet. See Trans. Cumberland Assoc. pt. v (1879–80) p. 155.

[3] Geol. Mag. vol. viii (1871) pp. 306–307.

It is about 2 miles long, and occurs in three main sections. Commencing on the north between the 800- and 900-foot contours, it descends to near the 500-foot contour about half a mile south-south-east of Seathwaite Church. The southern section, east of Seathwaite, has moutonné rock-surfaces protruding through it at its southern end. The middle section is similar, but conceals the rock-surface more thoroughly. South of Long House Gill, this section is most prominent near the top, where it forms a broad terrace. It consists of a tumultuous accumulation of huge sub-angular boulders which cover a considerable part of the hillside, and enclose many a marshy flat or swamp. The third section, north of Long House Gill, is more ridge-like, and divides into two mounds, covered with great angular blocks, many of which are of banded ash.

The moraine lies in an embayment where the contours on opposite sides of the Duddon Valley widen out. This widening doubtless caused a state of semi-stagnation, or, at any rate, of slow movement, in the ice on this side of the valley, resulting in the accumulation of surplus débris.

(2) Marginal Channels and Associated Sands and Gravels.

Before the Ice Age, the normal drainage of the country lying between the Duddon Estuary and the Esk was westerly or south-westerly. The Esk and the Whicham Beck, for example, flowed to the south-west, and the Kinmont Beck, near Bootle, to the west of south-west. Thus the main drainage then, as now, occupied channels running nearly, but not quite, at right angles to the coast-line, which trends slightly east of south.

There is, however, another series of channels, which are now for the most part either dry, or occupied by insignificant streamlets [1]; while their general trend corresponds more or less with the trend of the moraines upon the hillsides north and east of Bootle (p. 421).

In some cases the channels were merely carriers of the marginal drainage of the ice-sheet—now in the ice, now in the rock, or between the ice and the rock-face. In other cases they represent channels scoured out by overflow waters, from lakelets held up between the ice-front and embayments of the land.

As the position of the ice-margin altered from time to time, new channels were developed, so that two or more courses were sometimes formed in parallel sequence at consecutively lower levels. 'In-and-out' channels, and channels formed entirely in drift, or between an ice-wall and a drift-wall, are also represented.

(i) The Granite Area south of Eskdale.

The shelf-like western part of the granite outcrop (see p. 406) between Eskdale and Kinmont Beck is about a mile wide, and

[1] The River Annas being an exception.

slopes gently westwards from near the 500-foot contour to the 300-foot contour, from which it drops abruptly to the 200-foot level.

During the maximum extension of the ice the surface of this shelf was, like the slopes above it, covered mainly by boulder-clay of a somewhat sandy type (see p. 417). The retreat of the ice seems at first to have been unaccompanied by any great melting, but rather by evaporation, coincident with a falling-off in the amount of precipitation: for no signs of water-action at the margin of the Irish-Sea ice appear in this district above the 500-foot contour, although, apart from the ice itself, the gathering ground was large enough for water to be set in motion, had the snow-line been at a higher level.

When appreciable melting did take place, moving water began to modify the drift previously deposited upon the shelf or held in the melting ice; and, since this drift consisted largely of sandy Triassic waste, with granitic and volcanic débris, the resulting products are mainly of a sandy and gravelly nature.

For example, one of two pits, situated by Whatson Beck, nearly three-quarters of a mile north-north-east of Welcome Nook, shows 6 feet of false-bedded sand with gravelly layers, capped by about 3 feet of gravel, some layers of which are disintegrated granite. In the middle of the pit, about 3 feet of red stony clay rests on sand and gravel, and passes laterally into the same. At the top are some large boulders. Sections of a similar nature were seen at several points, as, for example, about a quarter of a mile south-east of Row, near Welcome Nook; 100 yards east of Park Nook; near Low Kinmont, and Kinmont Wood. In a pit near the 'Camp,' about 500 yards north-north-west of Corney Church, there was more than 20 feet of coarse roughly-bedded gravel, most of which is bound together by red muddy silt, but there are also beds of cleaner sand and gravel. Some fairly large erratics and pebbles of red sandstone were also noticed here. The gravel extends southwards to and beyond the neighbourhood of Corney Hall, where it forms a distinct feature above the granite, and is exposed a few yards north of the Hall in a pit in which 3 feet of coarse false-bedded granite sand overlies more than 6 feet of gravelly boulder-beds, on a similar deposit at a lower level. In all these cases the well-worn character of the gravel shows that the majority of the pebbles had been carried a long distance by running water before being finally deposited.

The method of occurrence and nature of the above-described deposits suggest that they were accumulated, as a lateral apron or fan, at the oscillating edge of the ice-sheet, by waters which slowly escaped in a southerly direction through indefinite or now-destroyed channels in the drifts.[1] At the same time, the more clearly-stratified portions were doubtless formed in temporary marginal lakes. As

[1] The method of formation of such gravels was discussed by the late Prof. Ralph S. Tarr in 'The Yakutat Bay Region, Alaska' U.S. Geol. Surv. Professional Paper 64 (1909) chapt. ix.

time progressed definite channels were cut through these first-formed deposits, in many cases into solid rock, by swiftly-running streams carrying a full burden of gravel and gritty sand.

(*a*) The Barnscar Channel.—The first of the drainage-channels to be described occurs about a mile north-east of Bridge End, east of Eskmeals Station. It is a shallow trough in granite, 20 to 30 yards wide, with a dry flat bottom, except at its southern end, where a small stream rises and joins Black Beck on an alluvial flat near Stainton Farm. This channel was probably excavated by the water which cut the channel that will be next described. The ground between them is low, and was occupied either by a small lake, or by a lobe of ice through, or across, which the water flowed. (See map, Pl. XLIII.)

(*b*) The Kinmont (Welcome Nook and Low Kinmont) Channel.—This channel commences rather vaguely, as a dry valley, near Grange Farm, just above the 400-foot contour, about three-quarters of a mile south-east of Bridge End. Immediately south of Welcome Nook, however, where it makes a bend to the east round a rather steep hillside more than half a mile from its head, it is quite prominent. The flat marshy alluvial bottom, about 90 yards wide, is traversed only by a narrow drainage-ditch, almost too small to carry off the accumulated water (Pl. XLI, fig. 2). The floor of the channel crosses the 400-foot contour at Welcome Nook, and the depth of the valley is from 60 to 70 feet. The walls then become less prominent, but south of the point where the River Annas crosses the valley near Foldgate, the profile of the (now dry) valley becomes once more pronounced. A few small hanging becks then tumble into the valley, and unite to form a little tributary to Kinmont Beck. Granite is exposed at several points, but especially near Low Kinmont, where the valley, which is quite 30 feet deep, comes to an end, its floor being slightly above 300 feet O.D. The channel is thus about 2½ miles long, and its floor falls 40 feet per mile.

(*c*) The Corney Channel.—At an average distance of a third of a mile west of that just described, another channel is still more strikingly developed. Commencing in granite, well below the 400-foot contour, at a point almost due west of Welcome Nook, it makes a convex bend to the west for half a mile, and then turns southwards, its floor crossing the 300-foot contour about a quarter of a mile north of Gillfoot, near which place it is fully 100 feet deep and quite dry.

The River Annas enters on the east immediately south of Gillfoot, through a steep-sided gorge which forms a cross-cut from the Kinmont Channel near Foldgate. An alluvial cone is thrown across the valley by the river, which then turns southwards. At the southern point of entry of the river, boulder-beds (with St. Bees Sandstone) capping stratified granite-sand were noticed, resting upon a cliff of rotten granite. On the opposite side of the main valley, 3 to 4 feet of red and yellow stratified granite-sand, with a south-easterly dip and embedded boulders, was exposed in the road-bank facing Skellerah House. The valley is 40 to 50 feet deep at Corney Mill, where 15 feet of boulder-beds and stratified sand rest upon more than 20 feet of exposed granite.

At Corney Hall, a low col gives access on the west to a transverse valley, about a fifth of a mile long, which is of a similar nature to that near Gillfoot and will be dealt with later on (pp. 426–28). About 100 yards south of Corney Hall there is a drop in the floor of the main channel, the depth of which increases to 100 feet, and its drift-capped sides become steeper. At Black Dub the floor crosses the 200-foot contour and turns abruptly westwards, round Seaton-Hall Wood, leaving the outcrop of the granite. South of this point the eastern granite-wall of the old channel, as far as Kinmont Beck, is still in existence; but the western wall is wanting, and was evidently formed of ice.

The complete channel is nearly 2 miles long, and its floor falls about 75 feet per mile.

(*d*) The Near-Bank 'in-and-out' Channel.—A third channel as long as, or longer than, the last, lies still farther west, its general course coinciding with the western outcrop of the granite which descends quickly from 300 to below 200 feet. The ice apparently rested for a considerable time against this slope, and steepened it by holding flowing water against it. At Near Bank, owing to the crowding of the ice, the water was forced to cross a spur of granite, and cut a splendid example of an 'in-and-out' valley about a quarter of a mile long. Its floor is 50 yards wide, and lies below the 200-foot contour; while its eastern wall is over 60 feet in height. A small stream dropping into the valley from this side throws across the floor a low delta, upon which the stream turns and takes a southerly course (Pl. XLII, fig. 2).

(*e*) The Gillfoot and Corney-Hall transverse channels.—The valley which introduces the Annas into the Corney Valley is rather steep-sided, and some 300 yards long. In this distance its floor falls about 50 feet, its almost abrupt descent being at the western end, where it drops into the Corney Valley. It connects the Kinmont Channel, the floor of which lies at from 360 to 370 feet above O.D. (the River Annas is at about 350 feet), with that of Corney, a little below 300 feet.

At Corney Hall there is a similar (but dry) valley, a quarter of a mile long, connecting the Corney with the Near-Bank Channel. At its head, immediately west of Corney Hall, is a low col, from which the floor of the cross-cut descends over 60 feet in a westerly direction. At its best the valley is quite 80 feet deep. Stratified sand and gravel occur in the wood on the southern slope at a rather low level, perhaps deposited in a small pre-Glacial stream-hollow (Pl. XLII, fig. 1).

Were it not for the transverse valleys at Gillfoot and Corney Hall, there would be nothing inconsistent in the view that the parallel sequence of channels—Kinmont, Corney, and Near Bank—was formed during a retreating movement of the ice, after it had advanced over the gravels which it had previously deposited, because the heads of the three longitudinal channels are so related to the contours that each would have come into operation after the next above it had been abandoned. The transverse valleys, however, seem to show that different parts of the longitudinal channels were cut at different times.

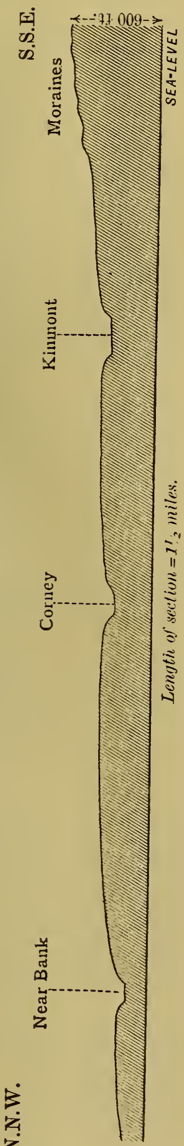


Fig. 6.—*Profile section of the parallel sequence of marginal channels in the granite north of Bootle.*

Assuming first that the ice, after an advance over the gravels, was retreating, and that the Kinmont Channel was cut, the formation of the Gillfoot cross-cut would require a small retreat of the ice, and a filling up of the lower part of the Kinmont Channel, so that the water would be compelled to flow over a low col, or along a pre-Glacial hollow, on the site of the Gillfoot Channel; and then, following the ice-margin, commence to cut that part of the Corney Channel which is south of Gillfoot. This result might conceivably be brought about by snow filling the lower part of the Kinmont Channel—local glaciation being out of the question. Further retreat of the ice-margin would cause the water to abandon the upper part of the Kinmont Channel and open up the whole length of the Corney Channel, which would be cut almost to its present low level. The formation of the Corney-Hall Channel may have been due to a similar process, the col at the Hall being formed by an oscillatory movement which threw the waters back for a short time from the Near-Bank Channel into the Corney Channel.

There is, however, a second possible explanation, namely, that the parallel sequence was cut during the forward movement of the ice when it overrode the gravels. It has been recently demonstrated[1] that a slight advance of a glacier is often followed by

[1] O. D. von Engeln, 'Phenomena associated with Glacier-Drainage & Wastage' Zeitschr. für Gletscherkunde, vol. vi (1911) pp. 128, 129.

the development of a visible marginal drainage, chiefly because of the choking and blocking of the courses previously occupied by the flowing water. A further advance may then force the stream to occupy a channel higher up the slope against which the ice is resting. In this case the stages of development would be as follows:—after the formation of the Near-Bank Channel the ice north of Corney Hall, advancing obliquely across the contours, caused the water to flow by way of the Corney valley and by a low col at Corney Hall, that is, along two sides of a right-angled triangle, of which the ice-margin formed the hypotenuse. A further advance would block the Corney-Hall transverse channel and the intake of the Corney Channel, and throw the water into what is now the Kinmont intake. It would then flow by way of the upper half of the Kinmont Channel and the Gillfoot notch into the lower part of the Corney Channel, and cut that part of the latter which lies south of the Corney-Hall intake. Further advance of the ice would account for the excavation of the lower part of the Kinmont Channel.

This explanation, in itself, postulates that the ice, in its advance, did not (although in all probability it would) fill up any of the overridden channels with morainic deposits, for they are, at present, quite empty and bare. If, however, the water occupied each channel a second time, during the withdrawal of the ice, it may have cleared them of all obstructive material.[1] In discussing, in the following paragraphs, the marginal channels in the volcanic tract south of Kinmont Beck, it will be seen that there is reason to believe that they were chiefly cut during an oscillatory retreat of the ice which followed upon a slight advance over the gravels. I am, therefore, inclined to think that the main cutting of the channels in the granite also was accomplished during retreat; but this need not prevent us from assuming that the watercourses may have been first blocked out during advance.

(ii) The Volcanic Tract east of Bootle.

During the maximum extension of ice, the volcanic tract near Bootle, together with those parts of the granite and slate areas which immediately bound it on the north and south, were covered by boulder-clay, which levelled up the hollows so that the surfaces formed of drift and solid rocks were in some cases continuous. The retreat of the ice after the formation of the moraines was, as before, marked by the accumulation of much fluvioglacial material, which now lies sometimes on solid rock.

The upper limit of this drift can be traced, just below the 500-foot contour, on the lower slopes of Bootle Fell (Damkirk Brow). The sands form two bold esker-like ridges (North and South Coppycow) on the moorland above the 400-foot contour south of Damkirk Brow, their striking shape being probably due

[1] For a description of the cutting of a complex series of marginal channels by alternations of advance and retreat, see *op. supra cit.* p. 130.

to denudation. Beds of sand and gravel also occur on the south side of Grassoms Beck, a few hundred yards east-south-east of Gibson's Spout; and on Bootle Bank they form a rather flat-topped feature, rising from a platform of andesite to 400 feet at its highest point (fig. 10, p. 432).

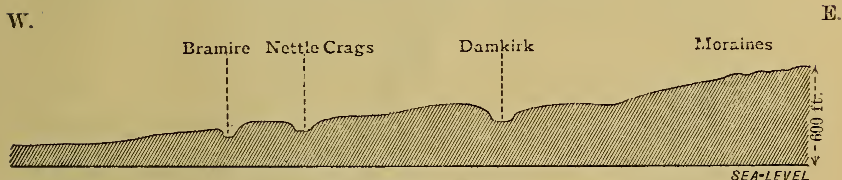
A pit at the northern end of the feature gave the following section:—

	Thickness in feet.
Layers of stratified sand and gravel, with boulders measuring up to 18 inches in greatest diameter	15
Well-stratified red [Triassic] sand and finer layers of gravel, chiefly of granite, lava, ash, etc. with occasional boulders.	4

The pits on Bootle Bank also contained fragments of red sandstone and striated slate.

These gravels are comparable with those described above as having been formed on the granite tract, but they differ in their more regular stratification and by lying at a higher general level.

Fig. 7.—*Profile section of the parallel sequence of marginal channels in the volcanic rocks near Bootle.*



Length of section = 1 mile.

They were probably accumulated beneath the waters of an ice-dammed lake about half a square mile in extent, held up in the embayment north of the north-western shoulder of Black Combe. The water drained away through, or over the ice, leaving no trace of its exit.

At a later stage, about the time when the Kinmont Channel was first initiated, and when a small lake probably existed at its lower end, these gravels began to be degraded and removed by a definite stream which finally cut the Damkirk Channel through the underlying andesite.

The andesitic ridge would form a more formidable barrier than the granite, for the rock decomposes less easily, and would not have been so thoroughly rotted to begin with. Consequently the drainage-channels are narrow and steep-sided, and begin and terminate rather abruptly, for the drift banked against the ridge has been to some extent removed by post-Glacial erosion.

As the water-level fell, roughly stratified or false-bedded gravels were formed at successively lower levels near the heads of the drainage-channels. A section 8 feet or more in depth, at the head of the Bramire Channel, shows sand and gravel with boulders up to 2 feet in greatest diameter, on coarse sand and gravel, resting upon fine sand and gravel inclined in a south-south-easterly direction,

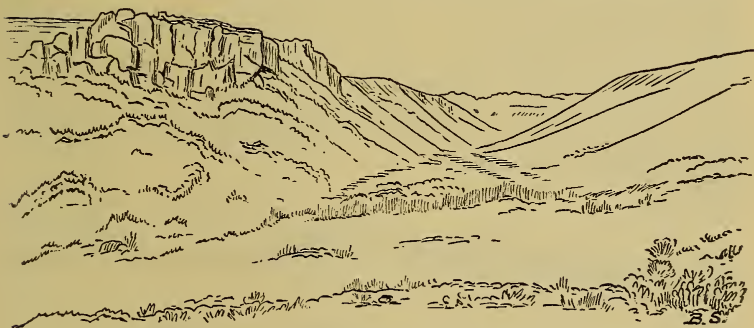
Fig. 8.—*The Damkirk Channel, Damkirk Bottom, looking northwards, with the delta of Old Close Gill in the right foreground.* *(See pp. 431–32.)*

that is, towards the head of the Nettle-Crags Channel. The boulders are chiefly of Eskdale Granite and Borrowdale rocks, but there are also small boulders and pebbles of soft Triassic sandstone and Skiddaw Slate. Another pit showed a similar section, consisting to a great extent of big granite-boulders in granite-sand. Many of the granites were quite rotten, and crumbled beneath the fingers.

(*a*) The Damkirk Channel.—At the time of the initiation of this channel the ice-margin, after a very small advance over the gravels, lay in an almost north-and-south line between the western side of the Kinmont Channel (350 feet approximately), Bootle Bank (350–386 feet), and the shoulder of Black Combe, holding up a small lake north of Bootle Bank. The outflow was first cut through drift, but was finally sunk into the rock-floor. The intake faces west, but the channel turns quickly southwards after crossing the junction between granite and andesite.

At its head the Damkirk Beck enters by a post-Glacial course, and traverses Damkirk Bottom as a stream hardly more than a foot wide, and an obvious misfit. At this part of its course the channel is a steep-sided flat-bottomed valley, about 45 yards wide and fully 70 feet deep. A few yards north of the road

Fig. 9.—*The Nettle-Crags Channel, looking northwards. (See p. 432.)*



[The original steepness of the walls is obscured by screes.]

over Damkirk Brow it receives Oldclose Gill, which enters from a post-Glacial ravine, and throws an alluvial cone across the valley floor, forming a marshy tract to the north of it, which Damkirk Beck is powerless to drain thoroughly (fig. 8, p. 430).

After crossing the road the main valley makes a bend to the south-east, receiving Grassoms Beck which cascades into it at Gibson's Spout. This is joined by Damkirk Beck, and the combination, under the name of Crookley Beck, traverses the valley (here cut along the junction between andesite and slate) and leaves it, on its western side, at Cat Crags, by its re-excavated pre-Glacial gorge. The Glacial channel then swings to the south, its marshy floor being slightly above the present alluvium of Crookley Beck.

The channel is five-sixths of a mile long, and its floor falls from 320 to 200 feet, that is, 144 feet per mile.

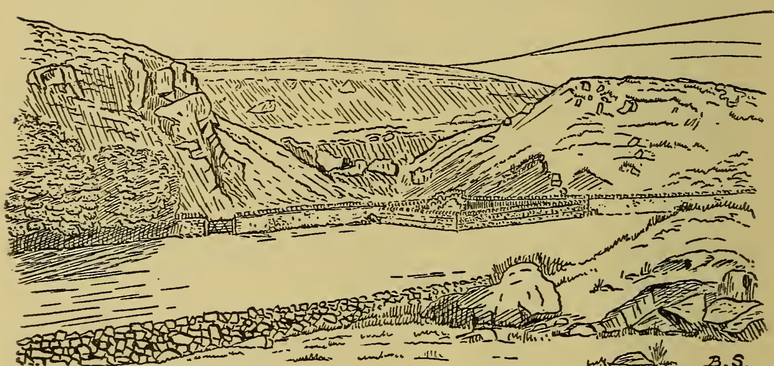
(*b*) The Nettle-Crags Channel.—This is a dry valley which lies directly in line with the Kinmont Channel, and is connected with it by a boulder-strewn hollow in the drift. Commencing in drift-covered granite, it becomes pronounced where cut in andesite, the western wall forming a precipitous crag some 50 feet high (fig. 9, p. 431).

Near Nettle Crags the main channel divides, and encloses an island formed of banded ashes.

At its head the floor is nearly 30 feet below the Damkirk intake; but, since the valley is fairly shallow at that point, there is every reason to suppose that its initiation led to the abandonment of the Damkirk Channel. It is half a mile long, and its floor descends about 90 feet, that is, at the rate of 180 feet per mile.

(*c*) The Bramire-Wood Channel.—This channel runs from north to south, close to, and nearly parallel with, the Nettle-Crags Channel. It also commenced in drift-covered granite,

Fig. 10.—*Bramire-Wood Channel, looking eastwards.*



[The Nettle-Crags Channel is in the middle distance. A feature is formed by the gravels of Bootle Bank on the sky-line. A cross-cut between the two channels occupies the centre of the picture. Black Combe is on the right.]

becoming pronounced after it crosses the boundary and enters the andesite. Its bottom is quite flat and dry throughout the upper half of its course, below which, however, there is a small drain. About half-way down the craggy eastern wall is 80 feet or more in height; the western side is mostly drift-covered (fig. 10, above). The floor falls from 270 to 180 feet, or at a rate of 180 feet per mile—about the same rate as the last.

The relationships between the Bramire and Nettle-Crags Channels seem to have been complicated by oscillatory movements on the part of the ice-margin, and different portions of both channels may have been in operation at the same time. After the Nettle-Crags Channel had been cut to a shallow depth, the ice appears to have retreated and allowed the Bramire Channel to be opened up. Then followed an advance which threw the water back again into the upper channel, so that its floor was lowered nearly to that of the Bramire Channel.

Fig. 11.—*Tarn Dimples, looking northwards: a water-cut gash in the hillside.*

Withdrawal of ice from the lower part of Bramire then allowed the water to fall, by a cross-cut, into that channel, near Nettle Crags. The subsequent opening-up of the upper part, and lowering of the floor, left the connecting channel as a hanging valley, opening upon the eastern wall of the Bramire Channel. This is shown in the accompanying figure drawn from a photograph and sketch made on the spot (fig. 10, p. 432).

The three channels—Damkirk, Nettle Crags, and Bramire—form a parallel sequence cut across the ridge of Borrowdale rocks, as shown in the diagram (fig. 7, p. 429). The first two appear to have been connected with the Kinmont Channel, but the Bramire-Wood Channel was probably fed to some extent by water from the Corney Channel, and the fluctuations of the ice-margin just discussed may have coincided with the fluctuations which led to the cutting of the transverse valley at Gillfoot (p. 426).

(iii) The Western Slope of Black Combe.

(*a*) The Tarn-Dimples Channel.—Tarn Dimples, situated between 200 and 450 yards south of Holegill Beck, is a notch in the hillside of rather striking appearance. From its situation, it seems certain that the mouth of Holegill was blocked by a lobe of ice,[1] and escaping water, after passing along a rock-ledge at the south-eastern edge of the lobe, immediately above the 400-foot contour, fell obliquely and rather rapidly along the mountain-side to the 300-foot contour. The head of the notch is almost precipitous, and must have formed a waterfall, which would account for the hollow occurring just below it. The hollow (partly filled by scree) is boggy, and contains several boulders, which may have been swirled round and round. A 7-foot boulder of Eskdale Granite, at a slightly higher level, has probably rolled down the hillside from above. The water at first escaped by a short oblique channel directed towards the south-west; but, when this became closed by ice, it cut a short valley running parallel to the hillside, and finally ending blindly in the open.

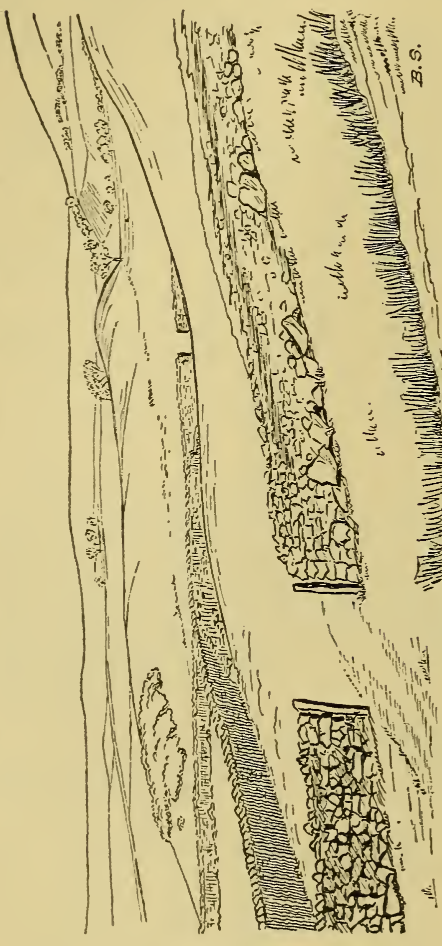


Fig. 12.—*The Monk-Foss 'in-and-out' Channel in drift, looking north-north-westwards.*

[The drift-plain is seen in the distance, and Black Combe on the right.]

The crag, thus isolated, is 40 feet high, and consists of slates riddled by reefs of vein-quartz. Its outer slope when continued upwards with its natural curve, corresponds exactly with that of the hill from which it has been severed (see fig. 11, p. 433).

Tarn Dimples is not an 'in-and-out' valley, but a rather complex 'out' valley, commencing with a waterfall.

(*b*) The Monk-Foss Channels in Drift.—From Fellside

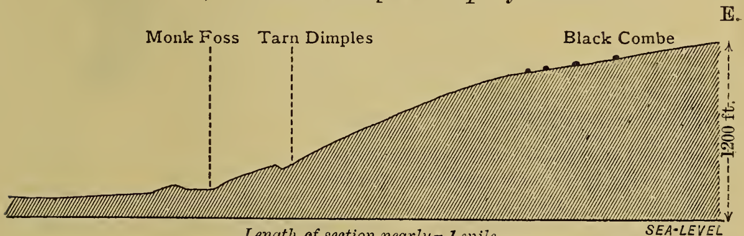
[1] Boulder-clay enters the mouth of Holegill (see p. 418).

near the termination of the Damkirk Channel (half a mile east of Bootle) a hollow in the drift runs to near Far End (a third of a mile). South of this point, to Holegill Beck, the western wall of the channel consisted of ice, and is therefore now wanting, the ground on that side falling away, as a gentle slope, to the 100-foot level. The eastern wall is a steep scarp-like bank, about 30 feet in height, running nearly to the 200-foot contour. South of Holegill Beck it is from 40 to 60 feet high, and consists in part of boulder-clay, as described above (p. 418), and in part of unstratified sandy drift.

Between Hallfoss Beck and Monk Foss, where the bank is about 80 feet high, there is an excellent example of an 'in-and-out' valley, the isolated ridge of drift forming, as it were, the string of the bow-shaped eastern wall of the channel. The ridge resembles an esker, but its origin is clear: it represents in a different medium the severed spur of granite at Near Bank (p. 426), only in this case the western face of the ridge had been shaped by water before the advance of the ice caused the channel to be cut. With the exception of one or two runnels which fall over the eastern side, the valley is dry (fig. 12, p. 434).

Near Stangrah, immediately south of Monk Foss, there is another dry 'in-and-out' valley, over 50 feet deep, and nearly as long, but not so well defined, as that just described. This channel isolates two small hummocks of drift, separated one from the other by a low col.

Fig. 13.—*Profile section of the Tarn-Dimples and Monk-Foss Channels, and the oversteepened slope of Black Combe.*



Length of section nearly = 1 mile.

South of this spot the course of the channel becomes vague. Thus from Fellside to Whitbeck, a distance of 2 miles, there is evidence of a marginal drainage-channel, the floor of which, starting at the 200-foot contour, falls to near 120 feet (40 feet per mile), and the western wall of which was the ice itself, except where the 'in-and-out' channels were developed.

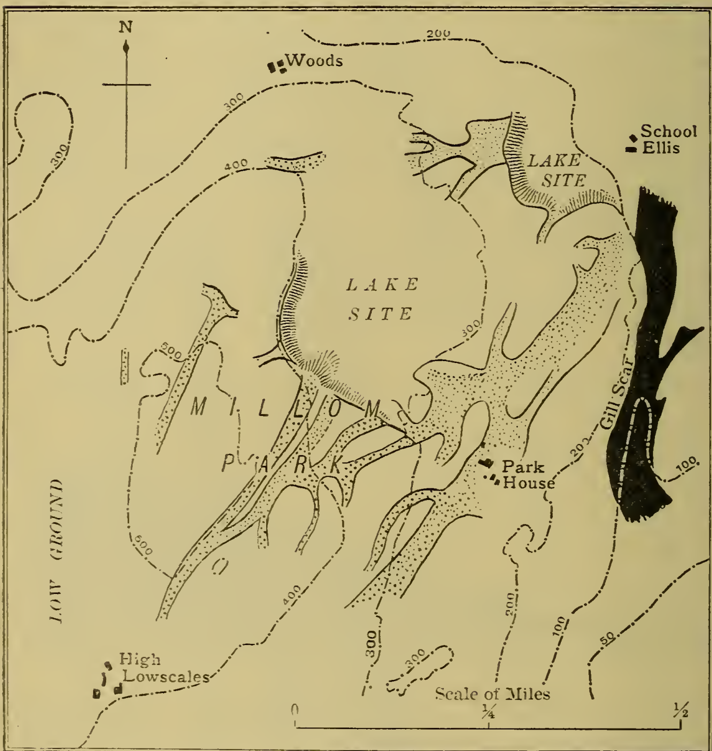
The age of this channel was apparently about the age of the Nettle Crags (late), Bramire and Corney (early) channels.

Its comparatively low grade was doubtless due to the nature of the floor upon which the ice was resting. Steeper gradients are to be expected where ice rests on rocky and irregular ground, and gentler gradients where it covers a softer, flatter, and more easily eroded floor.

(iv) The Volcanic Tract east of Black Combe.

(*a*) The Millom-Park Channels.—On Millom Park there is a series of channels of a somewhat peculiar character, the best examples forming a group of shallow trenches which unite with one another, or bifurcate, in a rather inconsequential manner (fig. 14, below). They either cut across the watershed (over 500 feet), or cut obliquely into the hillside, until they meet another channel

Fig. 14.—*Plan of the dry drainage-channels on Millom Park, showing the sites of the glacial lakes. (Scale=1 : 15,840.)*



[The dry channels are dotted over, and the Gillscar Channel is shown black.]

which started at a higher level. Their average direction is north-north-easterly, and most of them existed for only a short time. Some, however, have the characteristic trough-like aspect of drainage-channels, and their floors descend in steps. Channels also occur, but to a less marked extent, in the volcanic tract north of Knott Hill. Although their directions sometimes correspond with rock-structures, this is not usually the case, and they do not occur elsewhere in similar rocks.

When the hill-tops in this neighbourhood were first uncovered, the basin south-west of Millom Park was full of ice which formed a connecting-link between that of the Whicham Valley and that of the Duddon Estuary. Water from this ice, held up between the two living streams, seems to have been responsible for the Millom-Park channels. In its escape northwards some of it fell into a temporary lake, held against the hillside between the ice-streams where they parted and flowed eastwards and westwards along the flanks of Millom Park. On the 400-foot contour there is a shelf-like feature, with sand and gravel, suggestive of a beach or delta-front.

Further withdrawal of the ice drained the lake, and the waters, following the marginal slope of the ice, cut channels at a lower level. Another lake was formed a little below the 300-foot contour, where there is a north-eastward facing delta of sand, gravel,[1] and boulders, extending for quite 300 yards, with a front 30 feet in height.

As we look up the hillside (down which they descend 100 feet in every quarter of a mile) the empty troughs appear to be suggestive of miniature valleys, lately occupied by miniature glaciers.

(*b*) The Gill-Scar Channel.—After this episode water began to accumulate in the lower part of the Whicham Valley, which was now being rapidly opened up by the retreat of the Whicham-Valley glacier. The more powerful stream of ice in the Duddon Estuary, however, still held the low ground north-east of Millom Park. The water rose to a height of about 200 feet, forming the Whicham Lake, which was impounded at the mouth of the valley by a lobe of the Irish-Sea ice.

Overflow took place in a southerly direction on the eastern side of Millom Park, near the margin of the Duddon ice, and the water fell into what was probably another lake in the mouth of the estuary north of Millom. The channel, cut by the overflowing waters under Gill Scar, is now a fine example of a dry rock-valley half a mile long. Commencing as a slight hollow, a little below the 200-foot contour, it rapidly develops into a V-shaped gash the floor of which crosses the 100-foot contour about a quarter of a mile from its head, the valley at that point exceeding 70 feet in depth. Lower down it is nearer 90. About half-way down there is a step in the floor where a valley enters upon the eastern side.

The Whicham Lake will be dealt with more fully in a subsequent paragraph (p. 441).

(*c*) Windy-Slack and Knott-Gill Channels.—These are good examples of steeply-descending dry rock-valleys, the gradients of which bear a direct relation to the gradients of the glaciers wherewith they were connected.

Windy Slack is typically V-shaped, and begins rather abruptly. It is over 50 feet deep, 500 yards or more long, and its floor descends 100 feet in 400 yards. It was cut in the volcanic

[1] Some pieces of Triassic sandstone were found here.

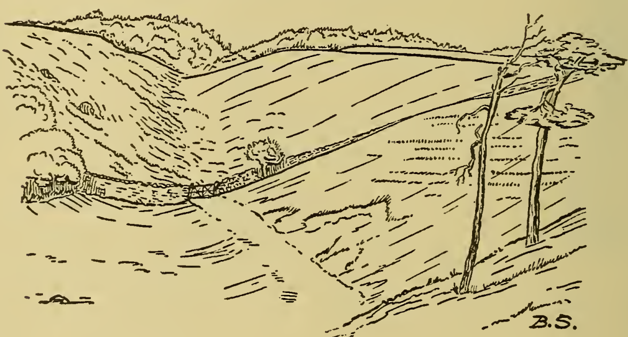
rocks when the western margin of the ice, west of the Duddon Valley, rested against the rising slope of Lathrigg at nearly 800 feet. A similar but smaller valley occurs in parallel sequence with Windy Slack about 200 yards farther east.

The head of the Knott-Gill Channel is about a mile to the south, and lies just below the 600-foot contour-line, that is to say, a little lower than the lower end of Windy Slack. It may, therefore, have been in operation at the same time as Windy Slack, the water crossing the gap between them by traversing the glacier that occupied the Black Beck valley.

The marginal channel takes a south-westerly trend across the south-eastern shoulder of Knott Hill. It is a V-shaped valley, 600 yards long, with a rather uneven floor descending about 150 feet, that is, at about the same rate as Windy Slack. It is excavated in volcanic rocks, but ends in boulder-clay on the lower ground. Near both its head and foot there is a little gravel (fig. 15, below).

At that time the Whicham Lake was probably in existence.

Fig. 15.—*The Knott-Gill marginal channel, looking north-north-eastwards.*



[This view shows the steep gradient common to the marginal channels which are associated with the steeply-descending inland glaciers.]

The ground on the west of the Duddon Valley north of Windy Slack was not examined in detail, but a dry valley was visible between the 500- and 600-foot contours on the eastern slope of Penn Hill, north of Logan Beck; and I have little doubt that others would be found in similar situations as far north as Seathwaite.

(3) Sand and Gravel of the Plain.

The coast-sections of sand and gravel which form so large a part of the plain have been already described (p. 416), and we have seen that these beds are to some extent stratified. Inland sections confirm this conclusion. The drift between Bootle and

Hycemoor is sandy, and the railway-cuttings south of Bootle, as also near Millom, show the presence of a great amount of sand and gravel with smaller interstratified beds of clay. Some 9 feet of stratified gravel has been exposed at Bootle Union Workhouse; and a section about 350 yards west of Far End also showed layers of red sand beneath gravel. Other sections occur near Kirksanton.

These deposits rest upon the Lower Boulder Clay, which rises from beneath them and climbs the rising flanks of Black Combe, or occupies the lower ground (as, for example, seaward of Silecroft and Millom) where the sands are absent (see fig. 2, p. 415).

Since, therefore, an almost continuous sequence of events has been traced from the time of maximum glaciation to the formation of the marginal channels, when the ice-front stood close to the hills, it is evident that the sands and gravels of the plain must have been formed at a later date.

The general level of the plain is rarely higher than 100 feet, although, at The Hawes, near Annaside Bank, it rises to 159 feet. It has been considerably dissected by post-Glacial denudation, which has had the effect of accentuating the original diversities of its surface.[1] Here and there small sheets of water, such as Barfield Tarn, a mile south of Bootle, lie in the hollow depressions (probably old kettle-holes).

Between Eskmeals and the Annas, south-west of Bootle and east of the railway, there is a long low-lying valley suggestive of an old marginal channel, now drained by streams flowing in both directions from a low watershed near Bootle Workhouse. In this neighbourhood are several other hollows and ridges, running north and south, which appear to be original features, slightly accentuated by denudation.

Taking everything into consideration, I am of opinion that the sands and gravels of the plain were accumulated during the period which followed upon the cutting of the lowest undoubted marginal channels, and that the water from the melting ice, fortified by that from Eskdale, etc., was more frequently spread out over a large area than concentrated in definite channels, because of the relatively low surface-gradient.

In the main, the material was deposited beyond the ice-limit, frequently in stratified layers beneath temporary sheets of water; but other parts were formed in a more irregular and tumultuous manner by torrential action. The deep hollows or kettle-holes are probably due to blocks of gravel-covered ice which, becoming detached from the ice-sheet, melted out and allowed their covering of drift to sink into the hollows thus formed.

A comparison may be made with the gravels of the northern side of Nunatak Fiord, Alaska, which form a series of benches altogether about a mile in width, the Fiord itself being only from

[1] Which would have been first toned down by the deposit of Upper Boulder-Clay.

1 to 2 miles wide. They were thus described by the late Prof. R. S. Tarr (U.S. Geol. Surv. Prof. Paper No. 64, 1909, pp. 128 & 129):—

'The wave-cut cliff ..... is from 75 to 100 feet in height and nearly vertical. The lower half consists of a rudely assorted till-like deposit, including horizontal bands of well-assorted materials; the upper half is well-stratified gravels. . . . There are layers of sand and gravel, with individual boulders of large size here and there, and with occasional beds of boulders. While most of the layers are gravel, there are also numerous beds of sand and, still more rarely, layers of clay. . . . The pebbles in the gravel layers are well rounded and varied in character, and include a large percentage of foreign fragments. No disturbance of the strata such as would have resulted from either ice-thrust or slumping was seen. These gravels attain great thickness, being revealed in some of the stream-cuts to a depth of more than 150 feet.'

'All evidence that is obtainable points to the conclusion that the gravels of Nunatak Fiord are remnants of marginal accumulations. . . . That they are waterlaid is evident from their stratification; and that, to some extent, at least, they were deposited in standing water is proved by the large boulders scattered through the gravels, which are too large to have been brought by a glacial torrent, but might have been transported in icebergs. So they were probably accumulated, in part at least, in local marginal lakes. . . . It is inferred, therefore, that the gravel supply came largely from glacial streams issuing from the main ice-tongue, and that the dip of the layers towards the valley axis is due to the removal of a substratum of ice on which a thick blanket of gravel was deposited.

The drifts accumulated at this period would necessarily be of a varied character: for, on the comparatively flat ground upon which the ice was then resting, any slight disturbances of equilibrium in its mass would be translated into marginal oscillations, which would give rise to varying conditions of deposit of sediment.

The sands and gravels are not found everywhere: in some cases, no doubt, because the ground was still occupied by ice which afterwards withdrew quickly; in other cases, perhaps, because they were removed during a re-advance.

In this connexion it is interesting to note that the largest areas of Lower Boulder Clay, not covered by sand and gravel, occur near the mouth of Eskdale and along the coast southwards to Annaside, and on the plain south-west of Silecroft and south of Millom. We might conclude, therefore, that the ice-margin rested (at the period which we are considering, after the tongues of land-ice had parted from it) on the Lower Boulder Clay, where the gravels are generally absent, with convex lobes thrust out towards the mouth of Eskdale, the Whicham Valley, and the Duddon Estuary, and concave embayments, in which sands and gravels were accumulated, swinging westwards between these lobes.

Thus the conclusion, previously expressed (pp. 412 & 420), that the Irish-Sea ice invaded the mouths of the valleys, and in its retreat seemed to withdraw from them reluctantly, is borne out. This wave-like contour of the ice-margin will probably be found to have obtained at other points, both north of Eskdale and south of the Duddon Estuary.

Accumulations of sand and gravel were formed, not only within embayments in the ice-front, but also in the converse embayments of the land-surface invaded by the lobed ice-margin.

(4) The Whicham-Valley and Duddon-Estuary Lakes.

When the Whicham-Valley ice broke connexion with the retreating lobe of the Irish-Sea ice, the valley, as explained above (p. 437), became the site of a lake with an ice-dam at its lower end.

The valley and lake formed a convenient place into which the surplus material from, and moving along, the ice-front could be shot; and we consequently find that for more than a mile above Silecroft the valley was filled from side to side with fluvioglacial deposits, ranging from clay and silt to sand and gravel, and boulder-beds (fig. 16, p. 442).

The deposits, still covering half a square mile between Silecroft and Whicham Hall, form a tract of typical hummocky ground, the higher parts of which fall from nearly 200 feet on the western side of the valley to 100 feet along its central line. On the eastern side they have been removed by the Whicham Beck, but some relics were found above the 100-foot contour on the eastern side of the intrusion at Nicle Wood.

Sections show that there is a great deal of red sand, which at times contains rolled lumps of red clay, or passes laterally into beds of clay. In the centre of the area a thin bed of fine loose sand overlay false-bedded sand dipping at 45° southwards. A neighbouring section in clear red sand showed a similar dip. A gravel-pit, a quarter of a mile south-south-east of Whicham Hall, is opened in a very roughly-stratified sandy and gravelly deposit of a morainic character, dipping on the whole in a south-south-westerly direction. It contains boulders which lie at all angles, as well as large lumps of red boulder-clay stuck full of stones. Boulders of granite and volcanic rock occur up to 18 inches in size, and also fairly large pieces of red sandstone, slate, and shale. Stratified sand and gravel, resting on Carboniferous Limestone, at the southern end of the valley has false-bedded layers dipping south-eastwards.

The floor of the Whicham Valley is covered by boulder-clay (p. 410), which also rises a little way up both sides. Thus the sand and gravels are flanked on each side by boulder-clay, and probably also rest upon it. In the part of the valley which was submerged the boulder-clay has been modified at the higher levels by denudation and the formation of terraces, and at the lower levels by deposit.

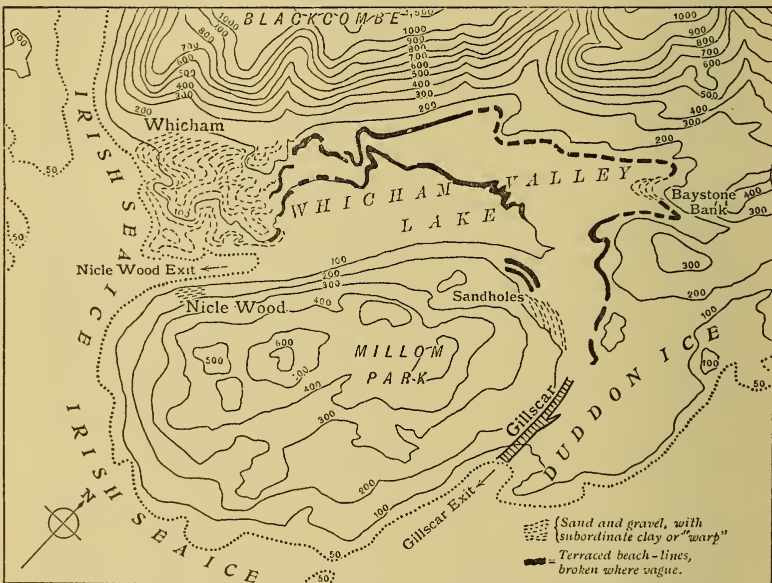
The terraces, or old beach-lines, which usually consist of flattish ledges, with sloping fronts, covered by slaty shingle, occur at various levels below the 200-foot contour, as shown on the accompanying map (fig. 16, p. 442). Near Whicham Hall there are three, the lowest being on the 100-foot contour and the highest at about 180 feet. The last-named can be traced, at intervals, round the northern end of the lake and some distance down the eastern side. The 100-foot terrace, when followed northwards, merges into the alluvium.

The deposits between the 180-foot and the 100-foot beach-lines consist of variegated (pale-grey, yellow, brown, and red) stony clay and loam full of slaty débris, many of the fragments being striated, This deposit presents a characteristically patchy appearance in ploughed fields.

In the beckside, 600 yards south of Whicham Mill, a stony clay rests unevenly upon a deposit containing strips of red and chocolate-coloured laminated clay and warp. In other places 2 feet or more of red sandy clay is seen.

At levels below 100 feet, shingle, consisting of unweathered slate, is mixed in a heterogeneous way with weathered slate-débris and patches of red, purple, or greyish clay. The clay breaks up into small cubes, somewhat like the fine loam of a river-deposit.

Fig. 16.—*Contour-map of the lower part of the Whicham Valley, illustrating the Glacial lake, on the scale of an inch to the mile (1 : 63,360).*



At the north-eastern extremity of the lake, close to Seathwaite Bridge, between 150 and 180 feet O.D., there is a deposit, probably of a deltaic nature, formed by waters from glacier-tongues which lingered in the hollows on both sides of Baystone Bank. It is composed of boulders with interstratified beds, a foot or more in thickness, consisting of rapidly alternating layers of yellowish sand, silt, and red warp. The dip observed at one point was in a south-south-easterly direction. This deposit may, however, have been formed, at a slightly earlier date, in a temporary lake enclosed between the two above-mentioned ice-tongues when they were confluent.

Another fluvioglacial deposit at Sandholes Wood, about 500 yards from the Gill-Scar outflow (p. 437), is not quite so easily explained, The greater part lies between 140 and 160 feet, but rises nearly up to the 200-foot level at its western end. A gravel-pit at the cross-roads at Sandholes Wood showed beds of stratified sand, gravel, and boulder-gravel. Some of the sandy bands were false-bedded, the dip of the thickest layer observed being to the east; others dip northwards.

The boulders are all Borrowdale rocks, with the exception of a few of pinkish quartz-porphyry or granophyre. In the finer gravels there are a few granite-pebbles, and slate is common. Much of the sand is of Triassic origin, and contains rolled lumps of reddish clay (like that of Silecroft brickyard), pebbles of Triassic sandstone (maximum diameter = 3 inches), and pieces of marl.

I consider this deposit to be also of a torrential and deltaic nature, chiefly due to the re-arrangement of material formed on the slopes of Millom Park at a slightly higher level and at a slightly earlier date, before the opening of the Gill-Scar Channel. Some of the Triassic material, and perhaps also sand and small boulders, may have been floated to the spot by icebergs, and incorporated in the deposit when it was undergoing re-arrangement.

The floor of the Gill-Scar intake being somewhere near 170 feet, it is clear that the emptying of the lake below this level required another exit, which appears to have been furnished by the withdrawal of the ice from the mouth of the valley and the opening-up of a pathway for the escaping water (perhaps through the ice) at its southern end. The reversal of flow may account, in part at least, for the southerly and south-westerly dip observed in places in the uppermost layers of the sands and gravels (p. 441).

East of Nicle Wood there is a saddle, which might be taken for an abandoned outflow-channel cut in the hillside. The notch, however, seems to be a natural gap due to differential weathering, the Skiddaw Slate of Nicle Wood being stiffened by a small intrusion. The floor of the saddle is covered by boulder-clay.

A temporary check gave rise to the 100-foot beach-line, after which the lake-barrier seems to have consisted entirely of drift,[1] and the life of the lake depended upon the time required for the overflowing water to cut its narrow valley (now occupied by the Whicham Beck) down to the level of the lake-bottom (fig. 17, p. 444).

A series of similar mounds of fluvioglacial material occupies the low ground north of the outskirts of Millom, and extends northwards for about a mile. It occurs at Pannet Hill at 100 feet O.D., and at a little lower level near Beck Farm, where 6 feet of coarsely-bedded Triassic sand is covered by 8 feet or more of gravel containing boulders and patches of reddish clay. Granites, red sandstones, and shingly slate-fragments occur here, as well as the usual assemblage of volcanic rocks.

The sand which rises from the alluvium as a low hill at Millom Castle appears to be part of an outwash fan in front of the coarser

[1] These deposits were noticed by Mr. J. D. Kendall, who, however, ascribed to them a very different origin.

deposits to the south, and was probably formed as a delta in a lake held up by ice crossing the estuary-mouth. A pit shows over 8 feet of finely-laminated and slightly false-bedded sands and silts, containing small pebbles of granite and sandstone measuring up to 3 inches in greatest diameter. The coarse boulder-, sand-, and gravel-beds of variegated tints, exposed in a quarry near the vicarage at the mouth of the Gill-Scar channel, three-quarters of a mile north of Millom Castle, are of a different origin, and the sandy layers consist of other than Triassic material; they may, however, have been deposited in the same sheet of water.

In one of the top layers I found a small boulder of rotten biotite-granite, which may have come down the Gill-Scar Channel from the Whicham-Valley Lake.

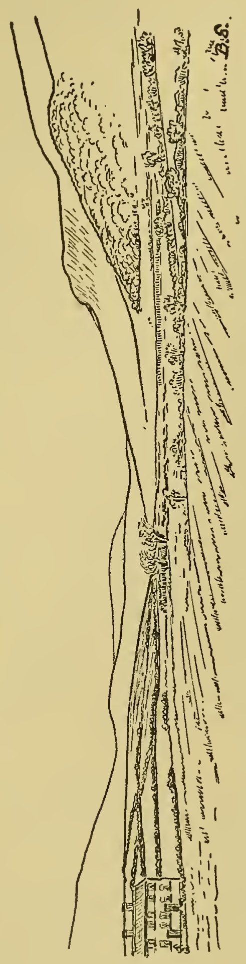


Fig. 17.—*The mouth of the Whicham Valley seen from the west.*

[The barrier of drift is seen behind the house on the left, the exit of Whicham Beck in the centre, and Nicle Wood on the right.]

The water accumulated in front of the ice crossing the Duddon Estuary must have escaped somewhere to the south along the coast-line of Furness, where signs of its passage may one day be found.

It would also be interesting to determine whether (as I suspect) the accumulations of sand and gravel in the mouth of Eskdale, the St. Bees Valley, and other valleys in the intervening tract of country, were deposited while the Irish-Sea ice was holding up extra-morainic lakes in these valleys.

Mellard Reade described Marine Drift [*sic*] in Eskdale and Miterdale[1] as occurring up to a height of 400 feet above sea-level, pebbles of St. Bees Sandstone being found as high up as 320 feet. In Miterdale they are found 2 to 3 miles up the valley from their nearest outcrop,[2] and as much as 4 miles up Eskdale. (In the Whicham Valley they are more than 2 miles from its mouth.) If there were lakes in these valleys, some of their overflow waters may have taken a share in cutting the marginal channels north of Bootle.

[1] 'Eskdale Drift, & its Bearing on Glacial Geology' Geol. Mag. dec. 3, vol. x (1893) p. 19.

[2] *Ibid.* p. 14.

X. The Upper Boulder Clay.

The origin of the Upper Boulder Clay, which frequently forms the highest division of the drifts, presents a problem to which this district, so far as I have studied it, furnishes few definite clues.

It is usually red, of a more loamy texture than the Lower Clay, and often contains very few stones; yet at other times it is full of stones, and the Lower Clay, becoming loamy, resembles it in tint and texture, making it difficult, were the gravels absent, to separate the two.

If—as is highly probable—the Upper Clay is the result of a temporary re-advance of the ice, which had withdrawn itself for some distance from the present coast-line, it is just the type of clay that we might expect to find deposited on the sands and gravels: for it would be naturally composed chiefly of the upper part of the previously-formed Lower Clay, mixed with a certain amount of sand and gravel, incorporated when it mounted and overrode those deposits. A re-advance would imply a lowering of temperature and a possible hardening of the gravels by freezing. The ice would then easily override the latter, and deposit the material which it dragged up with it on the surface of the gravels as loamy Upper Boulder Clay.

If we require a precedent for the overriding of gravels by ice and the deposition of till and morainic matter upon them without destroying them, it is furnished by examples in Nunatak Fiord, Hidden Glacier Valley, and Russell Fiord in Alaska.[1] The surfaces of these gravels (up to 150 feet in thickness) are carved into a series of swinging, undulating, or dome-shaped curves, which terminate the layers of gravel, and are characteristic of ice-erosion. A layer of till, or hummocks and ridges of morainic material deposited during the period of overriding, covers much of the surface-area.

If the Upper Boulder Clay of the Black Combe district was formed in this manner, the advance of ice did not greatly disturb the sands and gravels, and seems to have spent itself before the base of the hills was reached.

XI. Corrie-Glaciers.

After the maximum glaciation, when the ice had abandoned the hill-tops for the low ground, small glaciers lingered in some of the upland valleys, occupying the sites of those which must have been initiated there in the early stages of glaciation. They may have again come into existence during the formation of the Upper Boulder Clay. Black Combe is a typical mountain-corrie, the floor of which hangs above that of Whitecombe. It was occupied by a corrie-glacier,

[1] R. S. Tarr, 'The Yakutat Bay Region, Alaska' U.S. Geol. Surv. Prof. Paper No. 64 (1909) pp. 126, 128, & 132.

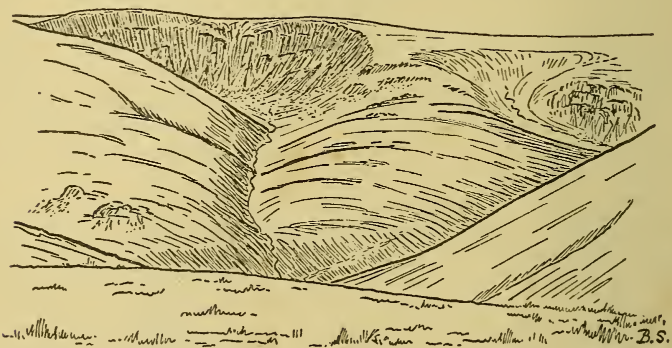
which, when it had dwindled to a mere snow-slope, left a small moraine 250 yards from the screes at the head of the combe.

This moraine formerly held up a small lake, which finally drained away through a breach. A similar small lake-site, with a breached moraine below it, may be seen below the crags at the head of Stoupdale Beck.

XII. Hanging Valleys.

Glaciation of this area has given rise to discordance in grade between some of the main and tributary valleys. On the western slope of Black Combe all the small valleys are hanging. The upper parts of the streams are gently graded; but, when they reach the

Fig. 18.—*The Black Combe hanging valley and corrie, looking westwards.*



oversteepened slope of the mountain, they occupy narrow post-Glacial gorges, down which they cascade to the level of the drift-plain.

Black Combe, drained by Blackcombe Beck, hangs 200 feet above the valley of Whitecombe Beck (fig. 18, above).

The floor of the Whicham Valley and the mouths of most of its tributaries being drift-filled, it is difficult to say whether the rock-floors are at accordant grade with the main floor: this much, however, is certain—with the removal of drift from the lower parts of the tributary-valleys there is great activity near the headwaters. In Stoupdale Beck, about half a mile west of Baystone Reservoir, for example, there are some small, but very neat, incised meanders cut in grey slate.

XIII. General Conclusions.

(i) With the exception of the coastal drift-plain, the main features of the district had been developed before the advent of the Ice Age.

(ii) At the period of maximum glaciation, the Black Combe district was completely swamped beneath an ice-sheet formed by the confluence of the Lake-District ice-cap and the Irish-Sea ice-sheet.

(iii) The Lake-District ice invaded the area from three main directions: (*a*) the Broughton Valley; (*b*) the Duddon Valley and high ground on the west; and (*c*) Eskdale.

(iv) The overmastering pressure of the Irish-Sea ice diverted the seaward flow of the Lake-District ice to the south or south-east, and in some cases forced it inland.

(v) The Lower Boulder Clay of the coastal-plain is the ground-moraine, chiefly of the Irish-Sea ice-sheet.

(vi) In the Lower Boulder Clay of the westward mountain-slopes there is evidence both of the interweaving of drifts of distant and strictly local origin, and of a certain amount of movement of ice inland.

(vii) Stages of withdrawal of the ice from the hills were marked by the occurrence of moraines, moraine-terraces, trails of boulders, and perched blocks.

(viii) Valleys, which are now for the most part either dry or occupied by insignificant streamlets, and do not accord with the pre-Glacial drainage-system of the district, represent channels subsequently cut by the marginal drainage of the shrinking glaciers or by the overflow waters from ice-dammed lakes.

(ix) On the granitic and volcanic tracts south of the mouth of Eskdale, the excavation of marginal channels followed upon a slight re-advance of the ice, which overrode gravels previously accumulated as a marginal outwash-fan.

(x) The sand and gravel of the plain was accumulated during the period which followed upon the cutting of the marginal channels upon its eastern border. The material was, in the main, deposited in embayments of the ice-margin, frequently beneath temporary sheets of water, but some parts were entangled with the melting edge of the Irish-Sea ice.

(xi) Sand and gravel were also accumulated at the extremities of lobes of ice thrust into the mouths of valleys, such as the Whicham Valley and Duddon Estuary.

(xii) The ice-lobes held up lakes in the lower ends of the valleys. The Whicham-Valley Lake at first drained into the Duddon Estuary by the Gill-Scar overflow, but afterwards through the obstructing barrier.

(xiii) The Upper Boulder Clay seems to be the result of a restricted re-advance of the Irish-Sea ice, which overrode the sands and gravels of the plain.

(xiv) The Lake-District ice, after the maximum glaciation, withdrew concurrently with the Irish-Sea ice, and corrie-glaciers lingered in sheltered combes at a late stage.

(xv) Certain hanging valleys are due to the oversteepening of hill-slopes, or overdeepening of main valleys by glacial action.

EXPLANATION OF PLATES XLI–XLIII.

Plate XLI.

Fig. 1. The Kinmont-Beck Valley, east of Low Kinmont, looking eastwards. The pre-Glacial granite valley was filled with Boulder Clay, which is now being removed and re-arranged as terraces by the stream. (See p. 422.)

2. The Kinmont dry valley south of Welcome Nook, looking southwards. This view shows a broad marshy floor and a steep wall on the outer side of the bend. (See p. 425.)

Plate XLII.

Fig. 1. The Corney-Hall dry valley, looking eastwards. The view is from the bottom, looking up towards Corney Hall at the eastern end. In the background the Corney valley crosses at right angles. (See p. 426.)

2. The Near-Bank 'in-and-out' valley, looking northwards. Near Bank is the farm on the right of the observer: the granite-crag on the left is isolated. A small stream enters upon the right, and throws a delta across the valley. (See p. 426.)

Plate XLIII.

Contour-map of the Black Combe district on the scale of 1 inch to the mile, or 1 : 63,360.

Discussion.

Mr. G. Barrow remarked that the Author was dealing with an incident in a great campaign. England had been invaded on both sides by ice-sheets—one from the east, the other from the west, which had left traces of their course in the form of dry valleys cut by streams flowing at the margin of the ice. The Author had described the phenomena produced along successive margins of the western sheet, in the south-western portion of the Lake District; the speaker had noted a great gorge (Rudyard Gorge) cut by a marginal stream at the southern end of the Pennine Range. What was now wanted was a description of the valleys and ledges left by the ice in the great intervening area, on the western side of the Pennines.

Mr. G. W. Lamplugh said that, having some time ago traversed part of the area described, he could corroborate the Author's account of the general conditions of its glaciation. The movements of existing glaciers had proved to be so irregular, that it was unnecessary to expect much regularity of arrangement in the marginal channels.

The Author, in replying, thanked the President and Fellows for their kindly reception of his paper.

Fig. 1.—*The Kinmont Beck Valley, east of Low Kinmont, looking eastwards.*

B. S. photo.

Fig. 2.—*The Kinmont dry valley, south of Welcome Nook, looking southwards.*

B. S. photo.

Fig. 1.—*The Corney Hall dry valley, looking eastwards.*

B. S. photo.

Fig. 2.—*The Near Bank 'in-and-out' valley, looking northwards.*

B. S. photo.


GENERAL MAP
OF THE
BLACKCOMBE DISTRICT
Illustrating the ice-movement during the maximum glaciation, and the occurrence of marginal channels formed during the retreat of the ice.
Indicates direction of ice-movement.
" glacial striae.
" roches moutonnées and smoothed rock-surfaces.
" drainage-channels.
" Do Do with one wall only.
Contour-lines are in red.
Scale: 1 inch = 1 Mile, or 1:63,360.
N
IRISH SEA
DUDDON SANDS
R. ESK
Eskmeals
FURNESS RAILWAY
Hycemoor
Bootle
Corney Fell
Bootle Fell
Black Combe
Whicham Valley
Millom
Haverigg
Haverigg Point
Hodbarrow Point
Ulpha
Duddon Bridge
Hesk Fell
Prior Park
Thwaites Fell
Swinside Fell
White Combe
Millom Park
Silecroft
Kirksanton

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CONTENTS.

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[No. 272 of the Quarterly Journal will be published next December.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

⁎ The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

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Vol. LXVIII. DECEMBER 1912. No. 272.
Part 4.

THE

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OF THE

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THE ASSISTANT-SECRETARY.

[With Eighteen Plates, illustrating Papers by Prof. E. J. Garwood and Mr. R. D. Vernon.]

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Session 1912–1913.

1913.

Wednesday,	January	22*
,,	February (*Anniversary*, Friday, Feb. 21st)	5*—26*
,,	March	5 —19*
,,	April	9 —23*
,,	May	7 —28*
,,	June	11 —25*

[*Business will commence at Eight o'Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

23. *The* Lower Carboniferous Succession *in the* North-West of England. By Edmund Johnston Garwood, M.A., V.P.G.S., Professor of Geology in University College, London. (Read May 10th, 1911.)

[Plates XLIV–LVI.]

Contents.

I. Introduction.

The Lower Carboniferous rocks of Westmorland and Cumberland crop out in a nearly continuous ring encircling the Lower Palæozoic rocks of the Lake District, broken only on the west by the overlap of the Triassic deposits. The south-eastern edge is situated in Yorkshire, and, though apparently continuous with the rest, is separated structurally by the Dent Fault; while the eastern margin of the ring is cut off from the Lower Carboniferous rocks of the Pennine Chain by the Pennine Fault, and by the mantle of Permian and Triassic rocks occupying the Vale of Eden.

The area dealt with in the present communication comprises some 400 square miles of country occupied by Lower Carboniferous rocks. It includes the whole of Westmorland and Yorkshire north and west of the Dent Fault, together with that portion of Lancashire which lies north of the Lune Valley. The small tract of Lower Carboniferous rocks, forming the northern extremity of Yorkshire, which lies between the Westmorland portion of the Pennine Chain and the River Tees is also included. The following are the points to which special attention has been given during the examination of the district:—

(1) The possibility of establishing a palæontological sequence from the base to the summit of the succession which would be applicable to the whole of the North-West of England.

(2) The general lithological characters of the different faunal horizons, and the variations which these undergo when they are traced laterally.

(3) The distribution of these faunal horizons in the area examined, and the relative dates of submergence of the pre-Carboniferous land-surface in the several districts included in this area.

(4) The possibility of applying the zonal succession determined for this area to the beds of corresponding age in Northumberland and Yorkshire, and of correlating this succession with that now established in the South-Western Province and elsewhere.
(5) The description of new or little-known fossil forms which have been met with during the examination of the area.

The investigation of the Lower Carboniferous rocks described in the following pages was begun as long ago as the year 1888, at the suggestion of Dr. J. E. Marr and the late Prof. Alleyne Nicholson. Throughout this investigation, and especially during the early stages of the work, I have received the greatest assistance from my friend and former teacher at Cambridge, Dr. Marr, and I am glad of this opportunity to acknowledge how much I owe to his help and encouragement.

By the year 1895, however, it was realized that the work of investigating the Carboniferous limestones of England in detail was too great a task for any one man, and a joint note was contributed to the British Association Meeting at Ipswich in 1895 [1] and subsequently to the 'Geological Magazine,' calling attention to the necessity of a detailed palæontological investigation of the Lower Carboniferous rocks. To further this object, a committee of the British Association was appointed in 1895.

For some years after this my attention was called to other matters, and my spare time was chiefly spent abroad.

In 1905 Dr. Vaughan read his now classical paper before this Society, and for the first time placed the zonal sequence of the Lower Carboniferous rocks of the Bristol District on a firm foundation. By his enthusiasm, eloquence, and the ungrudging way in which he has devoted his small amount of leisure to those who have sought his assistance, he has earned the gratitude of all who have the interests of British Stratigraphy at heart.

Dr. Vaughan's paper had the immediate effect of rekindling my interest in these rocks, and stimulated me to return once more to the scenes of my earlier work.

A preliminary account of the palæontological succession in Westmorland was given at the York Meeting of the British Association in 1906, and subsequently in the 'Geological Magazine.' [2] Since then further work has only served to confirm the general conclusions there stated.

As a result of these investigations, it has been found possible to divide the Lower Carboniferous rocks of the North-Western Province into a series of zones, sub-zones, and bands, each of which is characterized, either by one species which is not found outside that particular subdivision, or by a collection of forms which do not occur in association at other horizons.

For convenience of description, the area dealt with is divided into tho following districts:—

[1] Rep. Brit. Assoc. 1895, p. 696.
[2] Geol. Mag. dec. 5, vol. iv (1907) pp. 70-74.

(*a*) Shap and Ravenstonedale. (Type Districts.)
(*b*) Arnside and Carnforth.
(*c*) Kendal and Kirkby Lonsdale.
(*d*) Grange and Furness.
(*e*) The Westmorland Pennines and Middleton-in-Teesdale.

These districts, although they once formed portions of a continuous area of deposition, are now separated one from the other by tracts of Lower Palæozoic rocks, as the combined result of faulting and denudation.

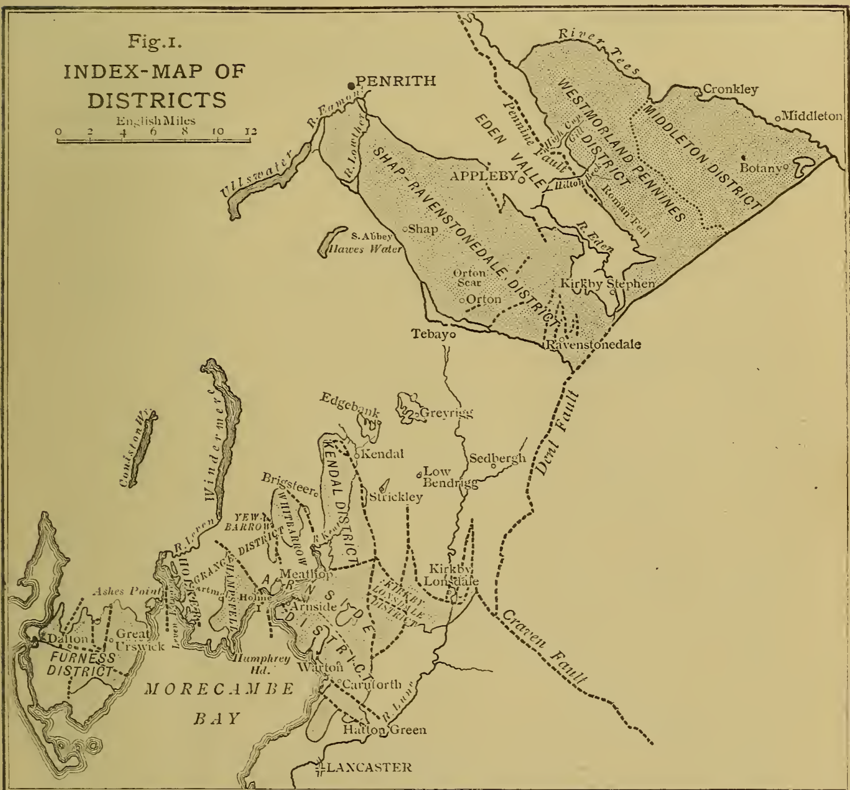
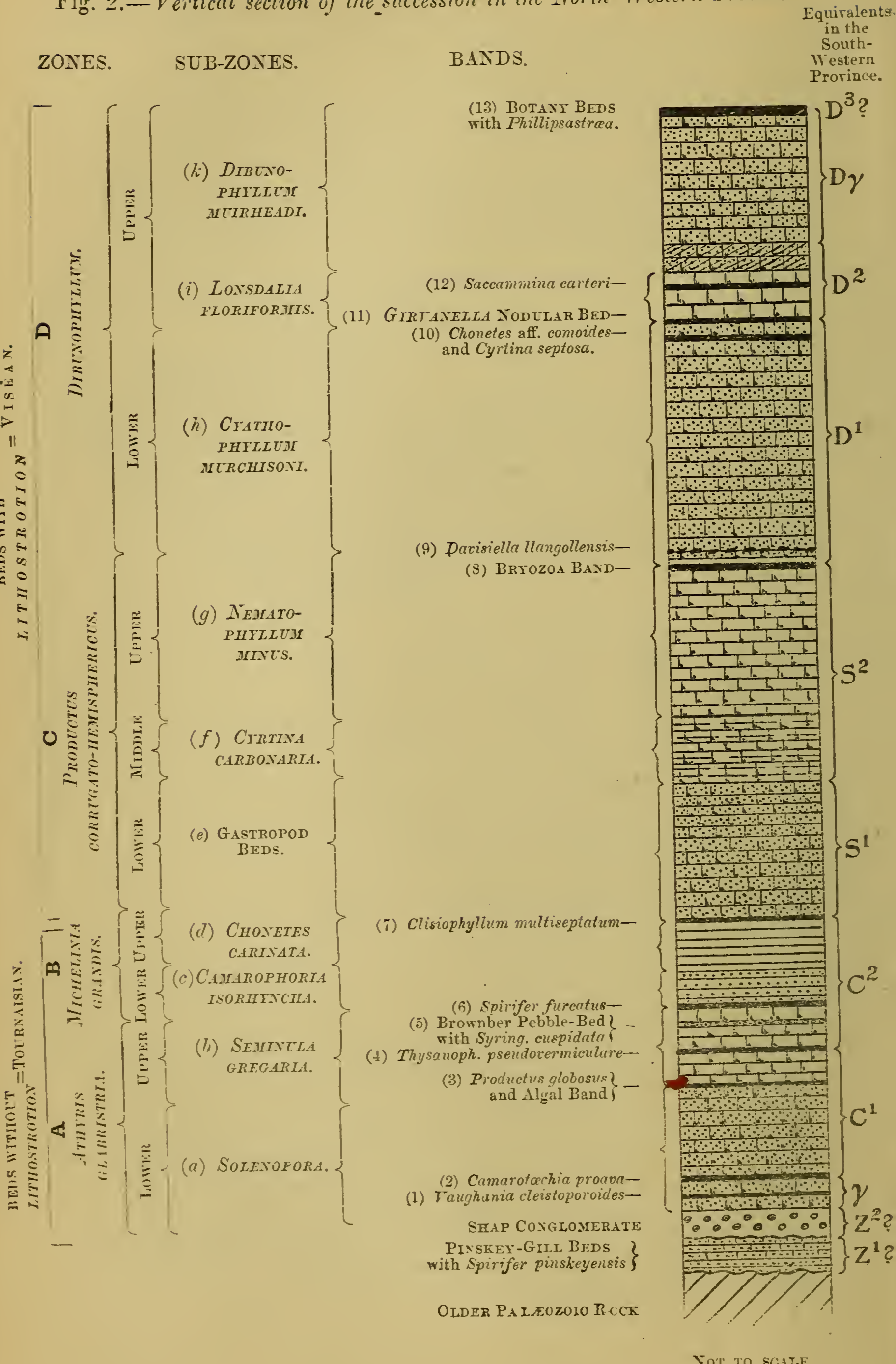


Fig. 1. INDEX-MAP OF DISTRICTS

The Shap and Ravenstonedale Districts are taken as the type districts for the area described, since they contain the complete sequence from the lowest horizon met with in the North-Western Province to the Millstone Grit. It was also in these districts that the zonal divisions were first established in detail.

In the accompanying table (fig. 2, p. 452) are set out the fossil forms which have been found most useful as indices for the different zones, sub-zones, and bands, on account of their wide distribution over the area dealt with.

Fig. 2.—*Vertical section of the succession in the North-Western Province.*



Although the general sequence tabulated in fig. 2 (p. 452) is applicable throughout the whole area under description, the detailed characters of certain portions of the succession vary in different parts of the area, so that parallel sections of districts situated far apart present at first sight considerable differences. When, however, the same levels are traced through the intermediate districts, the continuity of the faunal horizons can, as a rule, be readily established. For this reason two species have occasionally been cited as the indices for a particular band, since, although the two may occur together over a portion of the area, sometimes one and sometimes the other species may characterize the deposit when it is traced laterally into outlying districts.

For example, the band which lies near the summit of the Lower *Dibunophyllum* Sub-zone is characterized in the Grange, Arnside, and Furness districts by an abundance of *Cyrtina septosa*, together with somewhat rarer examples of *Chonetes* aff. *comoides*; while in the Shap District, at the same horizon, *Chonetes* aff. *comoides* occurs abundantly, but *Cyrtina septosa* is locally rare.

Any change in the fauna of any particular horizon when traced laterally is found to be accompanied, as a rule, by a corresponding lithological change; indeed, the fauna appears often to depend directly on the lithological character of the deposit, and one or more species may persist in a particular district into a higher horizon than is usual elsewhere, if the lithological character of the deposit remains unchanged. Thus *Cyrtina carbonaria*, which in the Kendal District is practically limited to its own sub-zone, is found in the Ravenstonedale District to persist into the base of the Lower *Dibunophyllum* Sub-zone. This local survival of *C. carbonaria* appears to be the direct result of the shallow-water phase, which in the Ravenstonedale District continued into the Lower *Dibunophyllum* Sub-zone, while elsewhere this sub-zone is coincident with a period of increased submergence. A good example of prolonged existence may also be cited from the same district, where the entrance of the typical fauna of the Lower *Dibunophyllum* Sub-zone is delayed, owing to the abnormal persistence of shallow-water conditions.

Another instance, of the influence exerted by the depth and character of the bottom on the distribution of a species, is found in the case of *Zaphrentis enniskilleni*. This species, which appears to have flourished only in shallow water, and preferably on a bottom composed of argillaceous material, enters at different horizons in the different districts. Thus, in the Arnside and Kendal Districts, it enters near the summit of the *Michelinia* Zone; in the Shap District it is found at the base of the Lower *Productus corrugato-hemisphericus* Zone, after the entrance of *Lithostrotion*; while, in the Ravenstonedale District, it occurs with several varieties near the summit of the Ashfell-Sandstone Series, immediately below the base of the *Cyrtina-carbonaria* Sub-zone.

A good instance of the association of a particular species with a definite type of deposit is afforded by *Syringothyris cuspidata*.

This species is practically confined to the *Seminula-gregaria* Sub-zone, and, though on the whole a rare shell in the North-Western Province, it sometimes occurs in fair abundance in the Eastern Districts, where it is invariably associated with arenaceous and oolitic deposits, and is especially characteristic of the Brownber Pebble-Bed. In the Western Districts, however, where this horizon is composed of calcareous rocks, it has scarcely ever been met with.

A further interesting feature which may be cited in this connexion, is the association of calcareous algæ with lagoon conditions. These organisms flourished only at three horizons in the North-Western Province, namely, in the *Solenopora* Sub-zone, at and near the base of the *Seminula-gregaria* Sub-zone, and again at the base of the Upper *Dibunophyllum* Sub-zone. In the first two cases the remains of calcareous algæ are closely associated with dolomitic deposits; while, in the last, clear but shallow-water conditions seem to have prevailed, in which masses of *Lithostrotion* and *Lonsdalia* grew somewhat after the manner of modern coral-reefs.

The most interesting lithological change met with in tracing the different horizons across the area from west to east occurs in the case of the *Michelinia* Zone and the beds immediately overlying it. This zone attains its fullest development in the Arnside and other western districts, where it contains one of the richest faunal assemblages found in the Lower Carboniferous rocks of the North-Western Province. In the Shap District and in the Westmorland Pennines this zone seemed, at first sight, to be entirely missing, and its apparent absence originally introduced a difficulty in correlating the individual beds of the Eastern with those of the Western Districts. The discovery, however, of *Michelinia grandis* in the *Camarophoria-isorhyncha* Bed at Shap proved conclusively, what had previously been strongly suspected, that the fossiliferous *Michelinia*-Beds of Arnside were represented in the Shap District by the almost barren deposits at the base of the Orton-Sandstone Series; while the corresponding horizon in the Westmorland Pennines has been found to lie in the oolitic grits and unfossiliferous sandstones underlying the Melmerby-Scar Limestone, along the foot of the Cross-Fell escarpment. This arenaceous deposit, the Orton and Ashfell-Sandstone Series, affords one of the most striking examples of the transgression of a definite lithological facies across a series of faunal lines. (See map, Pl. LIV.)

This sandstone episode, which in the Shap District occurs at the base of the *Michelinia* Zone, enters at a progressively later period as we travel southwards towards the Ravenstonedale District until, when we eventually reach the neighbourhood of the Dent Fault, the base of the Ashfell Sandstone is seen to lie some 100 feet above the base of the Lower *Productus corrugato-hemisphericus* Zone. At the same time, the faunas of both these zones gradually increase in importance as we pass southwards into the region where the sandstones are gradually replaced by calcareous rocks.[1]

[1] See map and description of the Shap and Ravenstonedale Districts.

The Bands.

These bands, at first sight, appear to indicate periods especially favourable for the development of certain organisms, but it is very doubtful whether this was really the case. It is equally probable that the bands are in many cases rich in certain species, not because the conditions were especially suitable for the growth of these organisms; but, on the contrary, paradoxical as it may seem, because the conditions were changing and becoming unfavourable: in consequence of which the organisms died more rapidly, and accumulated in greater relative abundance in a given thickness of deposit. The abundance of certain forms in a band would thus be due to a relatively sudden and drastic change of conditions, these forms being more affected than others: the change from a muddy to a sandy bottom, the variation in depth and temperature, the change from salt to brackish water, and the shifting of currents causing a change in the amount and character of the food-supply, would have different effects on different organisms according to their adaptability, their powers of locomotion, and their natural habitat. This view appears to be borne out by the fact that the bands are usually characterized by the abundance of certain species which occur also, though not so plentifully, in the underlying beds, but do not occur again above the bands which they characterize; and these are usually accompanied by other species which occur abundantly in the band, but are not again found above it. Further, the collection of species occurring in a band usually contains a large proportion of small immature individuals.

The division of the series into beds with and beds without *Lithostrotion*, given in fig. 2 (p. 452), is not intended so much as a stratigraphical subdivision, as a statement of fact. The names Viséan and Tournaisian are introduced out of deference to a wish expressed during the discussion which followed the reading of this paper; but, while I admit the priority of the subdivisions established for the Continental equivalents of these beds, these have, in my opinion, no real significance when applied to the rocks of the North-Western Province. There the Lower Carboniferous strata form a continuous series of marine deposits uninterrupted by any unconformity, the relative dates of submergence in the different districts depending essentially on the contour of the pre-Carboniferous land-surface. The sandstone episode which masks the palæontological succession in the Shap District is due, not to interrupted deposition, but to the introduction of detrital material from the east, consequent upon the submergence of the Pennine District at this period.

The palæontological break between the *Michelinia* Zone and the overlying *Productus corrugato-hemisphericus* Zone is no greater than that between the *Michelinia* Zone and the underlying *Athyris-glabristria* Zone, or between the Lower and the Upper *Dibunophyllum* Sub-zones.

During the progress of the work I have been indebted to many friends and geological colleagues for much kind help. I have already expressed my indebtedness to Dr. Marr and Dr. Vaughan, but am glad of this opportunity of acknowledging also the assistance received for some years past from students of University College, London. Among many others, I am especially indebted to Miss Edith Goodyear, B.Sc., and Mr. H. S. Bion, B.Sc., F.G.S., my assistants in the Geological Department at University College, who, together with Miss Munro, B.Sc., Mr. P. de G. Benson, B.Sc., F.G.S., and Mr. C. H. Cunnington, B.Sc., F.G.S., have for several years past accompanied me in the field. Without their ungrudging assistance it would have been impossible to have acquired the detailed information respecting the distribution of the zones set forth in the accompanying maps and description.

In the compilation of the fossil lists I am greatly indebted to Dr. A. Smith Woodward for the identification of the fish-remains; and to Miss Madeline Munro for the determination of the many forms of Bryozoa. The new forms met with during examination of this material are described in the appendices to this paper.

Finally, I should like to express my obligation to Dr. T. F. Sibly, for his kindness in reading the typescript of this paper, and for many valuable criticisms and suggestions.

II. The Zonal Divisions.

(A) The *Athyris-glabristria* Zone.

This zone includes the beds from the Shap Conglomerate up to the base of the *Michelinia* Zone, and, with the exception of the beds which underlie the conglomerate in Pinskey Gill, contains the oldest Carboniferous deposits in the North-Western Province.

The index-fossil ranges from the base of the zone to the lowest layer of the overlying *Michelinia* Zone. It is found at several horizons, and where present is generally abundant. No definite variants of zonal value can be distinguished at the different levels.[1]

Lithology.—The zone is characterized by impure limestones with occasional shaly partings. Many of the limestones are rich in magnesium carbonate, some containing up to 40 per cent. The magnesium carbonate appears always to be present combined as dolomite, and the little rhombohedra of this mineral are well seen in microscopic sections of the rock. The dolomitized beds frequently contain abundant geodes of calcite and dolomite. Many of the beds are porcellanous in texture, others are dun-coloured and somewhat earthy, and these are usually the richest in dolomite. Towards the summit of the zone, the deposits become

[1] Dr. Vaughan, who has kindly examined specimens from one of the lower horizons, reports that they include forms which are characteristic of Z 2 and C respectively in the Bristol District.

oolitic, while microscopic examination of numerous beds shows that foraminifera contribute largely to the calcareous portion of the formation throughout. A very interesting feature of the zone is the important part played by calcareous algæ as rock-builders, many layers at certain horizons being largely made up of the thalli of *Solenopora* and other more obscure forms.

The source of origin of the magnesium carbonate which is so constantly present in these beds is a question of some interest, and we may briefly review here the evidence bearing on this point, derived chiefly from the Shap District. This magnesium carbonate must either have been deposited contemporaneously with the rest of the rock, or have been introduced at some subsequent date. The latter is apparently the view taken by the officers of the Geological Survey, for they remark:

> 'In many places it [the limestone] is more or less dolomitic, apparently through the introduction of magnesium carbonate at some period subsequent to its deposition.'

If this view be adopted, the most likely source of the magnesium salts would be the waters of the Permian sea, but the Knipe-Scar Limestone, which overlies the Orton Sandstone, is practically devoid of magnesium carbonate; and it is difficult to see how the magnesium salts could have penetrated to the lower bed without affecting the overlying mass of limestone. If, on the other hand, the dolomitization was practically contemporaneous with the deposition of the beds, the magnesium salts must have been present in the Lower Carboniferous sea in which these limestones were deposited. That some shrinkage has taken place in the rocks since their deposition is shown by the abundance of drusy cavities present in the beds, and such shrinkage is well known to result from the conversion of calcareous rocks into dolomites. This shrinkage, however, would occur in any case, whether the dolomitization took place during Lower Carboniferous times or at any subsequent period. An interesting piece of evidence supporting the conclusion that dolomitization took place under the waters of the Lower Carboniferous sea, is furnished by the presence of drusy cavities in the Coniston Limestone, which is exposed immediately below the basement Carboniferous rocks in Blea Beck near Shap Wells. This limestone, which must have been exposed to the waters of the Lower Carboniferous sea, contains a considerable proportion of dolomite, apparently of secondary origin, and it is difficult to attribute this dolomitization to alteration during Permian times. This rock has been described by Mr. Harker & Dr. Marr.[1] It encloses pure white crystalline patches up to a quarter of an inch in diameter, which consist of clustered rhombohedra of unusually pure dolomite,[2] the carbonates of lime and magnesia being present in the rock in about equal proportions. Farther west, however, on the other side of the granite, where metamorphism

[1] Q. J. G. S. vol. xlix (1893) p. 367.

[2] See A. Harker, 'Petrology for Students' 4th ed. (1908) p. 271 & fig. 72.

of the Coniston Limestone has taken place, the proportion of magnesia to lime is only : : 3·65 : 11·50; this may be taken as the original relative proportion of these salts present in the limestone.

The bulk of the rock in Blea Beck, as shown by Mr. Harker, contains magnesium carbonate in addition to that found in the crystalline patches. The former may represent the magnesium originally present, corresponding to that found in the Coniston Limestone altered by the granite farther west; while the latter would then represent additional magnesia introduced after the intrusion of the granite, and therefore in Lower Carboniferous times. As shown by recent researches, when silicates are formed by metamorphism of magnesian limestones, the magnesia is always converted into silicates much more readily than the lime, and the abundance of lime-silicates in the metamorphosed portion of the Coniston Limestone seems to show that the rock contained but a small proportion of the magnesia before the intrusion of the granite.

It seems unlikely that the only outcrop of the Coniston Limestone known to contain a high percentage of crystalline dolomite should immediately underlie the Lower Carboniferous rocks (which also contain similar dolomitic geodes), unless the material of the geodes in both cases was derived from a common source. This fact, taken together with its absence from the overlying limestones, seems to point conclusively to the dolomitization having occurred in early Carboniferous times. It appears probable that this dolomitization is an expression of the shallow-water conditions which then prevailed. The deposition of the Shap dolomites in the depressions of the pre-Carboniferous land-surface suggests that lagoon conditions may have obtained during their formation, and in this connexion the reef-like masses of calcareous algæ, so characteristic of the lower portion of these beds, are of interest. Recent work on the origin of dolomite seems to point to the conclusion that the conditions most suitable for dolomitization occur in association with coral-reefs, in the formation of which calcareous algæ have been shown to play a conspicuous part.

In this connexion it is interesting to note that the other exposures of this horizon in the North-Western Province, namely those in the Ravenstonedale, Arnside, and Kendal Districts, are also rich in magnesium carbonate, and are again characterized by the abundance of *Solenopora* and other calcareous algæ.

We may conclude, then, that the dolomitization of the beds of the *Athyris-glabristria* Zone was practically contemporaneous with the deposits, in the sense that the coral-rock of the Funafuti Atoll and its dolomitization may be regarded as contemporaneous; that it took place under lagoon conditions in a subsiding area formed of the irregular pre-Carboniferous land-surface; and that these conditions were favourable to the growth of calcareous algæ, as in the case of recent coral-reefs.

Flora.—Calcareous algæ occur abundantly at two levels: namely, at the base of the lower and of the upper sub-zones respectively; while *Archæosigillaria vanuxemi* is apparently confined to this zone, but occurs at more than one level.

Fauna.—The fauna of this zone is, on the whole, a very distinctive one, and it is doubtful whether any of the forms pass up beyond the base of the overlying *Michelinia* Zone. The detailed account of the fauna will be best considered under the different subdivisions.

Geographical distribution.—This zone occurs in all the districts, but its full development is only found in the Shap and Ravenstondale Districts, where it attains its maximum thickness of 1335 feet. Elsewhere, as in the Westmorland Pennines, submergence took place at a somewhat later period, and only the upper portion of the zone is there represented. The zone may be divided into two sub-zones, which contain altogether six palæontological horizons or 'bands':—

Sub-zones.	Bands.
(*b*) *Seminula-gregaria* Sub-zone	(6) The *Spirifer-furcatus* Band. (5) The Brownber Pebble-Bed (*Syringothyris-cuspidata* Band). (4) The *Thysanophyllum-pseudovermiculare* Band. (3) The *Productus-globosus* Band (with an algal layer at the base).
(*a*) *Solenopora* Sub-zone	(2) The *Camarotœchia-proava* Band. (1) The *Vaughania-cleistoporoides* Band.

(*a*) The *Solenopora* Sub-zone.

In this sub-zone are included all the beds from the base of the Shap Conglomerate to the base of the *Productus-globosus* Band. In the Shap District about 100 feet of beds may be assigned to this sub-zone, while in the Ravenstonedale District it reaches its maximum thickness of 1020 feet. The two districts are directly continuous, the lowest bed in each representing approximately the same horizon. This difference in thickness is due to the thinning of the individual beds when traced northwards, and not to any appreciable overlap of the upper beds on to the underlying Lower Palæozoic rocks. The interesting calcareous alga *Solenopora* has been selected as the index-fossil, on account of its presence throughout the sub-zone and its wide lateral distribution (Pl. XLVII, fig. 1). It has not been met with above the base of the *Productus-globosus* Band, but is found wherever the lower beds of the *Athyris-glabristria* Zone are developed in the North-Western Province. This organism has not previously been reported from the Upper Palæozoic rocks; indeed, it was hitherto known only from beds of Ordovician and Jurassic age. Its discovery in the Lower Carboniferous rocks of Westmorland, therefore, will assist in bridging the gap which has so far appeared to exist in its vertical distribution.[1]

Lithology.—The character of the beds indicates shallow-water conditions following on the subsidence of a pre-Carboniferous area. The base of the zone is usually, but not always, composed of unfossiliferous conglomerate and red and yellow sandstones. Locally, as at the foot of Ullswater, north of Kirkby Lonsdale, and in the neighbourhood of Sedbergh, the beds are underlain by a coarse polygenetic conglomerate which has been attributed by several writers to torrential accumulations, laid down either in Upper Devonian or in Lower Carboniferous times.

The deposits near the base of the sub-zone are essentially shaly magnesian limestones; while, in the upper portion, the beds are more compact, and are frequently porcellanous, especially in the Ravenstonedale District. Many of the beds are almost unfossiliferous, and often contain drusy cavities. The detailed characters vary from place to place, and will be best described under the different districts.

Flora.

Solenopora garwoodi, sp. nov. Hinde MS.
Archæosigillaria vanuxemi Göppert.

Indeterminable remains, frequently abundant.

Fauna.

Hyolostelia cf. *smithii* (Young & Young). R.[2]

Aulopora sp.
Syringopora cf. *reticulata* Goldf.
Syringopora cf. *distans* Fischer.
Vaughania cleistoporoides gen. et sp. nov. (limited to special Band).
Zaphrentis aff. *costata* (M'Coy). R.
Zaphrentis densa Carr. R.
Zaphrentis konincki Ed. & H. R.
Zaphrentis omaliusi Ed. & H.

Archæocidaris sp.
Palæchinus lacazei Julian.

Spirorbis cf. *caperatus* M'Coy. R.

Fenestella nodulosa Phill.
Fenestella plebeia Portl.

Crania quadrata M'Coy.
Orbiculoidea sp.
Athyris glabristria (Phill.). Abundant.
Athyris cf. *lamellosa* (L'Éveillé). R.
Camarotœchia proava (Phill.) (limited to special Band).
Derbya sp.
Productus cf. *globosus* sp. nov.
Productus cf. *punctatus* Mart.
Productus pyxidiformis de Kon. R.
Reticularia cf. *lineata* (Mart.).
Rhynchonella sp.
Rhynchotreta angulata (Linn.). M.
Schellwienella crenistria (Phill.).
Seminula aff. *ficoides* Vaughan.
Spirifer clathratus M'Coy. R.
Spiriferina cf. *octoplicata* (Sby.).

Modiola cf. *lata* (Portl.). S.

Conularia quadrisulcata Sby.
Euomphalus sp., large.
Murchisonia sp.
Straparollus sp.

Orthoceras sp.

Kirkbya costata Jones. R.
Leperditia.

Deltodus garwoodi, sp. nov. Smith Woodward.
Pleuroplax sp. nov.
Psephodus cf. *magnus* (M'Coy).

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[1] This form, together with other calcareous algæ from the Lower Carboniferous rocks of Britain, will shortly be described by Dr. G. J. Hinde, F.R.S.

[2] S=limited to the Shap District; R=limited to the Ravenstonedale District; M=limited to Meathop (Arnside District).

Geographical distribution.—The full development of this sub-zone occurs only in the Shap and Ravenstonedale Districts. The upper portion is present at Meathop, and probably also on the western side of the Kendal outlier, and in the Furness District; but it is absent from the Pennine area, which was not submerged until a later period.

(*a* 1) The *Vaughania-cleistoporoides* Band.

This band consists of a yellow earthy dolomite a few feet thick, passing into more shaly beds above and below. It occurs about 20 or 30 feet above the base of the zone.

Geographical distribution.—It has only been met with in the Shap and Ravenstonedale Districts, and the index-fossil is connned to this band.

(*a* 2) The *Camarotœchia-proava* Band.

This band forms a well-marked horizon, about 80 to 100 feet above the Basement Conglomerate, in the Shap and Ravenstonedale Districts. The band reaches its greatest thickness in Ravenstonedale, and is characterized by the development of porcellanous magnesian limestones. It thins rapidly north-westwards, and disappears to the north of Shap. The fauna is scanty: it includes *Solenopora*, *Syringopora* cf. *reticulata*, *Seminula* aff. *ficoides*, and a large form of *Rhynchotreta angulata*.

Geographical distribution.—At the summit of the Abbey Cliff, Shap District. In Stone Gill, Piper Hole, etc. in the Ravenstonedale District. At Low Meathop in the Arnside District. Below Cunswick Scar in the Kendal District. Unknown in the Grange, Furness, and Pennine Districts.

(*b*) The *Seminula-gregaria* Sub-zone.

This sub-zone is comparatively thin. It includes the beds from the top of the porcellanous *Solenopora* series to the base of the *Michelinia* Zone. The index-fossil is shown in Pl. LI, fig. 5. It occurs in many of the layers, and is associated with a form resembling *S. ficoides* Vaughan. The base of the sub-zone is marked by the characteristic Algal Band.

Lithology.—In the Shap District the beds in the lower portion are compact and dolomitic, usually purple when freshly broken, abounding in drusy cavities, and often weathering to a dun colour. In the south of the district and in Ravenstonedale these beds take on a more shaly character; but in the upper portion of the sub-zone the beds become more calcareous, and are specially characterized by the development of oolites which are typical of this horizon in the North-Western Province. Associated with this oolitic development we frequently find an abundance of white quartz-pebbles, which are distributed over a wide area in the eastern districts and occur chiefly at a definite stratigraphical level—the Brownber Pebble-Bed. This bed has proved of great value in determining the exact horizon of the lowest Carboniferous deposits in the Westmorland Pennine District. In the Kendal District, layers of china-stone occur locally near the base of the sub-zone, crowded with *Calcispheræ* and allied forms.

Fauna.—In these beds fossils are usually scarce, and many of the dun limestones and dolomites are apparently unfossiliferous: they contain, however, ostracoda and foraminifera.

Of the four bands established in this sub-zone, enumerated above (p. 459), the three upper bands serve to link the lower beds of the type districts with those of the Westmorland Pennines on the east and with the Kendal and Grange Districts on the west; while the basal Algal Band has been traced in many of the districts.

Geographical distribution.—This sub-zone is well developed along the western escarpment of the Shap and Ravenstonedale Districts, where it reaches a maximum thickness of about 300 feet. At Meathop, in the Arnside District, about 80 feet of these beds are present, and contain a coral fauna of special interest. Their distribution in the Kendal, Grange, and Furness Districts is shown in dark green on the accompanying maps (Pls. LIII–LV). In the Westmorland Pennines, and at Lupton Row in the Kirkby-Lonsdale District, only the higher portion of this sub-zone has been met with.

(*b* 3) The *Productus-globosus* and *Rhynchonella-fawcettensis* Band.

The algal layer at the base of this band is of great interest, and is best developed in the Shap and Ravenstonedale Districts. It consists of a layer of shaly dun-coloured dolomite a few feet thick, in which are embedded dark calcareous nodules of a compact porcellanous texture weathering to a pale grey. These nodules average from 1 to 2 inches in diameter, and represent the thalli of calcareous algæ (see Pl. XLVII, fig. 2). In the district between Fawcett Mill and Ravenstonedale village, this shale is underlain by a more compact bed composed of reef-like masses of algæ, disposed in undulating layers, forming hemispherical domes with intervening depressions 3 to 4 inches in diameter. At least two different forms of algæ appear to be present in this layer, which can be traced at intervals between Shap Abbey and Ravenstonedale. It occurs also at the same horizon in the Kendal District; at Meathop in the Arnside District; and in the outliers between Kendal and Kirkby Lonsdale. It is of especial value for the correlation of the beds, in districts where *Productus globosus* itself has not been found.

The *Productus-globosus* Band marks a constant horizon throughout the Shap and Ravenstonedale Districts. It is not, however, clearly traceable in the districts to the west, and in the

Westmorland Pennines no Carboniferous rocks so low in the sequence have been met with. The beds are composed of alternations of compact dolomites and impure shaly limestones, and form a transitional series between the porcellanous beds of the *Camarotœchia-proava* Band below, and the more purely calcareous and oolitic rocks of the overlying beds. Where typically developed, *Productus globosus* is associated with *Pr. rotundus* and *Rhynchonella fawcettensis*. The last species being unknown in the North-Western Province outside this band, we may with advantage associate it with *Pr. globosus* as an index-fossil for this horizon. Near Shap Toll-Bar the beds are markedly dolomitic, and the fauna undergoes certain modifications, being characterized by its wealth in gastropod species.

The following fauna occurs normally in the *Productus-globosus* Band and overlying beds up to the base of the *Thysanophyllum-pseudovermiculare* Band[1]:—

Syringopora sp.
Zaphrentis cf. *omaliusi* Ed. & H.

Archæocidaris plates and spines.

Stenophragma lobatum, gen. et sp. nov. Munro. R.

Orbiculoidea cf. *nitida* (Phill.).
Athyris glabristria (Phill.).
Cyrtina cf. *carbonaria* (M'Coy). M. F. G.
Productus globosus, sp. nov. S. R.
Productus rotundus, sp. nov.
Rhipidomella michelini (L'Éveillé).
Rhynchonella fawcettensis, sp. nov.
Schellwienella sp.
Seminula aff. *ficoidea* Vaughan.
Seminula gregaria (M'Coy).
Spirifer sp.
Spiriferina sp.

Aviculopecten cf. *plano-clathratus* M'Coy. R.

Euomphalus sp. Very large. S. R.

Ostracoda. Abundant.

Deltodus sp.

(*b* 4) The *Thysanophyllum-pseudovermiculare* Band.

This band lies 25 to 50 feet above the base of the *Productus-globosus* Band, and forms a valuable horizon in the eastern districts. The band is usually composed of thickly-bedded, compact, grey limestones which are frequently oolitic; indeed, it forms the base of a series of oolitic deposits which persist into the *Micheliani* Zone in many districts. It is often cherty and occasionally contains a few white quartz-pebbles, foreshadowing the conditions that prevailed during the deposition of the overlying beds.

Fauna.

Cyathophyllum cf. *multilamellatum* M'Coy.
Caninia subibicina M'Coy.
Syringopora sp.
Thysanophyllum pseudovermiculare (M'Coy).
Fistulipora incrustans Phill. R.

Productus cf. *rotundus*.
Chonetes aff. *papilionacea* (Phill.). S. Small convex form.

Bellerophon costatus Sby.

[1] M=Meathop; F=Furness District; G=Grange District; S=Shap District; and R=Ravenstonedale District.

The index-fossil often occurs in reef-like masses up to 2 feet in diameter, which do not, however, form true coral-reefs, for they are often seen to lie in an inverted position: showing that they grew loosely attached to the bottom, and readily drifted after death. This fact in itself testifies to the prevalence of shallow-water conditions and to the presence of wave- or current-action at this period. *Caninia subibicina* first enters at this horizon in the Shap District, and persists to the summit of the *Michelinia* Zone in the Arnside District. At Rosgill and Ravenstonedale Moor, in the Shap District, we meet with the earliest examples of papilionaceous forms of *Chonetes*. The band is most fossiliferous in the Ravenstonedale District, where the lower layers are marked by the abundance of well-grown specimens of *Fistulipora incrustans*.

Geographical distribution.—Between Bampton and the Dent Fault in the Shap and Ravenstonedale Districts, an almost continuous outcrop (Shap village is built on the outcrop of this band). Along the western escarpment, and in the Grayrigg outlier, in the Kendal District. Near Broad Oak in the Grange District. In the Arnside District it has practically thinned out, and is absent in the Furness District. In the Westmorland Pennines it occurs only under Roman Fell, and serves here to mark the time when this district was first submerged under the Carboniferous Sea.

The beds immediately overlying the *Thysanophyllum* Band in the Shap District consist of a few feet of compact and oolitic limestones, occasionally abounding in specimens of *Bellerophon*. The beds thicken, and become more shaly when traced into the Ravenstonedale District. Above Brigsteer in the Kendal District they contain silicified specimens of *Cyathophyllum* cf. *multilamellatum*.

(*b* 5) The Brownber Pebble-Bed (*Syringothyris-cuspidata* Band).

This band depends for its value as a stratigraphical horizon chiefly on its lithological structure; at the same time, its fauna is decidedly characteristic. In its typical development it is confined to the Shap-Ravenstonedale and Pennine Districts, but it can just be traced in the Kendal District. The band is marked by a series of oolitic limestones and calcareous grits averaging 20 or 30 feet in thickness, enclosing layers of false-bedded conglomerate. This conglomerate is composed of white quartz-pebbles averaging about an inch in diameter (though occasionally much larger), embedded in an oolitic matrix. The layers of pebbles are very inconstant, and thicken and thin laterally. The band represents the most pronounced development of oolite in the North-Western Province. The quartz-pebbles appear to have been introduced by strong currents setting from the Pennine Area lying to the east, which was then being submerged for the first time and was undergoing marine denudation. The deposit is thickest in the neighbourhood of Roman Fell, and here the quartz-fragments are on the whole largest and the development of oolitic structure most pronounced.

Fauna.

Cyathophyllum cf. *multilamellatum* M'Coy.
Syringopora reticulata Goldf.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (M'Coy).
Schellwienella sp.
Productus cf. *hemisphericus* Sby.
Rhynchonella sp.
Spirifer furcatus M'Coy. Rare.
Syringothyris cuspidata (Mart.).

Bellerophon sp. Abundant.
Murchisonia cf. *angulata* Phill. Donald.[1]
Pleurotomaria sp.

The fossils are usually fragmentary, testifying to wave- or current-action. The characteristic fossil, almost invariably present in all exposures of this horizon, is *Syringothyris cuspidata*, which occurs locally in considerable numbers. Though sometimes present in the overlying beds, it is extremely rare, and the fullest development of this species is certainly at this horizon; it may, therefore, conveniently be used as the index-fossil to this band. In the Kendal District the band is represented by a hard calcareous grit, in which *Syringothyris cuspidata* is again the most abundant fossil.[2]

Geographical distribution.—Throughout the Shap and Ravenstonedale Districts; under Roman Fell in the Pennine District; below Cunswick Scar in the Kendal District. The band is of especial importance in determining the date of submergence of the Pennine District.

(*b* 6) The *Spirifer-furcatus* Band.

This forms a useful horizon near the summit of the *Athyris-glabristria* Zone. It is best developed in the Arnside and Grange Districts, and consists usually of an oolitic limestone, crowded with somewhat fragmentary shells which show signs of attrition. The index-fossil occurs locally in great abundance, and is somewhat variable in form; but many specimens closely resemble M'Coy's figure of *Sp. furcatus*.[3]

The following list includes species which occur in the upper portion of the sub-zone, above the *Thysanophyllum* Band:—

Carcinophyllum simplex, sp. nov. M.[4]
Lophophyllum meathopense, sp. nov. M.
Lophophyllum vesiculosum, sp. nov. M.
Carruthersella compacta, sp. nov. M.
Campophyllum ciliatum, sp. nov. M.
Zaphrentis konincki, Ed. & H.

Seminula cf. *ambigua* (Sby.).
Athyris glabristria (Phill.).
Camarophoria isorhyncha (Phill.).
Derbya sp.
Productus cf. *punctatus* (Mart.).
Productus cf. *hemisphericus* (Sby.).
Reticularia cf. *lineata* (Mart.).
Spirifer furcatus M'Coy. Very abundant.
Spirifer sp.
Syringothyris cuspidata (Mart.). One specimen.
Rhynchotreta angulata (Linn.). M.
Rhynchonella sp.

Euomphalus pentangulatus (Sby.).
Bellerophon costatus Sby.
Naticopsis plicistria Phill.

[1] See Q. J. G. S. vol. xliii (1887) p. 621. These specimens were identified by her as probably the above.

[2] The name 'Brownber Beds' is derived from the outcrop of this band near Newbiggin Station: it was first applied to the pebble-bed by Mr. R. H. Tiddeman in the Geological Survey Memoir on Kendal, Sedbergh, Bowness & Tebay, 1888, p. 31.

[3] 'Synopsis Char. Carb. Limest. Foss. of Ireland' 1844, pl. xxii, fig. 12.

[4] M=Found only at Meathop, in the Arnside District.

Geographical distribution.—At the summit of the old quarries on Meathop Fell, Arnside District; at Beck Head, Cat Crag, and near Cartmel in the Grange District; in Docker Beck (Oatmeal Bed) and on Ravenstonedale Moor in the Shap District; in Scordale Beck, east of Roman Fell, in the Pennine District.

(B) The *Michelinia* Zone.

This zone, though of no great thickness, is one of the most important in the North-Western Province. It attains its fullest development in the Meathop-Arnside section, where it is well exposed and extremely fossiliferous. It has, for convenience, been subdivided into two portions, which are as a rule both lithologically and palæontologically distinct.

(*c*) The *Camarophoria-isorhyncha* Sub-zone.

This sub-zone is characterized by the presence of *Michelinia grandis*, associated with *Camarophoria isorhyncha*—an association that is never found outside this sub-zone. The base of the sub-zone usually rests on the *Spirifer-furcatus* Band, and passes up into the shaly beds which characterize the upper portion of the zone.

Lithology.—Where typically developed in the Western Districts, as at Elliscales and Frith Hall, the sub-zone consists of fairly massive limestones. In the Ravenstonedale District it is not well exposed, and appears to be very thin and somewhat more shaly than in the Grange District; while at Shap it is represented by a single bed of sandy and oolitic limestone at the base of the Orton Sandstone.

Flora and Fauna.

Archæosigillaria vanuxemi Göppert.

Cyathophyllum cf. *multilamellatum* M'Coy.
Michelinia grandis M'Coy.
Zaphrentis konincki Ed. & H.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (Phill.).
Reticularia lineata (Mart.).
Spirifer furcatus M'Coy. Rare.
Derbya sp.

Bellerophon costatus Sby.

Specimens of *Michelinia* occur, measuring as much as 2 feet in diameter, which seem to be referable to *M. grandis* M'Coy, but differ from the type-specimen in the Sedgwick Museum by their much greater size and by the absence of an epitheca. They appear to belong to the same form as that which occurs abundantly at Ronaldsway (Isle of Man). *Camarophoria isorhyncha* is found in practically all exposures of this sub-zone, sometimes, as at Docker Beck (Shap), in great abundance. Although it makes its entrance in the North-Western Province in the Brownber Pebble-Bed, it is extremely rare there, and occurs plentifully only in the sub-zone under description. It has never been found in the upper portion of the zone, and with the exception of two rolled specimens collected from the Ashfell Sandstone, no occurrence of this form above the present horizon is known. *Athyris glabristria* also occurs sparingly, together with a fine mutation of *Cyathophyllum multilamellatum*.

Geographical distribution.—This sub-zone is represented in all the districts. It is well exposed in Docker Beck in the Shap District; at Elliscales in the Furness District; at Frith Hall and Cat Crag in the Grange District; at Meathop in the Arnside District; and above Brigsteer in the Kendal District. In the Ravenstonedale District it cannot be clearly separated from the upper portion of the zone. It is represented by unfossiliferous sandstones in the Pennine District.

(*d*) The *Chonetes-carinata* Sub-zone.

The upper portion of the *Michelinia* Zone is especially characterized by the occurrence of large specimens of *Chonetes carinata* (nobis MS.), a species confined to this sub-zone in the North-Western Province.[1] It is associated with *Michelinia grandis* and *M. tenuisepta*, together with *Caninia cylindrica* and *Cyathophyllum multilamellatum*. The upper limit is defined by a band which is marked by the abundance of *Clisiophyllum multiseptatum* and *Zaphrentis enniskilleni*. The beds are best developed in the districts bordering Morecambe Bay, and are especially well exposed along the shore to the west of Arnside; the latter exposure may, therefore, be taken as the fullest development of this sub-zone. Complete sections showing the relation of the two sub-zones one to the other occur at Frith Hall on the Leven Estuary; above Brigsteer in the Kendal District; and at Elliscales in the Furness District.

Lithology.—The rock is essentially a grey calcareous mudstone, enclosing harder layers of cement-stone. Some of the beds are shaly, especially towards the summit. In the Ravenstonedale District the sub-zone is represented by a small thickness of red and grey calcareous shales; but here this sub-zone is not so distinctly differentiated from the underlying beds as in the Western Districts. At Docker Beck, in the Shap District, it is apparently represented by the lower unfossiliferous portion of the Orton Sandstone.

Fauna.—The fauna is, on the whole, the richest, both in species and individuals, of any horizon in the North-Western Province. It also contains some of the largest forms of corals and brachiopods. In addition to the species mentioned above, *Zaphrentis konincki* and

[1] This form appears to be identical with *Chonetes* aff. *comoides* of Dr. Vaughan, Q. J. G. S. vol. lxi (1905) p. 295.

its variant *Z. kentensis*, together with a very large form of *Schellwienella* (cf. *crenistria*), are characteristic of this sub-zone. The following list is chiefly compiled from the exposures in the Arnside District:—

Amplexus sp. Rare.
Aulophyllum sp.
Caninia cf. *cornucopiæ* (Mich.).
Caninia cylindrica (Scouler) & variant.
Caninia subibicina M'Coy.
Clisiophyllum multiseptatum, sp. nov. (at the summit).
Cyathophyllum multilamellatum M'Coy.
Cyathophyllum (*Diphyphyllum*) *dianthoides* M'Coy.
Lophophyllum fragile, sp. nov.
Michelinia grandis M'Coy.
Michelinia tenuisepta Phill.
Syringopora distans Fischer.
Syringopora geniculata Thomson.
Zaphrentis konincki Ed. & H.
Z. konincki, forma *kentensis* nov.
Zaphrentis enniskilleni Ed. & H. and variants.

Rhombopora sp.

Athyris expansa (Phill.).
Athyris expansa, forma *sulcata* nov.
Chonetes papilionacea Phill.
Chonetes carinata, sp. nov. (MS.).
Dielasma cf. *hastatum* (Sby.).
Leptæna analoga (Phill.).
Schellwienella cf. *crenistria* (Phill.) (very large form).
Productus cf. *corrugato-hemisphericus* (small form).
Productus aff. *rotundus* sp. nov.
Productus laciniatus M'Coy.
Productus cf. *martini* Sby.
Productus cf. *pyxidiformis* De Kon.
Productus cf. *punctatus* Mart.
Rhipidomella michelini L'Éveillé.
Reticularia cf. *lineata* (Mart.).
Syringothyris cuspidata (Mart.). Rare.
Spirifer cf. *integricostus* (Phill.).
Martinia cf. *ovalis* (Phill.).

Conocardium aliforme Sby.

Baylea simplex De Kon.
Bellerophon sp.
Naticopsis plicistria Phill.
Platyschisma tiara Phill.
Schizostoma catillus Phill.

Polyrhizodus magnus M'Coy.

Geographical distribution.—At Arnside and Storth Road in the Arnside District. At Frith Hall, Park Head, near Cartmel, Longhowe End, and Broad Oak in the Grange District. At Plumpton, Gascow, Dalton, and Marton in the Furness District. In the Kendal District above Underbarrow, Brigsteer, Beethwaite Green, and at Kettlewell; also on the banks of the River Kent between Hawes Bridge and Levens Park. Near Lupton Hall in the Kirkby Lonsdale District. In the Docker-Beck section in the Shap District it is merged in the Orton Sandstone, but emerges from below it on Ravenstonedale Moor. Between Blea Flatt and Ashfell Farms, and in Tarn Sike in the Ravenstonedale District. In the Westmorland Pennines it appears to be represented by the unfossiliferous sandstone of Swindale Crag which underlies the Melmerby-Scar Limestone.

(*d* 7) The *Clisiophyllum-multiseptatum* Band.

At the summit of the zone occurs an important band of shale characterized by the abundance of *Clisiophyllum multiseptatum*, which is immediately overlain by beds containing the earliest examples of *Lithostrotion*. Though best developed in the Arnside District, this band occurs in all the Western Districts in the same position immediately below the base of the Gastropod Beds, and also at Tarn Sike (Ravenstonedale) in the Eastern Districts.

(C) The *Productus corrugato-hemisphericus* Zone.[1]

This zone is separated, for convenience of description, to include a group of beds lying between the *Michelinia* and the *Dibunophyllum* Zones. The name of the index-fossil was originally suggested by Dr. Vaughan, and is adopted here as representing the general type of *Productus* which is common throughout the zone. The form is not absolutely confined to this zone, for occasional specimens are met with in the upper portion of the underlying *Michelinia* Zone. There is no one species that can be cited as confined to the zone, and yet as characteristic of it throughout. This zone marks the passage between the lagoon and shallow-water phases characteristic of the beds of the lower zones and the clear and deeper-water conditions which obtained during the deposition of the beds of the overlying Lower *Dibunophyllum* Sub-zone. The fauna is also intermediate in character. The zone is present in all the districts, and may be subdivided as follows :—

Upper =*Lithostrotion (Nematophyllum)-minus* Beds.
Middle=*Cyrtina-carbonaria* Beds.
Lower =Gastropod Beds.

(e) The Gastropod Beds.

This sub-zone contains no one species that can be cited as an index, but is usually characterized by a rich assemblage of gastropods and other mollusca, such as *Bellerophon*, *Euomphalus*, etc.

Lithology.—The lower portion is a dark bituminous, somewhat shaly limestone, which in the Arnside and Grange districts passes gradually down into the underlying *Michelinia* Beds. In the districts where the *Cyrtina-carbonaria* Sub-zone is absent, the black limestone-beds are succeeded somewhat abruptly by the overlying compact white limestones of the *Nematophyllum-minus* Sub-zone.

Fauna.—In the Western Districts these beds contain many species in common with those of the underlying *Michelinia* Zone, but *Michelinia* and *Chonetes carinata* are absent. *Lithostrotion* is associated with *Bellerophon* and *Euomphalus*. *Seminula* occurs abundantly near the base, together with a large form of Diphyphylloid *Lithostrotion*. A similar fauna, including the same Diphyphylloid *Lithostrotion*, is found in the Ravenstonedale District. The fauna of the calcareous band which occurs in the Ashfell Sandstone of the latter district is, however, unique in the area, being rich in corals, especially in forms of *Lophophyllum ashfellense* and specimens of *Zaphrentis enniskilleni* and variants.

[1] This zone appears to represent almost exactly the *Seminula* Zone of the Avon Section. The index-fossil is described and figured by Dr. Vaughan as *Productus cora*, mut. S_2, in Q. J. G. S. vol. lxi (1905) p. 291 & pl. xxv, fig. 4.

Caninia cylindrica (Scouler). Rare.
Diphyphyllum cf. *lateseptatum* M'Coy.
Lithostrotion cf. *martini* Ed. & H.
Lophophyllum ashfellense, sp. nov.
Syringopora geniculata Phill.
Syringopora distans Fischer.
Zaphrentis enniskilleni Ed. & H. and variants.

Platycrinus sp.

Stenophragma gen. et sp. nov. Munro.

Athyris expansa (Phill.).
Athyris cf. *planosulcata* (Phill.).
Chonetes papilionacea Phill.
Dielasma sacculus (Mart.).
Productus corrugato-hemisphericus Vaughan.
Productus laciniatus M'Coy.
Productus productus Mart.
Productus pyxidiformis de Kon.
Pugnax cf. *pleurodon* (Phill.).
Reticularia aff. *lineata* (Mart.).
Schellwienella sp.
Seminula ficoidea Vaughan.
Martinia cf. *ovalis* (Phill.).

Allorisma sulcatum Flem.
Aviculopecten dissimilis Flem.
Conocardium aliforme Sby.
[1] *Cucullæa tenuistria* M'Coy.
[1] *Myalina crassa* Flem.
[1] *Myalina verneuili* M'Coy.
[1] *Nucula gibbosa* Flem.
Sanguinolites clavus M'Coy.
Sanguinolites subcarinatus M'Coy.

Bellerophon costatus Sby. Very abundant.
Bellerophon sulcatus Sby.
[1] *Bellerophon* (*Bucania*) *cornu-arietis* Sby.
[1] *Capulus trilobatus* (Phill.).
[1] *Euomphalus crotalostomatus* M'Coy.
Euomphalus pentangulatus Sby.
[1] *Euomphalus* (*Phymatifer*) *pugilis* Phill.
Straparollus acutus Sby.
[1] *Murchisonia kendalensis*.
Naticopsis ampliata (Phill.).
Naticopsis elliptica (Phill.).
Naticopsis elongata (Phill.).
Platyschisma helicoides (Sby.).
Schizostoma catillus (Mart.).

Psammodus rugosus Ag.
Psephodus magnus M'Coy.

The geographical distribution in the Western Districts is shown in the accompanying maps. In the Ravenstonedale District, the upper portion of the sub-zone is represented by the Ashfell Sandstone; while, in the Shap District, the whole of the sub-zone is included in the Orton Sandstone.

(*f*) The *Cyrtina-carbonaria* Sub-zone.

This sub-zone forms a well-marked horizon in the type districts. It is usually crowded with specimens of the index-fossil and with small gastropods, together with species of *Lithostrotion* and *Syringopora*. Its average thickness cannot exceed 50 feet. It is most fossiliferous towards its base, and passes up into the overlying *Nematophyllum-minus* Beds. Though *Cyrtina carbonaria* is especially abundant at this horizon, it is not absolutely confined to it everywhere. In the Arnside and Grange districts a few specimens (possibly referable to this species) occur at a much lower horizon, namely, in the upper portion of the *Athyris-glabristria* Zone, while in the Ravenstonedale District individual specimens persist into the base of the Lower *Dibunophyllum* Zone. In both these cases, however, they are associated with distinct faunas, and do not occur in anything like the same abundance as in this sub-zone.

Lithology.—The rock is a somewhat compact and gritty grey

[1] Preserved in Kendal Museum.

limestone, passing in places into more shaly and platy beds. The beds mark the beginning of the depression which reached its maximum in the overlying Lower *Dibunophyllum* Sub-zone. Except in the Kendal District, this horizon is usually notable for a considerable development of secondary silica, and the fossils are often preserved in beekite.

The fauna is characterized chiefly by the abundance of the index-fossil, together with *Seminula* and small gastropods, and by the absence of Orthotetinæ and *Chonetes*, while *Productus corrugato-hemisphericus* and *Lithostrotion martini* are still abundant. *Pugnax pugnus* is first met with in this sub-zone, but is very rare.

Fauna.

Cyathocrinus sp.

Archæocidaris plates.

Aulopora sp.
Lithostrotion martini Ed. & H.
Syringopora geniculata Phill.

Spirorbis sp.

Athyris planosulcata (Phill.).
Cyrtina carbonaria (M'Coy).
Productus corrugato-hemisphericus Vaughan.
Productus elegans M'Coy.
Productus laciniatus Sby.
Productus punctatus Mart.
Pugnax pugnus (Mart.).
Rhynchonella sp.
Rhipidomella michelini (L'Éveillé).
Seminula ficoidea Vaughan.
Spiriferina laminosa (M'Coy).
Spirifer bisulcatus Sby.

Bellerophon costatus Phill.
Bellerophon obsoletus M'Coy.
Flemingia sp.
Loxonema rugiferum Phill.
Murchisonia sp.
Pleurotomaria (*Ptychomphalus*) *vittata* Phill.
Pleurotomaria sp.
Rhineoderma fragile de Kon.
Schizostoma catillus (Mart.).
Straparollus sp.
Turbonitella biserialis (Phill.).

Psephodus magnus M'Coy.

Geographical distribution.—Typically developed along the base of the Shap-Ravenstonedale escarpment between Long Scar Pike and the Dent Fault, but dies away into the upper portion of the Orton Sandstone before reaching Shap village. In the old Kettlewell quarries and on Cunswick Scar in the Kendal District. In the Arnside and Grange Districts it cannot be distinguished as a separate horizon. In the Pennine Escarpment it appears to be represented by the unfossiliferous sandstone underlying the Melmerby Scar Limestone, in Swindale Beck and High Cup Gill.

(*g*) The *Nematophyllum-minus* Sub-zone.

This sub-zone forms one of the most important horizons, on account of its presence in all the districts throughout the North-Western Province. It is, however, much better developed in some districts than in others. In the type districts and on Kendal Fell it rests on the *Cyrtina-carbonaria* Sub-zone, but, where that horizon is absent in the Western Districts, the lower limit is taken at the base of the compact white limestone which rests upon the darker, more bituminous gastropod-beds of Red Hills under

Arnside Knott. This line is rather one of convenience than a strict zonal horizon, since the index-fossil is not found in the lowest compact limestone, which may indeed in part represent the *Cyrtina-carbonaria* Beds of the eastern districts. In the western districts the overlying Bryozoa Band is also absent, and the upper limit of the sub-zone is taken at the base of the Lower *Dibunophyllum* Sub-zone.

Lithology.—The rocks are always calcareous, and never dolomitic. They vary from compact white limestones to thinly-bedded calcareous shales. In the type districts and in the Westmorland Pennines they usually occur as a dark-grey, somewhat argillaceous and thinly-bedded limestone. Round Morecambe Bay the beds are divisible into a lower compact and an upper, thinly-bedded, shaly limestone, crowded with *Chonetes papilionacea*. In the Eastern Districts that form is practically absent, and the upper shaly *Ch.-papilionacea* Beds of Arnside Knott and Whitbarrow must include the horizon of the Bryozoa Band of the Eastern Districts. Where the sub-zone reaches its greatest development on Arnside Knott it cannot be far short of 330 feet in thickness; but, in the Shap District and along the Pennine Escarpment, the sub-zone is reduced to a comparatively thin deposit immediately overlying the Orton and Swindale Beck Sandstones, which probably include a part of this sub-zone, the upper portion only being represented by the lower portion of the Knipe-Scar and Melmerby-Scar Limestones.

Fauna.—*Nematophyllum minus* was described by M'Coy from specimens collected in the Kendal District. His name has, therefore, been retained, in order that the exact form characteristic of this sub-zone may be recognized with certainty, although (as pointed out on p. 564) it is undoubtedly a *Lithostrotion*, and this species may even be the genotype. The size of the corallites varies considerably, being smallest in the Eastern Districts, where siliceous deposits predominated in the lower portion of the sub-zone. In the Western Districts *Chonetes papilionacea*[1] occurs throughout the sub-zone, and is so abundant in the upper portion as to impart a fissile character to the limestone. So numerous are the individuals of this species that it might well give its name to the sub-zone, were it not that specimens are practically absent from the type districts and from the Pennine Escarpment, while *Nematophyllum minus*, as already mentioned, is found throughout. Again, forms which, though smaller, cannot be readily separated from this species of *Chonetes*, occur in the underlying portion of the zone, and even sparingly in the *Michelinia* Zone below. No other form is confined to this sub-zone, or can be deemed specially characteristic of it.

[1] This form is doubtfully referred to Phillips's species. The form alluded to here is that shown in fig. 5, pl. xlvi vol. ii of Davidson's 'Fossil Brachiopoda' (Monogr. Pal. Soc.) 1858–63.

Fauna.

Alveolites capillaris (Phill.).
Alveolites etheridgi Thomson.
Lithostrotion irregulare (Phill.).
Lithostrotion (Nematophyllum) minus M'Coy.
Syringopora geniculata Phill.
Syringopora sp.

Athyris cf. *expansa* (Phill.).
Chonetes papilionacea Phill.
Productus corrugato-hemisphericus Vaughan.
Productus cf. *fimbriatus* Sby.
Productus cf. *striatus* Fischer.
Seminula ambigua (Sby).

Bellerophon sp.
Murchisonia sp.
Straparollus sp.

Psephodus magnus M'Coy.

Geographical distribution.—Present in all districts throughout the North-Western Province.

(*γ* 8) The Bryozoa Band.

This band forms a very constant horizon everywhere in the type districts, and is also well developed along the Pennine Escarpment. It has not been met with in the Western Districts, where it appears to be merged in the upper portion of the *Nematophyllum-minus* sub-zone. The western boundary of the area in which the Bryozoa Band was deposited lay roughly somewhere parallel to a line joining Sedbergh and Kidsty Pike. East of this line the Bryozoa Band is typically developed; while west thereof it is absent, and we find the *Chonetes-papilionacea* Beds instead. The difference was evidently due to the somewhat deeper and clearer character of the sea to the west of this line.

Lithology.—The band varies considerably in lithological character from place to place. It includes some 30 or 40 feet of rock, and forms a passage-bed between the *Nematophyllum-minus* Sub-zone and the Lower *Dibunophyllum* Sub-zone. The band represents a change in the character of the deposits, due probably to a slightly increased rate of submergence which changed the direction of the currents. It is alternately a shaly limestone, a compact porcellanous cementstone, and a hard yellow fragmental limestone. In the Pennine District it becomes more crystalline and somewhat bituminous.

Fauna.—The band is not always fossiliferous throughout. It includes one or more layers crowded with fossils, notably bryozoa, together with *Spiriferina laminosa* and *Aviculopecten dumontianus*. In the Shap District the band abounds locally with *Naticopsis plicistria*, Capulids and other gastropods; while in places, especially in the Westmorland Pennines, it is characterized by the interesting bryozoan *Stenopora compacta*. The porcellanous layers often contain numerous minute spherical bodies, which appear to be identical with the form described by Williamson from the Carboniferous Limestone near Mold under the name of *Calcisphera*. These bodies are now preserved in calcite, but it is impossible to determine whether this was their original condition, or whether they were originally composed of chitin or even silica. Mr. R. C. McLean, in a recent note on these organisms,[1] in commenting on the poor mode of preservation usually exhibited by these forms in the Carboniferous Rocks, remarks:—

'This imperfection of outline strongly suggests that replacement of the original substance by secondary calcite has taken place. . . . . . It is noticeable that some species of Calcispheræ have left carbonaceous remains which suggests that they too might have been chitinous in life.'

Mr. McLean throws out the suggestion that these *Calcispheræ* may have developed from true radiolaria by becoming adapted to brackish waters. It is interesting to note in this connexion the invariable association of the *Calcispheræ* with abundant plant-remains in the deposits of the North-Western Province (Pl. XLVII, fig. 4).

Fauna.

Pemmatites constipatus Hinde.

Alveolites etheridgi Thomson.
Lithostrotion martini Ed. & H.

Archæocidaris sp.

Stenopora compacta, sp. nov. Munro.
Cystodictya sp.
Fenestella membranacea (Phill.).
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
Fistulipora incrustans (Phill.).
**Hemitrypa hibernica* M'Coy.
Tabulipora sp.
Polypora sp.
Rhabdomeson sp.
Rhombopora sp.

Chonetes cf. *hardrensis* Phill.
**Athyris* cf. *expansa* (Phill.).
Crania cf. *quadrata* (M'Coy).
Cyrtina carbonaria (M'Coy).
Productus corrugato-hemisphericus Vaughan.
Productus laciniatus M'Coy.
Productus cf. *martini* Sby.
Productus cf. *maximus* M'Coy.
Productus punctatus Mart.
Pugnax pleurodon (Phill.).
**Pugnax pugnus* (Sby.).
Rhynchotreta angulata (Linn.).
Seminula ambigua (Sby.).
Seminula ficoidea Vaughan.
Spirifer bisulcatus Sby.
Spirifer duplicicostus Phill.
Spiriferina laminosa (M'Coy).

Myalina verneuili M'Coy.
Aviculopecten dissimilis Flem.
Pterinopecten dumontianus de Kon.

Bellerophon scalifer de Kon.
Capulus sp.
Naticopsis plicistria (Phill.).
Pleurotomaria sp.

Pleuroplax woodi Davies.

[* = Pennine District.]

Geographical distribution.—Throughout the Shap and Ravenstonedale Districts. In the Westmorland Pennines, in the Melmerby-Scar Limestone east of Roman Fell.

(D) The *Dibunophyllum* Zone.

The beds which succeed the *Productus corrugato-hemisphericus* Zone appear to correspond generally with the *Dibunophyllum* Zone of the South-Western Province. The highest limestones, however, as, for instance, those at Botany, and possibly a portion of the underlying Yoredale Beds, represent a horizon comparable to some portion of the D_3 Beds of Derbyshire. The zone may be considered under two divisions:—

[1] 'A Group of Rhizopods from the Carboniferous Period' Proc. Camb. Phil. Soc. vol. xvi, pt. 6 (1912) p. 512.

(*h*) The Lower *Dibunophyllum* Sub-zone.

This sub-zone is notable for its great thickness, for the purity of its limestones, and for its uniformity throughout. It represents the period of greatest submergence in the North-Western Province, and consequently presents very similar characters throughout the different districts. It can also be readily correlated with the beds of the corresponding age in the South-Western Province; and, as there can be no doubt regarding the contemporaneity of this sub-zone with the Lower *Dibunophyllum* Sub-zone of the Bristol District, we may adopt Dr. Vaughan's nomenclature without fear of causing confusion in the future.

Lithology.—The sub-zone is characterized over the greater part of the North-Western Province by the occurrence of somewhat massive grey and dove-coloured limestones, and by the complete absence of shaly partings or sandy intercalations. The rock is made up entirely of foraminifera and microscopic fragments of calcareous organisms in which the larger fossils are embedded. The sub-zone is remarkable for the development of certain structures, namely, (1) 'spotted' beds and (2) 'pseudo-breccias.' These occasionally pass into one another, but are usually distinct.

The 'Spotted' Beds.

These are especially characteristic of the base and summit of the sub-zone. They consist of small spherical patches of darker limestone surrounded by a lighter matrix, the dark spots averaging an inch in diameter. At a distance, therefore, a broken surface resembles a conglomerate rather than a breccia: on closer inspection, however, the edges of the dark spots seem to fade gradually into the matrix, and are evidently not of fragmental origin, both portions of the bed having been deposited contemporaneously. The spots are not typical concretions: for they exhibit neither concentric nor radial structure, and do not separate readily from the matrix on weathering. Again, in the majority of examples analysis shows no marked or constant difference between the chemical composition of the spots and that of the matrix. This is especially the case with the spotted beds which occur so constantly near the base of the sub-zone. Microscopic examination throws but little light on the origin of the spots: sections show that portions of the rock are richer in foraminifera than others, and sometimes these organisms seem to be more densely packed in the spots than in the matrix; but this arrangement does not by any means obtain generally, and appears to be accidental. So far as can be ascertained, the spots are due to a slight tendency to concretionary action, but this action has been practically confined to the coloured impurities in the original deposit, which have been concentrated locally to form the dark spots, leaving the bulk of the rock nearly free from colouring-matter. Since the rock is almost a pure limestone, the amount of material capable of being affected by concretionary action must have been very slight. The foregoing remarks apply to the typical 'spotted' limestones found in the lowest beds of this sub-zone.

There are, however, other 'spotted' beds showing evidence of the separation of a definite portion of the deposit to form spots, which have a mineral composition different from that of the matrix; and these beds may throw light on the more obscure cases just described. The best example of this second type occurs in the Melmerby-Scar Limestone of Great Rundal Beck in the Pennine District. In this rock the spots are rather more nodular in character than usual, and the rock has a tendency to weather irregularly, the spots standing out slightly in relief. A fractured surface also shows the same tendency, pointing to the conclusion that the spots are denser and more compact than the matrix. On the other hand, the spots are readily attacked by acid, while the matrix, though easily disintegrated, leaves a large proportion of insoluble residue. In microscopic sections, the mineral composition of the spots and the matrix, unlike the examples previously described, proves to be essentially different: for, whereas the dark spots are composed, as usual, of fragmentary organic remains, foraminifera, and calcite-crystals, the lighter-coloured matrix is largely composed of subangular quartz-grains embedded in calcite. The matrix also presents somewhat the appearance of the 'flow-structure' of a rhyolite (Pl. XLVII, fig. 3). In the Melmerby-Scar rock, then, we find definite evidence that segregation of material has taken place, the fragmentary calcareous portions having collected together in patches, while the quartz-grains constitute the enveloping matrix; at the same time, the coloured impurities have also concentrated in the calcareous portions, giving rise to the dark spots.

The study of these different occurrences would thus appear to show that two types of 'spotted' rocks occur: in the first, which is by far the commoner—where the rock consisted originally of a nearly pure calcareous deposit—the concretionary action was necessarily limited to the concentration of the colouring-matter round centres to form dark spots; in the second case—where the original deposit contained a considerable proportion of sand-grains—a more marked concretionary action took place: the calcareous fragments together with the colouring-matter being concentrated in the spots, leaving the sand-grains to form a pale-grey matrix, in which the darker concretionary spots lie embedded. Though this seems to be essentially what has taken place, the actual process by which the calcareous material in the second case has effected a separation from the quartz-grains is not so easy to understand, for the quartz-grains evidently represent original detrital quartz, and not silica which has been introduced subsequently in solution. The concentration of one substance in a deposit to form concretions, as in the case of flints in Chalk or the nodules in the Magnesian Limestone of Durham, has generally been regarded as a chemical process affecting material in solution, or at least in a colloid state; but, in the present case, it would appear to require the actual migration of the foraminifera and other calcareous fragments and their mechanical separation from the sand-grains, for these grains must have been originally distributed uniformly throughout the deposit. It is true that a ground-mass of crystalline calcite exists throughout the rock, which may have been in solution while the concentration of the calcareous elements took place, and may thus have facilitated the migration of the fragments and the coloured impurities during the consolidation of the deposit.

The development, then, of 'spotted' beds would seem to be the result of a greater or less manifestation of concretionary action, depending upon the relative purity of the original deposit. This concentration of the material to form the spots appears to have taken place during the consolidation of the deposit, and not at any subsequent period; it may therefore be regarded as pene-contemporaneous.

The 'Pseudo-Breccias.'

These are practically limited to the higher portions of the sub-zone. The rock varies in appearance, from a somewhat concretionary-looking nodular limestone to an angular breccia of which the fragments measure several inches across. The structure differs from that of the 'spotted' beds in two ways; in the first place by the more rugged and angular character of the darker patches when these are present, and secondly by the manner in which the rock weathers. As a rule, it is composed of similar fragments which cannot be differentiated into inclusions and matrix, and the mode of origin of these breccias is evidently different from that of the spotted beds described above. It appears to be due to weathering along definite irregular lines of strain set up in the rock either during, or subsequent to, consolidation (most probably the former), rather than to the separation of material by concretionary action. In fact, the lines would appear to be analogous to the spheroidal structures observed in basaltic rocks, and attributed to the strain set up on cooling and consolidation.

These beds of 'pseudo-breccia' form the higher dip-slopes of the Lower *Dibunophyllum* Sub-zone in all the districts. They are specially well developed on Hampsfell and along the coast, in the Grange and Arnside Districts.[1]

Fauna.—*Cyathophyllum murchisoni* occurs throughout the sub-zone, and *Dibunophyllum* and *Carcinophyllum* also occur abundantly—the latter being especially characteristic of the upper portion, which also contains rare examples of *Aulophyllum* cf. *pachyendothecum*. Many of the beds are rich in *Lithostrotion martini* and *L. junceum* in the higher layers, especially in the Ravenstonedale District. Both *Alveolites etheridgi* and *A. capillaris* are locally abundant. Large Campophyllids are also characteristic of the

[1] Since this paper was read, Mr. E. E. L. Dixon has described similar structures in the limestones of South Wales; see Q. J. G. S. vol. lxvii (1911) pp. 507–11.

higher portion of the sub-zone. *Productus* cf. *maximus* (M'Coy) appears to be confined to this sub-zone. *Cyrtina septosa* enters in the upper portion, but only becomes abundant in the band which it especially characterizes near the summit, and the same statement applies to *Chonetes* aff. *comoides*. The following list includes the species most generally met with:—

Alveolites capillaris (Phill.).
Alveolites etheridgi Thomson.
Aulophyllum cf. *pachyendothecum* Thomson, at the summit.
Campophyllum sp. (Caninoid.)
Carcinophyllum θ Vaughan.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum φ Vaughan.
Dibunophyllum cf. *muirheadi* Nich. & Thomson.
Lithostrotion junceum (Flem.), coarse form.
Lithostrotion martini Ed. & H.
Lithostrotion portlocki (Bronn).
Syringopora geniculata Phill.
Syringopora sp.

Stenophragma grandyense, gen. et sp. nov. Munro.

Cyrtina septosa (Phill.). Rare.
Dielasma cf. *sacculus* (Mart.).
Productus cf. *cora* D'Orb.
Productus laciniatus M'Coy.
Productus cf. *maximus* M'Coy.
Productus cf. *martini* Sby.
Spirifer bisulcatus Sby.
Spirifer striatus Mart.

Allorisma sp.
Conocardium aliforme Sby.

Bellerophon sp.
Flemingia sp.

Geographical distribution.—The sub-zone occurs in all the districts, but it has been almost entirely denuded from the neighbourhood of Kendal. Its detailed distribution is shown on the maps (Pls. LIII–LV). In the Shap District it forms the greater portion of the escarpment and dip-slopes of the Knipe Scar Limestone, and along the Cross-Fell escarpment constitutes the whole of the Melmerby-Scar Limestone above the Bryozoa Band. In the Ravenstonedale District only the lower portion of the zone is present, and this is overstepped at Kirkby Stephen by the Permian deposits. As we go northwards from here, however, higher beds are seen to crop out successively from beneath the lower Brockrams, until, in the neighbourhood of Crosby Garrett, the highest beds of the zone are exposed. The sub-zone bulks largely in the Kirkby Lonsdale District, in the eastern portion of the Arnside District, in the Grange District, and in the eastern portion of Furness. Nearly everywhere it forms the summit of the limestone hills, notably Farlton Knott, Wharton Crag, Whitbarrow, Hampsfell, Birkrigg Common, and many minor elevations.

(*h* 9) The *Daviesiella-llangollensis* Band.

This interesting band is confined to the southern end of the Shap and Ravenstonedale Districts, where it appears to lie a little above the base of the Lower *Dibunophyllum* Sub-zone, as shown by its position relative to the Bryozoa Band and by its association with *Productus* cf. *maximus*. No specimens of *Dibunophyllum* have, however, been found associated with it. *Daviesiella llangollensis* would seem, therefore, to have entered the North-Western Province slightly later than it appeared in North Wales, as its horizon in the latter region is usually assigned to S_2 of the South-Western Province.

(*h* 10) The *Chonetes*-aff. *comoides* and *Cyrtina-septosa* Band.

This band forms a well-marked horizon, a few feet thick, at or near the summit of the sub-zone. In the type districts it consists of a thin bed of very pure platy limestone, which lies about 15 or 20 feet below the base of the lowest Yoredale sandstone. It is everywhere characterized by the abundance of *Chonetes* aff. *comoides*, associated with *Cyrtina septosa* and a small form of *Productus striatus*.

The form of *Chonetes* aff. *comoides* so characteristic of this band appears to be identical with that figured by Dr. Vaughan[1]; it does not differ essentially from Sowerby's type, except that the shell is, as a rule, less thickened. In the Western Districts the band is of a pale buff colour, is usually slightly dolomitic, and contains abundant remains of *Cyrtina septosa*. The band is associated with beds of 'pseudo-breccia,' and underlies a compact nodular bed the surface of which is covered with stick-like concretions, a bed that occurs at this horizon over the whole of the Morecambe-Bay area (Pl. XLVI, fig. 2, facing p. 518).

Geographical distribution.—The band is shown by a special symbol on the accompanying maps (Pls. LIII–LV). It occurs in most of the districts where the highest layers of the Lower *Dibunophyllum* Sub-zone are exposed, notably on the dip-slopes at Grandy and on Gathorn Plain in the Shap District; along the coast in the neighbourhood of Jenny Brown's Point in the Arnside District; on Grange shore, Holm Island, and at Humphrey Head in the Grange District; also in Little Urswick Quarries and along the coast-line in the Furness District. The band is not distinctly marked in the Westmorland Pennines; but a similar layer, separated by some 40 feet of rock from the base of the Upper *Dibunophyllum* Sub-zone, occurs in West Yorkshire between Ribble Head and Great Whernside, where the band again appears in the form of a yellow dolomite, and contains casts of large specimens of *Cyrtina septosa*. The specimens figured by Phillips[2] and Davidson[3] appear to have been collected from this band.

(*i* & *k*) The Upper *Dibunophyllum* Sub-zone.

This sub-zone comprises by far the thickest series of deposits of the Lower Carboniferous sequence in the North-Western Province, and marks the return of shallower water; the conditions, however, differed considerably from those which obtained during the deposition of the *Athyris-glabristria* Zone. The same conditions must have prevailed over a large area in Westmorland, Lancashire, Cumberland, Durham, Northumberland, and Yorkshire; and, as in the case of the lower sub-zone, there appears to have been direct connexion also with the South-Western Province, at all events, at the beginning of the period, for *Lonsdalia floriformis* marks the

[1] Q. J. G. S. vol. lxi (1905) p. 295 & pl. xxvi, fig. 4.
[2] 'Illustrations of the Geology of Yorkshire' vol. ii (1836) pl. xi, fig. 7.
[3] Monogr. Pal. Soc. 'Brit. Foss. Brachiopoda' vol. ii (1858–63) pl. xiv, fig. 8.

lower stage of the sub-zone almost everywhere throughout the country. In the Eastern Districts the beds belong to the Yoredale type of Phillips and the Geological Survey. The base of the sub-zone is, for convenience, taken at the lowest sandstone which there overlies the Melmerby or Knipe Scar Limestone, as it ushers in the change in lithological character. The upper limit of the sub-zone is much more difficult to define, and in one district at least (the Pennine District) the sub-zone persists well up into beds mapped as Millstone Grit by the officers of the Geological Survey. The separation of these beds into two divisions represented by the symbols D_2 and D_3 in other areas, cannot be satisfactorily attempted at present in the North-Western Province. This is due to the almost complete absence of *Cyathaxonia* Beds, examples of this genus being extremely rare and confined, so far as is known, to local occurrences in the Westmorland Pennine District; while no beds referable to the Pendleside Series have been met with in the districts described.

Another difficulty is introduced by the marked difference in the lithological and palæontological characters presented by the higher beds of the *Dibunophyllum* Zone in the Eastern and Western Districts respectively. Unfortunately, these beds have been denuded from the greater part of the Western Districts, so that the exact areas originally occupied by the two types and the character of the passage from one to the other cannot now be definitely stated. Of the portions still remaining, the northern and eastern outcrops, forming the Shap-Ravenstonedale and Pennine Districts, belong to the 'Yoredale' type, while the Southern and Western Districts belong to what we may, for convenience of description, call the Western or 'Kirkby Lonsdale' type. These two types are now separated over the greater part of the area by a wide tract of Lower Palæozoic rocks, although the eastern margin of the Kirkby Lonsdale District lies within 2 miles of the Yoredale rocks of Casterton Fell, from which, however, it is separated by the Dent and Craven system of faults.

It is no part of the object of this communication to enter into a detailed discussion of the causes which produced this difference in the character of these two types. The writer, however, has long been of the opinion that, although the change from the Yoredale type of deposits, now found north of the Craven Faults, to that found on the south side must originally have been a gradual one, the close proximity of these two types east of Kirkby Lonsdale at the present day suggests that here, at all events, the two types have been brought into their present positions by tectonic movements. This view was expressed by Dr. Marr as long ago as 1899, for he remarked in his work on the Limestone Knolls in the Craven District of Yorkshire that

'the Middle Craven Fault, in fact, appears to be a thrust-plane inclined downward towards the north . . . . . . if the fault be a thrust the disposition of the rocks is perfectly explicable . . . . . . if my interpretation of the structures south of the fault be true, these structures require thrusting to account for them.' (Q. J. G. S. vol. lv, 1899, pp. 352–53.)

(1) The Yoredale type.—This type is limited to the Shap and Pennine Districts.

Lithology.—The beds resemble generally the Yoredale rocks of the type area in Wensleydale, and also the well-known development of these beds on Ingleborough and Penyghent. They consist of alternations of limestones and sandstones, with subordinate shales and occasional thin coal-seams. The limestones vary in number in the two districts: eleven distinct beds being recognized in the Shap area, and fifteen in the Cross-Fell range. Occasionally one or two of these may unite to form a single thick limestone, as in the case of the Brackenslack and Maulds-Meaburn-Edge Limestones, which unite in the northern portion of the Shap District to form the Lowther Limestone. The exact correlation of the individual limestones of the two districts is not, however, of importance, except in so far as they contain similar faunas. The rocks in the two districts appear to have been deposited in direct continuity, and are only now separated as a result of the denudation which has taken place on the upthrow side of the Pennine Fault. The limestones are, as a rule, dark, impure, and ferruginous; they are frequently crinoidal, while many of them are markedly bituminous. Some are argillaceous, and these show a tendency to nodular and concretionary structures. The lower beds are usually fairly fossiliferous in both areas, but the fossils are seldom well-preserved. In the Shap District the higher beds are almost barren, and are locally dolomitized and impregnated with silica and hæmatite. In the Pennine District the corresponding beds are much richer in fossils. The sandstones are seldom fossiliferous, except in the neighbourhood of Middleton-in-Teesdale, where one bed occurs near the summit of the Yoredale Series crowded with casts of *Spirifer* cf. *bisulcatus*. The shales are quite subordinate in the Shap District, and are seldom exposed. In the Pennine area, however, several beds of black shale occur, which are often crowded with bryozoa and small brachiopods.

The Yoredale Beds may, for convenience of description, be considered under two divisions:—

	Bands.
Upper, with *Dibunophyllum muirheadi* abundant.	'Botany Beds.' *Phillipsastræa* Band. *Saccammina-carteri* and *Productus-edelburgensis* Band.
Lower, with *Lonsdalia floriformis* and *Cyathophyllum regium*.	*Productus*-cf. *giganteus* Band. Nodular *Girvanella* Bed. (At the base.)

The lower division with *Lonsdalia floriformis* includes all the beds, from the lowest sandstone to the base of the Maulds-Meaburn Limestone of the Shap District or the Jew Limestone of the Pennine Escarpment (the Hardraw-Scar Limestone of Wensleydale). All these beds lie above the Knipe-Scar Limestone and the true Melmerby-Scar Limestone; but one or two of the lower limestones are occasionally included in the term Melmerby-Scar Limestone on the maps of the Geological Survey, in such wise that the upper boundary of the Melmerby-Scar Limestone sometimes does, and sometimes does not coincide with the base of the Upper *Dibunophyllum* Sub-zone. The beds contain a similar fauna throughout these two districts, and much the same assemblage is also met with at Humphrey Head in the Grange District. *Lonsdalia floriformis* and *Cyathophyllum regium* are the most characteristic fossils, together with reefs of *Lithostrotion junceum*, while *Diphyphyllum lateseptatum* is also present in the sub-zone in many places. *Productus giganteus* again is common in the Pennine area, but is rare in the Shap District; and *Dibunophyllum muirheadi* occurs locally in the southern portion of the Shap District.

(*i* 11) The Nodular *Girvanella* Band.

This is one of the most constant horizons in the North of England, and occurs at intervals, from the extreme north of Northumberland to Penyghent. It invariably forms the base of the Upper *Dibunophyllum* Sub-zone, and consists of a few inches of impure nodular limestone. The nodules, which average about an inch in diameter, are not true concretions, but are formed of concentric coats of carbonate of lime deposited round fragments of shells, crinoid-stems, etc. Microscopic sections show that the deposit is probably of organic origin, and is associated with more than one form of algal growth. *Girvanella* tubes occur in many of the nodules, while in others the microscopic structure is obscure. On freshly-broken surfaces the nodules appear as brown spots, and exhibit a porcellanous texture resembling *Solenopora* and other algal growths. On weathered surfaces they stand out in relief, and their concentric structure is clearly visible. In some exposures the nodules are stained by hæmatite. The best exposure of the band occurs on the east side of Humphrey Head in the Grange District, and at Tirell and Wintertarn in the Shap District. In the Pennine District it is again found in the lowest Yoredale limestone, exposed in Scordale Beck and High-Cup Gill.[1]

The *Productus*-cf. *giganteus* Band.—This band has only been met with in the Shap and Pennine Districts: that is to say, where the Yoredale type is developed. It is well exposed on Gathorn Plain, and there forms the highest layers of the Maulds-Meaburn Limestone. This band has also been found at the same horizon in the Pennine escarpment. Where present, it may be taken as the upper limit of the *Lonsdalia-floriformis* Beds.

(*i* 12) The *Saccammina-carteri* Band

is especially well developed in the Shap District, where it occurs in the Little Strickland Limestone and can be traced throughout

[1] Outside the area under description the same band occurs in the Oxford Limestone in Northumberland, and in the first limestone above the massive Lower Scar Limestone above Hunt Pot, Penyghent, and near Ribble Head.

the district, between the Eamont and Great Asby. This species has long been known from the Yoredale beds of Durham and Northumberland, and the horizon at which it occurs in the Shap District appears to agree with its lowest-known occurrence in Northumberland. The index-fossil is associated with *Productus edelburgensis*, *Pr. latissimus*, and *Aulophyllum* cf. *pachyendothecum*. The band is also marked by the absence of *Lonsdalia floriformis* and *Cyathophyllum regium*, characteristic forms in the underlying beds.

The higher Yoredale beds, as stated above, are separated locally as a matter of convenience. They are characterized by the abundance of *Dibunophyllum muirheadi*, which, however, is found also, locally, in the *Lonsdalia* Beds below. This species occurs in great abundance in many of the Upper Yoredale limestones, notably the Great or Main Limestones, and persists into the Botany Beds in the Pennine Area. The division includes all the beds, from the Little Strickland or Tyne-Bottom Limestone to the highest limestone at Botany in the Middleton-in-Teesdale District. In the Shap District the majority of these beds are almost devoid of fossils; but in the Pennine District many of the limestones, such as the 'Great' and 'Four-Fathom,' are highly fossiliferous, and abound in specimens of *Dibunophyllum muirheadi*, *Lonsdalia floriformis*, *Productus giganteus*, *Pr. latissimus*, etc.: many of the shales, and occasionally also the sandstones, are fossiliferous.

(*k* 13) The Botany Beds (*Phillipsastræa* Band).

This band is formed of calcareous shales and limestones, and is about 30 feet thick. It is situated high up in the series of grits and shales coloured as 'Millstone Grit' in the Geological Survey maps. The fauna is of considerable interest, and includes numerous specimens of *Dibunophyllum muirheadi*, together with species of *Productus* and *Spirifer* characteristic of the higher limestones of Derbyshire. It is the highest truly marine fauna met with in the Lower Carboniferous beds of the North-Western Province, and contains thin reefs of *Phillipsastræa radiata*.

(2) The Kirkby Lonsdale or South-Western type.—This type is developed only in the southern portion of the area west of the Craven and Dent Faults. It is exposed in three districts: namely, in the country south of Kirkby Lonsdale; in the neighbourhood of Gleaston and Little Urswick, in the Furness District; and in two small inliers south of Carnforth, in the Arnside District. It differs from the Yoredale type just described by the almost total absence of limestone, except at the base, and by the affinities which many of its fossils exhibit to those of Derbyshire and the 'Knoll-Reef' country south of the Craven Faults. The two inliers of limestone which occur in the Millstone Grit south of Carnforth, although much crushed, contain patches of highly fossiliferous rock. We can best regard them as the western

continuation of the Clitheroe and Gargrave limestone-knolls, brought into their present positions by thrusting.

Lithology.—The base of the zone is composed of dark limestone and calcareous shales, following directly upon the Lower *Dibunophyllum* Sub-zone. These beds are succeeded by shales and massive sandstones, which have been extensively quarried for building-stone. In the Kirkby Lonsdale District they contain only one band of limestone, almost entirely made up of crinoid-fragments and destitute of other fossils. At Hawkfield, in the Furness District, however, this horizon is rather more fossiliferous.

Fauna.—The fauna of the lowest limestones and shales is poor in corals, but rich in brachiopods. On the whole, both in the Kirkby Lonsdale and in the Furness Districts, it is characterized by the large number of brachiopods which are met with in the higher portion of the Derbyshire limestone massif, such as *Productus semireticulatus*, *Pr. latissimus*, etc.

[1] *Girvanella* nodules.

Aulopora sp.
Caninoid *Campophyllum*.
[1] *Cyathophyllum regium* Phill.
Aulophyllum cf. *pachyendothecum* Thomson.
Dibunophyllum muirheadi Nich. & Thomson.
Diphyphyllum lateseptatum M'Coy.
Lithostrotion irregulare (Phill.).
Lithostrotion junceum (Flem.).
Lithostrotion m'coyanum Ed. & H.
Lithostrotion portlocki (Bronn).
Lonsdalia floriformis (Mart.).

Syringopora sp.

Chonetes cf. *compressa* Sibly.
Productus cf. *costatus* Sby.
Productus giganteus Mart.
Productus latissimus Sby.
Productus cf. *longispinus* Sby.
Productus semireticulatus Mart.
Pugnax pugnus (Mart.).
Spirifer bisulcatus Sby.
Spirifer duplicicostus Phill.
Spirifer triangularis Mart.
Spirifer crassus de Kon. = *planicostus* M'Coy.

Edmondia sulcata (Phill.).

III. The Shap and Ravenstonedale Districts. (Type Districts.)

The development in these districts may be taken as typical of the succession in the North-Western Province, for it contains the whole of the northern sequence of the Lower Carboniferous rocks up to the Millstone Grit. The *Michelinia* Zone, however, is here but poorly developed, and the higher beds of the Upper *Dibunophyllum* Zone are almost devoid of fossils. These zones must, therefore, be studied more fully in the Arnside District on the south-west and in the Pennine District on the east respectively.

The districts comprise the Carboniferous area lying between the River Eamont and the Dent Fault. The general strike of the beds is north-north-west and south-south-east; but in the neighbourhood of Orton it sweeps round, and runs more directly east and west, returning again to its original direction in Ravenstonedale. The average dip in the neighbourhood of Shap is between 3° and 4° north-eastwards; but east of Orton, where the strike slews

[1] Not found outside this horizon.

round and the ground is traversed by dip-faults, it is higher and more irregular, averaging about 10° north-north-eastwards.

The districts are included in Sheets 30, 31, 39, and 40, Old Series, of the Geological Survey map, and the Carboniferous rocks have been briefly described in the sheet memoirs on Appleby and Mallerstang by Tiddeman, Goodchild, Dakyns and others. A description of a general traverse, from Wasdale Crag, by way of Shap, to the Valley of the Eden near Appleby, is given by J. S. Bland.[1]

The lowest Carboniferous rocks of this area may conveniently be divided into five lithological divisions. The relation of these to the palæontological subdivisions is expressed in the following table:—

Lithological Divisions.	Palæontological Zones.
(7) The Yoredale Beds. Alternations of sandstones with subordinate shales and impure limestones.	Upper *Dibunophyllum* Sub-zone.
(6) The Knipe-Scar Limestone. Pure white limestones forming the 'Scars' of the District, passing near Kirkby Stephen into shaly limestones.	Lower *Dibunophyllum* Sub-zone. *Nematophyllum-minus* Sub-zone. *Cyrtina-carbonaria* Sub-zone (south of Shap only).
(5) The Orton and Ashfell-Sandstone Series. Red and yellow sandstones, with a few calcareous bands in the south.	*Cyrtina-carbonaria* Sub-zone (north of Shap only). Gastropod Beds (upper portion only in Ravenstonedale). *Michelinia* Zone (north of Orton only).
(4) The Blea-Flatt and Tarn-Sike Limestones. Grey and pink shaly limestones, occurring only between Orton and the Dent Fault. In the north they are merged in the Orton Sandstone.	Gastropod Beds (lower portion). *Michelinia* Zone.
(3) The Shap and Ravenstonedale Dolomite Series. Including porcellanous limestones, algal beds, and shales with ostracods.	*Athyris-glabristria* Zone.
(2) Basement Beds. Red shaly sandstones and conglomerates containing Shap-Granite felspars.	No fossils.
(1) Pinskey Beds. Yellow sandy dolomites and dark mudstones, only found in Ravenstonedale.	*Spirifer-pinskeyensis* Zone.

The faunal zones run approximately parallel to the outcrop of the lithological divisions, but the Orton Sandstone enters

[1] Trans. Manch. Geol. Soc. vol. iv (1862–64) pp. 44–61.

at a progressively earlier period as we approach the northern end of the district: thus cutting out first the Gastropod Beds, then the *Michelinia* Zone, and finally the highest beds of the underlying Shap Dolomites. The upper beds of this sandstone also gradually replace the *Cyrtina-carbonaria* Sub-zone in the same direction. As a result, the overlying *Nematophyllum-minus* Sub-zone rests directly upon the sandstone at the base of Hardendale Nab. Even this sub-zone is almost merged in the sandstone at the northern extremity of the district. At the same time, the thickness of the Orton Sandstone diminishes in the same direction, from about 500 feet under Ashfell Edge to 200 feet or less in the neighbourhood of Shap. The net result may be summarized by stating that the individual beds thin gradually when traced from south to north. This thinning is not due to an overlapping of the higher Carboniferous zones against the Lower Palæozoic land-surface, for the Shap Dolomites continue uninterruptedly as far north as the district extends, but is due to the wedge-like thinning of zone after zone in a northerly direction. This would point to a more rapid deepening towards the southern end of the district, especially during the period when the lower zones were being deposited. It will be best to describe a typical section across the district in the neighbourhood of Shap, which may be supplemented by a description of the beds in Ravenstonedale where some of the zones are more fully developed.

The Shap District.

A general section across the district is shown in the accompanying diagram (Pl. LVI, fig. 1). Starting near Shap Abbey it traverses the *Thysanophyllum* Band, a little to the west of Shap village. The section is then transferred along the strike to the outcrop of the same band in Docker Beck. From here it runs nearly due eastwards through Hardendale Nab to the base of the Upper *Dibunophyllum* Sub-zone on Wickerslack Moor. At this point it is again transferred about 2 miles in a north-westerly direction, along the line of strike, to Wintertarn Quarry. From here onwards it traverses the higher beds of the *Dibunophyllum* Zone, until they disappear under the Permian rocks in the neighbourhood of King's Meaburn.

The *Athyris-glabristria* Zone.

The lowest beds are exposed on the right bank of the River Lowther in the cliff opposite Shap Abbey, while the upper portion of the zone is well seen in Docker Beck, a little to the south of Shap village.

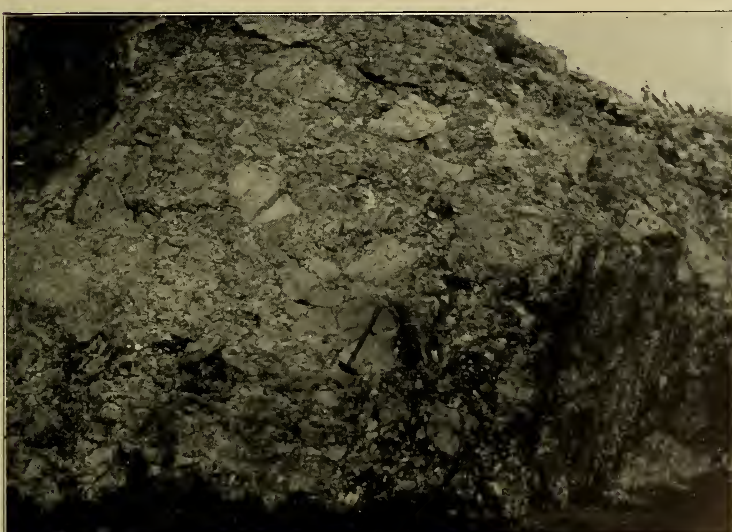
The Basement Beds here consist of some 30 feet of irregularly-bedded shaly sandstone and conglomerate; they contain pebbles of the underlying Ordovician rocks, together with fragments of Shap Granite.

Fig. 1.—*Shap Abbey Cliff:* Solenopora *Sub-zone.*

P. de G. B. photo.

[The figure points to the Lower *Solenopora* Band: the *Proava* Band lies at the top of the cliff.]

Fig. 2.—*Halton Green, Arnside District: Knoll-reef Breccia* (D_2–D_3). *(See p. 515.)*



E. J. G. photo.

The *Solenopora* Sub-zone.—The beds overlying the conglomerate in the Shap-Abbey section consist of 60 feet of compact cement-stones and dun-coloured magnesian limestones with partings of shale (see Pl. XLIV, fig. 1). Under the microscope many of the beds are seen to contain quartz-grains, and to be rich in the remains of foraminifera. The following is a typical percentage analysis [1] of the dun limestones :—

$CaCO_3$	71·13
$MgCO_3$	19·72
FeO, etc.	1·78
Insoluble residue	7·37
Total ...	100·00

The origin of the magnesium carbonate has already been discussed (see pp. 457–458).

The shale-band which occurs about half-way up the cliff is crowded with the remains of bryozoa and the flattened shells of *Athyris glabristria* still bearing their fringe-spines. A *Solenopora* Band occurs in the lowest limestone immediately below the bryozoa-shale, and another similar layer is seen near the top of the cliff. It is interesting to note that the specimens of *Solenopora* show no trace of dolomitization, notwithstanding the fact that the matrix in which they occur is highly dolomitic. Miss K. Burke, B.Sc., of University College (London), to whom I am indebted for analyses of specimens of *Solenopora* from this section, finds that they contain over 99 per cent. of calcium carbonate. This fact would appear to point to the process of dolomitization having been selective, and affords food for speculation regarding the original composition of the thalli constituting these organisms, since among living calcareous algæ some are formed of aragonite and others of calcite. It is possible, however, that the markedly compact character of the *Solenopora* nodules may have enabled them to resist alteration; while the fragments of brachiopods and other organisms have been more readily dolomitized.[2] *Athyris glabristria* occurs abundantly, and forms a band at the top of the cliff. Dr. Vaughan, who has kindly examined specimens from this locality, reports that many of these resemble closely forms from Z_2 of the Bristol District. The general fauna of this sub-zone has already been tabulated (see p. 460).

The *Camarotoechia-proava* Band crops out a few yards back from the top of the cliff; it is poorly developed here, and has not been traced any farther in a northerly direction. To the south-east, however, the zone increases in importance, and in the neighbourhood of Rayne the band is crowded with the index-fossil. At the base of this bed occurs a layer largely made up of plates

[1] For this and other analyses I am indebted to Miss Winifred May, B.Sc., and Mr. M. R. Reid, of University College (London).

[2] The *Girvanella* nodules at the base of the Upper *Dibunophyllum* Sub-zone on the other hand, are frequently much more highly impregnated with hæmatite than the surrounding matrix.

and spines of *Archæocidaris*, together with the plates of *Palæchinus*. This layer has been largely quarried in the neighbourhood of Keld, and slabs from this horizon form a feature of the walls in the neighbourhood; the exposures are, however, now grassed over. Above the *C.-proava* Band occurs a series of dun-coloured magnesian limestones, which are well exposed in the lower portion of Docker Beck, west of the main road; these contain numerous drusy cavities, but have yielded no fossils.

North of Shap the *Solenopora* Sub-zone thins out gradually, and fossils are scarce. To the south-east very few exposures occur at this horizon, until we reach the neighbourhood of Fawcett Mill and Kelleth.

The *Seminula-gregaria* Sub-zone: the *Productus-globosus* Band.

The algal layer lying at the base of the band attains its fullest development in this district. On the line of section it is found cropping out in the field above the Abbey Cliff; but it is better exposed in Docker Beck, at the base of the old quarry beside Force Bridge, 300 yards south of the Greyhound Inn. The general outcrop over the district is shown on the map (Pl. LIII). The most important exposures occur between Chapel Beck and Newbiggin, and include a curious series of thin undulating sheets of limestone apparently representing another form of algal growth.

The main portion of the band is exposed in the Force-Bridge quarry, where it is represented by the hard purple dolomite behind the lime-kiln. The band is not very fossiliferous, but contains the chief forms characteristic of this horizon (tabulated on p. 463), and, in addition, specimens of *Murchisonia marri* and examples of the teeth of *Chomatodus cinctus*.

Farther south, a third of a mile beyond Shap Toll-Bar, occurs an old excavation now grassed over, first pointed out to me by Dr. J. E. Marr. It has yielded a comparatively rich fauna, especially characterized by the large number of gastropods, notably *Murchisonia marri*, for which it is the type-locality. The fossils occur in a pale buff-coloured magnesian limestone, most of the shells being replaced by crystalline calcite. In the upper part of the quarry, this bed is succeeded by a dark dun-coloured rock containing numerous casts of *Syringothyris cuspidata* and *Athyris glabristria*.

Fauna.

Archæosigillaria vanuxemi Göppert.

Athyris glabristria (Phill.).
Seminula gregaria (M'Coy), abundant.
Syringothyris cuspidata (Mart.).

Aviculopecten sp.

Conularia quadrisulcata Sby.
Euomphalus acutus Sby.
Flemingia suturalis (Phill.).
Loxonema acutum de Kon.
Loxonema rugiferum Phill.
Murchisonia marri Donald, abundant.
Naticopsis (*Pileopsis*) *neritoides* (Phill.).
Pleurotomaria (*Ptychomphalus*) *vittata* Phill.

Nautilus biangulatus Sby.
Cycloceras lævigatum M'Coy.
Orthoceras sp.

Leperditia okeni.

This development is somewhat exceptional, the gastropod fauna being unusually rich. When the band next appears near Fawcett Mill, 5½ miles to the south-east, the character of the deposit, as well as its fauna, has resumed the normal development. The rock here consists of a grey compact limestone, containing patches crowded with *Rhynchonella fawcettensis* and *Productus rotundus,* together with a few examples of *Pr. globosus.* Above the *Pr.-globosus* Band in Docker Beck the beds are composed of unfossiliferous dun-coloured dolomites which contain occasional 'fucoid' impressions, similar to those found at identically the same horizon at Meathop (Arnside District).

The *Thysanophyllum-pseudovermiculare* Band crops out as a low escarpment in Shap village, between the railway-station and the old Moot Hall. The rock is a compact grey limestone; and the coral occurs in reef-like masses, accompanied by 'fucoid' impressions and early examples of *Productus* cf. *corrugato-hemisphericus.* The outcrop of the band is influenced by the shallow synclinal fold which alters the strike of the beds to the east of Rosgill; it crosses the village of Shap, and runs north-westwards to the neighbourhood of Helton Flecket. Along this line it is exposed in several shallow workings. In Docker Beck this band forms the lower waterfall about 350 yards east of the railway-arch. The rock here contains oolitic layers, with *Bellerophon costatus* and *Seminula gregaria.* Everywhere in the neighbourhood of Shap this band is thin and inconstant, but increases in importance as it is traced in a south-easterly direction. It is well exposed on Birkbeck-Fells Common, in Rais Beck, and on Ravenstonedale Moor. The beds overlying the *Thysanophyllum* Band form the lower waterfall in Docker Beck, and are rich in *Bellerophon.* They are still composed of magnesian limestones, but are, on the whole, more calcareous and show a marked tendency to oolitic structure. Above the lower waterfall, the bed of the stream forms a nearly level reach covered with alluvium.

The Brownber Pebble-Bed is not well seen in Docker Beck, but a good exposure occurs in the railway-cutting east of Shap village, behind St. Michael's Church, where it immediately overlies the *Thysanophyllum* Band. It is here over 20 feet thick, and contains *Syringothyris cuspidata*, *Camarophoria isorhyncha,* and *Athyris glabristria.* The bed is not well exposed between Shap and Orton; but to the east of the latter village it has been extensively quarried on Ravenstonedale Moor, about three-quarters of a mile north of Wath. This is the best exposure of the bed, and its special petrographical characters can be well studied; it is also more fossiliferous here than elsewhere, and the faunal list tabulated on p. 465 is chiefly compiled from this section. Still farther east it is exposed in the type-locality, near Brownber, in a small cutting by the roadside, west of the railway-arch. There are good reasons for supposing that this bed is contemporaneous with similar pebble-beds found at the base of the succession in the Westmorland portion of the Pennine Chain, and that the pebbles were derived from the quartz-veins which traverse the Lower Palæozoic rocks in the neighbourhood of Brownber Pike in the Cross-Fell Inlier.

The *Spirifer-furcatus* Band forms a thin bed, with a structure resembling oatmeal; it crops out in Docker Beck about 20 yards above the upper waterfall, and just below the ford. The matrix is somewhat oolitic, and the shells are replaced by crystalline calcite. This 'oatmeal bed' may be correlated with the *Spirifer-furcatus* Band of Meathop in the Arnside District.[1]

The *Michelinia* Zone enters in Docker Beck near the base of the Orton Sandstone Series, about 12 feet above the *Sp.-furcatus* Band and about 160 yards up-stream from the upper waterfall. It is represented by a band of oolitic limestone about a foot thick, crowded with the shells of *Camarophoria isorhyncha*. The oolitic coatings have in many cases been deposited round rolled quartz-grains, and the fossils are also rolled and somewhat fragmentary, pointing to a continuation of shallow-water conditions and current-action throughout this period.

Fauna.

Cyathophyllum multilamellatum M'Coy. Abundant.
Michelinia grandis M'Coy.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (M'Coy). Abundant.
Derbya sp.
Productus cf. *corrugato-hemisphericus* Vaughan.
Reticularia lineata (Mart.).
Seminula cf. *ambigua* (Sby.).
Syringothyris cuspidata (Mart.). Rare.

Bellerophon costatus Sby.
Straparollus sp.

Polyrhizodus sp.

As previously mentioned,[2] the rich fauna of the *Michelinia* Zone of the Western Districts is almost unrepresented in the Shap and Pennine Districts. The occurrence of a large example of *Michelinia grandis*, associated with *Camarophoria isorhyncha*, in this section shows that the lower portion of the *Michelinia* Zone is represented here, and that the upper portion of the zone must therefore be merged in the overlying Orton Sandstone. No fossiliferous exposures of the *Michelinia* Zone are observed south of Docker Beck until we reach Ravenstonedale Moor, where small outcrops of this zone occur in two potholes immediately above the quarries opened in the Brownber Pebble-Bed.

Productus corrugato-hemisphericus Zone: The Gastropod Beds.—The exposures of the Orton Sandstone in Docker Beck below Water's Farm call for no special comment, and they yield no fossils beyond obscure casts of lamellibranchs and plant-remains; a thin layer of pebbles, however, recalling the Brownber

[1] See Geol. Mag. dec. 5, vol. vii (1910) p. 118.
[2] *Ibid.* dec. 5, vol. iv (1907) p. 70.

Pebble-Bed, occurs a short distance below the farm. Above Water's Farm a bed of hard calcareous mudstone crops out on the left bank of the stream, and from it the following species have been collected:—

Syringopora cf. *distans* Fischer.
Lithostrotion martini M. Edw.
Zaphrentis enniskilleni M. Edw.

Productus cf. *punctatus* Mart.
Productus cf. *pyxidiformis* de Kon.
Rhipidomella michelini (L'Éveillé).

Seminula ambigua (Sby.).
Spirifer sp.

Allorisma variabilis (M'Coy).
Aviculopecten cf. *interstitialis* Hind.
Crenipecten semicircularis (M'Coy).

This fauna is evidently the attenuated representative of that which characterizes the lower portion of the Gastropod Beds at Blackstone Point in the Arnside District, described later, and shows that this sub-zone (as well as the greater portion of the *Michelinia* Zone) is merged in the Orton Sandstone. South of Docker Beck very few exposures are met with in the sandstone, and these contain only casts of *Stigmaria*. South of Long-Scar Pike, however, a calcareous mudstone occurs, resembling that just described above Water's Farm. As we pass to the south-east of the Shap District, the sandstone episode begins at progressively higher horizons; so that the lower portion of the Gastropod Beds as well as the *Michelinia* Zone eventually crop out as calcareous deposits beneath the sandstone on Ravenstonedale Moor, and in the neighbourhood of Scandal Beck. Above the sandstone the lowest layers of the limestone which underlies the *Cyrtina-carbonaria* Sub-zone on Orton Knott, appear also to belong to this sub-zone; they include bands of lighter-coloured breccia, embedded in a darker, more crystalline, matrix. It seems probable that, in this case, the breccia is due to contemporaneous erosion.

The *Cyrtina-carbonaria* Sub-zone has not been observed in the Docker-Beck section. It appears to be merged in the upper portion of the Orton Sandstone. A short distance to the south, however, it is met with below Long-Scar Pike, and it gradually increases in importance as it is traced eastwards into Ravenstonedale. The lithological characters and organic contents of this sub-zone have already been described (see pp. 470–71).

Localities.—Long-Scar Pike, Orton Knott, Sunbiggin, Severals, and Smardale Gill.

The *Nematophyllum-minus* Sub-zone is comparatively thin in the neighbourhood of Shap; it is exposed near a dried-up pond, about 80 yards west of 'The Nab' Farmhouse, and also near the head of Docker Beck. It is neither so thick nor so well developed as in the Western Districts, and *Chonetes papilionacea* is a rare fossil here, although so abundant at this horizon in the Arnside and Grange Districts. The rock is a grey limestone, weathering white. The sub-zone increases in thickness as it is traced southwards and eastwards into the Ravenstonedale District. The index-fossil occurs somewhat abundantly, and is accompanied by species of *Syringopora* and *Lithostrotion*. These are usually silicified, and form conspicuous tufts on the weathered surfaces. The general outcrop is shown on the accompanying map (Pl. LIII); a list of the fauna has already been tabulated (p. 473).

The Bryozoa Band crops out on the line of section near 'The Nab' Farmhouse, a few feet above the highest occurrence of *Nematophyllum minus*; it is here about 30 feet thick. The rock is fine-grained, frequently porcellanous, and contains a few thin layers rich in *Calcispheræ* and allied forms associated with plant-remains. From 'The Nab' Farmhouse this band can be traced in a north-westerly direction along 'the Edges' to the lime-kiln at Sweetholme, where it is highly fossiliferous, and thence by the base of Knipe Scar to Whale. To the south of Hardendale Nab it is exposed under Long-Scar Pike, and occurs also as an inlier near the head of Lyvennet Beck, where it includes the interesting porcellanous layer containing *Calcispheræ* and plant-remains (see Pl. XLVII, fig. 4). At the southern end of the district the band is exposed on Crosby Garret Fell, Weather Hill, and Begin Hill, and in the neighbourhood of Scandal Beck; it is usually much more fossiliferous than the overlying and underlying beds. It reaches its most massive, and in many respects most interesting, development on Orton Knott, where it includes a bed of fine grey and yellow limestone crowded with bryozoa, in particular *Fenestella*, and is further characterized by the abundance of Capulids and the large size of the specimens of *Pterinopecten dumontianus*. The exposure of this band on Crosby Garret Fell closely resembles the Bryozoa Band which occurs at the same horizon in the Pennine District to the east of Roman Fell, both exposures being characterized by the abundance of *Stenopora compacta*.

The Lower *Dibunophyllum* Sub-zone forms the main mass of the Knipe-Scar Limestone throughout the Shap District, and gives rise to the fine series of escarpments which constitute so marked a feature of the country between Askham and Little Asby: notably, Knipe Scar, Hardendale Nab, Long-Scar Pike, and Orton Scar. On the east of the water-parting these beds form the bare dip-slopes in the neighbourhood of Oddendale, Great and Little Asby, and Gathorn Plain. The beds are composed of massive sub-crystalline grey limestones, and include (as usual) a 'spotted' bed near the base, which is well exposed at Trainrigg. Pseudo-breccias are also conspicuous on the surface of the dip-slopes near the summit of the sub-zone, and west of Oddendale they form the limestone-ridges locally known as 'Deadmen's Graves.'

In the neighbourhood of Shap the sub-zone is about 300 feet thick; but it increases in thickness to the south of Hardendale Nab, and on Gathorn Plain cannot be far short of 500 feet thick. A conspicuous feature of the fauna is the abundance and size of the specimens of *Alveolites capillaris*, which occur in subspherical masses measuring as much as 10 inches in diameter.

The *Chonetes*-aff. *comoides* Band is well developed in this district. It lies about 20 feet below the summit of the Lower *Dibunophyllum* Sub-zone, and is well exposed on the line of section at Grandy, close to Oddendale Farm, and elsewhere along the strike, notably on Gathorn Plain.

Fauna.

Nematophyllum (*Lithostrotion*) cf. *minus* M'Coy.
Lithostrotion junceum (Flem.).
Lithostrotion portlocki (Bronn).
Dibunophyllum muirheadi Nich. & Thomson.
Chonetes aff. *comoides* (Sby.).
Daviesiella cf. *llangollensis* (Dav.) (young).
Cyrtina septosa (Phill.).
Productus striatus Fischer.
Productus hemisphericus Sby.
Productus cf. *maximus* M'Coy.

This band is succeeded by about 20 feet of a dark nodular limestone, which is almost devoid of fossils.

The Upper *Dibunophyllum* Sub-zone: The *Lonsdalia* Beds.—In the Shap District the rocks of this sub-zone belong to the Eastern or Yoredale type described above. The massive Knipe-Scar Limestone is everywhere overlain in this district by a thin sandstone which forms the base of the Yoredale Series, and this may conveniently be taken as the base of the Upper *Dibunophyllum* Sub-zone. The three lowest limestones, from the Askham to the Maulds-Meaburn Limestone inclusive, contain *Lonsdalia floriformis*.

On the Geological Survey map the Askham Limestone is correlated with the middle portion of the Melmerby-Scar Limestone of the Pennine escarpment; but, as shown below, the Melmerby-Scar Limestone contains the upper portion of the *Nematophyllum-minus* Sub-zone and the Lower *Dibunophyllum* Sub-zone, and is therefore the equivalent of the Knipe-Scar Limestone of the Shap District.

The Askham Limestone and the beds immediately overlying it are best examined at Wintertarn Quarry, about 2 miles north-west of Oddendale, the point to which the line of section is transferred.

The *Girvanella* Band occurs near the base of Wintertarn Quarry, close to the lime-kiln, the nodules being stained with hæmatite: fossils are scarce, but *Lonsdalia floriformis*, *Chonetes* cf. *compressa* Sibly, and *Pugnax pugnus* occur. A small exposure in the overlying limestone has also yielded specimens of *Lonsdalia*. The same beds may be further examined on Wickerslack Moor, where they contain reefs of *Lithostrotion junceum* at the base and *Cyathophyllum regium* near their summit. Farther north the band forms an outlier on Outscar, where it contains a fairly rich and characteristic fauna. At Thorp, on the extreme northern border of Westmorland, the band is again met with, and the nodules are here also stained by hæmatite.

The *Lonsdalia* Beds are well exposed in the neighbourhood of Haber, west of Crosby Ravensworth; and on Bank Moor, close to the road from Orton to Appleby, where they contain reefs of *Lithostrotion m'coyanum* and *Cyathophyllum regium*. Farther east good exposures occur at Beecham's Quarry and in Coal-Pit Sike, both of which are characterized by the abundance of *Dibunophyllum muirheadi*; the horizon of these beds may, however, be slightly higher in the Yoredale Series than that of the beds exposed at Outscar and Wintertarn.

The *Productus*-cf. *giganteus* Band.—The highest limestone containing *Lonsdalia floriformis*, which crops out on Bank Moor, is locally known as the Mauld's-Meaburn Limestone; it is characterized in this locality by a great abundance of specimens of *Pr.* cf. *giganteus*,[1] which occur embedded in shale near the summit of the limestone. As this form has not been met with outside the two Eastern Districts, it is thought well to append a list of the chief fossils found associated with it:—

Lithostrotion portlocki (Bronn).	*Productus* cf. *giganteus* Mart.
Lithostrotion junceum (Flem.).	*Productus latissimus* Sby.
Lonsdalia floriformis (Mart.).	*Productus* cf. *edelburgensis* Phill.

The *Saccammina-carteri* Band occurs in the Little Strickland Limestone, which is separated from the preceding band by a somewhat massive sandstone. It is exposed near High Sides on the line of section. Fossils are not abundant, but the following occur:—

Saccammina carteri Brady.	*Lithostrotion junceum* (Flem.).
	Lithostrotion irregulare (Phill.).
Aulophyllum cf. *pachyendothecum* Thomson.	*Productus latissimus* Sby.
Diphyphyllum lateseptatum M'Coy.	*Productus edelburgensis* Phill.

Lonsdalia does not, apparently, persist up to this horizon in the Shap District. *Saccammina carteri* occurs abundantly near the top of the bed, recalling the well-known 'Spotted Post' of the Durham quarrymen. This is the only horizon at which I have met with this interesting foraminifer in the North-Western Province, and it has not been previously recorded from Westmorland or Lancashire. In Northumberland and Durham it is especially characteristic of the Acre and Four-Fathom Limestones, although it is occasionally found in the limestone below.

The Little Strickland Limestone of the Shap District corresponds to the Tyne-Bottom Limestone of the Pennine District and, probably, to the Eelwell Limestone of the Lowick district in Northumberland, which lies next below the Acre Limestone. The band can be traced from Little Strickland, by Greenrigg and Bysteads, to Bank Moor; everywhere it is characterized by the abundance of *Saccammina* associated with *Productus edelburgensis*.

The higher beds of the Yoredale Series to the east of Shap call for no special description: they are, as a rule, unfossiliferous, and the limestones are locally dolomitic and frequently stained with hæmatite. Farther south, between Crosby Ravensworth and

[1] This fossil is probably distinct from *Pr. giganteus* Mart., and is practically limited to this horizon in the North-Western Province.

Burrells, the limestones are occasionally fossiliferous, but no examples of *Cyathaxonia*, which is so characteristic of the D_3 beds of the Midland area, have been found, nor any of the forms usually met with at that horizon. The upper limestones are here highly magnesian, and the dolomitized fragments in the Permian Brockrams at Burrells may well have been directly derived from these magnesian limestones.

The Ravenstonedale District.

The rocks in this district form the southern continuation of the Shap sequence.[1] The district includes all the Carboniferous rocks which lie between the North-Eastern Railway and the Dent Fault. The lower beds dip fairly uniformly north-eastwards at about 15°: decreasing somewhat on the east of the water-parting, but increasing again in the neighbourhood of Kirkby Stephen. The total thickness of Carboniferous rocks exposed in the district is between 3000 and 3500 feet. The lowest beds are well seen between the base of the Howgill Fells and Ashfell Edge, while the higher beds form the dip slope between Ashfell Edge and Kirkby Stephen; here, in places, the dip almost coincides with the slope of the ground, so that the *Nematophyllum-minus* Beds, the Bryozoa Band, and the Lower *Dibunophyllum* Sub-zone occupy a considerable extent of country on the east of the water-parting. The highest beds near Kirkby Stephen cannot, however, lie far below the base of the Upper *Dibunophyllum* Sub-zone. The district is traversed by a series of nearly north-and-south faults which, nevertheless, do not affect the general interpretation of the succession. The section (Pl. LVI, fig. 2) gives a general idea of the sequence in this district. The important points to be noted in a comparison of this development with that in the Shap District are:—

(1) The presence of a fossiliferous series of deposits in Pinskey Gill, which underlie the Shap Basement Conglomerate and represent older beds than any found elsewhere in the area, and moreover contain an unique fauna.

(2) The increased thickness and consequent greater importance of the members of the series lying below the Ashfell Sandstone.

(3) The distinctly later period at which the sandstone phase (represented in the north by the Orton Sandstone and in the south by the Ashfell Series) begins in the Ravenstonedale District. Thus the base of the Gastropod Beds in Tarn Sike, close to the Dent Fault, lies about 350 feet below the base of the Ashfell Sandstone; whereas the same horizon at Shap (in the Docker-Beck section above Water's Farm) lies 60 feet above the base of the corresponding Orton Sandstone.

(4) The change in the petrological and palæontological characters of the Lower *Dibunophyllum* Sub-zone, which is here represented by a shaly argillaceous limestone and is characterized by the general absence of Dibunophyllids and *Cyathophyllum murchisoni*, also by the presence, in its upper portion, of reefs of *Lithostrotion junceum* which are elsewhere characteristic of the base of the Upper *Dibunophyllum* Sub-zone.

(5) The absence of the Upper *Dibunophyllum* Sub-zone, due to the overlap of the Permian beds on the Lower *Dibunophyllum* Sub-zone in the neighbourhood of Kirkby Stephen.

[1] Geol. Mag. dec. 5, vol. iv (1907) pp. 70–74.

The Pinskey-Gill Beds.—These beds are named from their occurrence in Pinskey Gill, a mile south of Ravenstonedale Station. They are first seen about 150 yards down stream from the easternmost outcrop of the Bannisdale Slates. The lowest beds consist of a fine-grained, grey and yellow, banded sandstone, about a foot thick, containing conspicuous black specks. Immediately above this sandstone lies a bed of gritty, dun-coloured, calcareous mudstone having the following percentage composition :—

$CaCO_3$	69·96
$MgCO_3$	8·84
Fe_2O_3, etc.	4·47
Insoluble residue	16·73
Total	100·00

The bed shows little or no trace of lamination, and breaks into small irregular blocks. Occasionally, it encloses thin lenticular pebbles measuring up to 2 inches in diameter, composed of a finer material which resembles a volcanic ash : these pebbles are frequently coated with a thick layer of pyrite. A few small quartz-pebbles also occur. The bulk of the insoluble material is composed of sand-grains, and although search has been made for fragments of Shap-Granite felspar-crystals, which occur so abundantly in the overlying conglomerate, no trace of these has been discovered. The bed has yielded fossils in fair abundance, but only in the form of casts—with the exception of specimens of *Lingula* and *Orbiculoidea*, in which the shell is still preserved.

Fauna.

Fenestella sp.

Lingula cf. *squamiformis* Phill.
Orbiculoidea sp.
Athyris, between *glabristria* (Phill.) and *concentrica* Von Buch.

Rhynchonella sp.
Spirifer pinskeyensis, sp. nov.

Psephodus sp.[1]

This sandstone is overlain by dark sandy shales, which have only yielded casts of lamellibranchs.

Farther down the stream higher beds are exposed, consisting of compact mudstones interstratified with shales. These have yielded the following fossils :—

Lingula cf. *squamiformis* Phill.

Aviculopecten, 2 spp.
(?) *Myalina* sp.

Posidoniella sp.

Naticopsis sp.

Psephodus sp.[1]

On the right bank a small cliff-section exposes flaggy and shaly beds, containing worm-tracks and plant-remains which are referable

[1] Kindly determined by Dr. A. Smith Woodward, F.R.S.

to *Pteridorhachis* sp.[1] Above the plant-shales occurs a yellow cellular dolomite containing drusy cavities. This is the highest bed in the series exposed in the bed of the stream, but it has yielded no determinable fossils. The total thickness seen is about 65 feet, and the beds are dipping at 17° north-north-eastwards, or about the same average dip as that of the overlying Lower Carboniferous rocks in the district.[2]

About 8 yards below the road-bridge is a small outcrop of thinly-bedded, red, shaly conglomerate, which contains pebbles ranging up to 2 inches in diameter and composed of Silurian grits and rhyolites; also scattered through the deposit are pink orthoclase-crystals, similar to those commonly found in the conglomerate at Shap Wells, and there can be little doubt that this deposit is the southerly continuation of the Shap Basement Conglomerate. The beds in Pinskey Gill, described above, are therefore of peculiar interest, since they apparently underlie the Shap Conglomerate which forms the usual base of the Carboniferous in the Shap District, and must therefore represent the oldest fossiliferous horizon in the Carboniferous rocks of the North-Western Province. The beds were evidently deposited in a depression which was invaded by the Carboniferous sea before the general submergence of the districts lying immediately to the north and south, and apparently prior also to the submergence of the Shap Granite. How much earlier it is impossible to say, by comparison with any beds in the North of England—since the nearest exposures of Carboniferous rocks, which may possibly represent their equivalents in time, are not met with until we reach the extreme north of Cumberland; and my recent investigation of the beds in this district has revealed no fauna at all similar to that recorded from Pinskey Gill. Again, if these beds are of Carboniferous age, it should be possible to correlate them with some definite horizon in the Lower Carboniferous succession of the South-Western Province, but such a correlation is by no means easy.

If we are to consider the Pinskey Beds as conformably succeeded by the conglomerate which crops out below the bridge, and by the fossiliferous series exposed in Stone Gill hard by, they should represent some portion of the *Zaphrentis* Zone of the Bristol district; but Dr. Vaughan, who has kindly examined my collections, and also specimens collected by Mr. Cosmo Johns from this district, reports that the characteristic *Spirifer* of the Pinskey Beds is quite unknown to him from the Carboniferous rocks of the Bristol area, while none of the other fossils appear to throw any further light on the problem.

Considered on stratigraphical grounds alone, these beds may be of any age between the date of the post-Silurian movement in the district, and the deposition of the lowest beds of the *Solenopora* Sub-zone: that is to say, there is apparently nothing in the strati-

[1] *Teste* Prof. A. C. Seward, F.R.S.

[2] A detailed section of these beds is given in 'The Geology of the Country around Mallerstang, &c.' Mem. Geol. Surv. 1891, p. 79.

graphical evidence to prove that the deposit is not of late Devonian age. On the other hand, no marine deposits of Devonian age are known in the North of England, while the Polygenetic Conglomerate, which occurs north of Bampton and in the neighbourhood of Sedbergh and elsewhere, has been considered by some authorities as a torrential deposit of Upper Devonian age. This conglomerate is certainly older than the beds which form the usual base to the Carboniferous in the North-Western Province, and its sporadic distribution would seem to point to extensive denudation in pre-Carboniferous times. No definite evidence can, however, be deduced from a study of the fauna of the Pinskey Beds in favour of the Devonian, any more than of the Carboniferous age of the deposit. In this connexion the statement, made in the Geological Survey Memoir on Mallerstang, &c., that one of the beds contains *Producti* is important: for, though *Productella* does occur in the Devonian beds of North Devon, the occurrence of true *Producti* at Pinskey would settle the question in favour of the Carboniferous age of the beds. I have not, however, met with any specimen of *Productus* in these beds; and a search among the collections and records of the Geological Survey at Jermyn Street has also failed to produce any corroboration of the statement contained in the Memoir. Under these circumstances the record of the occurrence of *Productus* in these beds must be regarded as unsupported.

Summary.—We have, then, in Pinskey Gill a series of fossiliferous deposits which are of considerable interest, on account of their unique character and their uncertain age. The facts, so far as they have been ascertained, may be summarized as follows:—

(1) The beds lie apparently between the Silurian rocks and the basement Carboniferous conglomerate of the district.
(2) Their relation to the underlying Silurian slates and overlying Carboniferous conglomerate is obscured by drift, but the dip of the beds does not differ appreciably from that of the overlying Carboniferous rocks.
(3) They are undoubtedly older than any Lower Carboniferous beds so far met with elsewhere in the North-Western Province.
(4) Their lithological and palæontological characters differ markedly from those of the overlying beds.
(5) They are entirely devoid of fragments of the Shap-Granite felspars, which are so characteristic of the basement-beds in this district and occur abundantly in the overlying conglomerate.
(6) The fossils, with the exception of inarticulate brachiopods, are preserved as casts, whereas the organic remains in the beds overlying the conglomerate have their tests well preserved.
(7) The fauna is difficult to correlate with that from any known horizon in the Lower Carboniferous succession of the South-Western Province.

[Since the above was written, I have again visited the section in Pinskey Gill, in the company of Mr. R. G. Carruthers, on which occasion some additional fragments of fish-teeth were obtained. Dr. A. Smith Woodward, who has kindly examined these specimens, reports that they represent a Cochliodont of some kind, probably *Psephodus*, and, so far as they go, therefore, point to the Carboniferous age of the deposit.]

Despite careful search, no other undoubted occurrence of the Pinskey-Gill Beds has been met with. A few feet of unfossiliferous dolomite and mudstone are, however, exposed in Weasdale Beck, along the same line of strike; while below Shaw Mire in Thackthwaite Gill, shales, gritty mudstone, and dolomite are exposed: these have, however, yielded no organic remains, and the same remark applies to the lowest beds exposed in Artlegarth Beck.

The *Solenopora* Sub-zone.—The fossiliferous beds overlying the basement Carboniferous conglomerate are best studied in the series of gills which rise on the northern slopes of the Howgill Fells between Pinskey Gill and the Dent Fault. The general character of the succession is shown in the section (Pl. LVI, fig. 2). The best exposures of the lower beds are seen in Stone Gill and Artlegarth Beck. In Stone Gill some 80 feet of dolomites and calcareous shales crop out about a third of a mile above Colbeck Bridge. Unfortunately the lowest beds, including the basement conglomerate, are not exposed here.

Section in Stone Gill.

	Thickness in feet	*inches.*
Porcellanous limestone with *Camarotœchia proava*—		
Black shale	4	0
Massive limestone with shaly partings	14	0
Black shales with *Orthoceras*	4	0
Hard, compact, grey limestones with geodes	3	6
Black shales with plates of *Archæocidaris*	2	0
Earthy limestone	1	0
Shale-band	2	0
Solenopora Band	2	0
Drift-covered (unseen)	5	0
Hard dolomite and shaly calcareous flags	7	0
Palæchinus Limestone, with *Zaphrentis omaliusi* and *Cidaris* spines	1	6
Fragmental bed	4	0
Shaly dolomite	7	6
Dolomite with *Vaughania cleistoporoides*	9	0
Hard, dun-coloured, shaly limestone	6	0
Platy shale with *Athyris glabristria*, ostracods, etc.	3	3
Hard blue limestone with *Syringopora* and *Hyalostelia*	3	0

Base not seen.

These beds represent approximately the same horizon as those exposed in Shap-Abbey Cliff already described (p. 487). The beds, as in the case of the Shap section, contain abundant remains of *Solenopora*: one layer, 45 feet from the base, being almost entirely composed of the thalli of these organisms. The abundance of *Athyris glabristria* in the lowest shale-bed, near the base of the section, recalls a similar layer near the top of Shap-Abbey Cliff; while the presence of a bed composed almost entirely of the plates of *Palæchinus* and *Archæocidaris* corresponds with the *Archæocidaris* Bed north of Keld. The interesting band containing *Vaughania cleistoporoides* has only been met with elsewhere in the Shap section, and there the coral-remains are very scarce and fragmentary. The fauna from these beds is tabulated in the general list on p. 460.

The *Camarotœchia-proava* Band attains its maximum development in Stone Gill, where it cannot be far short of 700 feet in thickness, and consists of a compact porcellanous limestone containing layers crowded with the index-fossil. Another good exposure of this band occurs near Piper Hole in the line of section, where it is underlain by the *Palæchinus* Limestone, which in turn overlies a black calcareous shale containing *Modiola*, etc.

The *Seminula-gregaria* Sub-zone. — The *Productus-globosus* Band, with the algal layer at its base, enters the district at Friar Bottom immediately east of the railway. It crops out at intervals between here and the Dent Fault. An interesting exposure at about this horizon occurs in a small quarry on the north side of the road between Ravenstonedale and Claylands. Here a red calcareous shale is seen crowded with specimens of *Stenophragma lobatum* Munro, apparently a new form of Trepostomatous Bryozoa, of an irregularly lobate habit.[1] Examples also occur of an interesting compound coral, which shows affinities both with *Thysanophyllum* and with *Lonsdalia*.[2]

A good section, showing the relation of the band to the overlying *Thysanophyllum* Band, is seen opposite Brunt-Hill Farm, where about 80 feet of fossiliferous shales and limestones are exposed. Fossils obtained from this section are included in the general list (p. 463).

The *Thysanophyllum* Band is well developed in this district; its outcrop is shown on the map (Pl. LIII).

Localities. — Cowpland Sike, Breakyneck Scar, Blea-Flatt Spinney, and near Brunt Hill. The exposure in Cowpland Sike is remarkable for the abundance of well-grown specimens of *Fistulipora incrustans.*

The Brownber Pebble-Bed, exposed at the type-locality west of the railway, crops out again above the *Thysanophyllum* Band on the west side of Scandal Beck, but it is only seen in two small exposures at the eastern end of the district: one at a point a little north-east of Claylands Farm, and the other in Tarn Sike, east of Crooks Beck. In both of these places it appears to be thinning out southwards.

The *Michelinia* Zone is better developed and better exposed here than in the Shap District; it is, however, difficult to say what thickness of beds should be included in the *Chonetes-carinata* Sub-zone of the Arnside District. *Michelinia grandis* has been collected in an old quarry by the roadside immediately opposite Blea-Flatt Farm, and again at one or two points between Keld Sike and Ashfell Farm. The beds are shaly impure limestones, often stained red, and the fossils are usually silicified; specimens of a small form of *Productus corrugato-hemisphericus* abound, and these are

[1] Described in Appendix II, pp. 574–76.

[2] Pending the thorough revision of this group, the description of this form has been deferred.

associated with a large Diphyphylloid *Lithostrotion* resembling the species found at Blackstone Point. The *Michelinia* is the large form of *Michelinia grandis* characteristic of the base of the zone in the Furness and Grange Districts. A few feet of fossiliferous beds, apparently lying near the summit of the zone, crop out in Tarn Sike; and here *Caninia cylindrica* is associated with early specimens of *Lithostrotion martini*. One specimen of *Clisiophyllum multiseptatum* has also been collected from this exposure. The conclusion, therefore, must be drawn, either that *Michelinia* did not enter this district until the end of the period during which the *Michelinia* Beds were being deposited at Arnside; or that the Diphyphylloid *Lithostrotion* fauna entered here somewhat earlier than in the Arnside District. The latter view is adopted here, chiefly for convenience in mapping, and these beds are therefore represented in the map and section of the district as belonging to the *Michelinia* Zone (Pl. LIII & Pl. LVI, fig. 2).

The following species have been collected from the exposures mentioned above:—

Caninia cylindrica (Scouler).
Clisiophyllum multiseptatum, sp. nov.
Cyathophyllum multilamellatum M'Coy.
Diphyphyllum aff. *lateseptatum* M'Coy.
Lithostrotion martini M.-Edw.
Lophophyllum sp.
Michelinia grandis M'Coy.
Syringopora geniculata Phill.

Chonetes carinata, sp. nov.; rare.
Productus hemisphericus Sby.
Productus corrugato-hemisphericus Vaughan; early form.
Martinia cf. *ovalis* (Phill.).

Schizostoma catillus (Phill.).

The *Productus-corrugato-hemisphericus* Zone: the Gastropod Beds.—As already pointed out, a considerable thickness of calcareous rocks referable to this sub-zone occurs below the Ashfell Sandstone in this district, and passes downwards into the *Michelinia* Bed of Keld Sike. The sub-zone includes the whole of the Ashfell-Sandstone Series, and also probably a few feet of the overlying grey platy limestones, which immediately underlie the *Cyrtina-carbonaria* Beds of Ashfell Edge. At the western end of the district near Scandal Beck, below Gallows Hill, the highest layers of limestone yield numerous casts of *Bellerophon* and masses of *Alveolites etheridgi*. The Ashfell Sandstone contains two or three calcareous layers, the most interesting of which occurs near the top of the sandstone, and is well exposed in the old quarries (north of the road) a little below the summit of Ashfell Edge. Here several species of corals and brachiopods occur in a good state of preservation. The fossils are quite unsilicified, in marked contrast with those which occur in the overlying *Cyrtina-carbonaria* Sub-zone. This calcareous layer is covered by a thin layer of reddish marl, which may have served to protect the fossils from solution or silicification. The fauna is, on the whole, that which is characteristic of the Gastropod Beds elsewhere; but it includes also two rolled specimens of *Camarophoria isorhyncha*, and a fragment of *Syringothyris cuspidata*. *Zaphrentis enniskilleni* enters here at a somewhat higher horizon than at Shap, and in addition to the typical form at least two variants occur. A new species of *Lophophyllum* (*L. ashfellense*) found here is of interest: it was provided with strong roots, which seem to have been attached in several cases to specimens of *Lithostrotion martini*. The most abundant fossils are, however, *Spiriferina laminosa* and *Seminula ambigua*.

Fauna.

Alveolites etheridgi Thomson.	*Pugnax pleurodon* (Phill.).
Lophophyllum ashfellense, sp. nov.	*Seminula ambigua* (Sby.); abundant.
Lithostrotion martini M.-Ed.	*Spirifer* cf. *bisulcatus* Sby.
Zaphrentis enniskilleni M.-Ed. & variants.	*Spiriferina laminosa* (M'Coy); abundant.
Spirorbis sp.	*Aviculopecten* cf. *dissimilis* (Flem.).
	Conocardium aliforme Sby.
Cliothyris cf. *royssi* (L'Éveillé).	*Edmondia* sp.
Camarophoria isorhyncha (Sby.). (Derived.)	*Sanguinolites* sp.
Productus corrugato-hemisphericus Vaughan.	*Naticopsis* sp.
	Pleurotomaria sp.
Productus hemisphericus Sby.	
Productus laciniatus M'Coy.	*Produs* sp. (?).
Productus pustulosus Phill.	*Psephodus magnus* M'Coy.
Productus cf. *punctatus* Sby.	*Streblodus* cf. *oblongus* Portl.
Reticularia sp.	

The fauna, as a whole, is of shallow-water character, and appears to result from a slight falling-off in the deposition of arenaceous material.

The *Cyrtina-carbonaria* Sub-zone.—The lowest rocks overlying the Ashfell Sandstone consist of a few feet of compact grey limestone, poor in fossils. They contain, however, masses of *Lithostrotion martini* in the position of growth, together with a few specimens of *Cyrtina* near their summit. They pass up into rather more flaggy limestones, which are often crowded with fossils, especially *Cyrtina carbonaria* and *Syringopora geniculata*, together with an abundance of small gastropods. The fossils are frequently replaced by beekite. This sub-zone is better exposed along the summit of Ashfell Edge than elsewhere in Westmorland. The fauna has already been tabulated on p. 471.

The *Nematophyllum-minus* Sub-zone consists of the usual grey platy limestones. It occupies a considerable stretch of country on the dip side of the escarpment on Ash Fell, where several good exposures occur. The fauna is in no respect different from that which occurs in the Shap District, and there is the same absence of the shaly *Chonetes-papilionacea* Beds which are so characteristic of the upper portion of this sub-zone in the districts on the west.

The Bryozoa Band is especially well-developed on Ash Fell, and is exposed in Blue Quarries on the north side of the road.

The band is much more argillaceous than is the case at Orton and Shap, and consists of dark calcareous shale crowded with bryozoa and *Spiriferina laminosa*.

Localities.—Blue Quarries, Smardale Fell, Ash Fell.

The Lower *Dibunophyllum* Sub-zone is not very typically developed in this district. The base of the sub-zone is exposed in Lane-Head Quarries. This horizon cannot lie far above the highest bed seen in Blue Quarries. The beds here are rolling, and it is difficult to estimate the exact thickness of the strata which overlie the Bryozoa Band between Blue Quarries and the Midland Railway Station. They differ both lithologically and palæontologically from their normal development elsewhere, being much more argillaceous than in the Shap District. No specimens of either *Cyathophyllum murchisoni* or *Dibunophyllum* have been met with; but the abundance of crushed specimens of *Productus* cf. *maximus* (M'Coy) and caninoid Campophyllids seems to point to the correlation of these beds with the Lower *Dibunophyllum* Sub-zone elsewhere. The matter in itself is of no consequence, for we may regard them as passage-beds between the two zones; but it becomes important when we consider the position of the overlying *Daviesiella-llangollensis* Band, to be mentioned presently. In Lane-Head Quarries, on the west side of the Sedbergh road, the beds are fairly fossiliferous, and contain abundant examples of the *Producti* and crushed corals mentioned above, together with large Orthocerata which are unknown from any other horizon in the district. Species of *Syringopora* and *Alveolites* are also common.

Localities.—Lane-Head Quarries; Waitby Common.

Fauna.

Alveolites capillaris (Phill.).
Alveolites etheridgi Thomson.
Aulopora sp.
(?) *Caninia*.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum ϕ Vaughan.
Lithostrotion junceum (Flem.).
Lithostrotion martini M.-Edw.
Syringopora geniculata Phill.
Syringopora ramulosa Goldf.

Chonetes papilionacea Phill.
Cyrtina carbonaria (M'Coy).
Orthotetes sp.
Productus corrugato-hemisphericus Vaughan.
Productus cf. *maximus* M'Coy.
Productus punctatus Mart.
Reticularia sp.
Seminula ambigua (Sby.).
Spirifer bisulcatus Sby.

Sanguinolites sp.

Straparollus sp.
Bellerophon scalifer de Kon.
Bellerophon sp.

Poterioceras cf. *cordiforme* Sby.

The presence of *Cyrtina carbonaria* in the Lane-Head quarry on the east side of the road marks the highest horizon at which this species has been found, as these beds certainly lie above the Bryozoa Band, whether we consider them as belonging to the base of the Lower *Dibunophyllum* Sub-zone or to the summit of the *Productus-corrugato-hemisphericus* Zone.

The *Daviesiella-llangollensis* Band.—No good exposures occur in the line of section to the east of Lane-Head Quarries, until we pass the Midland Railway-station; but, immediately east of the railway, several good outcrops of an impure shaly limestone can be seen between the station and Wharton Hall: these abound in specimens of *D. llangollensis*, together with *Productus* cf. *maximus*. This band is of especial interest since, with the exception of the young and doubtful examples occurring in the *Chonetes*-aff. *comoides* Band at Grandy, this species has not been met with in the North-Western Province. As at Llangollen, the band appears to lie near the base of the Lower *Dibunophyllum* Sub-zone.

Above the *D.-llangollensis* Band the beds resemble the typical white limestones of the Lower *Dibunophyllum* Sub-zone of other districts; they are, however, cherty and somewhat barren of fossils, and neither *Cyathophyllum murchisoni* nor *Dibunophyllum* occur. The highest exposures contain reefs of *Lithostrotion junceum*, which elsewhere is more characteristic of the base of the Upper *Dibunophyllum* Sub-zone. On the whole, then, the Lower *Dibunophyllum* Sub-zone in the Ravenstonedale District is characterized by its shaly and cherty character, by the absence of *Dibunophyllum* and *Cyathophyllum murchisoni*, and by the presence of the *Daviesiella-llangollensis* Band near its base.

No beds of Upper *Dibunophyllum* age occur in the Ravenstonedale section.

IV. The Arnside and Carnforth Districts.

The Arnside District.

This district may be conveniently considered under the following heads:—(1) A western portion, comprising a considerable area to the south of the Kent estuary and west of the Furness Railway, and also the small outlier of Meathop lying on the north side of the estuary. (2) An eastern portion, lying wholly to the south of the Kent estuary and east of the Furness Railway, treated separately on account of the tectonic disturbances. (3) The faulted inliers of Swantley and Halton Green, lying on the southern margin of the district.

In comparing this district with the type-districts, we may note:—

1. The absence of the greater portion of the *Solenopora* Sub-zone, which is only represented at Meathop by a few feet at the summit of the *Camarotœchia-proava* Band, a fact which shows that this district was submerged at a slightly later period than the type-districts.

2. The development of a special coral fauna in the *Seminula-gregaria* Sub-zone at Meathop.

3. The great importance of the upper portion of the *Michelinia* Zone, which at Arnside attains its fullest development in the North-Western Province.

4. The great thickness of the middle and upper portions of the *Cyrtina-carbonaria* Sub-zone and the Bryozoa Band of the type-districts: the latter being apparently replaced by the *Chonetes-papilionacea* Beds which occur near the summit.

5. The abundance of specimens of *Cyrtina septosa* in the *Chonetes*-aff. *comoides* Band, which here far outnumber the chief index-fossil of the type-districts.

6. The evidence of important tectonic disturbances, especially in the eastern portion of the district, by which the beds are so thrust and tilted that the zones are, in places, inverted.

7. The presence of isolated inliers of limestone among the rocks of the Millstone Grit Series on the southern margin of the district, which exhibit lithological and palæontological characters unknown at any horizon in the type-districts, and in their faunal and structural peculiarities recall the brecciated limestones of the knoll-reef country on the south-east, of which they appear to be fragmentary continuations, brought into their present position by thrusting.

(1) The Western Portion of the Arnside District.

Athyris-glabristria Zone: the Meathop Outlier.—The lowest beds are exposed on the north side of the Kent estuary at Low Meathop, in a small quarry on the east side of the lane leading down to the farm. The actual junction with the Silurian is not seen, but the latter crops out in a field hard by. The exposure consists of a few feet of very tough blue limestone, overlain by unfossiliferous earthy shales. The limestone contains one or two layers crowded with the remains of *Camarotœchia proava*, associated with the following species:—

Solenopora, sp. nov.

Carcinophyllum, sp. nov.
Lophophyllum meathopense, sp. nov.

Athyris glabristria (Phill.).
Camarotœchia proava (Phill.).

Rhynchotreta angulata (Linn.). A large form.
Seminula aff. *ficoidea* (Vaughan).

Modiola cf. *lata* Portl.
Myalina sp.

The form of *Seminula* found here and in the overlying beds east of the road is a large inflated form, difficult to distinguish from *S. ficoides* (Vaughan) of the Bristol *Seminula* Zone.[1] The association of *Solenopora* with *Camarotœchia proava* and *Athyris glabristria* in this exposure points clearly to the horizon being that of the *C.-proava* Band of the Shap-Abbey and Stone-Gill sections already described.

The *Seminula-gregaria* Sub-zone is well exposed in a succession of old quarries between the railway and the road to the east of the gas-works; the total thickness to the top of the cliff is about 140 feet. The beds consist chiefly of compact limestones and dolomites, some of the latter containing up to 30 per cent. of magnesium carbonate.

The Algal Layer.—The layers near the base of the Meathop section are largely made up of the remains of calcareous algæ, which occur on weathered surfaces as grey concretionary spots and nodules

[1] See Pl. LI, fig. 6; also A. Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 122.

embedded in a yellow dolomitic matrix. These layers contain forms identical with those found in the algal layer lying at the base of the *Productus-globosus* Band in the Shap and Ravenstonedale Districts, and undoubtedly represent the same horizon. About 30 feet above the base occurs a compact, porcellanous, grey limestone, containing crushed and recrystallized crinoid-stems, together with teased-out corallites of *Syringopora*. In the succeeding 40 or 50 feet fossils are scarce, with the exception of *Seminula* aff. *ficoidea* and *S. gregaria*. One or two thin black shaly layers, however, occur containing plant-remains, among which fragments referable to *Archæosigillaria vanuxemi* Göppert may be recognized.[1]

In the upper portion of the cliff, silicified fragments of a small *Cyrtina* (aff. *carbonaria*) occur; these are in too fragmentary a condition for exact determination, but the form is not unfrequently met with at this horizon in the Western Districts. The *Thysanophyllum-pseudovermiculare* Band has almost died out here, though one or two corallites, referable to this species, have been collected about 40 feet below the summit of the section.[2] About 30 feet below the top of the cliff the beds become rather more fossiliferous, and in addition to *Seminula* at least two species of *Syringopora* occur in some profusion.

The following species have been collected from the *Seminula-gregaria* Sub-zone at Meathop, up to the base of the *Spirifer-furcatus* Band:—

Archæosigillaria vanuxemi (Göppert).
Fucoid markings.
Calcareous algœ.

Campophyllum ciliatum, sp. nov.
Carcinophyllum simplex, sp. nov. and variant.
Clisiophyllum aff. *curkeenense* (Vaughan).
Carruthersella compacta, gen. et sp. nov.
Lophophyllum meathopense, sp. nov.
Lophophyllum vesiculosum, sp. nov.

Syringopora cf. *reticulata* Goldf.
Syringopora cf. *geniculata* Phill.
Thysanophyllum or *Lonsdalia*.

Athyris glabristria (Phill.).
Athyris cf. *lamellosa* L'Éveillé.
Camarophoria isorhyncha (M'Coy). Rare.
Cyrtina aff. *carbonaria* (M'Coy).
Seminula aff. *ficoidea* Vaughan.
Seminula gregaria (M'Coy).

This assemblage, although containing several new species, agrees with the fauna of the *Seminula-gregaria* Sub-zone of the Shap District, while the Algal Layer, which is so well developed along the bottom of the cliff, may be taken, here as elsewhere, to represent the base of the sub-zone. The Brownber Pebble-Bed has entirely thinned out here, and the *Thysanophyllum* Band is scarcely represented; but the dolomitic character of the rock and the abundance of *S. gregaria* and *S.* aff. *ficoidea*, taken together with the fact that the beds are underlain by the *Camarotœchia-proava* Band and overlain by the *Spirifer*-cf. *furcatus* Band, leaves no

[1] These have also been collected by Mr. J. Wilfrid Jackson, who has in addition identified fragments of *Bothrodendron*, Geol. Mag. dec. 5, vol. vii (1910) p. 78.

[2] These may possibly be identical with the form met with at the same horizon in Ravenstonedale, mentioned on p. 500.

doubt that these beds may be correctly correlated with the *Seminula-gregaria* Sub-zone of the type-districts. The new forms of cup-corals included in the foregoing list, though occasionally met with at the same horizon in other portions of the Western Districts, occur here in much greater abundance than elsewhere. The occurrence of a few specimens of *Camarophoria isorhyncha* below the *Spirifer-furcatus* Band on the east side of the outlier, is of interest, since the horizon coincides with that at which this species is first met with in the Shap District, namely the Brownber Pebble-Bed.

The *Spirifer-furcatus* Band lies at the top of the quarries, and the fossils which it contains are somewhat rolled and fragmentary. The fauna has been tabulated above (p. 465), and, as already pointed out,[1] resembles very closely that of the Oatmeal Bed near the summit of the *Athyris-glabristria* Zone in the Docker-Beck section at Shap. The bed forms the surface of the ground at the southern end of Meathop Fell, and dips at about 5° south-eastwards (that is, towards Arnside). At Meathop-Marsh Farm, on the south-eastern side of the outlier, the beds are more bituminous, and include a thin parting of black shale crowded with the remains of *Lophophyllum meathopense.* East of the quarry this shale-band disappears under the alluvium of the Kent estuary, and has not been met with in the quarry-sections on the west.

The *Michelinia* Zone: its lowest portion, the *Camarophoria-isorhyncha* Sub-zone, is present in the Meathop outlier, and, with the possible exception of a small block of fault-breccia which comes to the surface in Arnside Moss, no other exposure of this sub-zone is met with in the Arnside District. The base of the zone on Meathop Fell appears to lie immediately above the *Spirifer-furcatus* Band at the southern end of the Fell, and this corresponds with its position in the Docker-Beck section at Shap, where it overlies the Oatmeal Bed. The beds consist of a grey and purple, somewhat bituminous limestone containing *C. isorhyncha* and *Cyathophyllum* cf. *multilamellatum*, overlain by a compact dolomite which forms the top of the Fell (172 feet), and can be traced round to the summit of Meathop-Marsh Quarry. No specimen of *Michelinia* has been obtained *in situ* on Meathop Fell, but the walls encircling the western end of Limegarth Wood and the southern edge of the Fell contain numerous specimens of that large form of *M. grandis* which is characteristic of the sub-zone in Docker Beck, Elliscales and elsewhere. Examples of *C. isorhyncha* and *Zaphrentis konincki* also occur associated with *Michelinia* in these blocks. The blocks evidently once formed portions of the dip-slope at the top of the Fell, and this supposition is confirmed by the statement of the present tenant, who informed the writer that the above-mentioned walls were made from the rocks cropping out on the surface of the Fell.

[1] Geol. Mag. dec. 5, vol. vii (1910) p. 118.

The relation of the rocks of the Meathop outlier to the *Michelinia* Beds at Arnside is naturally to some extent problematical, but there appears to be no good reason why the two exposures should not form portions of a continuous sequence separated by the Kent estuary, since beds containing *Michelinia*, identical with the highest Meathop beds, occur immediately below the shales of the *Chonetes-carinata* Sub-zone at Frith Hall, Elliscales. The main north-and-south fault which runs through Lindale continues southwards into Morecambe Bay, passing between Holme Island and Meathop Fell, and brings the beds, near the top of the Lower *Dibunophyllum* Sub-zone, on the island, against the beds of the *Athyris-glabristria* Zone of the Meathop section. It is exactly here that Morecambe Bay ends and the narrow estuaries of the Kent and the Gilpin begin. There is no evidence of an east-and-west fault in the Kent estuary, though the Gilpin-estuary fault is probably continuous with the Arnside-Carnforth disturbance which runs past Silverdale Station. Again, the dip of the Meathop beds on the south side is the same, in direction and amount, as that of the beds which crop out on the Arnside shore a mile away.

The *Chonetes-carinata* Sub-zone is admirably exposed along the shore between Arnside and Blackstone Point. The rocks here consist of dark-grey, somewhat nodular, bituminous limestones, with partings of shaly calcareous mudstone. The strike of the beds coincides generally with the trend of the coast-line, and the different layers of the sub-zone are exposed at short intervals in a series of anticlines and domes. The best exposures occur in the cliff between Mr. Crossfield's boat-house and the Corporation bathing-shed, but fossiliferous outcrops also occur at intervals along the foreshore between the Crown Hotel and New Barns Farm.

In the cliff near the boat-house the beds are compressed into a sharp synclinal fold, the eastern limb of which is replaced by a fault: several small dislocations also occur farther east, produced by a series of overthrusts from the west; while a fault runs along the foot of the cliff, the beds in its neighbourhood being traversed by calcite-veins. These beds must lie near the top of the zone, for the first Diphyphylloid *Lithostrotion* is met with here, in the synclinal fold, about 25 feet above the beach. This coral is again found abundantly at Blackstone Point, and resembles very closely a form occurring at about the same horizon in Tarn Sikes (Ravenstonedale). The bed in which it is found may be conveniently taken as the base of the *Productus-corrugato-hemisphericus* Zone. A little farther west, a vertical fault plastered with breccia-fragments passes through the face of the old quarry. West of the bathing-shed lower beds are exposed, including several layers of a shaly mudstone which abounds in specimens of *Michelinia grandis* and *M. tenuisepta*. M'Coy's type-specimen of *M. grandis*, from these beds at Arnside, has for many years been referred to *M. megastoma* of Phillips; and the type-specimen is so labelled in the Sedgwick Museum, on the supposition that it was a synonym for Phillips's species. Pending the revision of the species of this genus, M'Coy's name for the Arnside form is retained here, so as to prevent any doubt as to which form is intended in this paper. There is, however, a marked difference in size between the Arnside specimens and the reef-like masses which occur in the *Camarophoria-isorhyncha* Sub-zone below; neither does the latter form show the well-developed epitheca characteristic of the Arnside specimens. *M. tenuisepta* is also fairly abundant in the Arnside section, and grows to a considerable size. A list of the fauna from this locality has already been given (see p. 468). M'Coy's type-specimen of *Cyathophyllum multilamellatum* preserved in the Sedgwick Museum was probably obtained from this bed. Specimens of *Chonetes carinata* occur abundantly, with the keeled valve lying uppermost. On the shore close to the Crown Hotel, large specimens of *Caninia* cf. *cylindrica* occur, crushed perfectly flat; and Dr. Sibly informs me that he has met with the same form, similarly flattened, at the same horizon in the Mendip area. West of the bathing-house, the beds crop out at intervals along the foreshore, while a small fault which runs down the bay to the east of New Barns Farm brings in the beds with *Chonetes carinata* again, north of the farm. At Blackstone Point the junction of the *Michelinia* Zone with the beds of the overlying zone is well seen in the old quarry, and in the cliff to the west of the limekiln. *Caninia cylindrica* occurs here in great plenty.

The *Clisiophyllum-multiseptatum* Band is well exposed above the limekiln at Blackstone Point, as a bed of dark shale containing abundant specimens of the index-fossil, together with *Zaphrentis enniskilleni* and *Cyathophyllum multilamellatum.* This layer is immediately overlain by the earliest *Lithostrotion* seen in the section, and may conveniently be taken as the dividing-line between the *Michelinia* Zone and the *Productus-corrugato-hemisphericus* Zone.

The occurrence of *Zaphrentis enniskilleni* in beds representing C_2 of the Bristol succession deserves some comment. The exact horizon of the beds in which it was first collected in Ireland does not appear to be known, but the species was originally considered to be characteristic of D_2. A closely similar, if not identical, form has lately been recorded from S_2 (?) by Mr. James Douglas[1] from County Clare, and is found also, as mentioned above, with variants in the upper portion of the Ashfell Sandstone, below the *Cyrtina-carbonaria* Sub-zone, and therefore in beds of an age equivalent to S_1 of the South-Western Province. In the Isle of Man I have found this species occurring abundantly in the lower beds exposed on the shore at Ronaldsway (Derbyhaven), where it is associated with *Michelinia grandis*, *Chonetes carinata*, *Syringothyris cuspidata*, and the large forms of *Schellwienella crenistria* recorded from Arnside. This association is found nowhere in the North-Western Province outside the *Michelinia* Zone, and it seems more than probable that the horizon of the Ronaldsway Beds in the Isle of Man lies near the top of C_2 and the base of S of the South-Western Province.

[1] Q. J. G. S. vol. lxv (1909) p. 554.

It is true that no specimens of *Zaphrentis konincki* have been found in the Ronaldsway Beds, although I have specially sought for them; it is difficult, however, to ignore the weight of evidence derived from the above association. Dr. Wheelton Hind has expressed the opinion that the Ronaldsway Beds of the Isle of Man belong to the *Dibunophyllum* Zone,[1] and the same author has expressed to me his strong conviction that the Arnside Beds are also of *Dibunophyllum* age. It is possible that this view was founded, in part, at all events, on the presence of *Zaphrentis enniskilleni* in both sections. In the Isle of Man, however, that form is not confined to these lower beds, but passes up into beds which are (at all events) high in S if not actually of *Dibunophyllum* age. All the beds of the succession are dark argillaceous and bituminous limestones, and it seems highly probable that we have here an example of the dependence of faunal development on lithological character, and that *Z. enniskelleni* continued to flourish in the Isle of Man area through a considerable period of time—as long as the conditions remained suitable. At Arnside, on the other hand, the typical corals of the argillaceous *Chonetes-carinata* Beds disappeared with the subsidence which introduced clearer water conditions and white limestone deposits. Where *Zaphrentis enniskilleni* occurs in the Upper *Dibunophyllum* Zone in other areas, it is again associated with argillaceous limestones.

The *Productus-corrugato-hemisphericus* Zone is characterized by the absence of the sandstone episode of the type-districts, the beds being fairly fossiliferous throughout. The lower portion is a dark crinoidal limestone, fossiliferous at the base, but becoming compact and rather barren towards the summit. The upper portion is a pure pale-grey limestone, compact near the base but platy above.

The Gastropod Beds form a semicircular outcrop round the northern base of Arnside Knott, and overlie the *Michelinia* Bed of the coast. The upper boundary lies round about the 200-foot contour on the north-eastern flank of the Knott, but there is no hard-and-fast line of division between the two portions of the zone. The beds are seen in the upper part of the cliff near Arnside, behind New Barns Farm, in Gubbins Wood and Frith Wood; and between Blackstone Point and the edge of the salt marsh to the south of Arnside Point, where they are much altered, and roughly cleaved by close-set vertical joints. They are also occasionally exposed in the upper portion of Arnside village, when foundations are being dug for new buildings; they are fairly fossiliferous, and towards the base contain a band of small *Seminula ficoidea*. The fauna is in some respects similar to that of the underlying *Michelinia* Beds, but it is devoid of *Michelinia* and *Chonetes carinata*, and abounds locally in specimens of *Lithostrotion*. The higher and more massive

[1] 'The Palæontological Succession of the Carboniferous Rocks in the South of the Isle of Man' Proc. Yorks Geol. Soc. n. s. vol. xvi, pt 2 (1907) p. 39.

portion of the sub-zone is well exposed in a series of quarries under the Red Hills, where it contains a sparse fauna consisting chiefly of Bellerophons preserved as casts.

The *Nematophyllum-minus* Sub-zone reaches a thickness of 350 to 400 feet on Arnside Knott, and forms the whole of the Knott above the Red Hills. The lower portion, a compact cream-coloured limestone, is well exposed at Hare Parrock on the western flank of the Knott, and is frequently quarried in the district, as at Wharton Crag and Sandside. *Productus-corrugato-hemisphericus*, *Chonetes papilionacea*, and *Seminula ambigua* occur in some abundance. The upper portion abounds with specimens of *Chonetes papilionacea*, which in places give a fissile character to the bedding-planes. Occasional masses of *Nematophyllum minus* in the position of growth occur, and these persist to the summit of the Knott. On the coast the beds are disturbed by small faults and crushes, and in places are much jointed, and stained with hæmatite. The general outcrop is shown in the map (Pl. LIV). The Bryozoa Band has not been recognized in this district.

The Lower *Dibunophyllum* Sub-zone covers a considerable area to the south and east of Silverdale village, the prevalent dip being southwards and south-eastwards; but east of Silverdale Green the beds turn over to the east, as they approach the disturbance which runs near Silverdale Station. The beds are also well exposed along the coast, between that station and Jenny Brown's Point.

The *Chonetes*-aff. *comoides* Band crops out at intervals along the shore, and is here specially rich in specimens of *Cyrtina septosa*; it is overlain by markedly-brecciated beds containing elongated concretionary structures—the 'Stick Bed,' which is constantly found associated with this band in all the western districts.

No beds that can be definitely assigned to the Upper *Dibunophyllum* Sub-zone occur in the Silverdale section. West of Jenny Brown's Point the band is brought in again by a small strike-fault; the pseudo-breccia beds here show a more definite brecciated structure than usual, the fragments being cemented by hæmatite and calcite. In places, however, the brecciated beds appear to pass laterally into ordinary compact limestones.

In Middlebarrow Quarry, close to the Furness Railway, an interesting thrust-plane, making a small angle with the bedding and hading nearly due east, has been laid bare by the quarrying operations (Pl. XLV, fig. 2, facing p. 512). The exposure is unfortunately being rapidly quarried away: this is much to be regretted, as it is seldom that so clear a demonstration of the effects of a strike-fault is to be seen in the field.

(2) The Arnside District East of the Furness Railway.

That portion of the Arnside District which lies east of the Furness Railway presents the same general development as the area just described, but contains in addition the higher portion of the *Dibunophyllum* Sub-zone, which towards the south passes upwards into the Millstone Grit. The palæontological succession is perfectly normal; the beds of the Upper *Dibunophyllum* Sub-zone belong here to the Western or Kirkby Lonsdale Type. This area is separated from the western tract by Arnside Moss and Silverdale Moss, which appear to mark a dislocation running roughly parallel with the railway, as the result of which the beds are frequently tilted vertically and in places are even reversed. The oldest rocks seen occur near Black-Dyke Cottage, on Arnside Moss; they appear to represent a fragment of fault-breccia belonging to the *Camarophoria-isorhyncha* Sub-zone, and contain *Lophophyllum meathopense*. The *Chonetes-carinata* Beds are well exposed on the south side of the road between Arnside and Sandside, and, near the summit, include the *Cyathophyllum-multiseptatum* Band. Near Dick-Fell Cottage the beds dip steeply eastwards; but, before reaching the railway-bridge, they become vertical, and a little farther on along the shore become inverted with an apparent dip of 70° northwestwards. The inverted position of the beds is confirmed by the fact that the shells of *Chonetes carinata* have their concave valves exposed by weathering; whereas, in normal sections on Arnside shore and elsewhere, the keeled convex valve is almost invariably found projecting from the weathered upper surfaces of the bedding-planes, showing that it is the under surface of the beds which is here exposed. The best section of these inverted beds is seen in the railway-cutting south-west of Sandside Station. At the western end of the cutting the highest beds of the *Michelinia* Zone are found dipping with a reversed inclination towards the south-west, followed by beds which, though apparently underlying them, belong in reality to the Gastropod Beds of the succeeding zone. The great pressure to which the beds have been subjected is shown by the marked development of phacoidal structure, and by slickensiding on the surfaces of the bedding-planes, testifying to intense horizontal movement. On this account the zonal succession is rendered exceedingly obscure, and it is not until we reach the eastern end of the cutting that the beds resume their normal characters, and we find beds marked by layers of *Chonetes papilionacea* dipping gently towards Sandside Station. A small section opposite the station contains *Nematophyllum minus*, and the beds are seen to form part of the dome in which Sandside Quarry is excavated. The inverted *Michelinia* Beds are again exposed along the line of strike, in a small quarry at the corner of the cross-roads near Hazelslack Tower. Here the reversed shells of *Chonetes carinata* and the phacoidal and slickensided surfaces are again noticeable. The line of strike of these vertical and reversed beds can be traced in a southerly direction past the east side of Haweswater and thence through Trowbarrow Hill, to the south of which the beds disappear under Storrs Moss, cut off apparently by a north-and-south cross-fault. The strike of the vertical fold, however, is oblique to the strike of the beds, so

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Fig. 1.—*Trowbarrow Quarry, Silverdale, showing vertical beds of* D_1.

E. J. G. photo.

Fig. 2.—*Middlebarrow Quarry, Silverdale, showing thrust-plane in* D_1.

E. J. G. photo.

that on Trowbarrow the fold has affected the beds of the Lower *Dibunophyllum* Sub-zone, and the *Michelinia* Beds do not again appear at the surface.

The *Productus-corrugato-hemisphericus* Zone crops out to the east of the *Michelinia* Beds, the beds being also reversed along the north-and-south line of disturbance. The *Nematophyllum-minus* Beds are well exposed in Sandside Quarry, where they occur in the dome-shaped fold already mentioned.

The Lower *Dibunophyllum* Sub-zone comes on at the summit of Sandside Quarry, where the beds show distinct traces of horizontal movement; they form the highest ground between Sandside and Hale, and in many places the pseudo-breccia beds constituting the summit of the sub-zone are well exposed. Farther south-west the beds of this sub-zone come under the influence of the north-and-south line of disturbance, and on Trowbarrow Hill they are tilted into a vertical position. The massive limestones here include a band of calcareous shale 16 feet thick, which, being more readily denuded than the limestones, is marked along the summit of the ridge by a trough-like depression, a feature whence the hill doubtless derived it name. Both the shale and the limestone are now well exposed in the quarry (Pl. XLV, fig. 1, facing p. 512). The horizon of these beds appears to lie near the summit of the Lower *Dibunophyllum* Sub-zone, and the limestone includes beds of the 'spotted' rock characteristic of this horizon. The limestone is much hardened and recrystallized, and fossils are difficult to identify. Specimens of *Lithostrotion* cf. *portlocki*, *Dibunophyllum* and *Productus* cf. *maximus* have, however, been collected from the bedding-planes exposed on the eastern face of the quarry. The shale-bed, which is a concretionary calcareous mudstone, contains a fair number of fossils, but many of these (and especially the corals) are much compressed. The following species have been collected from this shale-bed:—

Aulophyllum cf. *pachyendothecum* Thomson.
Caninoid *Campophyllum*.
Carcinophyllum ϕ Vaughan.
Clisiophyllum aff. *keyserlingi* M'Coy.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum ϕ Vaughan.
Lophophyllum sp.
Lithostrotion cf. *irregulare* (Phill.).
Lithostrotion junceum (Fleming).
Lithostrotion m'coyanum Ed. & H. East side.
Lithostrotion cf. *portlocki* (Bronn). East side.

Athyris planosulcata (Phill.).
Chonetes compressa Sibly.
Chonetes hardrensis Phill.
Chonetes cf. *interstriata* Dav.
Dielasma sp.
Productus elegans M'Coy.
Productus fimbriatus Sby.
Productus cf. *latissimus* Sby.
Productus cf. *maximus* M'Coy.
Productus semireticulatus Mart.
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Spirifer bisulcatus Sby.

Edmondia sulcata (Phill.).
Posidoniella sulcata Hind.
Posidoniella sp.
Pterinopecten cf. *rigidus* (M'Coy).
Sanguinolites sp.

Loxonema rugiferum Phill.

Orthoceras sp.
Vestinautilus sp.

This shale probably represents the argillaceous band near the summit of the Lower *Dibunophyllum* Sub-zone, exposed in the railway-cutting west of Kent's Bank Station in the Grange District. The altered limestones on the western face may possibly contain a few feet of the overlying Upper *Dibunophyllum* Sub-zone.

On the south of Storrs Moss another excellent exposure is provided by Wharton Crag. The beds, though still showing signs of crushing, dip at a much lower angle, and appear to form portions of a dome cut off on the west and north by faults. The southern margin also shows evidence of an important disturbance running close to the road, as the beds are here much tilted and crushed, and stained by hæmatite. This disturbance must represent a dislocation of considerable magnitude, as at Ing's Point it brings the Gastropod Beds against a sandstone which may represent a part of the Millstone Grit Series, as suggested in the Geological Survey map. The mass of limestone forming Wharton Crag belongs to the *Productus-corrugato-hemisphericus* Zone, but beds of the Lower *Dibunophyllum* Sub-zone come in immediately to the north.

The Upper *Dibunophyllum* Sub-zone is only represented north of Carnforth by a small patch of dark bituminous limestone to the east of Leighton Beck, containing the *Girvanella* Nodular Band. Farther south, however, near Borwick and to the south of Nether Kellet, the sub-zone is exposed at several points on the west side of the Kendal Fault. In all the exposures the beds are tilted into a more or less vertical position, and represent an horizon near the summit of the sub-zone. They are usually much altered, and fossils are poorly preserved. The best continuous section of these beds is exposed in a series of old quarries near Park House, south of Over Kellet. The beds here terminate abruptly towards the south, and appear to be cut off by an east-and-west disturbance of considerable importance; whether this is of the nature of a thrust or not, it is difficult to say.

(3) The Southern Inliers.

The two inliers of Carboniferous Limestone which occur in the Millstone Grit country near Swantly and Halton Green are of considerable interest. My attention was first called to these by Dr. Marr, who had noticed their lithological resemblance to the knoll-reef limestones of the Cracoe District. They appear to represent a western extension of the series of knoll-reef limestones which crop out west of Sladburn, and are mapped by the Geological Survey as faulted on all sides against the Millstone Grit.

The Swantly Inlier consists of crystalline cream-coloured limestone, but contains also darker portions. The beds appear to have been subjected to considerable pressure, and much of the rock is unfossiliferous; patches of fossiliferous rock, however, occur, and the fossils are here entirely recrystallized. The bedding is throughout obscure, and the lithological changes abrupt. The rock is not well exposed, and so the mutual relations of the different outcrops are difficult to determine. It is possible that portions of the rock represent a breccia similar to that exposed at Halton Green described below, derived from several horizons.

Fauna.

Lithostrotion portlocki (Bronn).

Athyris planosulcata (Phill.).
Productus costatus Sby.
Productus martini Sby.
Pugnax pugnus (Mart.).
Reticularia lineata (Mart.). Common.
Spirifer bisulcatus Sby.
Spirifer cf. *duplicicostus* Phill.
Spirifer cf. *striatus* Fischer.

This fauna, although scanty, shows a close resemblance to that collected from the Botany Beds in the Middleton-in-Teesdale District, and certainly represents beds high up in the *Dibunophyllum* Zone.

The Halton-Green Inlier.—The exposure near Halton Green appears to belong to the same general horizon as that at Swantly, and to have been brought into its present position by the same set of earth-movements. It affords, however, a much better section, and throws a great deal more light on the origin of these interesting inliers. The beds are exposed in an old quarry in Halton Park high up on the right bank of the Lune Valley. The exposure consists of two portions. In the western corner, the quarry has been excavated in a compact, nearly barren, stratified limestone; while in the weathered portion close to the limekiln we find an intensely brecciated mass, composed of angular and subangular fragments, many of which are rich in fossils: these, however, are usually rather fragmentary and badly preserved (Pl. XLIV, fig. 2, facing p. 486). The fossils are not distributed regularly through the breccia, but are confined to certain blocks, many of the fragments being quite unfossiliferous. The breccia indeed appears to be derived from several different beds of limestone, and to represent a crush-breccia on a large scale. It resembles in many respects that described by Mr. Tiddeman from Winterburn and elsewhere in the knoll-reef country near Gargrave [1]; and it is highly probable that the blocks belong to the series of crystalline limestones which, as shown by Dr. Marr, are characteristic of the knoll-reef country south of the Craven Fault,[2] and that they owe their present position to the series of thrust-movements which that author has suggested as having taken place in connexion with the Middle Craven Fault in the neighbourhood of Settle.

[1] Trans. Leeds Geol. Assoc. pt. vi (1891) p. 111.
[2] Q. J. G. S. vol. lv (1899) p. 339.

Fauna.

Carcinophyllum sp.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum cf. *muirheadi* Nich. & Thomson.
Lithostrotion m'coyanum Ed. & H.
Lithostrotion cf. *martini* Ed. & H.
Syringopora.
Zaphrentis cf. *enniskilleni* Ed. & H.

Fenestella plebeia M'Coy.

Athyris planosulcata (Phill.).
Chonetes cf. *papilionacea* Phill.
Dielasma hastatum (Sby.).
Dielasma cf. *sacculus* (Mart.).
Leptæna analoga Phill.
Productus costatus Sby.
Productus latissimus Sby.
Productus cf. *maximus* M'Coy.
Productus striatus Fischer.
Pugnax acuminatus (Mart.).
Pugnax pleurodon (Phill.).
Pugnax pugnus (Mart.).
Reticularia lineata (Mart.).
Spirifer bisulcatus Sby.
Spirifer duplicicostus Phill.
Spirifer triangularis Mart.

Gervillia squamosa Phill.
Posidoniella pyriformis Hind.

This fauna is of considerable interest, especially with respect to the brachiopoda. Such forms, for instance, as *Pugnax acuminatus* and *Spirifer triangularis* are only known to me from rocks lying south of the Craven Faults: therefore, so far as the scanty fauna collected can be taken as affording an indication of the position of these rocks, it would appear to emphasize the view suggested by the physical characters—namely, that we are here dealing with fragments of the higher limestones of the knoll-reef country in the south-east, brought into their present position by extensive thrusting.

V. The Kendal and Kirkby Lonsdale Districts.

The Kendal District.

This district forms a connecting-link between the Shap and the Arnside Districts, not only on account of its geographical position, but also on account of the lithological and palæontological characters of the strata. The district forms an elongated strip about 9 miles long by 3 miles wide, stretching from Hall-Head Farm southwards to the northern boundary of the Arnside District. The development in this district, as displayed in the exposures between Kendal and Scout Scar, resembles that found in the eastern portion of the Arnside District. The succession differs from that already described in the Shap District in the following characteristics:—

1. In the absence of the greater portion of the *Solenopora* Sub-zone.
2. In the absence of the Brownber Pebble-Bed, which has apparently thinned out here and is represented only by a bed of very compact and gritty oolite containing *Syringothyris cuspidata.*
3. In the absence of the sandstone episode, which is so characteristic of the *Michelinia* Zone and of the overlying Gastropod Beds in the Shap District.
4. In the absence of the greater part of the *Dibunophyllum* Zone, which is only represented by the lower portion of this zone in two places: namely, in the neighbourhood of the Serpentine Walks, and north-east of Haversham in the southern portion of the district.

On the other hand, the succession agrees with that in the Shap and Ravenstonedale Districts in the presence of the *Cyrtina-carbonaria* Sub-zone and the *Thysanophyllum-pseudovermiculare* Band. It differs, therefore, from the development noted in the Arnside District by the presence of these horizons, which are absent from that district and from the districts farther west.

The district is directly continuous with the Arnside District on the south, but is otherwise bounded by Silurian rocks. On the west the beds that form magnificent escarpments of Cunswick Scar and Scout Scar rest unconformably upon a platform of Bannisdale Slates; while on the east the Carboniferous rocks are again brought against the Silurian by the great fault which passes through Kendal and runs southwards, past Farlton to the neighbourhood of Lancaster. A small offshoot of this main fault near Kettlewell, immediately north-west of Kendal, brings up a fragment of the lower beds on the east, and thus the *Michelinia* Zone is exposed on both sides of the district.

At four places outliers of Lower Carboniferous rocks are preserved on the Silurian platform to the east, namely: at Skelsmergh, Grayrigg, Strickley, and Low Bendrigg; they may, for convenience, be included in this district. A fifth outlier, lying on the eastern edge of the district, occurs immediately west of Summerlands; and, although it appears on the 1-inch map of the Geological Survey as forming part of the main mass of Carboniferous Limestone lying to the west of the Kendal Fault, it belongs really, as shown by its fauna, to the eastern or upthrow side of the fault. All these five outliers are composed of beds belonging to the *Seminula-gregaria* Sub-zone, and with the exception of that near Summerlands, to be described later, call for no special description. The Grayrigg outlier contains the whole of the sub-zone, from the Algal Layer up to the *Thysanophyllum* Band, and includes also a few feet of the overlying Lower *Michelinia* Beds with *Cyathophyllum* cf. *multilamellatum*. The development is identical with that observed at Brigsteer; but the beds are much altered, and for the greater part unfossiliferous. The finest exposure of the upper beds occurs in an old quarry west of Cockin.

It will be best first to describe the development of the zones in the northern portion of the district, where excellent exposures occur, and afterwards to mention a few points of interest exhibited by the beds in the southern portion. The general dip is eastward, and averages from about 5° to 8°; but in the southern portion the beds roll slightly, and the dip changes locally.

(1) The Northern Portion.

The slope of the country as shown in the section (Pl. LVI, fig. 3) very nearly coincides with the dip of the rocks, and the greater portion of the surface is occupied by the beds of the *Nematophyllum-minus* Sub-zone.

The *Athyris-glabristria* Zone crops out at intervals along the base of the western and northern portions of the escarpment. The basement-beds are usually obscured, and though a somewhat extensive area at the northern end of the district is represented as occupied by these beds on the Geological Survey map, very few exposures occur at the surface.

The lowest beds met with consist of sandy dun-coloured dolomites, containing little in the way of fossils except obscure plant-remains. Between Hall-Head Farm and Cunswick Hall a series of dolomitic limestones are exposed on both sides of the road; the lowest few feet of these appear to belong to the summit of the *Solenopora* Sub-zone, and contain a few specimens of *Camarotœchia proava* and *Seminula* aff. *ficoides*. The beds, therefore, correspond generally with the lowest horizon found at Low Meathop in the Arnside District, already described; no specimen of *Solenopora* has, however, been met with in this district. The lowest beds usually exposed belong to the Algal Layer, but the typical algal structure can only occasionally be identified in microscopic sections. Certain porcellanous layers, which occur near the base of the sections in Hall-Head Quarries, are of interest, as they closely resemble layers of a similar character that are found in the Bryozoa Band of the Shap District and, like them, contain *Calcispheræ* associated with plant-remains (see Pl. XLVII, fig. 4).

The *Thysanophyllum* Band is well exposed immediately above these beds in Hall-Head Quarries, and from here to Cunswick Hall it forms a nearly continuous outcrop. Farther south it is well exposed in the cutting for the Kendal-Underbarrow road, and again in Crag-Mollet Scar immediately above Brigsteer village. The fauna is normal, and examples of *Cyathophyllum* aff. *multilamellatum* are found near the summit.

Interesting evidence of horizontal movement may be observed in the limestone forming the floor of Hall-Head Quarries, where certain layers have been pinched up into sharp anticlinal folds, while those immediately above and below still remain horizontal and undisturbed; one of these pinched anticlines is shown in Pl. XLVI, fig. 1 (facing this page). The lateral displacement which gave rise to this interesting phenomenon was doubtless connected with the movements that brought down the Carboniferous rocks against the Silurian at Kendal hard by. Such lateral movement is common throughout the North-Western Province—as shown by the variation in the thickness of certain shale-partings, and also by the slickensiding constantly observed on the surfaces of the bedding-planes.

Above the *Thysanophyllum* Band under Cunswick Scar occurs a bed of hard siliceous limestone, which forms a small scar a few feet thick. Many of the layers are oolitic, while others are almost entirely composed of sand-grains cemented by calcite. The deposit is not very fossiliferous, but contains a few well-preserved specimens of *Syringothyris cuspidata*, and it was doubtless from

Fig. 1.—*Fold in* Thysanophyllum *Band, Hall Head Hall, Kendal.*

A  B

E. J. G. photo.

[This view shows horizontal movement along the bedding-plane AB.]

Fig. 2.—*Pseudobreccia and 'Stick Bed,' Lower* Dibunophyllum *Sub-zone, Chapel Island, Furness.* *(See p. 533.)*

C 

E. G. photo.

[The pseudo-breccia structure is shown at C.]

this bed that the specimen was obtained which is figured by Davidson from the Kendal District.[1] This bed appears to be the attenuated representative of the Brownber Pebble-Bed of the Shap District, as it occurs at about the same horizon; while the presence of *Syringothyris cuspidata* is in keeping with this view. The band also closely resembles the gritty compact limestone with *S. cuspidata*, which crops out in Swindale Beck behind Roman Fell, in the Pennine District. The following species occur in this bed[2]:—

Cyathophyllum cf. *multilamellatum* M'Coy.
Zaphrentis konincki Ed. & H. (mutation).
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Spirifer furcatus M'Coy.
Syringothyris cuspidata (Mart.).
Aviculopecten sp.

The *Michelinia* Zone.—The most important outcrop of this zone occurs along the face of the western escarpment; but the zone is again exposed on the east side of the district at Kettlewell, where it is brought up by an offshoot of the main Kendal fault. The lower sub-zone, corresponding to the beds which occupy the summit of Meathop Fell, is only found on the western escarpment, where it is represented by 20 to 30 feet of pale, somewhat platy, siliceous limestone, which crops out on each side of the cart-track immediately above Crag Mollet. This bed contains large examples of *Michelinia grandis*, together with *Camarophoria isorhyncha*. On the west side of the track, at a slightly lower horizon, the limestone contains abundant remains of *Cyathophyllum* cf. *multilamellatum* partly silicified. These are the earliest examples of *Cyathophyllum* met with in the North-Western Province, and are found also at this horizon at Hall Head, in the outlier at Grayrigg, and at Cat Crag and Broad Oak in the Grange District.

The *Chonetes-carinata* Sub-zone crops out at intervals along the foot of the main escarpment below Helsington Barrows; but the beds are best exposed in the cutting for the Brigsteer-Kendal road. The total thickness of the *Michelinia* Zone here is between 150 and 170 feet. The beds of the upper portion of the zone consist of impure limestone and shaly calcareous mudstone, similar to those seen in the Storth-Road section and on the foreshore at Arnside; and, though not abundantly fossiliferous, they contain most of the characteristic species of the sub-zone. This section is an important one, since it shows clearly the position of the *Thysanophyllum* Band relatively to the overlying *Michelinia* Zone. Farther north, the beds are well exposed on each side of the Kendal-Underbarrow road. As in the case of the underlying

[1] 'Brit. Foss. Brachiopoda' Monogr. Palæont. Soc. vol. ii (1858–63) pl. viii, fig. 20.

[2] This bed is mentioned by Mr. R. H. Tiddeman in the revised Survey Memoir on the district, and correlated by him with a portion of the Orton Sandstone Series, one of the many examples of the careful deductions made by that acute observer on stratigraphical grounds alone. See 'The Geology of the Country around Kendal, &c.' Mem. Geol. Surv. 2nd ed. (1888) p. 29.

Athyris-glabristria Zone, the beds rise gradually in this direction, and so, while the base of the zone on the Brigsteer-Kendal road lies at a height of about 220 feet above O.D., on the Underbarrow-Kendal road ($2\frac{1}{2}$ miles farther north) it has risen above the 500-foot contour-line.

The *Michelinia* Zone which crops out at Kettlewell, on the east side of the district, is similar in character to that exposed above Brigsteer, and the beds contain the usual fauna. The *Clisiophyllum-multiseptatum* Band, with *Zaphrentis enniskilleni*, is also present at this locality.

The *Productus corrugato-hemisphericus* Zone: the Gastropod Beds occupy the surface over a considerable area in this district. On the west, under Scout Scar, the beds are usually covered by screes, while the Plumgarth Quarries opened in these beds north-west of Kendal are almost devoid of organic remains, except specimens of *Bellerophon* and *Productus*. The large quarries at Kendal Fell have, however, furnished numerous fossils to local collectors, and a rich assemblage is preserved in the Kendal Museum. The most interesting feature of this collection is the great number of species of mollusca and the large size which many of the gastropods and cephalopods attained, recalling Mr. Douglas's description of a similar rich molluscan fauna from the limestone of County Clare, which, however, belongs to a lower horizon.[1] A list of this collection is given in the Geological Survey Memoir on the Kendal District, 2nd ed. (1888) table iv, pp. 85–88. Some of the species in this list are, however, incorrectly named.

The *Cyrtina-carbonaria* Sub-zone is well developed, especially on the east side, where the beds are exposed in the upper portion of the old Kettlewell Quarry.[2]

The *Nematophyllum-minus* Sub-zone forms the greater part of the high ground, from the edge of Scout Scar and Cunswick Scar to the summit of the Kettlewell Quarries. It was doubtless from this locality that M'Coy obtained his type-specimen of the index-fossil now preserved in the Sedgwick Museum at Cambridge. Masses of this coral occur in the upper layers of the white limestone on Scout Scar; on Cunswick Scar above Kettlewell; and in the neighbourhood of 'The Heights.'

The Bryozoa Band, which lies at the summit of this zone in the Shap and Ravenstonedale Districts, has not been noticed here; this may be due to the denudation of the highest beds of the zone, but it is possible that the band has died out in this district, as it is nowhere met with farther west.

[1] Q. J. G. S. vol. lxv (1909) p. 551.

[2] The specimens figured by M'Coy in the 'Brit. Pal. Fossils' 1855, pl. iii *d*, figs. 12–18, under the name '*Pentamerus carbonarius*,' and by Davidson 'Brit. Foss. Brachiopoda' Monogr. Palæont. Soc. vol. ii (1858–63) pl. xv, figs. 7–12, were obtained from this locality.

The Lower *Dibunophyllum* Sub-zone is only represented by a small thickness of limestone in the 'Serpentine Walks.'

(2) The Southern Portion.

From Brigsteer as far south as Gilpin Bridge and the mouth of the Kent, the lower beds are a continuation of the sequence described above. The dip is uniformly eastward, and the beds of the *Seminula-gregaria* Sub-zone form a low cliff, bordering the Gilpin estuary. They crop out at the surface in Brigsteer Park, and are also well exposed in a series of old quarries in the neighbourhood of Cinderbarrow; but the beds are here almost devoid of fossils. The overlying *Michelinia* Beds extend somewhat farther east in the neighbourhood of Sizergh Castle. To the east of Sizergh an interesting inlier of the upper portions of the *Michelinia* Zone occurs in the valley of the Kent (the Kent Inlier), between Hawes Bridge and Levens Park. The beds are disposed in a broad anticlinal fold, the axis of which strikes east and west; locally, however, the dip is modified by several minor folds, some of which are well shown in the river-bank between Sedgwick and Levens.

The *Clisiophyllum-multiseptatum* Band is exposed above Hawes Bridge, and the beds here contain the general assemblage found at Blackstone Point; while, near the southern end of the inlier, somewhat lower beds are found, which have yielded *Michelinia grandis*, *Cyathophyllum multilamellatum*, and other common Arnside species.

The *Nematophyllum-minus* Sub-zone, which forms the southern end of Scout Scar, does not extend far southwards, the southernmost exposure where *N. minus* has been found occurring behind Grate Farm. East of the Kent Inlier the Gastropod Beds come on, but the *N.-minus* Beds are again met with in the railway-cutting south-west of Oxenholme Junction, about half a mile east of Natland: here the beds are much crushed and altered by their proximity to the Kendal Fault. No beds belonging to the *Dibunophyllum* Zone have been traced in this portion of the district. South of the Kent drainage-area the geological structure of the district becomes more complicated. The country is heavily covered with drift, and very few exposures occur: this is especially the case in the eastern portion of the area. The chief feature is an important disturbance running in a general east-and-west direction in the neighbourhood of Hincaster, between Levens Hall and Heversham. Owing to the absence of any outcrop south of Stainton, it is impossible to gauge the extent or direction of this disturbance; to the south of it, however, we find massive limestones that belong to the Lower *Dibunophyllum* Sub-zone dipping due northwards at 25° to 30°, and forming the high ground between Leasgill and High Greenside, immediately north-east of Heversham. This dip would carry them under the *Michelinia* Beds in the Kent

Inlier, described above; and, as there are no beds of Lower *Dibunophyllum* age on the north, there is evidently a considerable dislocation in this neighbourhood.

Another interesting example of the value of the zonal method in detecting disturbances in these rocks may be quoted from this district. On the eastern edge of the Carboniferous Limestone area, the Kendal Fault is shown in the Geological Survey map as curving outwards rather sharply to the east near Summerlands. This protruding portion of Carboniferous rocks should, therefore, consist of the highest beds in the district, as the dip, when last seen, is eastwards. Fortunately, an exposure is met with in some small quarries in Eskrigg Wood, just where the greatest eastward extension of these Carboniferous rocks is shown in the Geological Survey map. The following forms have been obtained from these beds:—

Calcareous alga.	*Syringopora* cf. *geniculata* Phill.
Campophyllum ciliatum, sp. nov.	*Seminula* aff. *ficoidea* Vaughan.
Lophophyllum meathopense, sp. nov.	

This fauna is met with nowhere in the North-Western Province, except at the base of the *Seminula-gregaria* Sub-zone: therefore this protruding portion of the Carboniferous outcrop must belong, not to the western side of the Kendal Fault, but to the Silurian area on its eastern side, as shown in the accompanying map (Pl. LIV). It must once have formed part of a continuous spread of limestone overlying the Silurian on the upthrow or eastern side of the fault, of which the outliers at Strickley, Low Bendrigg, Grayrigg, and Skelsmergh are the fragmentary remains.

The Kirkby Lonsdale District.

This district comprises the area occupied by Lower Carboniferous rocks between the Kendal Fault, south of Farleton, and the Dent Fault. It constitutes, on the whole, the most complicated portion of the North-Western Province. This complication is due, in the first place, to the existence of a large number of important dislocations; and secondly to the fact that, so far as the upper beds of the series are concerned, they occupy a geographical position intermediate between the Yoredale type on the north and east, and the knoll-reef type which characterizes the area south and west of the Craven Faults.

The chief dislocations run in a general north-and-south direction, but have a tendency to converge on points, usually northwards, so as to enclose triangular areas of Carboniferous rocks, as shown in the accompanying map (Pl. LIV).

The *Athyris-glabristria* Zone.—A small thickness of rocks which appear to belong to this zone occurs at the northern or pointed end of the western triangular inlier north of Lupton Hall. The beds are exposed on both sides of the road to Lupton-Row Farm, and consist of compact dolomite very much crushed.

The only organic remains that have been obtained from them are badly-preserved remnants of calcareous algæ and *Seminula gregaria*. The occurrence of these fossils, taken together with the lithological character of the beds and their position (apparently underlying the horizon to be next described), leaves little doubt that they belong to the upper portion of the *Athyris-glabristria* Zone, although the country immediately south of these outcrops unfortunately affords no exposures.

The *Michelinia* Zone.—In the neighbourhood of Hunger Hills, on the east side of the outlier, a good section of dark earthy limestones belonging to the upper portion of the *Michelinia* Zone is exposed in an old quarry close to the eastern boundary-fault, while smaller outcrops of the same horizon occur farther west. The beds contain the following fossils :—

Caninia cylindrica (Scouler).
Diphyphyllum aff. *lateseptatum* M'Coy.
Michelinia grandis M'Coy.
Syringopora cf. *distans* Fischer.

Athyris expansa (Phill.).
Chonetes carinata, sp. nov. (MS.).
Productus cf. *corrugato-hemisphericus* Vaughan.
Rhipidomella michelini (L'Éveillé).
Schellwienella crenistria (Phill.) ; the large Arnside form.

In the upper portion of this exposure occur also *Zaphrentis enniskilleni* and *Clisiophyllum multiseptatum*, which mark the passage-band at the summit of the *Michelinia* Zone in the Arnside District.

The *Productus corrugato-hemisphericus* Zone.—The beds of the lower portion of this zone are not well exposed, but occupy the ground east of the road in the neighbourhood of Lupton Hall, where they are seen in a small anticlinal fold. The *Cyrtina-carbonaria* Beds have not been noticed in this exposure ; but a pale crystalline limestone with *Nematophyllum minus* and *Chonetes papilionacea* is exposed on the west side of the road above the lime-kiln opposite Lupton Hall, where the beds are crushed and veined with calcite in the neighbourhood of the western fault. The strike of the beds, as shown on the map, leaves little room for doubt that the outlier is bounded by faults or thrusts on both its eastern and western margins.

The triangular mass of Lower Carboniferous rocks lying between Farleton village and Hutton Roof, which culminates in the conspicuous escarpment of Farleton Fell, forms another isolated mass, cut off apparently on all sides by faults. It includes a complete succession of the zones, from the summit of the *Michelinia* Zone up to the base of the Upper *Dibunophyllum* Sub-zone. The beds dip in a south-easterly direction, the lowest beds being exposed near Farleton village. The succession is normal up to the summit of the Lower *Dibunophyllum* Sub-zone, which includes examples of the lower 'spotted' beds : these are well exposed in Clawthorpe Quarries.

The Upper *Dibunophyllum* Sub-zone crops out west of Hutton Roof, where the beds are seen dipping steeply to the Hutton Roof Fault. They consist of the usual dark limestones, and contain *Productus latissimus* and the following characteristic fossils:—

Caninia cf. *cylindrica* (Scouler); cf. Humphrey Head form.
Dibunophyllum muirheadi Nich. & Thomson.
Lithostrotion irregulare (Phill.).
Lithostrotion junceum (Fleming).

East of Hutton Roof we find another good sequence of the upper zones. The Lower *Productus corrugato-hemisphericus* Zone crops out in a small cliff, on the north side of the road from Kirkby Lonsdale to Lupton Beck, which is bounded on the north by a continuation of the eastern Lupton Fault. The *Nematophyllum-minus* Beds are not well exposed; but the beds of the Lower *Dibunophyllum* Sub-zone make, as usual, a considerable feature to the south of the road. They are also well exposed in the River Lune below the bridge.

The dark limestone at the base of the Upper *Dibunophyllum* Sub-zone crops out again in the neighbourhood of Sellet Mill; here the beds are extremely fossiliferous, and contain, among others, the following species:—

Aulophyllum cf. *pachyendothecum* Thomson.
Caninia cf. *cylindrica* (Scouler).
Dibunophyllum muirheadi Nich. & Thomson.
Zaphrentis enniskilleni Ed. & H.

Martinia ovalis (Phill.).
Productus cf. *antiquatus* Sby.
Productus edelburgensis Phill.
Productus latissimus Sby.
Productus semireticulatus Mart.
Productus sulcatus Sby.
Schizophoria resupinata (Mart.).
Spirifer triangularis Mart.

Sections along the Dent Fault.

In the area between the Kirkby Lonsdale and Ravenstonedale districts the Carboniferous rocks have been denuded from the surface, as the result of the uplift on the north-west side of the Dent Fault. With the exception of the outliers east of Kendal already described, the only patches of Carboniferous rocks serving to connect these districts are found in the tributaries of Hebblethwaite Gill and in the River Clough east of Sedbergh. Throughout the greater part of the district traversed by the Dent Fault, its north-western margin is bordered by rocks of pre-Carboniferous age, while the southern side of the fault is occupied, for the most part, by Yoredale Beds. The presence, however, of some of the lower zones, preserved on the upthrow side of the fault in these sections, is of importance, since it affords valuable evidence regarding the date of the Carboniferous submergence of this portion of the North-Western Province.

In Norgill, the northern tributary of Hebblethwaite Gill, the Polygenetic Conglomerate, which is here crowded with blocks of Keisley Limestone, is succeeded by compact cementstones and dark calcareous shales. Some of these shaly layers contain plant-remains and ostracods, among which *Leperditia okeni* is conspicuous; while in one dark compact band a small rhynchonellid also occurs, together with fish-remains. The *Rhynchonella*, although as a rule badly crushed, appears to be referable to *Rh. fawcettensis*, which, as already mentioned, characterizes in the Shap and Ravenstonedale Districts the *Productus-globosus* Band at the base of the *Seminula-gregaria* Sub-zone. Dr. A. Smith Woodward, who has kindly examined the fish-remains, reports that they include a species of *Deltodus* which is probably new, together with a spine of *Oracanthus*; but the remains are not sufficiently well-preserved for specific description.

In Pennyfarm Gill, the eastern tributary of Hebblethwaite Gill, there is a good section exposed, from the Polygenetic Conglomerate, through basement Carboniferous sandstones with obscure plant-remains, to the lowest beds of Carboniferous Limestone. The beds are dipping at a high angle, and include the upper portion of the *Michelinia* Zone. This zone occurs at a sharp bend in the stream, about 180 yards above the junction of Pennyfarm Gill with Hebblethwaite Gill, and consists of dark impure limestone, which contains, among others, the following fossils :—

Clisiophyllum multiseptatum, sp. nov.
Zaphrentis enniskilleni Ed. & H.
Zaphrentis konincki Ed. & H.
Athyris cf. *expansa* (Phill.).
Chonetes carinata, sp. nov. (MS.).

This assemblage is characteristic, elsewhere in the North-Western Province, of the upper portion of the *Michelinia* Zone.

The main line of the Dent Fault appears to pass to the east of these beds, and soon brings in the typical Yoredale limestones. The greater part of the *Productus corrugato-hemisphericus* Zone and the Lower *Dibunophyllum* Sub-zone would, therefore, seem to be absent in the section; while the Lower *Michelinia* Zone appears also to be cut out by a subsidiary fault. Farther south-west, in the River Clough, only a small portion of the lower series is exposed on the west side of the fault; while, to the east of it, we find a continuous section of the *Productus* Zone and the Lower *Dibunophyllum* Sub-zone leading up to the Yoredale beds above. The Lower *Dibunophyllum* Sub-zone here also includes the 'spotted' beds already described.

It will thus be seen that the Dent Fault traverses the lower zones of the Carboniferous obliquely, and that, so far as these zones are preserved, they are similar to those found in the Kirkby Lonsdale District on the west, the lowest fossiliferous horizon (as in the Lupton District) being somewhere near the base of the *Seminula-gregaria* Sub-zone.

VI. The Grange and Furness Districts.

The rocks of these districts, forming the northern shore of Morecambe Bay, constitute the southern portion of the ring of Lower Carboniferous rocks bordering the Lake District between the Duddon estuary and Scout Scar. They are divided by a system of north-and-south strike-faults into a series of blocks, separated one from the other, either by estuaries or by valley-depressions. The general dip of the Carboniferous rocks being uniformly eastward, and the downthrow being on the west of each fault, we find a series of similar blocks of Lower Carboniferous strata, in each of which a complete sequence is exposed from the Silurian to the highest Carboniferous bed (usually somewhere near the summit of the Lower *Dibunophyllum* Sub-zone) remaining, after denudation, in each block (Pl. LVI, Section 3, & fig. 1, p. 451).

The numerous sections of the lower beds thus exposed show that the general surface of the Silurian platform upon which the Carboniferous strata were deposited must have been, on the whole, a remarkably even one, and the Carboniferous submergence must have taken place simultaneously over a large area.

Everywhere resting upon the Silurian rocks occurs some portion of the *Seminula-gregaria* Sub-zone, succeeded by the *Michelinia* Zone. Outside the Furness District there is practically no equivalent of the Shap Conglomerate or the barren basement-sandstone which occurs in the type-districts; still less is there any trace of the underlying Polygenetic Conglomerate of the Sedbergh and Ullswater areas farther east.

The area with which we are now concerned may, for convenience, be divided into an eastern portion—'The Grange District,' and a western portion—'The Furness District,' separated by the Leven estuary.

(1) The Grange District.

This district lies between the Leven estuary and the Kendal District already described. It is separated from the latter by the fault which runs down the Gilpin valley. Four fault-blocks occur in this district. These are, counting from the east to the west: Whitbarrow, Yewbarrow, Hampsfell, and Holker. The succession resembles closely that in the Arnside District, and the beds are, as might be expected, intermediate in their development between those of the Arnside and of the Kendal Districts. Thus the *Thysanophyllum* Band of the type-districts is only found in the easternmost block; while the character of the Upper *Dibunophyllum* Sub-zone, so far as it is preserved at Humphrey Head and Holker, is intermediate between the Yoredale and the Kirkby Lonsdale types. The *Spirifer-furcatus* Band and the *Camarophoria-isorhyncha* Sub-zone are also locally developed.

The Whitbarrow–Yewbarrow block is separated from the Kendal District on the east by the Gilpin-valley Fault, and from the Hampsfell block on the west by the Newby-Bridge & Lindale Fault, which brings up the Silurian tract of Higher Newton and the Winster Valley. Whitbarrow and Yewbarrow are also separated one from the other by a north-and-south fault which passes near Witherslack Hall. The general dip is eastward. The lowest beds are exposed in both Yewbarrow and Whitbarrow, along the base of the western escarpments. The zonal development is intermediate between that of the Kendal and that of the Arnside District. It differs from the North Kendal succession, chiefly in the more pronounced development of the *Chonetes-papilionacea* Beds near the summit of the *Nematophyllum-minus* Sub-zone.

The *Seminula-gregaria* Sub-zone consists, as usual, of sparingly fossiliferous, purple, magnesian limestones with *Seminula* aff. *ficoidea* and *Cyrtina* cf. *carbonaria.* They are exposed along the foot of the escarpment between Cat Crag and Strickland Hall; and a few feet belonging to the same horizon occur also at the base of the section at Beck Head, in the Whitbarrow portion of the block.

The *Thysanophyllum* Band crops out behind the old limekiln between Broad Oak and Row, but appears to die away southwards before reaching Beck Head.

The Brownber Pebble-Bed has not been traced so far west; but a single specimen of *Syringothyris cuspidata* was collected in a compact gritty layer near the base of the escarpment. *Spirifer furcatus,* however, is met with plentifully at Beck Head and at Cat Crag; and the bed in which it occurs may be correlated with the *Sp.-furcatus* Band at the summit of Meathop Fell.

The *Camarophoria-isorhyncha* Sub-zone is found in several exposures at the foot of both of the escarpments, notably at Cat-Crag Cottage and Long-Howe End, and again between Beck Head and Witherslack Hall.

The *Chonetes-carinata* Sub-zone which succeeds in both sections is perfectly normal, though thin, and contains all the common species found at Arnside; while the overlying *Clisiophyllum-multiseptatum* Band is also represented. Both horizons are exposed above Broad Oak and west of Long-Howe End, and again in an old quarry opposite St. Paul's Church. The overlying beds call for no very special description; their general distribution is shown on the accompanying map (Pl. LIV).

The *Cyrtina-carbonaria* Sub-zone has practically died out here; but the *Nematophyllum-minus* Beds are thick as well as fossiliferous, and near the summit contain layers rich in *Chonetes papilionacea.* Both the *N.-minus* Beds and the Gastropod Beds are well exposed at the southern end of Whitbarrow behind Low Fell End. The highest beds met with occur in the small outlier at Gilpin Bank; they belong to the upper 'spotted' beds, and cannot lie far below the base of the Upper *Dibunophyllum* Sub-zone. The *Chonetes*-aff. *comoides* Band has not, however, been noticed in this block.

The Hampsfell block is separated from the Yewbarrow block by a tract of Silurian rocks about 3 miles wide; it lies to the south-west, and forms the largest spread of Lower Carboniferous rocks in the Grange District. It includes the peninsula of Humphrey Head, and the detached outliers of Holme Island and Hazel Rigg. It forms a lenticular mass stretching for about 8 miles in a north-and-south direction from Ayside to Humphrey Head Point, and some 3 or 4 miles in an east-and-west direction from

Lindale to Cartmel. The western outcrop forms a fairly steep escarpment, culminating in Hampsfell Hospice at a height of 727 feet. It rests on the Silurian tract of Cartmel and Broughton, and is cut off on the north-east by the Newby-Bridge & Lindale Fault. On the south-east it forms the coast-line between Castle Head and Humphrey-Head Point, and constitutes the foreshore between Grange and Kent's Bank. The block includes the beds from the *Seminula-gregaria* Sub-zone to the *Lonsdalia-floriformis* Beds at the base of the Upper *Dibunophyllum* Sub-zone. The former, which consist of unfossiliferous purple dolomites, crop out in some old quarries between Cartmel and Cark; they doubtless represent the horizon exposed at the southern end of Meathop Fell. The overlying Lower *Michelinia* Beds are not well exposed; but *Chonetes carinata* and *Caninia cylindrica* have been collected from several exposures, along the base of the escarpment between Birkby Hall and St. Paul's Church near Field Broughton. The outcrops of the higher zones run parallel to this escarpment, or nearly due north and south, as shown on the map (Pl. LV). At the northern end of the block the Lindale Fault cuts across the strike of the Carboniferous rocks, so that successively lower zones are brought against the Silurian as we travel in a north-westerly direction.

The Gastropod Beds occupy the country north and west of the Cemetery, and stretch thence northwards to Hampsfield Hall.

The *Nematophyllum-minus* Beds are well exposed in Haggs Quarry, and the upper portion of the sub-zone shows the shaly development of the *Chonetes-papilionacea* Beds characteristic of the Western Districts.

The Gastropod Beds are not well exposed, and no attempt has been made on the map to separate the upper and the lower portions of the zone, as the *Cyrtina-carbonaria* Beds are again indistinguishable. The beds, however, which crop out in Great Eskett Wood, about half-a-mile south-east of Cartmel, certainly belong to the lower portion of the zone.

The Lower *Dibunophyllum* Sub-zone is exposed in the quarries on the Cartmel Road between the Cemetery and Low-Fell Gate, and here the lower 'spotted' beds are well developed; they can be followed almost continuously along the escarpment to the edge of the wood above Hampsfield Hall. North of this the beds form a broad synclinal fold, and they reappear on the heights of Newton Head to the south of Head-House Farm; while the summit of Hampsfield Fell affords good exposures of the upper beds of the sub-zone, including the bands of pseudo-breccia. These upper beds are brought by the prevailing easterly dip of 10° on to the coast in the neighbourhood of Grange. A good section is exposed in the road-cutting a little to the east of the railway-station, where they are extremely fossiliferous and contain abundant specimens of *Dibunophyllum* ϕ; while the pseudo-breccia beds, including the *Chonetes*-aff. *comoides* Band, are exposed on the foreshore below the promenade. This band is again associated with the peculiar concretionary layer covered with 'stick-like' impressions, which has already been mentioned as occurring in the Silverdale coast-section at the same horizon. The band itself, which is exposed on the shore on each side of the pier, is conspicuous on account of its more shaly character and its yellower colour, as compared with the beds among which it lies. It contains large examples of *Cyrtina septosa*, together with specimens of *Chonetes* aff. *comoides* and *Productus hemisphericus*. The overlying beds exposed at low tide to the west of the pier cannot be far below the base of the Upper *Dibunophyllum* Sub-zone, and they contain abundant specimens of *Lithostrotion portlocki* and other corals. Brachiopods are, on the whole, rare; but *Productus* cf. *maximus* and *Pr. hemisphericus* are locally abundant. South of Grange promenade no exposures occur on the coast, until we reach Seawood cottages; here and farther south-west, beyond Kent's Bank Station, the beds of the Upper *Dibunophyllum* Sub-zone come on and the Nodular *Girvanella* Band is well exposed. At Kirkhead End these beds are cut off by a small north-and-south fault, which runs down the east side of the Bay opposite Wyke House. This fault brings in again the *Chonetes*-aff. *comoides* Band in the corner of the bay close to the railway-embankment.

A good section of the strata at the base of the Upper *Dibunophyllum* Sub-zone is seen in the railway-cutting immediately to the north. This includes a bed of shale, along which horizontal movement appears to have taken place, as the shale has been nipped out, and occurs in patches between the harder limestone-beds above and below.

On the west side of the Bay, south of Wyke House, the lower beds of the Upper *Dibunophyllum* Sub-zone again appear at the surface, and from here to Humphrey Head a continuous section of these beds is exposed on the foreshore. This section affords one of the best exposures of the *Lonsdalia* Beds to be met with in the North of England. It consists of 20 to 25 feet of grey limestones, including, near the middle, a thin layer of black shale containing specimens of *Chonetes compressa*, while the Nodular *Girvanella* Bed at the base is exposed along the greater part of the section. The nodules are very abundant; they form compact concentric incrustations round small fossils averaging about an inch in diameter, and weather out prominently at the surface. Under the microscope, tubes of *Girvanella* can sometimes be observed, arranged concentrically round the nodules. The greater number of the nodules, though undoubtedly due to organic agency, present a somewhat obscure structure; it seems probable, however, that calcareous algæ, and especially *Girvanella*, directly or indirectly contributed largely to their formation.

The beds are particularly rich in corals, and contain reef-like masses of *Lithostrotion*, *Lonsdalia floriformis*, and *Cyathophyllum regium*. Brachiopods are scarce, but *Productus giganteus* and *Pr. hemisphericus* occur locally in some abundance, while specimens of *Schellwienella* cf. *senilis* occur in patches. The following is a list of species collected from this interesting locality:—

Girvanella sp.

Alveolites capillaris (Phill.).
Aulophyllum sp. (large) cf. *pachyendothecum* Thomson.
Aulopora sp.
Caninia cf. *cylindrica* (Scouler).
Carcinophyllum ϕ Vaughan.
Clisiophyllum aff. *keyserlingi* M'Coy.
Cyathophyllum regium Phill.
Dibunophyllum muirheadi Nich. & Thomson.
Dibunophyllum turbinatum (M'Coy).
Heterophyllia grandis M'Coy.
Lithostrotion junceum (Fleming).
Lithostrotion martini Ed. & H.
Lithostrotion m'coyanum Ed. & H.
Lithostrotion aff. *portlocki* (Bronn).
Lonsdalia floriformis (Fleming).
Lophophyllum sp. Compound form.
Michelinia cf. *tenuisepta* (Phill.). Very small form.
Zaphrentis aff. *constricta* Carruthers MS.

Syringopora geniculata Phill.

Chonetes cf. *compressa* Sibly.
Dielasma hastatum (Sby.).
Orbiculoidea nitida (Phill.).
Productus giganteus Mart.
Productus aff. *grandicostatus* M'Coy.
Productus cf. *margaritaceus* Phill.
Productus quincuncialis Phill.
Productus scabriculus Mart.
Productus semireticulatus Mart.
Rhipidomella michelini (L'Éveillé).
Pugnax cf. *pleurodon* (Phill.).
Schellwienella cf. *senilis* (Phill.).
Spirifer antiquatus Sby.
Spirifer bisulcatus Sby.
Spirifer (*planicostus* M'Coy) = *crassus* de Kon.
Spirifer duplicicostus Phill.
Spirifer aff. *grandicostatus* M'Coy.

Loxonema rugiferum Phill.
Pleurotomaria sp.

The three small outliers of Hazel Rigg, Castle Head, and Holme Island on the east side of the main mass consist of large masses of fault-breccia let down against the Lindale Fault. Holme Island itself consists of a small dome of limestone crushed against the downthrow side of the fault; the beds here lie near the summit of the Lower *Dibunophyllum* Sub-zone. The little outlier of Hazel Rigg probably represents a much lower horizon, near the base of the succession, but the beds are crushed, recrystallized, and quite unfossiliferous. A fault passes between Holme Island and the Meathop outlier, with the result that, whereas the island is composed of beds near the summit of the Lower *Dibunophyllum* Sub-zone, the Meathop outlier, as already shown, contains beds as low as the *Camarotœchia-proava* Band.

In the Holker block we meet with beds from the base of the *Michelinia* Zone to the Upper *Dibunophyllum* Sub-zone; and a nearly continuous section occurs, from the lowest beds at Park Head to near the summit of the Lower *Dibunophyllum* Sub-zone. This block is bounded on the west by the Leven estuary, and is cut off on the east by the Cark-Haverthwaite fault. East of this fault the Silurian rocks form a conspicuous fault-scarp; while, on the west side, the country is occupied by alluvial deposits forming Deer Dyke Moss and Barker Moss, out of which rise several islands of Lower Carboniferous rock.

The *Camarophoria-isorhyncha* Sub-zone is exposed in two sections—one situated between Park Head and Barker Scar, and the other farther north, between Skelwith Hall and Reake Hill in the neighbourhood of Low-Frith Farm, where the two subdivisions of the *Michelinia* Zone are seen in direct upward continuation one with the other. These sections are of especial interest, since they confirm the conclusion, already arrived at from a study of the Arnside and Kendal Districts: namely, that the bed containing the massive form of *Michelinia grandis*, seen on Meathop Fell, underlies the higher beds of the zone with *Chonetes carinata* exposed on the opposite shore at Arnside. In the Park-Head section the lower portion of the zone is seen at low water in the neighbourhood of Barker Scar, where it consists of about 20 feet of massive limestone containing large specimens of *Michelinia grandis*. This is overlain by dark limestones and calcareous mudstones, forming the upper portion of the *Michelinia* Zone, which crops out on the beach and also in a small cliff farther up the shore below the flagstaff.

The mudstones contain identically the same fauna as that already described from the Arnside Beds, and the section includes the *Clisiophyllum-multiseptatum* Band at the summit.

The *Productus-corrugato-hemisphericus* Zone.—Immediately overlying this band comes a purple limestone with *Lithostrotion* and *Seminula* aff. *ficoides*, representing the lower portion of the *Pr.-corrugato-hemisphericus* Zone; and these beds are succeeded by the paler limestones containing *Nematophyllum minus* and *Chonetes papilionacea*, belonging to the upper portion of the zone. The beds dip here at about 20° south-eastwards.

On the east side of Ravenbarrow Point a small fault occurs, but a good exposure of the overlying beds of the Lower *Dibunophyllum* Sub-zone is seen a little farther east; and these beds can be followed in a northerly direction to Old-Park Farm, where the 'spotted' beds, already mentioned as very characteristic of this zone elsewhere, are found in the quarry in Waitham Wood.

Beds belonging to the Upper *Dibunophyllum* Sub-zone crop out in Holker Park, and consist of a series of sandstones and thin bituminous limestones near Quarry Flat. These deposits appear to approach the Kirkby Lonsdale type in character.

The section near Frith Hall farther north is a continuation of that just described. It is of interest, chiefly on account of the exposure of the beds of the *Camarophoria-isorhyncha* Sub-zone and the evidence which it affords regarding their relation to the overlying beds of the upper portion of the zone, which are also well exposed here.

The lower beds are much indurated, recrystallized, and traversed by calcite-veins, indicating their proximity to a considerable disturbance. The importance of this disturbance is further emphasized by the presence of a thrust-plane accompanied by a red crush-breccia. This breccia is well seen in the cliffs a few feet above the shore, in several places in the neighbourhood of Hazelhurst Point.

These evidences of movement are doubtless connected with the disturbance which runs up the Leven estuary, one of the series of north-and-south faults previously mentioned.

(2) The Furness District between the Duddon and the Leven Estuaries.

The beds, on the whole, resemble those of the Grange District, and include the succession from the *Seminula-gregaria* Sub-zone to the Upper *Dibunophyllum* Sub-zone. The country is drift-covered, and very few natural exposures of the lower zones occur. The central portion between Great Urswick, Stank, and Dalton is considerably faulted, and the limestones here and farther west are much altered and impregnated with hæmatite. The points of special interest in the district are:—

1. The presence of conglomerate and shales at the base of the succession in the north-western border between Marton and Elliscales, representing the *Athyris-glabristria* Zone of the type-districts.
2. The excellent development of the lower portion of the *Michelinia* Zone in the neighbourhood of Elliscales, and the presence of exposures showing the relationship of the upper and lower portions of this zone.
3. The fine series of exposures of the *Nematophyllum-minus* Sub-zone in the Longlands quarries.
4. The presence of the Southern or Kirkby Lonsdale facies of the Upper *Dibunophyllum* Sub-zone.

The *Athyris-glabristria* Zone.—The lowest beds consist of a conglomerate, overlain by calcareous shales and limestones which crop out between Marton and Elliscales. These are not well exposed at the present time; but a complete section of the beds, from the Silurian to the summit of the *Michelinia* Zone, can be examined in a core from an old boring near Maidenlands Quarry. This boring, which was carried to a depth of 168 feet, shows a thickness, from the base to a level somewhere below the summit of the *Michelinia* Zone, of about 150 feet. The lower half of this core, judging from the character of the rock, appears to belong to the upper portion of the *A.-glabristria* Zone. The presence of a basal conglomerate, which occurs in several layers in a red sandstone, is an interesting feature of the section, as no such basement-beds occur elsewhere in the Furness, Grange, or Arnside Districts. West of Elliscales, exposures of these lowest beds occur near the tramway-cutting, and on the east side of Elliscales Quarry. Specimens of *Carruthersella compacta* have been collected from the latter exposure, showing the analogy of these beds with the Meathop dolomites. On the east side of the Furness District two outcrops of the *A.-glabristria* Zone occur. The northernmost of these forms a small outlier resting upon the Silurian at Ashes Point, on the western shore of the Leven estuary. The small thickness exposed belongs to the *Seminula-gregaria* Sub-zone, and doubtless represents the upper portion of this zone at Meathop. A little farther south, the beds which form the base of the escarpment west of Plumpton Hall appear to belong to the same horizon.

The *Camarophoria-isorhyncha* Sub-zone is well exposed in the quarries at Elliscales, where some 20 or 30 feet of the lower portion of the *Michelinia* Zone are seen. The rock is a compact grey limestone, and contains very large examples of *Michelinia* *grandis*; they are associated with *C. isorhyncha*, *Syringopora*, and *Cyathophyllum* cf. *multilamellatum*. The overlying beds of the Upper *Michelinia* Zone crop out on the other side of the Dalton road, where they are exposed in a small quarry and contain the usual Arnside species, including *Caninia cylindrica*.[1]

The beds of the Upper *Michelinia* Sub-zone extend southwards to the neighbourhood of Dalton, and are also met with in the spoil-heap from the mine-shaft close to the cross-roads, about a quarter of a mile south of Lindale Cote. The shale taken out of the shaft contains abundant remains of *Zaphrentis konincki* and other characteristic fossils. It is, nevertheless, probable that the beds are here overlain by the Gastropod Beds; but the surface is drift-covered. On the east side of the district good exposures occur in the large quarry at Gascow, and again nearer the coast in the outlier near Plumpton Hall. At both these localities the fauna appears to be normal. In the Gascow section the beds come to the surface in a dome-shaped inlier, only the upper portion of the zone being exposed near the floor of the quarry; the fauna is especially rich in specimens of *Zaphrentis konincki* and *Z. enniskilleni*, while the *Clisiophyllum-multiseptatum* Band is also well developed. M'Coy's interesting form *Diphyphyllum dianthoides* also occurs in both these sections.

The Gastropod Beds call for no comment, and succeed the *Michelinia* Zone in the sections at Gascow and Plumpton; they also occupy a considerable area to the south and east of Lindale.

The *Nematophyllum-minus* Sub-zone is well exposed in places, especially in Longlands Quarry, which is chiefly excavated in these beds. Quarries have also been opened at this horizon near the cross-roads on the west side of Birkrigg Common, and the rocks crop out at the surface between this latter exposure and Gascow Quarry.

The Lower *Dibunophyllum* Sub-zone forms the high ground on the east side of the Urswick-Tarn Fault. It occupies the whole of Birkrigg Common, and also the coast-line from Conishead Priory to Baycliff and Aldingham; while the base of the zone forms an irregular outcrop from Bighead Wood, round the west side of Birkrigg Common, to Scroggs Close and Baycliff. Chapel Island also affords a good exposure of the rocks of this zone, which include the 'Stick' bed and the beds of pseudo-breccia (see Pl. XLVI, fig. 2, facing p. 518).

On the west side of the Urswick-Tarn Fault these beds occupy the high ground immediately west and south-west of Little Urswick. South of Stainton the zone is faulted back to the west by a north-west and south-east fault, and the 'spotted' beds characteristic of

[1] I have to thank Mr. Mellon, the manager of the Elliscales Quarries Syndicate Ltd., for his kindness in allowing me to examine this section, and for the gift of the fine specimen of *M. grandis* exhibited in the collection at University College (London).

the zone are seen in the quarry half-a-mile west of Stainton on the road from Dalton to Dendron.

The *Cyrtina-septosa* Band is exposed in the old quarries at Little Urswick, on the shore below Sea Wood and on Chapel Island.

The Upper *Dibunophyllum* Sub-zone occupies much of the district to the south of Little Urswick, between Hawkfield and Gleaston. The development here resembles the southern or Kirkby Lonsdale type, and the limestone near the base contains the following species:—

Aulophyllum cf. *pachyendothecum* Thomson.
Caninia cf. *subibicina* M'Coy.
Dibunophyllum turbinatum M'Coy.

Athyris expansa (Phill.).
Athyris planosulcata (Phill.).
Cliothyris royssi (L'Éveillé).
Camarophoria crumena (Mart.).
Chonetes laguessiana de Kon.
Leptæna analoga Phill.
Martinia glabra (Mart.).
Productus cf. *auritus* Phill.
Productus costatus Sby.
Productus fimbriatus Sby.
Productus giganteus Mart.
Productus latissimus Sby.
Productus pugilis Phill.
Productus scabriculus Mart.
Productus semireticulatus Mart.
Productus cf. *spinulosus* Sby.
Productus cf. *youngianus* Dav.
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Spirifer bisulcatus Sby.
Spirifer pinguis Sby.
Spirifer triangularis Mart.
Spiriferina octoplicata Sby.

Phillipsia eichwaldi Fischer.

VII. The Westmorland Pennines and the Middleton-in-Teesdale District.

A portion of the Pennine escarpment east of Appleby lies in the county of Westmorland. This Carboniferous tract is separated from the Shap District by the Permian and Triassic rocks which occupy the Vale of Eden, and by the Pennine Fault.

For purposes of comparison with the rest of the North-Western Province, the lower beds of the Pennine escarpment which are exposed at intervals between Great Rundale Beck and Great Musgrave Scar have been especially studied; the rocks here appear to include the lowest horizons met with along the escarpment, and are less disturbed by faults than those which occupy the country farther south.

The higher beds in the same area have also been examined, but the results recorded here are limited to a comparison with the general sequence already described; no attempt is made to give an exhaustive account of the fauna of the Yoredale rocks of the northern portion of the Pennine Chain.

The succession in Upper Teesdale includes a series of marine beds in the neighbourhood of Botany to the south of Middleton, mapped by the officers of the Geological Survey as Millstone Grit. Though not in Westmorland, the series forms a direct continuation of the Westmorland succession, and is included here, as it is the only district where a sequence from the Lower to the Upper Carboniferous rocks can be readily obtained in the North-Western Province.

Comparison with the Type Districts.

The chief noteworthy features are:—

1. The absence of the Shap Dolomite Series below the *Thysanophyllum* Band, that is to say, of practically the whole of the *Athyris-glabristria* Zone: a fact which points to the submergence of the area now occupied by the northern portion of the Pennine Chain, at a considerably later date than the Shap and Ravenstonedale Districts.
2. The presence of a series of fossiliferous mudstones and pebble-beds at the base of the succession, overlain by barren sandstones. These represent all the beds from the *Thysanophyllum* Band up to the middle of the *Nematophyllum-minus* Sub-zone.
3. The fuller development of the Yoredale rocks, which in the Middleton District approximates to the normal development of this series in Wensleydale.
4. The presence of a series of impure cherty limestones and calcareous shales (the Botany Beds), which occur high up in the Millstone Grit Series of the Geological Survey map, and contain abundant remains of *Dibunophyllum muirheadi* and *Phillipsastræa radiata*, associated with a fauna which closely resembles that of the *Cyathaxonia* Beds of D_3 in Derbyshire.
5. The presence of an intrusive sheet of dolerite, the Whin Sill, which has altered the rocks locally to such an extent, that the correct determination of the fossils in the beds in contact with it is often rendered impossible.

The Basement Series.—These beds are best exposed in the neighbourhood of Roman Fell, and the whole series is mapped by the officers of the Geological Survey as the 'Roman-Fell Beds.'[1] On the Geological Survey map, however, a patch of pebble-beds which occurs on the west side of Roman Fell is separated as an underlying series called 'Basement Beds' (red conglomerate).

It is extremely doubtful, however, whether the conglomerates seen on Roman Fell itself really belong to the same series as the fossiliferous grits and pebble-beds which crop out east and south of Roman Fell. If they do, they must certainly lie below these latter beds; but it is much more probable that they represent an older series, and are contemporaneous with the Polygenetic Conglomerate of the Sedbergh and Ullswater Districts: as, however, they have yielded no fossils of Carboniferous age, they need not be further discussed in detail. One word, nevertheless, may be said as regards their relation to the fossiliferous basement series which will be next described. The Roman-Fell Beds are coloured as Basement Carboniferous on the Geological Survey map, and are shown passing conformably up into the Melmerby-Scar Limestone Series of Long Fell on the east; this mapping does not appear to be correct, as one fault, at least, separates Roman Fell from the Carboniferous Limestone Series of Long Fell. This fault, which is marked by a row of potholes (fig. 3, p. 536), passes close to the old sheepfold near the summit of the col between Roman Fell and Long Fell. From the top of the col it runs nearly due south towards the Druid's Temple, where it apparently joins the main, or outer, Pennine Fault. There can be no doubt regarding the existence of this fault, for it brings the Bryozoa Band (B, fig. 3) on the east, which crops out at a height of 1750 feet, below the level of the highest beds of the Roman-Fell Conglomerate on the west, which rise to 1946 feet O.D.,

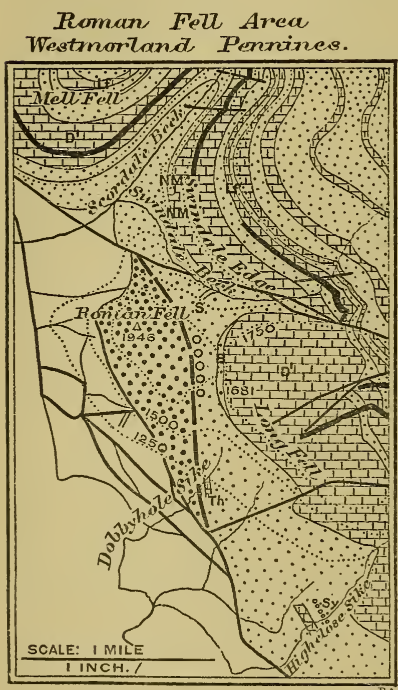
[1] New Series, Sheet 31 (Brough-under-Stainmoor).

thus cutting out the whole of the grit-and-sandstone series and the *Nematophyllum-minus* Band which are exposed below in Swindale Beck. This unmapped fault is, indeed, of much greater importance than that which runs along the upper part of Swindale Beck, marked on the Geological Survey map. It appears to be the southerly continuation of the inner Pennine Fault, which is seen crossing Scordale Beck immediately north-north-west of the summit of Roman Fell. From here it curves round under the scree-covered northern slope of Roman Fell to the col already mentioned. The Roman - Fell Beds are therefore entirely cut off by this fault from the Carboniferous succession on the east and south. (See fig. 3.)

The beds, again, on the two sides of the fault are totally different; for, whereas the pebbles in the Roman-Fell Conglomerate are largely composed of Lower Palæozoic rocks, those in the Carboniferous pebble-beds on the east are almost entirely composed of quartz. Again, the matrix in the Carboniferous pebble-beds is marked by well - developed oolitic structure; while no such structure is met with in that of the Roman-Fell Beds.

Lastly, whereas Carboniferous fossils, including *Syringothyris cuspidata* are not uncommon in the oolitic pebble series (S & Sy, fig. 3) on the east, no fossils beyond those contained in the pebbles derived from Lower Palæozoic rocks have ever been met with in the conglomerate of Roman Fell.

Fig. 3.—*Geological map, on the scale of 1 inch to the mile, or 1 : 63,360.*



[ooo = Potholes. The suggested fault (broken line) has been erroneously shown west of the potholes, instead of east of them. NM = *Nematophyllum-minus* Sub-zone; Th = *Thysanophyllum* Band; S & Sy = Brownber Pebble-Bed with *Syringothyris*; B = Bryozoa Band; LF = *Lonsdalia-floriformis* and Nodular *Girvanella* Band; D_1 = Lower *Dibunophyllum* Sub-zone. The thick black bands indicate the course of the Whin Sill. The heavily dotted area represents the Roman-Fell Conglomerate; the lightly dotted areas represent the fossiliferous grits and pebble-beds.]

On the north side of Roman Fell the lowest Carboniferous deposits are exposed in Scordale and Swindale Becks, and close to the junction of these streams they are brought down against the Skiddaw Slates by the Inner Pennine Fault.

In Scordale Beck above Hilton, on the right bank of the stream, chocolate-coloured grits with green streaks occur interbedded with fine conglomerates and green and red shaly sandstones, containing pebbles of the underlying Silurian rocks. The deposit appears to be completely unfossiliferous, but the outcrop is buried under landslips and scree-material. In Swindale Beck, which drains the north-eastern flank of Roman Fell, this series of basement beds is better exposed, and consists of false-bedded, green, pebbly grits containing fragments of felsite, Skiddaw Slate, etc. These are overlain by yellow concretionary sandstones passing upwards into a coarse conglomerate, which gives rise to a small waterfall in the beck.

The *Athyris-glabristria* Zone.—In Swindale Beck, about two-thirds of a mile above its junction with Scordale Beck, a fossiliferous bed crops out on the left bank of the stream (S in fig. 3, p. 356). This outcrop is of especial interest, as it is the only fossiliferous exposure met with in the beds below the Melmerby-Scar Limestone north of Roman Fell. The rock is predominantly a crinoidal limestone stained by limonite; some of the layers, however, consist of a calcareous grit enclosing small quartz-pebbles and crinoid-ossicles. This deposit appears to be a beach-formation, most of the fossils being fragmentary, and some of them probably derived. A few feet higher in the series, and farther up the stream, a calcareous breccia occurs on the same bank of the stream, nearly opposite Swindale Crag; this contains a similar fauna, but in a still more fragmentary condition. The most abundant fossil in both exposures is *Syringothyris cuspidata*. The following is the list of species obtained from these two exposures:—

Syringopora sp.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (M'Coy).
Productus cf. *punctatus* Mart.
Productus cf. *hemisphericus* Sby.
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Schellwienella cf. *crenistria* (Phill.).
Seminula cf. *ambigua* (Sby.).
Spirifer furcatus M'Coy.
Syringothyris cuspidata (Mart.).

Bellerophon sp.

This assemblage recalls that found in the Brownber Pebble-Bed and in the *Spirifer-furcatus* Band of the type-districts. The presence of *Syringothyris cuspidata* and *Athyris glabristria* is sufficient evidence that the deposit must underlie the *Michelinia* Zone; for, although rare in the North-Western Province, *S. cuspidata*, as noted above, occurs only in beds at and below the base of that zone. Again, the bed resembles very closely the *Syringothyris* Grit at the base of the *Michelinia* Zone under Cunswick Scar in the Kendal District, and may, therefore, represent, in part, the Brownber

Pebble-Bed of the type-districts. If this view be correct, the sandstone of Swindale Crag, which underlies the Melmerby-Scar Limestone, must represent an attenuated development of the Orton Sandstone of the Shap District.

In High-Cup Gill these beds are not well exposed; but in Great Rundal Beck, farther north, fragments of *Syringothyris cuspidata* have been collected from the hard gritty beds which crop out below the Melmerby-Scar Limestone on the south side of the beck, and these beds may, therefore, be correlated with the fossiliferous rocks of Swindale Beck. South of Roman Fell these beds are much obscured by superficial deposits: two interesting exposures, however, do occur, one in Highclose Sike and the other in Dobbyhole Sike (Th & Sy in fig. 3, p. 536). In Highclose Sike the stream has cut down through an anticlinal fold, exposing 30 or 40 feet of calcareous sandstones, mudstones, and pebble-beds. In the lower part of the exposure, below the wood, the stream runs along a bed of hard calcareous mudstone. This bed is much jointed, and weathers into nodular concretionary masses; it contains a few fragmentary fossils. The overlying beds are well exposed on the left bank of the stream below the old limekiln, where they consist of calcareous grits and pebble-beds and layers of dun-coloured impure limestone. The latter have yielded the following fossils:—

Productus cf. *corrugato-hemisphericus* Vaughan.
Rhipidomella michelini (L'Éveillé).
Rhynchonella cf. *fawcettensis* sp. nov.
Schellwienella cf. *crenistria* (Phill.).
Syringothyris cuspidata (Mart.).

The specimens of *S. cuspidata* are found in the upper pebble-bed, and are, as usual, in a somewhat fragmentary condition. An interesting feature of this pebble-bed is the occurrence of layers of coarse oolite, forming the matrix in which the white quartz-pebbles are embedded. This is by far the best-developed oolite met with in the North-Western succession, and the bed resembles very closely the Brownber Pebble-Bed already described from the type-districts. The presence of this oolitic pebble-bed affords valuable evidence as to the relative date of the submergence of the area now occupied by this portion of the Pennine Chain. The submergence must have occurred about the period when the *Thysanophyllum* Band was being deposited farther west: that is to say, during the deposition of the C_2 beds in the South-Western Province. This view is confirmed by a study of the section in Dobbyhole Sike. Here the rocks consist of impure gritty and bituminous limestones containing a few fossils, in a bad state of preservation. The fauna is of rather an ambiguous character, but among others occur specimens of *Thysanophyllum pseudovermiculare*, which appear to be unrolled, and even if derived must have grown somewhere in the immediate neighbourhood.

The presence of quartz-pebbles at the horizon of the Brownber Beds all along the Shap-Ravenstonedale escarpment, and their absence from this horizon farther west, are very interesting features which have been mentioned already, and appear to show that the land which supplied the quartz-pebbles lay to the east of the type-districts. The most likely source of these pebbles would appear to be the quartz-veins of the Skiddaw Slates and other Lower Palæozoic rocks, a fragment of which is exposed in Brownber Pike.

We cannot, therefore, go far wrong in correlating the beds which underlie the Melmerby-Scar Limestone in the Pennine District with the succession from the *Thysanophyllum* Band to the base of the *Nematophyllum-minus* Sub-zone in the type-districts.

The *Nematophyllum-minus* Sub-zone.—The Melmerby-Scar Limestone, which overlies the basement sandstones and pebble-beds described above, consists for the greater part of rocks belonging to the Lower *Dibunophyllum* Sub-zone; but a small thickness at the base represents the *N.-minus* Sub-zone, and the index-fossil, though not abundant here, can usually be found. The beds are exposed on the right bank of Scordale Beck, on Middle Fell, Middle Tongue, and elsewhere along the escarpment.

The associated fauna is similar to that already described in the neighbourhood of Shap, and calls for no special remark, though the *Cyrtina-carbonaria* Sub-zone has not been separated in this district. The beds, therefore, correspond closely with the Shap sequence from the Orton Sandstone upwards, and strengthen the view that the lower sandstone at Scordale Beck represents the Orton Sandstone.

The Bryozoa Band is well developed in this district, and good exposures occur near the col at the northern end of Long Fell, close to the old sheepfold east of the line of fault already mentioned (p. 535); indeed, it was in this district that the importance of this band was first recognized.

The rock here is composed of a shaly, grey, bituminous limestone, containing a rich fauna closely resembling that of the Bryozoa Band on Weather Hill, in the Shap District.

The Lower *Dibunophyllum* Sub-zone presents no unusual features; it appears, however, to be somewhat thinner than in the Western Districts. It forms the bulk of the Melmerby-Scar Limestone along the Pennine escarpment. The 'spotted' beds towards the summit of the sub-zone are especially well developed in Great Rundal Beck, behind Dufton Pike.

The Upper *Dibunophyllum* Sub-zone. — The Yoredale Beds are more fully developed here than in the Shap District. The base of the sub-zone is taken at the first sandstone above the Melmerby-Scar Limestone.

The *Lonsdalia* Beds are well exposed on the north side of Scordale Beck, in High-Cup Gill, and in Great Rundal Beck. In the first-named beck the base of the sub-zone lies above the Whin Sill, which is there intrusive in the Melmerby-Scar Limestone; but in High-Cup Gill the Whin Sill has risen in the series, and at High-Cup Nick lies near the base of the Tyne-Bottom Limestone. It is interesting to note that the Nodular *Girvanella* Band, which is very characteristic of the base of the sub-zone elsewhere, is also present in this district. This sub-zone includes the beds from the summit of the Melmerby-Scar Limestone up to the top of the 'Jew' Limestone inclusive. The fauna is similar in all respects to that which characterizes the *Lonsdalia* Beds in the Shap District.

The *Saccammina* Band appears to be represented by the Tyne-Bottom Limestone, which is well exposed on the eastern flank of High-Cup Gill. Here, as in the Shap District, the horizon is marked by the abundance of *Productus edelburgensis*, associated with *Zaphrentis* aff. *constricta* Carr. MS.

The higher beds of the Upper *Dibunophyllum* Sub-zone, overlying the Tyne-Bottom Limestone, are much more fossiliferous than is the case in the Shap District; thus, in Great Rundal Beck, the shale overlying the Scar Limestone contains the following forms:—

Cyathaxonia cornu Mich.
Dibunophyllum muirheadi Nich. & Thomson.
Diphyphyllum sp. nov.
Zaphrentis costata M'Coy.

Cyathocrinus sp.
Platycrinus sp.

Fenestella membranacea (Phill.).
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
Fistulipora incrustans (Phill.).
Glauconome sp.

Lingula squamiformis Phill.
Orbiculoidea nitida (Phill.).
Cliothyris royssi (L'Eveillé).
Leptæna analoga Phill.
Pugnax pugnus (Mart.).
Rhipidomella michelini (L'Éveillé).

The presence of *Cyathaxonia cornu* at this horizon is of interest, and may possibly indicate that we have here reached the base of the *Cyathaxonia* Beds of Dr. Sibly's Derbyshire sequence. At the same time, it must be admitted that *Cyathaxonia* is rare in the Pennine Area, and has not been definitely met with in the other districts.

The Middleton-in-Teesdale District.

In Upper Teesdale the local base of the Carboniferous is exposed between High Force and Cauldron Snout. Here a shaly conglomerate crops out under Falcon Clints, on the left bank of the Tees above Widdybank Farm; it cannot lie far above the Lower Palæozoic floor, and is represented on the Geological Survey map as resting on felsite and Ordovician slates north of the farm. Above this conglomerate occur grey shales which have been much metamorphosed by the intrusion of the Whin Sill, with the production of the interesting pisolitic structures described by Mr. Hutchings.[1] The base of the overlying limestone has also been much metamorphosed with a development of garnets.

[1] Geol. Mag. dec. 4, vol. ii (1895) pp. 122 *et seqq.*

The shales and basement-beds are apparently unfossiliferous, but specimens of *Nematophyllum minus* altered into saccharoidal limestone have been collected from the overlying limestone. This indicates that the base of the Lower Scar Limestone in Teesdale lies, as in the case of the Pennine escarpment, in the *N.-minus* Sub-zone.

The Lower *Dibunophyllum* Sub-zone is found overlying the Whin Sill on Widdybank Moss, but is also much metamorphosed. Below High Force no further exposure of these lower beds is seen, the Yoredale Beds being here brought in by the Burtreeford Fault, so that they occupy both sides of the valley as far as Middleton-in-Teesdale.

The Upper *Dibunophyllum* Sub-zone, composed of the Lower Yoredale limestones up to the Great Limestone, contains a fauna similar to that already described. Some of the intercalated shales are rich in fossils. A good exposure of a fossiliferous shale occurs above Holm-Road Bridge in Huddeshope Burn. This appears to be near the horizon of the Four-Fathom Limestone, and is rich in the remains of brachiopoda and bryozoa.

Fauna.

Aulophyllum cf. *pachyendothecum* Thomson.

Cystodictya sp.
Fenestella membranacea (Phill.).
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
Goniocladia cellulifera Eth. jun.
Pinnatopora sp.
Polypora sp.
Rhabdomeson sp.

Orbiculoidea nitida (Phill.).
Cliothyris royssi (L'Éveillé).
Productus cf. *edelburgensis* Phill.
Productus longispinus Sby.
Productus punctatus Mart.
Rhipidomella michelini (L'Éveillé).
Spirifer bisulcatus Sby.

Loxonema sp.
Murchisonia sp.

Orthoceras sp.

Phillipsia farnensis Tate.

The higher Yoredale Beds, from the Scar Limestone upwards, are best studied in the sections and quarries exposed in the Huddeshope and Snaisgill valleys north of Middleton, and along the road between Middleton and Brough. The beds are throughout characterized by the abundance of *Dibunophyllum muirheadi*. In the Great Limestone, in addition to *Productus giganteus*, *Pr. latissimus*, and other characteristic Yoredale forms, we meet with a large columnar form of *Lonsdalia* which appears to differ specifically from *L. floriformis* of the *Lonsdalia* Beds at the base of the zone. Many of the shales are rich in lamellibranchs, and casts of brachiopods occur frequently in the sandstone layers. One such band crowded with *Spirifer* cf. *bisulcatus* forms the highest fossiliferous horizon of the Yoredale Series in Teesdale, and the same band appears to extend into the upper part of Weardale.[1]

[1] Casts of this species show, along the inner margin of the hinge-line of the pedicle-valve, a row of pits which must represent, either casts of spine-bases, or a row of granules that forms an articulating surface between the two valves.

The Botany Beds (*Phillipsastræa* Band).

These deposits comprise impure limestones and calcareous shales about 20 feet thick, intercalated in the series of grits and shaly sandstones which are coloured as Millstone Grit on the Geological Survey map. The beds lie some distance above the base of this series, and occupy a tract extending for 2 miles in a general east-and-west direction on Hurdorthwaite Moor, south of Botany Farm. They are repeated by a strike-fault with a southward upthrow, which causes an extension of the outcrop round the south of the moor and affords additional exposures.

The beds are well seen in several old quarries at Scoletree, Howgill Head, and Greenhill. They consist of a few feet of compact crystallized limestones at the base, which is overlain by some 10 to 15 feet of impure calcareous and ferruginous shales. The shales are hard and nodular in places, but present a curious cellular appearance seemingly due to partial solution. Cherty bands occur in irregular patches; these are almost confined to the upper layers, and yield the chief examples of *Phillipsastræa*. The corals are often replaced by silica, which in thin sections exhibits marked spherulitic structure. The beds are of considerable interest, as they represent the highest horizon in the North-Western Province containing a typical Lower Carboniferous marine fauna.

Fauna.

**Hyalostelia parallela* M'Coy.

Dibunophyllum muirheadi Nich. & Thomson.
Lithostrotion junceum (Fleming).
Lithostrotion portlocki (Bronn).
Michelinia cf. *tenuisepta* (Phill.).
**Phillipsastræa radiata* (Woodward).

Archæocidaris sp.

Spirorbis sp.

**Anisotrypa* sp.
Fenestella membranacea (Phill.). Very abundant.
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
(?) *Goniocladia* (casts only) Eth. jr.
Pinnatopora sp.
Polypora dendroides M'Coy.

Lingula cf. *squamiformis* Phill.
Athyris cf. *ambigua* (Sby.).
Cliothyris royssi (L'Éveillé).
Dielasma hastatum (Sby.).
Leptæna analoga Phill.
**Productus aculeatus* Mart.
Productus costatus Sby.
Productus elegans M'Coy.
Productus cf. *longispinus* Sby.
Productus martini J. de C. Sby.
Productus plicatilis J. de C. Sby.
Productus cf. *pugilis* Phill.
Productus aff. *punctatus* Mart. (with more numerous bands than the typical *punctatus*).
Productus punctatus (typical) Mart.
Productus scabriculus Mart.
Productus semireticulatus (typical) Mart.
Productus cf. *sulcatus* J. de C. Sby.
**Schellwienella radialis* (Phill.).
Schizophoria resupinata (Mart.).
Spirifer bisulcatus Sby.
Spirifer triangularis Mart.

Aviculopecten dissimilis (Fleming).
Conocardium aliforme Sby.
Sanguinolites cf. *monensis* Hind.

Capulus sp.
Dentalium sp.
Loxonema sp.
**Naticopsis* cf. *globosa* Hœninghaus.
Pleurotomaria sp.

Orthoceras sp.
**Prolecanites (?)* fragment.

Petalodus acuminatus Ag.

The fossils are well preserved in calcareous nodules in the shale, and the fauna may be compared with that of D_3 of Derbyshire; some of the species (marked with an asterisk) have not been met with elsewhere in the area described in the present paper.

Among the corals, an interesting occurrence is that of *Dibunophyllum muirheadi*, showing the persistence of this form throughout the Yoredale Series of the Pennine District; it enters near the summit of the *Lonsdalia-floriformis* Sub-zone, is found plentifully in several of the higher Yoredale Limestones, especially the 'Great' Limestone, and is still abundant in the Botany Beds. Another interesting form, practically limited to this horizon, is *Phillipsastræa radiata*, which occurs somewhat abundantly in the upper chert-bearing portion of the deposits. I have never found it *in situ* at any other horizon, but two specimens were collected as loose blocks. One of these was found resting upon the Tyne-Bottom Limestone in High-Cup Gill, and, as the specimen was quite angular and unworn, may possibly have been derived from one of the overlying Yoredale limestones close by; the other was found washed out of the drift-deposits in Ravenstonedale, the coral being preserved as a cast in a hard gannister-bed which must have been derived from the higher Yoredale or Millstone-Grit beds of the Pennine Chain on the east or north-east. Outside the North-Western Province *Phillipsastræa* is also apparently characteristic of the higher beds of the *Dibunophyllum* Zone.

Many of the brachiopods are also characteristic of a high horizon in Derbyshire; and some species as, for instance, *Schellwienella radialis*, have not been met with at a lower horizon in the North-Western Province.

So far as I am aware, this is the highest truly marine fauna yet met with in the North of England. The appearance of this fossiliferous limestone deposit, overlying a considerable thickness referred to the Millstone Grit by the officers of the Geological Survey, is of some interest. The fauna cannot be considered as a remnant of the local Yoredale fauna that collected here before being completely exterminated: for, not only is the fauna as a whole not characteristic of the underlying beds, but the arenaceous character of the deposit immediately below makes this hypothesis untenable.

These deposits must have resulted from a local depression, which carried the sea-floor temporarily beyond the area of mechanical deposition, and opened a communicating channel with the deeper sea that still existed on the south or west. The limited area now occupied by the limestone deposit near Botany would seem to point to the west as the direction whence this fauna migrated: since, in that direction, denudation has removed all the upper beds of the *Dibunophyllum* Zone, and also the Millstone Grit; and so there is nothing to prevent the deposit now described from having previously extended in that direction. On the north-west and south, on the other hand, there is a continuous upward sequence into the Coal Measures; but no limestones representing these beds occur elsewhere in Durham or Yorkshire north of the Craven Faults. On the whole, then, we can best regard the 'Botany Beds' as the result of a depression which temporarily established communication with the deeper water lying on the west or south-west.

This view receives support from the character of the brachiopod fauna in the highest limestone layers in the Kirkby Lonsdale and Furness Districts, many of the species being identical with those found in the Botany Beds. The fossiliferous shale, shown on the Geological Survey map as occurring well up in the Millstone Grit in the district south and south-east of Kirkby Lonsdale,[1] would appear to mark the southern shallow-water continuation of this deposit.

A small outlier of these shales is situated in the Kirkby Lonsdale District, on the northern bank of the River Lune at its junction with the River Wenning.[2] Farther south-east in the Bowland District the band is still found occupying the same position in the Millstone Grit, overlying the Pendleside Series of Dr. W. Hind. If this correlation of the Botany Beds with these fossiliferous shales be correct, it affords additional evidence, if it were necessary, of the Lower Carboniferous age of the Pendleside Series, for the fauna of the Botany Beds which are thus shown to overlie the Pendleside Series is, as already pointed out, characteristic of the highest limestones of Derbyshire.

VIII. Correlation with the South-Western Province and other Areas.

The correlation of the zones described in the foregoing pages with those established by Dr. Vaughan in the Bristol District is set forth in the last column of the table (p. 547). In comparing the different horizons in the two districts, it will be best to begin with the Lower *Dibunophyllum* Sub-zone, which, as already stated, appears to be identical in the two provinces. Thus, in both provinces, this horizon is characterized as a rule by fine-grained crystalline limestones containing beds of pseudobreccia typically near the summit; while the fauna is characterized by the abundance of specimens of *Dibunophyllum* ϕ, *Cyathophyllum murchisoni*, and *Carcinophyllum* θ. This similarity is undoubtedly due to the fact that it was during the period when these beds were being deposited that the greatest submergence in Lower Carboniferous times occurred in Britain.

The beds immediately overlying the Lower *Dibunophyllum* Sub-zone in the North-Western Province can also be readily correlated with the *Lonsdalia* Beds of the South-Western Province, as they are characterized by the presence of *Lonsdalia floriformis*, *Cyathophyllum regium*, and *Dibunophyllum muirheadi*, belonging to Dr. Vaughan's group of Dibunophyllids in the stage ψ. The Yoredale beds above the 'Scar' Limestone of the Pennine District

[1] This bed is coloured green, and in the legend stated to be fossiliferous; but, unfortunately, no fossils from it have been preserved in the Museum of Practical Geology, Jermyn Street.

[2] Mr. C. H. Cunnington has obtained numerous crushed specimens from this exposure, referable apparently to *Posidoniella lævis*, and three species of Goniatites.

would then correspond to horizon ϵ and some part of the 'Millstone Grit' of the Bristol Area.

The limiting line between the beds known as D_2 and D_3 in the Midland and other areas is by no means clearly defined in the North-Western Province, partly on account of the barren character of the higher limestones in the Shap District, and partly on account of the complete absence of fossils from the whole of the upper portion of this series in the Kirkby Lonsdale and Furness Districts. It is true that, in the Pennine District, one or two specimens of *Cyathaxonia cornu* have been collected from the shale underlying the Scar Limestone; but this circumstance does not entitle us to correlate the beds above this horizon with the *Cyathaxonia* Beds of the Midlands.[1]

With regard to the highest fossiliferous marine limestone which occurs at Botany, there can be no doubt that it must be correlated with an horizon well up in the *Cyathaxonia* Beds of the Midland area, such forms as *Schellwienella radialis*, *Productus aculeatus*, *Spirifer triangularis*, and *Phillipsastræa*, together with several others, never occurring below the summit of the *Lonsdalia* Beds in the North-Western Province.

With regard to the beds underlying the *Dibunophyllum* Zone, the *Productus-corrugato-hemisphericus* Zone appears to represent closely the *Seminula* Zone of Dr. Vaughan's Bristol paper[2]; as, however, the upper and lower limits are not absolutely certain, it will be best at present to avoid absolute correlation with this zone. The name '*Seminula* Zone' also, is scarcely applicable to this division in the North-Western Province, although *Seminula ficoidea* is present occasionally in the zone. This genus is, however, much more characteristic of the upper portion of the *Athyris-glabristria* Zone in the North-Western Province, where it is represented by abundant specimens of *S.* aff. *ficoidea* together with *S. gregaria*.

Of the three portions into which the zone is divided, the Gastropod Beds, which form the lower portion, appear to be closely equivalent to the S_1 beds of the Bristol Area, while S_2 is represented by the *Cyrtina-carbonaria* and *Nematophyllum-minus* Beds of this classification.

The *Michelinia* Zone has been considered by me to represent generally C_2 of the South-Western Province, the upper limit being taken at the *Clisiophyllum-multiseptatum* Band, above which the first specimens of *Lithostrotion* occur; but the exact horizon where the base of C_2 should be drawn in Westmorland is not easy to fix. In the type district the base of C_2 is taken at the Oatmeal Bed in Docker Beck, and this corresponds with the *Spirifer-furcatus* Band of the Arnside and Grange Districts. This will throw the beds between the *Camarotœchia-proava* Band and the *Thysanophyllum* Band inclusive, into C_1 of the Bristol Area. The lower beds at Shap Abbey and Stone Gill contain a form of *Athyris glabristria* (near *A. lamellosa*), which, Dr. Vaughan informs me,

[1] This view has been arrived at after conference with Dr. Sibly.

[2] Q. J. G. S. vol. lxi (1905) p. 194.

is characteristic of Z–C in the Bristol, Malahide, and Tournai areas. The lowest layers, therefore, containing the *Vaughania-cleistoporoides* Band must be provisionally correlated with Z–C of the South-Western Province.

The lowest fossiliferous horizon in the North-Western Province, found in Pinskey Gill (Ravenstonedale), contains a somewhat unique fauna. The characteristic *Spirifer* appears to be unknown in the Lower Carboniferous deposits of the Bristol District. The casts of the little *Camarotœchia*-like brachiopod bear a distinct resemblance to *C. mitcheldeanensis*, but are in too imperfect a state of preservation for exact determination. It will be best, therefore, for the present to leave the correlation of these beds as an open question, merely suggesting that they probably represent some portion of the *Zaphrentis* Zone of the Bristol sequence, since they underlie the conglomerate which forms the base of the Z–C beds mentioned above.

[Since this paper was read before the Society, I have had the pleasure of going over a good deal of the ground in the Shap and Ravenstonedale Districts with Dr. Vaughan, Mr. E. E. L. Dixon, and Mr. R. G. Carruthers, when special attention was given to the correlation of the beds with those of the South-Western Province. At the conclusion of the visit, Dr. Vaughan expressed himself in general agreement with the correlation set forth in the table on p. 547. He would, however, not only include the *Thysanophyllum* Band in C_2, but would extend that sub-zone downwards to the top of the Algal Limestones. Although only a small thickness of beds is involved, the change is important, as it throws the *Syringothyris-cuspidata* Beds into C_2, instead of C_1, where the index-fossil occurs typically in the Bristol District.

Mr. Dixon, while recognizing that the fauna of the *Solenopora* Sub-zone has affinities with that of C_1, considers that the physical evidence is in favour of his original view that submergence in the northern area did not take place until deposits of C_2 age were being laid down in the South-Western Province; his view will be found in the discussion published at the end of this paper (p. 585).]

Correlation with Northumberland.

The classification described in this paper can also be broadly applied to the Lower Carboniferous succession in Northumberland and North Cumberland, and by this means it is possible to establish with some degree of certainty the equivalents, in Northumberland, of the Bristol Zones. I have already given a general comparison elsewhere.[1] More recent work in Cumberland has shown that several of the horizons established in Westmorland are also clearly recognizable in the North Cumberland and Border Districts; but the detailed investigation of the succession is not yet complete. Mention may be especially made of the important development of algal limestones in North Cumberland at an horizon equivalent to that of the *Solenopora* Beds of Shap; while other bands also present in both districts are included in the accompanying table.

[1] 'Geology in the Field' (Jubilee vol. Geol. Assoc.) pt. iv (1910) p. 683.

North-Western Province.			Northumberland and North Cumberland.	S.W. Province and Midlands.
		Botany Beds (*Phillipsastræa* Band).	Millstone Grit.	D_3.
Dibunophyllum Zone.	Upper Sub-zone.	Upper Yoredale Beds. Dy.	BERNICIAN. Beds above the Acre Limestone. Dy.	D_2.
		Lower Yoredale Beds. *Saccammina* Band	...Acre Limestone.	
		Lower Yoredale Beds. *Lonsdalia* Beds	...Eelwell Limestone.	
		Lower Yoredale Beds. Nodular *Girvanella* Band.	...Oxford Limestone with Nodular *Girvanella* Band.	
	Lower Sub-zone.	...*Cyathophyllum murchisoni*	Woodend or Four Laws Limestone. Dun or Redesdale Limestone with *Spiriferina laminosa*.	D_1
Productus-corrugato-hemisphericus Zone.	Upper Sub-zone.	Bryozoa Band with *Spiriferina laminosa*. *Nematophyllum minus*	Scremerston or Plashetts and Lewisburn Coal Series.	S_2.
	Lower Sub-zone.	...including the Ashfell & Orton Sandstone.	TUEDIAN. Fell Sandstone, with fossil-bands in Cumberland yielding *Michelinia* and *Camarophoria isorhyncha*.	S_1.
Michelinia Zone.	Upper Sub-zone.	...*Chonetes carinata* & Orton Sandstone.		
	Lower Sub-zone.	...*Camarophoria isorhyncha*		C_2
Athyris-glabristria Zone.	Upper Sub-zone.	...*Seminula gregaria* with *Syringothyris cuspidata*. Algal Layer.	Cement-stones with *Syringothyris cuspidata* and *Mitcheldeania*. *Productus* Beds with *A. glabristria*.	C_1
	Lower Sub-zone.	...*Solenopora* Beds *Camarotœchia-proava* Band.	Lower Freestones of Northumberland, Algal Reefs of Bewcastle District, and *Camarotœchia-proava* Band of the Border.	γ Z (?)

I have already tabulated the Yorkshire equivalents in Geol. Mag. dec. 5, vol. iv (1907) p. 73.

IX. Summary and Conclusions.

Zonal Divisions.

The Lower Carboniferous rocks of the North-Western Province may be divided into a series of palæontological zones and sub-zones, set forth in the table (fig. 2) on p. 452, which, with the exception of the *Cyrtina-carbonaria* Sub-zone, have been recognized in all of the districts described.[1]

In the type-districts of Shap and Ravenstonedale a series of palæontological horizons or 'bands' have also been determined which are of great local value; the majority of these can be traced in the other districts whenever the same horizons are exposed. As examples, I may cite the *Chonetes*-aff. *comoides* Band at the summit of the Lower *Dibunophyllum* Zone; the *Camarotœchia-proava* Band, which is found throughout the Shap and Ravenstonedale Districts, and at Meathop in the Arnside District; the Algal Layer, which occurs at the base of the *Seminula-gregaria* Sub-zone, and extends throughout the type-districts, the Kendal and Arnside Districts, and as far west as Plumpton in the Furness District; and the *Thysanophyllum* Band, which forms a well-defined horizon throughout the type-districts, under Roman Fell in the Pennine District, in the Kendal District, and in the eastern portion of the Grange District. On the other hand, some bands (such as the Bryozoa Band, the *Saccammina-carteri* Band, and the *Daviesiella-llangollensis* Band) are limited to certain portions of the eastern districts.

Lithology.

The sea in which the Lower Carboniferous rocks of the North-Western Province were deposited does not appear ever to have reached a great depth, the majority of the beds being evidently laid down in shallow water. The period of greatest submergence occurred during the deposition of the upper portion of the *Productus-corrugato-hemisphericus* Zone and the Lower *Dibunophyllum* Zone.

The lithological characters which mark the different horizons are, as a rule, constant over large areas. Dolomites and porcellanous cementstones are characteristic of the *Athyris-glabristria* Zone, and locally also of the highest Yoredale limestones. This dolomitization was penecontemporaneous, as shown by a study of the dolomites in the Shap District. Occasionally, it would seem to have been selective: thus *Solenopora* and other calcareous algæ are usually quite unaffected, although they are typically associated with dolomitic deposits. Oolites are specially characteristic of the Brownber Pebble-Bed and of the beds immediately overlying it in the Eastern Districts; but thin bands of fine oolite occur also

[1] The *Cyrtina-carbonaria* Sub-zone cannot be clearly differentiated from the overlying *Nematophyllum-minus* Sub-zone in the Arnside, Grange, and Furness Districts.

locally at several other horizons, the nuclei of the oolitic granules being frequently quartz-grains.

Dark bituminous limestones occur universally at the base of the Upper *Dibunophyllum* Sub-zone, and are also found in many of the overlying Yoredale limestones. Pure white limestones are limited to the deeper-water deposits of the *Nematophyllum-minus* and the Lower *Dibunophyllum* Sub-zones. True crinoidal limestones are almost entirely absent, with the exception of the thin limestone which occurs in the Upper *Dibunophyllum* Sub-zone in the Kirkby Lonsdale District.

Calcareous mudstones are specially characteristic of the upper portion of the *Michelinia* Zone in the Western Districts, where that zone is most fully developed. Thin layers of 'china-stone' occur locally at two horizons: namely, near the base of the *Seminula-gregaria* Sub-zone, and in the Bryozoa Band immediately underlying the *Dibunophyllum* Zone. These layers are usually crowded with small spherical bodies, many of which appear to be identical with *Calcisphera fimbriata* (Williamson).[1] These are invariably associated with plant-remains at the upper, and with calcareous algæ at the lower, horizon. The deposits appear to represent a fine impalpable mud, laid down in the shallow but quiet waters of a lagoon or estuary.

Shales and sandstones are, in most districts, limited to the Yoredale rocks of the Upper *Dibunophyllum* Sub-zone. Spotted limestones and pseudobreccias are peculiar to the beds of the Lower *Dibunophyllum* Sub-zone, and are found in all the districts. The 'spotted' limestones occur typically at the base and summit of this zone, and appear to represent an incipient attempt at concretionary segregation of the coloured impurities. In a few cases, however, as at Great Rundal Beck in the Pennine District, where this structure is very marked, the spots are due to a definite separation of the calcareous constituents from the detrital sand-grains. The pseudobreccias are practically confined to the upper portion of this sub-zone, and are specially associated with the *Chonetes*-aff. *comoides* Band. They appear to owe their origin to the shrinkage of the deposit during consolidation, occasionally accompanied by the same tendency to incipient concretionary action as that which gave rise to the 'spotted' beds. They would seem to have been deposited under special conditions, involving a general elevation of the sea-floor.

The lithological conditions which characterize the different horizons are, on the whole, remarkably constant throughout the area; but three notable exceptions may be mentioned. The first is the important transgression of an arenaceous type of deposit across several of the faunal horizons that occurs in the Shap and Ravenstonedale Districts, traces of which can also be found in the Pennine District on the east and the Kendal District on the west. This sandstone episode, which begins at the base of the *Michelinia*

[1] Compare also *Sporocarpus elegans*.

Zone at Shap, does not make its appearance at Ravenstonedale until the middle of the Lower *Productus-corrugato-hemisphericus* Sub-zone; it also persists up to a higher horizon in the former district than in the latter. At the same time, the actual thickness of the sandstone series is greater in the southern than in the northern portion of the area. As a result of this incursion of arenaceous material, the normal faunas are very much reduced, or entirely absent from the horizon at which it occurs.

The second important change in the lithology of an horizon when traced laterally occurs in the Upper *Dibunophyllum* Sub-zone. This sub-zone presents two distinct facies, each of which has a separate geographical distribution: a northern and eastern facies, characterized by a Yoredale type of deposit, and consisting of a series of bituminous limestones, separated by shales and sandstones; and a southern and western facies (situated in the neighbourhood of Kirkby Lonsdale, Carnforth, and Gleaston), characterized by the absence of the typical series of Yoredale limestones, by the presence of a bed of true crinoidal limestone in the middle of the series, and by the local occurrence (in the upper part) of crystalline and brecciated limestones, which resemble the knoll-reef limestones of the Cracoe district and contain a similar fauna.

A third type of deposit, which is only met with at Botany, in the Middleton portion of the Pennine District, consists of a series of fine limestones and cherty calcareous shales lying high up in the Millstone Grit Series. These beds constitute an important fossiliferous deposit unknown elsewhere in the North of England, containing a fauna characteristic of the higher portion of the Derbyshire limestone-massif.

The Flora and Fauna.

Of the organisms which contribute to the deposits, corals and brachiopods are by far the most important, but foraminifera are present in nearly all the deposits, and are frequently abundant; ostracods and bryozoa are also locally plentiful in the more argillaceous layers.

One of the most interesting facts brought out by a microscopic examination of the rocks of this area is the important part played by calcareous algæ in the formation of the more compact and porcellanous layers of the deposit. The genus *Solenopora*, which occurs so universally in the lower portion of the *Athyris-glabristria* Zone, is of peculiar interest, not only on account of the part that it plays as a rock-builder, but also on account of the fact that it has not previously been recorded from any formation between the Ordovician and the Jurassic. Its discovery here assists, therefore, in bridging over the gap previously existing in the history of its vertical distribution. Another form, *Girvanella*, appears to have borne a large share in the formation of the nodular band so characteristic of the base of the Upper *Dibunophyllum* Sub-zone throughout the North of England. Other interesting forms also occur which cannot be fully described here, although they contribute largely to the formation of the Algal Layer at the base of the *Seminula-gregaria* Sub-zone. With the exception of calcareous algæ, plant-remains are but sparingly represented; mention, however, may be made of *Archæosigillaria vanuxemi*, which was first described in Britain from the Shap District. So far as is known, this species is limited to the lowest zone, in which, however, it occurs at several horizons; associated with it, occasionally, are specimens of *Bothrodendron*.[1]

Siliceous organisms are on the whole rare, though some of the spherical bodies associated with *Calcispheræ* may perhaps come under the category of radiolaria, the siliceous skeleton of which has been subsequently replaced. Sponge-remains are occasionally found, and include examples of *Pemmatites*, together with two species of *Hyalostelia*. Chert is met with locally, especially in the higher portion of the *Dibunophyllum* Zone, but never in any great quantity; and true beds of chert are practically absent. Replacement of the fossils by beekite and other forms of silica is not uncommon at certain horizons, the various species of *Syringopora* and other corals being especially prone to this replacement.

Good examples occur in the *Camarotœchia-proava* Band, and again in the *Cyrtina-carbonaria* Beds of the type-districts, while partial silicification of the coral-surfaces is characteristic of the *Seminula-gregaria* Zone and the Lower *Michelinia* Beds in several districts. In all cases, the interstratification of these silicified layers with beds in which no such replacement occurs appears to point conclusively to the silicification having taken place contemporaneously with the formation, or at all events previous to the solidification of the deposit in which it occurs.

Correlation.

The pre-Carboniferous land-surface in the North-West of England, upon which the rocks of Lower Carboniferous age now rest, does not appear to have been submerged until some time after the Carboniferous sea had invaded the South-Western Province. This is shown by the almost entire absence from the North-Western Province of the lower zones of the Bristol District, namely, all the beds below Z_2 of Dr. Vaughan's classification. The possible exception to this generalization: namely, the deposits found in Pinskey Gill in the Ravenstonedale District, though undoubtedly representing the lowest horizon met with, are difficult to correlate with any beds in the Bristol succession. The beds lie in a pocket in the Lower Palæozoic rocks, and are overlain by the Shap Conglomerate which elsewhere forms the usual base of the Carboniferous deposits in Westmorland.

[1] J. W. Jackson, Geol. Mag. dec. 5, vol. vii (1910) p. 78.

So far as stratigraphical evidence is concerned, the *Spirifer-pinskeyensis* Beds may be of any age between Upper Devonian and the *Zaphrentis* Zone of the Bristol succession inclusive. The evidence from fossils, especially fish-remains, taken together with the general probabilities, though perhaps not absolutely conclusive, appears to point to the deposits being of Carboniferous rather than Devonian age, although the exact correlation of these beds with the corresponding beds in the South-Western Province at present remains unsettled.

With the exception, then, of the depression in which the Pinskey Beds occur, the North-Western Province was not submerged until a period when the upper portion of the *Zaphrentis* Zone was being deposited in the South-Western Province, while the submergence of some parts of the area did not take place until a still later period, when the C_2 beds of Bristol were being laid down. Judging by the character of the deposits first laid down, the Lower Palæozoic floor on which the Carboniferous rocks now rest must have been of the nature of a peneplain rather than a plain of marine denudation.

The earliest deposits, consisting as they do of dolomites and porcellanous limestones almost free from admixture of mechanical sediments, would appear to have been laid down in a land-locked lagoon-like area, from which wave- and current-action was entirely excluded. This supposition is confirmed by the character of the organisms which are entombed in these deposits. The presence of calcareous algæ, in such abundance as occasionally to make up the bulk of the rock, sufficiently testifies to the lagoon-like conditions which prevailed during their growth; while the wealth of brachiopods, such as *Athyris glabristria* and *Camarotœchia proava*, some of which occur unbroken, with their valves united and their brachial supports intact, points to the same conclusion. In the case of *Athyris*, even the delicate external fringes are not infrequently found still attached to the surface of the shell.

The dolomitization of the limestones, if we regard it as practically contemporaneous with the deposits, would seem most naturally to have taken place under conditions similar to those which now exist in the neighbourhood of barrier-reefs and atolls, as shown by the recent investigation on the composition of coral-reefs.[1] An interesting point in connexion with the distribution of these earlier deposits is their relation to the underlying Lower Palæozoic rocks over the North-Western Area. According to one view, the Lower Carboniferous sediments were deposited against an island of Lower Palæozoic rocks which rose above the sea near the centre of the area, so that, as this island sank, it was covered by successively higher deposits of Carboniferous age, and its centre may even have remained above the surface throughout the duration of the Lower Carboniferous sea.

[1] Report of the Coral-Reef Committee of the Royal Society: 'The Atoll of Funafuti' 1904.

Another view, which has been strongly advocated for many years past by Dr. Marr, supposes that the Lower Carboniferous deposits were laid down upon an even surface of Palæozoic rocks over the whole site now occupied by the Lake District, and subsequently elevated into a dome which has been denuded to form the present ring of Carboniferous rocks.

The results of the investigation recorded above would appear to show that the latter view is almost certainly correct. The lowest deposits met with in the North-Western Province occur in close proximity to the present margin of the Lake District, namely, between Pooley Bridge and Shap Wells, at the foot of the Howgill Fells in Ravenstonedale, at Meathop in the Arnside District, and near Elliscales and Marton in the Furness District.

As we travel away eastwards and south-eastwards from the Lake District, we find that the lower Shap dolomites thin out. Hence, far from being an island at that period, the present site of the Lake District probably represents the portion of the area first submerged beneath the Carboniferous sea, while land lay to the east over the tract now occupied by the Cross-Fell range. Further evidence of the same kind is forthcoming from the Ingleborough and Penyghent area to the south-east, in which area submergence does not appear to have taken place until a still later period after the deposition of the *Michelinia* Zone at Arnside.

The present outcrop of Lower Carboniferous rocks, as shown in the index-map published by the Geological Survey, forms an irregular ring round the outskirts of the Lake District, and it is possibly this arrangement which first gave rise to the suggestion that they had been deposited against an island, in much the same manner as the similar beds in Northumberland are regarded as having been deposited against the denuded stump of the old Cheviot volcano. A detailed examination, however, of the dip of the Carboniferous strata which form this ring shows that they constitute the inner edge of a denuded dome, and that, if continued, they would easily clear the highest summits of the Cumbrian Hills.

The beds corresponding to the C Zone of the Bristol District are most probably represented by all except the lowest portion of the *Athyris-glabristria* Zone, together with the whole of the *Michelinia* Zone. The *Seminula* Zone appears to correspond exactly with the *Productus-corrugato-hemisphericus* Zone, while the Lower and a portion of the Upper *Dibunophyllum* Sub-zones correspond very closely in the two areas. A difficulty lies in drawing an exact line in the North-Western Province which will represent the base of the *Cyathaxonia* Beds of the Midland Area; but this may be provisionally drawn somewhere about the Scar Limestone or the beds immediately overlying it, at which horizon *Cyathaxonia cornu* has been found, though sparingly, in the Westmorland Pennines.

The Submergence of the Pennine Area.

In considering the date of this submergence, much interesting evidence is afforded by the Brownber Pebble-Bed, which lies a few feet above the *Thysanophyllum* Band. In the first place, this bed marks an important change which took place in the physiography of the region. Hitherto the Carboniferous beds had been deposited in shallow land-locked seas or lagoons, which favoured the formation of dolomites and fostered the growth of calcareous algæ. The deposits laid down under these conditions were characterized also by the absence of mechanical sediment and freedom from wave- and current-action. During their deposition a land-barrier must have existed to the east of the Shap District in the neighbourhood of the present Pennine range; this is evident from the absence from the Pennine area of any Carboniferous deposits older than the *Thysanophyllum* Band. At the time, however, when this band was being deposited a general submergence took place over the North-Western Province, and for the first time the present site of the Cross-Fell range was covered by the waters of the Carboniferous sea. This is shown, not only by the presence of *Thysanophyllum* at the base of the Carboniferous succession on the south side of Roman Fell, but also by the occurrence of the oolitic Brownber Pebble-Beds over the whole of the Shap and Ravenstonedale Districts and the Roman-Fell area. This submergence of the eastern land-barrier abolished the lagoon-conditions which had hitherto prevailed, letting in the sea from the east with the accompanying effects of wave- and current-action. The distribution of the quartz-pebble beds is of importance in this connexion, for the material of which they are principally composed undoubtedly originated in the Cross-Fell area and travelled westwards. The original source of the pebbles is difficult to determine; but it seems probable that it may be traced to the quartz-veins which occur in the Lower Palæozoic rocks, especially in the Skiddaw Slate Series of the Cross-Fell Inlier, and notably the rocks of this age now exposed in Brownber Pike, which had been plentifully injected with quartz-veins in pre-Carboniferous times.

The effect of wave-action is manifested by the rounding of the quartz-pebbles, while the presence of strong currents setting in from the east is indicated by the sifting of the material and the transport of the pebbles and sand over a large area to the west of Appleby hitherto free from mechanical sediment. The markedly false-bedded character of the pebble-beds and the fragmentary condition of the shells which they contain further bear witness to current-action. The pebbles are, on the whole, largest and most abundant in the east of the area under Roman Fell, and gradually die away when we trace this horizon into the Western Districts. In the intermediate area to the west of Kendal, the deposit is represented under Scout Scar by the calcareous grit which closely resembles the band that occurs at the same horizon at the base of the series in Scordale Beck.

X. PALÆONTOLOGY.

Introduction.

In the preparation of the following accounts of new and little-known forms of corals met with during the examination of the area described in the foregoing pages, I have received the greatest assistance from Mr. R. G. Carruthers, to whom I here offer my most sincere thanks, and after whom I have named the new genus described below. To Dr. Ivor Thomas I am indebted for advice regarding the affinities of the Productids collected. I am also greatly indebted to Dr. A. Smith Woodward, F.R.S., and Miss Madeline Munro for their kindness in allowing me to publish descriptions of the new forms of fish-teeth and bryozoa which appear in Appendix I and Appendix II respectively.

I have also to thank my friend Prof. T. McKenny Hughes, F.R.S., for the special facilities which he has afforded me for studying M'Coy's specimens of Carboniferous corals and brachiopods preserved in the Sedgwick Museum at Cambridge, and for leave to cut sections of the type-specimens of *Caninia subibicina* and *Cyathophyllum multilamellatum*, photographs of which appear in the accompanying plates.

In conclusion, I wish to express my indebtedness to Mr. J. W. Tutcher for the admirable photographs of brachiopods which are reproduced in Pl. LI, and the corals (fig. 1 & fig. 2 *a*), reproduced in Pl. XLIX.

CARRUTHERSELLA, gen. nov.

Corallum simple, with an outer zone of dissepiments not radiated by the septa. Columella strong, formed of straight lamellæ in complete contact, mostly separated from the major septa, although some may be in direct connexion.

The genus is closely allied to *Aulophyllum* and *Carcinophyllum*, but differs in having a solid columella formed of straight radiating lamellæ in complete contact throughout; it differs from *Lophophyllum* in having a purely dissepimental outer area, not radiated by septa.

CARRUTHERSELLA COMPACTA, sp. nov. (Pl. XLVIII, figs. 1 *a*–1 *d*.)

External characters.—Corallum simple, elongate-conical.

The largest specimen met with measures 17 mm. across the calyx, but the length of this specimen is unknown: it must have exceeded 35 mm. Cross-section circular. Calyx deep, with a solid columella projecting as a well-defined boss. In well-preserved specimens the proximal end is seen to bifurcate, so as to form two subequal root-like processes. Surface smooth, or covered with inconspicuous longitudinal striæ and well-marked growth-lines.

Transverse section (figs. 1 *a*–1 *c*).—Central area well defined, formed of a solid and conspicuous spindle-shaped columella, composed of a narrow plate from which radiate fifteen to twenty closely-packed lamellæ, usually in contact throughout this area: the majority of these lamellæ are directly continuous with the attenuated ends of the major septa; occasionally, additional lamellæ appear to be inserted, and occupy positions facing the minor septa, but these do not as a rule reach the central plate, and occur as bifurcations towards the outer margin of the columella.

The central plate appears to be continuous with the counter-septum, and with one of the major septa which bound the fossula. There appears to be a tendency for the lamellæ forming this compact columella to separate slightly in the neighbourhood of the calyx in the adult form.

In sections through the calyx there is also occasionally seen a tendency to the formation of a pseudo-wall dividing off an inner nucleus round the central plate (Pl. XLVIII, fig. 1 *c*).

The medial area is radiated by very strong major septa, which taper rapidly into fine thread-like prolongations continuous with the lamellæ of the columella, the bases of the inner ends of these septa being thickened and fused together to form a pseudo-wall.

The minor septa are practically confined to this thick pseudo-wall; they are visible in thin transparent sections, as short thick spines alternating with the major septa. A small and inconspicuous septal fossula is present, which is marked by the shortened cardinal septum.

The outer area is formed of a narrow zone, of somewhat coarse dissepiments, and is not radiated by the septa. This outer zone is only developed in the neighbourhood of the calyx in mature specimens.

Longitudinal section (fig. 1 *d*).—The central columella is seen to be composed of thickened and somewhat undulating, closely-packed, vertical lamellæ which are irregularly anastomosing; but the figured section (1 *d*) is cut too far from the axis to show these clearly.

The medial area is composed of a broad zone of somewhat loose vesicular tabulæ arranged in oblique rows, the convex surfaces pointing upwards and outwards. The outer area is made up of nearly vertical rows of smaller vesicles, the convex walls of which point upwards and inwards.

All the specimens of this interesting genus so far collected belong to the same species.

Horizon and locality.—Summit of the *Seminula-gregaria* Sub-zone. Meathop Fell, Arnside District.

CARCINOPHYLLUM SIMPLEX, sp. nov. (Pl. XLVIII, figs. 3 *a*–3 *c* & 4 *a*–4 *b*.)

Corallum simple cornute, tapering rather rapidly. Surface covered by well-marked, coarse, vertical ribbing, and by distinct but irregular growth-constrictions. Specimens occur measuring up to 2·5 cm. in length, with a maximum width of 2 cm.

Transverse section.—If a set of serial sections be examined, it is found that in the earliest stages the central area is not composed of vesicular tissue, but is occupied by a columella composed of a number of thick, irregularly twisted, vertical lamellæ, the majority of which are continuous with the inner ends of the major septa. The spaces between these are almost filled with secondary stereoplasm, which is also deposited thickly in the interseptal area. In the later stages (fig. 3 *c*) the majority of the septa are discontinuous with the lamellæ; but the central columella remains attached, even in the most mature stages, to one thickened major septum, which appears in all cases to be the counter-septum. The medial area is radiated by the major septa, which are rather thick and blunt and few in number. In a transverse section having a diameter of 17 mm. there are twenty-eight major septa; these are confluent at their bases to form a thick Zaphrentid type of wall. The minor septa are inconspicuous in the earliest stages, and when they first appear are entirely buried in the deposit of stereoplasm. In adult forms they are never more than a quarter of the length of the major septa. It is only in calicinal sections of big specimens that dissepiments appear, when they form large loose vesicles of the *Carcinophyllum* type.

Longitudinal section.—The central area is composed of the sections of the irregular twisted lamellæ which form the columella; these are connected by loose vesicular tabulæ, which pass outwards to the epitheca in a highly irregular manner.

This interesting species appears to be essentially a *Carcinophyllum*, although it is not until the final growth-stages that the non-septate dissepiments of that genus appear; the curious contorted columella is of a much simpler type than in any species hitherto described.[1]

Horizon and localities.—*Seminula-gregaria* Sub-zone, *Spirifer-furcatus* Band and underlying bed, Meathop, Arnside District; and at the same horizon at Marton, Furness District.

LOPHOPHYLLUM MEATHOPENSE, sp. nov. (Pl. XLVIII, figs. 2 *a*–2 *e*.)

This species conforms exactly to the revised diagnosis of the genus *Lophophyllum*, as recently defined by Mr. Carruthers.[2]

Corallum.—Elongate-cylindrical, usually twisted, tapering rather sharply at the curved proximal end. Epitheca thin; external surface covered with fine growth-lines and occasional deeper constrictions. Specimens occur, measuring up to 25 cm. in length and 3·25 cm. in diameter. Calyx deep: a specimen which has the above-mentioned diameter at the base of the calyx has a depth of calyx of 4·5 cm.

Transverse section.—In the earlier stages (Pl. XLVIII, fig. 2 *c*) the major septa only are developed, and there is no peri-

[1] [When this paper was read, this form was described as a new genus—*Meathopia*. Investigation of further material appears to render this separation unwarranted, as pointed out to me by Mr. R. G. Carruthers.—*E. J. G., November 1912.*]

[2] Trans. Roy. Soc. Edin. vol. xlvii (1909) p. 152.

pheral zone of dissepiments. The septa are somewhat flexuous and thick, tapering towards their inner ends, which either reach to the centre, or else coalesce with adjoining septa forming groups of which one septum is continued to the centre. In more mature stages a septal fossula is present and the central plate becomes more irregular, but can be seen to be continuous with the attenuated inner end of the counter-septum (Pl. XLVIII, figs. 2 *a* & 2 *d*).

A zone of dissepiments is developed, which becomes wider as the diameter of the calyx increases; this zone is radiated by fine major and minor septa, the latter being continued into the medial area as short thickened spines; in a section having a diameter of 32 mm. there are fifty stout major septa in the medial area, which become rapidly attenuated where they enter the central area, and also decrease in thickness in the peripheral zone.

A longitudinal section shows a vertical undulating median plate. The tabulæ are rather widely spaced and arch steeply where they intersect the median plate (Pl. XLVIII, fig. 2 *e*).

The dissepimental zone is finely vesicular and of moderate width, and the vesicles are arranged in vertical rows.

This form resembles in general characters *Lophophyllum cherneyense* Carruthers.[1] It differs from that species in having a much more elongated form, in possessing a greater number of septa which are thickened in the medial area, and in having strong minor septa.

Horizon and localities.—*Seminula-gregaria* Sub-zone. Meathop-Marsh Quarry, Arnside District; Marton, Furness District.

LOPHOPHYLLUM FRAGILE, sp. nov. (Pl. XLIX, figs. 5 *a* & 5 *b*.)

Corallum cornute; epitheca smooth, with occasional growth-constrictions.

Transverse section.—Septa straight, numerous and delicate, not thickened, not reaching the centre, but continued outwards to the theca; inner wall inconspicuous. Central area with a short, thin columellar plate, the major septa projecting only a short distance into this area. Concentric intersections of the tabulæ few in number: appearing as broad bands, on account of the flat and generally horizontal disposition of the tabulæ. External area very broad, radiated by both the major and the minor septa; dissepiments numerous and fine; cardinal fossula poorly developed, only indicated by the slightly-shortened cardinal septum which stops short of the central area.

Longitudinal section.—Dissepimental area broad, nearly as wide as the central area; tabulæ thin and rather widely spaced, frequently showing a marked tendency to a horizontal arrangement, but curving sharply upwards near their intersection by the columellar plate.

This species is distinguished by its slightly-developed columellar plate, the delicate structure of the septa and dissepiments, the short

[1] Trans. Roy. Soc. Edin. vol. xlvii (1909) pl. i, figs. 1 & 2.

and unthickened character of the major septa, and the relatively great width of the dissepimental zone.

Horizon and locality.—The upper portion of the *Michelinia* Zone. Arnside.

Lophophyllum vesiculosum, sp. nov. (Pl. XLVIII, figs. 5 *a* & 5 *b*.)

In transverse sections this species is characterized by a distinct and thickened plate and the regular symmetry of the central area. The radial lamellæ are few in number, and are composed of the attenuated inner ends of some of the major septa. The concentric intersections are numerous, indicating the closely-set and strongly-arched character of the tabulæ; these intersections diminish towards the outer part of the median area, where the tabulæ flatten out, while at the extreme outer margin next to the dissepimental area, stereoplasmic thickening of the tissues takes place (Pl. XLVIII, fig. 5 *a*).

The external area is broad: it consists of a wide zone of fine closely-set dissepiments, which are radiated by major and minor septa, and a narrow border of rather coarse vesicles not radiated by the septa. The longitudinal section (fig. 5 *b*) shows these characters clearly.

This species differs from *L. meathopense* by the thickened central plate; by the more numerous, closely-set tabulæ in both the central and the medial zones; by the broad outer zone of dense dissepimental tissue; and by the outer border of coarse tissue not radiated by the septa.

Horizon and locality.—*Seminula-gregaria* Sub-zone. Meathop, Arnside District.

Lophophyllum ashfellense, sp. nov. (Pl. L, figs. 9 *a* & 9 *b*.)

Corallum simple, markedly cornute, tapering rapidly. Surface with fine longitudinal ribs and marked concentric growth-constrictions. Calyx deep; central plate projecting slightly above the floor of the calyx, forming a narrow ridge. A distinct septal fossula is present in the cup, which is marked by a shortened septum and also by the slightly Zaphrentid-like curving of the septa bounding the fossula, which coalesce at their inner margins with contiguous septa. The proximal end bifurcates to form broad root-like processes, which in all specimens collected have grown round the shell of a brachiopod, a bryozoan, or a coral. The largest specimen met with measures over 11 cm. in length, and its diameter across the cup is 4·5 centimetres.

Transverse section (fig. 9 *a*).—The columella is very thin and lath-like. In the final growth-stages it may appear isolated in the centre of the tabulate area, but lower down it is usually in direct connexion with both cardinal and counter major septa, giving a general bilateral symmetry to cross-sections; it is surrounded by irregular wavy lines, due to the truncation of the surrounding tabulæ.

There are fifty-two major septa in a specimen having a diameter of 23 mm. The majority of these stop short some distance from the centre. They are not much thickened except at their bases, where they enter the vesicular zone. The minor septa are short, and confined to the vesicular area; some of them do not even reach the inner margin of that area. In the peripheral zone the dissepimental tissue is abundant and closely set.

Longitudinal section (fig. 9 *b*).—The central plate appears as a thin rod intersecting the tabulæ, which are slightly arched and moderately closely set. The zone of dissepiments consists of vertical rows of very fine vesicles. The columellar line is not usually continuous, but the interruptions are due to local curvature of the corallum taking the columella out of the line of section.

Horizon and locality. — *Productus-corrugato-hemisphericus* Zone, Gastropod Beds. Ashfell Sandstone, Ashfell Edge, Ravenstonedale District.

CLISIOPHYLLUM MULTISEPTATUM, sp. nov. (Pl. L, figs. 1–4 *b*.)

This species resembles closely *Cl. keyserlingi* M'Coy,[1] but differs from that species in having (1) more closely-set septa (having sixty when the type of the same diameter has fifty); (2) more closely-set tabulæ in the centre; (3) a central area more sharply separated from the median area. In *Cl. multiseptatum* the central plate becomes more prominent with age, while in *Cl. keyserlingi* it becomes less so. The coral frequently attains a length of 5 inches, and shows a spiral mode of growth. The epitheca, though on the whole smooth, shows annular wrinkles and, in unrolled specimens, distinct longitudinal ribbing. The cross-section is typically circular, becoming elliptical in the neighbourhood of the calyx in well-grown specimens. The septal fossula is well developed in the adult stage.

Horizon.—The summit of the *Michelinia* Zone, where it constitutes an important stratigraphical band, which forms a passage-bed between the *Michelinia* Zone and the Gastropod Beds. A similar coral, indistinguishable from the type-specimen, occurs in the Trowbarrow Shale-Bed at a much higher horizon, about the base of the Upper *Dibunophyllum* Sub-zone.

Localities.—Blackstone Point and Storth Road, Arnside District. Also at the same horizon in the Ravenstonedale, Kendal, Grange, and Furness Districts.

[Quite recently Dr. Vaughan[2] has figured a similar coral from the same horizon under Ingleborough, under the name of *Clisiophyllum ingletonense*. This species differs, however, from the form described above in having septa always strongly thickened in the median area, and its inner septa rarely projecting into the median area.]

[1] 'British Palæozoic Rocks & Fossils' 1855, pl. iii *c*, fig. 4.
[2] Proc. Yorks. Geol. Soc. n. s. vol. xvii, pt. iii (1911) p. 251.

CAMPOPHYLLUM CILIATUM, sp. nov. (Pl. XLVIII, figs. 6 *a*–6 *c*.)

Corallum rather small, simple, cylindrical. Epitheca with coarse longitudinal ribbing and very well-marked growth-lines. Hollow root-like processes are given off from the proximal end.

Transverse section.—Central area tabulate and wide. Outer margin of the area radiated by a series of thickened pointed septa, which are undulating and contiguous near their bases. They usually occur in pairs, and have a tendency to coalesce near their inner ends, one of them being prolonged as a single thread-like septum. The fused bases of these septa give the appearance of an inner wall; outside this 'wall' occurs a zone of fine tissue radiated by the septa. There is an external zone of very coarse vesicular tissue not radiated by the septa. A septal fossula is but feebly developed.

Longitudinal section.—Tabulæ widely spaced, and interrupted by occasional circular vesicles, which appear like nearly spherical bubbles in a longitudinal section.

Remarks.—This form is doubtfully placed under the genus *Campophyllum*. In many respects it appears to resemble Billings's genus *Blothrophyllum* from the Devonian (Corniferous Limestone) of Ontario, as figured in the 'Canadian Journal'[1] and refigured by Mr. L. M. Lambe in 'Contributions to Canadian Palæontology'[2]; this genus is characterized by the very large and blister-like vesicles which form the outer zone, but has a distinct septal fossula and minor septa.

Horizon and locality. — *Seminula - gregaria* Sub - zone. Meathop, Arnside District.

CANINIA SUBIBICINA M'Coy. (Pl. XLIX, fig. 3.)

The type-specimen of this species figured by M'Coy,[3] is preserved in the Sedgwick Museum, Cambridge. It was obtained from the Kendal District of the North-Western Province. A figure of a transverse section cut from this type-specimen is given here, through the courtesy of Prof. McKenny Hughes. There can be little doubt that the horizon from which the specimen was obtained is that of the *Michelinia* Zone of the classification adopted in the present paper. The coral is not infrequently met with in the upper portion of this zone at Arnside, and in other exposures at the same horizon in the Kendal, Grange, and Furness Districts.

In the Shap District it enters somewhat earlier, and is there characteristic of the *Thysanophyllum* Band.

ZAPHRENTIS KONINCKI, forma KENTENSIS nov. (Pl. XLIX, fig. 4.)

This form differs from the typical form of this species described by Mr. Carruthers,[4] in its greater size and in the more pronounced

[1] Canadian Journal (Canad. Inst.) n. s. vol. iv (1859) fig. 25 & p. 130.
[2] Geol. Surv. Canada, vol. iv, pt. ii (1901) p. 171 & pl. xv, fig. 1.
[3] 'British Palæozoic Rocks & Fossils' 1855, pl. iii *i*, figs. 35 & 35*a*.
[4] Geol. Mag. dec. 5, vol. v (1908) p. 67.

development of the minor septa. Specimens having a length of 9·5 cm. and a diameter of 3·5 cm. across the calyx are not uncommon. This form has been stated by Dr. Vaughan to bear a striking resemblance to *Cyathophyllum* ϕ Vaughan.[1] A transverse section of a typical specimen from Gascow is here figured.

Horizon and localities.—Abundant in the upper portion of the *Michelinia* Zone in the North-Western Province; Arnside and Storth-Road section in the Arnside District; Gascow and Plumpton in the Furness District; Park Head and Frith Hall in the Grange District.

CYATHOPHYLLUM MULTILAMELLATUM (M'Coy).[2] (Pl. L, figs. 5–7.)

The type-specimen of this species was obtained by M'Coy from Arnside. The species occurs abundantly in the upper portion of the *Michelinia* Zone—not only at Arnside, but wherever that horizon is exposed. It is not found above that zone; but a closely allied (though somewhat smaller) form is met with in the lower portion of the zone, at Brigsteer in the Kendal District and elsewhere. M'Coy's name is retained here, as the exact relation of this form to *C. murchisoni* (Ed. & H.) remains uncertain until the type of that species is found and cut. There is, however, a certain variation of the form in the different specimens collected from this horizon. These may be divided into two groups:—Group A differs both from *C. murchisoni* and *C.* ϕ in having more widely-spaced septa and a more strongly-marked fossula, while the tabulæ are intermediate in type between these two forms (figs. 6 & 7). This form appears to be identical with M'Coy's *C. multilamellatum*, a transverse section of which, cut from the type-specimen preserved in the Sedgwick Museum, I am able to give for comparison through the courtesy of Prof. McKenny Hughes (fig. 5). Group B contains forms having still more widely-spaced septa and an even more distinct cardinal fossula.

THYSANOPHYLLUM PSEUDOVERMICULARE (M'Coy). (Pl. XLIX, figs. 2 *a*–2 *d*.)

This species was originally described by M'Coy under the name of *Cyathophyllum pseudovermiculare*, from specimens collected in the Kendal District.[3]

It is refigured here, in order to show (1) the great variation in the size of the corallites and the characteristic lateral budding (fig. 2 *a*); (2) the coarsely-ribbed epitheca (fig. 2 *a*); (3) the outer zone of coarse vesicular tissue, which is typically not radiated by the septa, except in young forms (fig. 2 *b*); and (4) the marked tendency for one of the septa to be prolonged into the centre of the tabulate area, as shown in figs. 2 *b* & 2 *c*.

This species would appear to belong to Nicholson & Thomson's

[1] Geol. Mag. dec. 5, vol. v (1908) p. 70.
[2] 'British Palæozoic Rocks & Fossils' 1855, pl. iii *c*, figs. 3 & 3 *a*.
[3] *Ibid.* p. 86 & pl. iii *c*, fig. 8.

genus *Thysanophyllum*,[1] and subsequently figured by Thomson.[2] It agrees with the latter author's figure of *Th. minus* in most particulars, especially in the fact that one septum is characteristically prolonged into the centre of the tabulate area, and that a few of the septa occasionally extend into the outer vesicular zone. M'Coy's species seems to differ from both of Thomson's species, chiefly by the coarser character of the vesicles in the peripheral zone. This species appears to represent an early form of *Lonsdalia floriformis*. Mr. R. G. Carruthers, who has devoted special attention to the ancestry of *Lonsdalia*, has demonstrated that *L. floriformis* passes through a very distinct *Thysanophyllum* stage in early life: this would appear to show that *Lonsdalia* has descended, not through *Dibunophyllum*, as sometimes suggested, but through *Thysanophyllum*. This view seems to be further strengthened by the existence of the form intermediate between *Lonsdalia* and *Thysanophyllum*, already mentioned as occurring with *Stenophragma* in Ravenstonedale.

Horizon and localities.—This species is limited to an horizon near the summit of the *Athyris-glabristria* Zone, in the Eastern Districts of the North-Western Province. It is found at many places between the River Eamont and the Dent Fault, in the type-districts; in Hall-Head Quarries and in the cuttings for the Underbarrow and Brigsteer roads, Kendal District; above Broad Oak in the Grange District; and in Dobby-Hole Sike to the south of Roman Fell.

DIPHYPHYLLUM aff. LATESEPTATUM M'Coy. (Pl. L, figs. 8 *a* & 8 *b*.)

This form differs from *D. lateseptatum* of M'Coy in the greater breadth of the tabulate area, which extends across four-fifths of the width of the corallite. The tabulæ are perfectly horizontal throughout the greater portion of their extent, but bend down steeply at their margins, and frequently have the appearance of bifurcating before reaching the peripheral zone, which consists of a double row of very fine vesicles (Pl. L, fig. 8 *b*).

In transverse sections the oblique lateral margins of the tabulæ are intersected, to form sparse interseptal tissue (fig. 8 *a*).

Horizon and localities.—Base of the *Productus-corrugato-hemisphericus* Zone. Blackstone Point, Arnside District; Tarn Sike, Ravenstonedale District.

LITHOSTROTION (NEMATOPHYLLUM) MINUS M'Coy.

The form figured by M'Coy in 1849 in the Annals of Natural History (ser. ii, vol. iii, p. 17), and afterwards in his 'Palæozoic Rocks & Fossils' 1855, p. 99 & pl. iii *b*, fig. 3, was collected from the Kendal District, where it occurs abundantly on the summit of Scout Scar and Kendal Fell. M'Coy gives good figures, and the type-specimens are preserved in the Sedgwick Museum at Cam-

[1] Proc. Roy. Soc Edin. vol. ix (1876) p. 150.
[2] Proc. Phil. Soc. Glasgow, vol. xii (1880) pp. 255–58 & pl. iii, figs. 11–12, 14.

bridge, so that there can be no mistake as to the form which is characteristic of the Upper *Productus-corrugato-hemisphericus* Zone in the North-Western Province. It is for this reason that M'Coy's name has been adopted for this zonal form in the stratigraphical portion of this paper. At the same time, there is good reason to suppose that this species is synonymous with *Lithostrotion basaltiforme* of several authors. Llwydd's original type of *Lithostrotion* is a basaltiform species, as shown by his figure, and not a dendroid form; but, unfortunately, we do not know the horizon in Wales from which it was obtained.[1]

Phillips's type of *Cyathophyllum basaltiforme*[2] came from Moughton Scar in Ribblesdale, where *N. minus* occurs abundantly at the same horizon as in the Kendal District; but, as the figures and description are very inferior to M'Coy's, it has been considered better to emphasize the latter for stratigraphical identification.

Conybeare & Phillips's name *L. basaltiforme* (1822) has been widely adopted for all large basaltiform corals of that genus from the Carboniferous rocks; indeed M'Coy's type-specimens in the Sedgwick Museum are so labelled, and appear under this title in Mr. Woods's Catalogue of the type-fossils in the Sedgwick Museum.

Some confusion may arise from M'Coy's statement that the corallites are inseparably united, and cannot be divided. This statement is not true of the Kendal specimens, and the separation or non-separation of the corallites appears to be entirely a question of mode of preservation and weathering. The separation of the corallites is most difficult to effect in specimens which have been entirely recrystallized.

VAUGHANIA,[3] gen. nov. (Pl. XLVIII, fig. 7 & text-figs. 4–6, p. 565.)

Corallum discoid, upper surface convex, margin lobulate; size variable, specimens occur measuring up to 5 cms. in diameter. Thickness in centre = 3 or 4 mm., becoming somewhat less towards the margin. Base concave, covered with a well-marked wrinkled epitheca, wrinkles arranged in festoon-like concentric folds parallel to the margin. Corallum apparently free. Corallites very short, closely set, polygonal, as a rule irregularly hexagonal; on an average, ten corallites occur in a length of 4·5 cm. Calices shallow, rather over 1 mm. deep, walls less than 0·75 mm. thick; floors nearly smooth and flat, but curving upwards at the margins to meet the base of the walls.

In well-preserved specimens the surface of the walls presents a somewhat rugose appearance, resembling Nicholson's figure of *Cleistopora geometrica*,[4] but there are no definite ridges or striæ representing septa.

[1] 'Lithophyllacii Britannici Ichnographia' epistola 5, tab. xxiii (1760).

[2] 'Geol. of Yorks.' pt. ii (1836) p. 202 & pl. ii, fig. 21.

[3] I have named this new genus in honour of Dr. Arthur Vaughan, and in testimony of my admiration for his epoch-making work among the Lower Carboniferous rocks and fossils.

[4] Geol. Mag. dec. 3, vol. v (1888) p. 151.

The corallum is traversed by a system of large perforations or tubes, arranged on a definite plan. This is found in all well-preserved specimens, though it is liable to slight variation in detail.

Round the base of the wall of each calyx runs a polygonal or roughly circular perforation or ring-canal, which follows the contour of the wall ; this lies just inside the angle formed by the junction of the wall with the floor of the calyx, and slightly below the level of the floor. Thus the base of each wall is traversed by two such tubes bordering the margins of two contiguous corallites (fig. 4, below). From these ring-canals branches are given off, which open by pores into the floor of the calices near the base of the walls (fig. 5). Other branches are given off in the opposite direction from the ring-canals and traverse the wall horizontally, connecting the ring-canals of two adjacent corallites (fig. 6). Other pores are also occasionally seen, opening higher up on the walls of the calices ; these are, however, more irregular in their distribution.

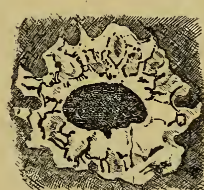
Figs. 4–6.—*Vaughania cleistoporoides*, gen. et sp. nov.

4

[× 22 diameters.]

5 [Natural size.]

6 [Natural size.]



The pores opening round the basal margin of the calices are fairly numerous, and are placed close together, the distance between them being generally not much greater than the diameter of the pores themselves (fig. 5).

In microscopic sections the walls and floors of the corallites exhibit a finely-crystalline fibrous structure, similar to that which characterizes many recent corals. The long axes of the fibres are arranged perpendicularly to the walls and floors of the calices (fig. 4, above). There is no trace of the trabecular structure figured by Nicholson in his descriptions of *Cleistopora* and *Palæacis*, while tabulæ are entirely wanting. This compact fibrous cœnenchyma is perforated by the tubes described above ; and, in the neighbourhood of the tubes, the fibres are arranged in a radial manner perpendicularly to the walls of the tubes (fig. 4). Vertical sections cut at right-angles to a corallite-wall show two perforations below the base of the wall and on each side of it, representing transverse sections of the two ring-canals of contiguous corallites (fig. 4, p. 565). From these, in many sections, tubes can be observed passing obliquely outwards and upwards, and penetrating the floors of the calices at the base of the walls, where they terminate at the surface to form the pores already described. In horizontal sections, prepared so as to expose the base of the walls a short distance below the floors of the calices, the system of ring-canals and their connecting tubes can be well seen, the canals being rendered conspicuous by their infilling of darker argillaceous material (fig. 6).

Affinities and differences.—In general appearance in hand-specimens this organism, especially when weathered, closely resembles the form from the Avon section referred by Dr. Vaughan to *Cleistopora (Michelinia) geometrica* Ed. & H.[1] It differs, however, from this genus, as described and figured by Nicholson (*op. supra cit.*), in the following points:—

1. The absence of the trabecular structure which characterizes that genus.
2. The presence of compact fibrous cœnenchyma, forming the whole of the corallum.
3. The presence of a definite system of ring-canals and branches.
4. The presence of a well-developed basal epitheca, which is unattached.

From *Pleurodictyum* the form here described differs by the calices being low and vertical, not funnel-shaped; by having no trace of tabulæ or septal spines; by not being attached; and by the absence of the commensal vermiform body. Again, the ring-canals which are so characteristic of *Vaughania* have never been observed in *Pleurodictyum*. The former resembles *Pleurodictyum* in the presence of intra-mural pores and of a concentrically striated basal epitheca. It differs from *Palæacis*[2] in

1. Having a much greater number of calices.
2. The corallites not being wedge-shaped, but arranged with their walls perpendicular to the basal plate.
3. The calices having narrow and polygonal walls rising from the basal plate, and not excavated as circular pits in the general mass of the corallum.
4. The absence of vertical striæ in the calices.
5. The regular arrangement of the perforations to form ring-canals.
6. Not being attached.

It resembles *Palæacis* in having rows of pores connecting the corallites, but the minute structure of the basal plate of *Palæacis* is unknown.

It resembles more closely in its internal structure *Microcyathus*,[3] which is formed of fibrous calcareous tissue, and in the possession of a wrinkled basal epitheca; also in the possession of a porous cœnenchyma, which characterizes the base and spaces between the

[1] Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 99.
[2] J. Haime, in H. Milne Edwards, 'Hist. Nat. Corall.' vol. iii (1860) p. 171.
[3] G. J. Hinde, Q. J. G. S. vol. lii (1896) p. 447.

calices: but the pores in the cœnenchyma of *Microcyathus* are irregular, and can scarcely be described as a definite tubular system.

Our form differs again in general appearance by the polygonal character of the calices, which are closely packed; whereas the cups of *Microcyathus* are some distance apart, and circular in outline: also in the absence of a rugose surface and of blunt spines in the calices, which in *Microcyathus* seem to represent septa.

VAUGHANIA CLEISTOPOROIDES, sp. nov.

This is the only species of the genus so far known.

Horizon and locality.—Near the base of the *Solenopora* Sub-zone. Stone Gill and Artlegarth, Ravenstonedale District; Shap-Abbey Cliff, Shap District.

Brachiopods.

CAMAROTŒCHIA PROAVA (Phill.). (Pl. LI, figs. 1*a*–1*c*.)

This species was first figured by Phillips in his 'Geology of Yorkshire' pt. 2 (1836) pl. xii, fig. 37 & p. 223, and described under the name *Terebratula proava* as follows:—'Beak produced; radiations obtuse; mesial fold square.'

Davidson, 'Brit. Foss. Brach.' Monogr. Pal. Soc. vol. ii (1858–63) p. 111 & pl. xxv, fig. 10, refigures Phillips's specimen, and adds the following description:—

'Of an elongated oval shape, with nineteen or twenty small ribs in each valve, but which become obsolete at the beaks; the mesial fold is of but small elevation above the general convexity of the valve, and is ornamented by five ribs; the sinus is shallow.'

He doubts, however, whether it is a good species, and suggests that it may be an abnormal shape of *Camarophoria crumena*.

The type-specimen is preserved in the British Museum.

Our species resembles very closely figures of *Camarotœchia congregata* of Hall, from the Hamilton Group of North America.[1] The size of the specimen, the slight mesial fold and sinus, and the character of the ribbing all agree. Owing to silicification, it is difficult to find well-preserved specimens exhibiting the interior; but one or two collected from the Ravenstonedale District show distinctly an incipient spondylium in the brachial valve. This spondylium and the position and shape of the dental sockets correspond almost exactly with the internal view of *C. congregata* shown in the figures of Hall & Clarke.

Horizon.—This species forms a very marked band in the upper portion of the *Solenopora* Sub-zone, and, when present, occurs in great abundance, making up layers of the rock; it is of great value as a zonal horizon, especially in the type-districts.

[1] J. Hall & J. M. Clarke, 'Palæontology of New York' vol. viii, pt. ii: 'An Introduction to the Study of the Brachiopoda' pt. ii (1894) pl. xliii, figs. 1 & 2–4 (13th Ann. Rep. State Geol. N.Y. for 1893, vol. ii).

Localities.—Piper-Hole Quarry, Ravenstonedale; above Shap-Abbey Cliff, Shap District; under Hall-Head Farm, Kendal District; Low Meathop, Arnside District.

RHYNCHONELLA (PUGNAX) FAWCETTENSIS, sp. nov. (Pl. LI, figs. 2 *a* & 2 *b*.)

Description.—General form subrhomboidal. Shell rather small: an average specimen measures in length 10·5 mm., in width 12 mm., and in thickness 8 mm. Apical angle = about 125°. Plications extend from the beak to the anterior margin. There are six plications on each side of the median fold in the brachial valve. Sinus shallow, only well marked in the anterior portion of the shell. The plaits in the fold are typically three in number, and are usually produced slightly beyond the general margin (fig. 2 *a*).

This small rhynchonellid, although belonging to the same group as *Pugnax pleurodon*, possesses marked and constant characters which differentiate it from that well-known species. The points of difference are:—

1. Mature specimens have a considerably smaller size than *P. pleurodon*.
2. It has a relatively narrow and more swollen form.
3. The sinus is more rounded and less pronounced.
4. There are a smaller number of plications in the sinus.

This form resembles in many respects *Rh. acutirugata* of L. G. de Koninck.[1] It differs from that species, chiefly in the general form of the fold and sinus, and in the character of the apical angle.

Horizon and localities.—*Productus-globosus* Band; *Seminula-gregaria* Sub-zone. Fawcett Mill, Shap District; near Park House, Ravenstonedale District; under Cunswick Scar, Kendal District.

PRODUCTUS GLOBOSUS, sp. nov. (Pl. LI, figs. 4 *a* & 4 *b*.)

Shell small: an average specimen measures 8 or 9 mm. along the hinge-line. Length of specimen, as usually preserved, from umbo to anterior margin = 33 mm.

Pedicle-valve.—General form globular, tapering rapidly to the umbo. Umbonal region greatly inflated, strongly arched and incurved. Hinge-line straight, and scarcely as wide as the greatest width of the shell. Shell devoid of any trace of sinus, but almost uniformly convex.

Ribs very fine, thirty-five in 10 mm., measured at the middle of the anterior portion of the visceral disc. In this region the ribs are but slightly undulating, and the region is typically devoid of intercalated ribs. In the umbonal region, just where contraction takes place rapidly, there is a regular zone of fresh intercalations, as shown in Pl. LI, fig. 4 *a*. Ears covered with numerous well-marked wrinkles, which are confined to these regions. There are no traces of concentric lines of growth over the visceral disc. Groups

[1] 'Faune du Calcaire Carbonifère de la Belgique' pt. vi, Ann. Mus. Roy. Hist. Nat. Belg. vol. xiv (1887) pl. xvi, figs. 1–14.

of short, blunt, and curved spines cluster on the ears, and are continued as a double row along the hinge-line. Spines are also given off sparingly from the skirt, which is slightly undulating.

Horizon and localities.—This form appears to be confined to a definite band at the base of the *Seminula-gregaria* Sub-zone. Friar's Bottom, Ravenstonedale District; Fawcett Mill, Shap District.

PRODUCTUS aff. GLOBOSUS.

This form resembles *Pr. globosus* closely, in size and in general appearance. It differs, however: (1) by the more clearly-defined character of the ribs, which are both coarser and more clearly cut; (2) by the more pointed and less globose character of the visceral disc, from which results the fact that the intercalation of fresh ribs takes place much farther from the umbo, in the region near the anterior portion of the visceral disc.

Only two specimens of this form have been met with, at the base of the Lower *Dibunophyllum* Sub-zone, in the Bryozoa Band, east of Roman Fell, in the Pennine District.

PRODUCTUS ROTUNDUS, sp. nov. (Pl. LI, figs. 3 *a* & 3 *b*.)

Pedicle-valve.—Resembles *Productus globosus* in general appearance, but differs in the following points:—

1. Shell slightly larger.
2. The greater width of the shell across the region near the anterior end of the visceral disc, in which region, as also over the skirt, there is in some specimens a slight tendency to a sinus.
3. The coarse character of the ribbing. Seventeen ribs in 10 mm.
4. The continuation of the wrinkles over the visceral disc, producing a slightly scrobiculate appearance in that region.
5. The presence of fine concentric lines of growth, which are specially conspicuous on the skirt.

Horizon and localities. — Abundant in the *Productus-globosus* Band at the base of the *Seminula-gregaria* Sub-zone. Friar's Bottom, Ravenstonedale District; Fawcett Mill, Shap District.

PRODUCTUS cf. GIGANTEUS Mart.

This form is very close to, if not identical with, that figured by Davidson.[1] It differs from the typical *Pr. giganteus* of Martin by its smaller size, more globose form, and slight development of ears. The coarse ribbing characteristic of the type-species is but faintly developed, and the convex valve has the shell greatly thickened in the neighbourhood of the hinge-line. The shell resembles rather closely in external appearance well-grown examples of *Daviesiella llangollensis*; but internal casts of the convex valve show conspicuous eminences, representing the cavities for the fleshy arms shown in Davidson's figure. These casts, indeed,

[1] 'Brit. Foss. Brachiop.' Monogr. Pal. Soc. vol. ii (1858–63) pl. xxxvii.

resemble at first sight those of *Productus sublævis*, originally figured by Sowerby as *Pr. humerosus*.

Horizon and localities.—This form is confined to one horizon in the North-Western Province, at the summit of the *Lonsdalia* Beds, where it is present in such abundance as to make up a definite band at the summit of the Mauld's-Meaburn Limestone. Bank Moor, Gathorn Plain, Shap District; High-Cup Gill, Pennine District.

PRODUCTUS cf. MAXIMUS M'Coy.[1] (Pl. LI, fig. 8.)

This species resembles *Pr. giganteus* in general form, but differs by its much smaller size, the full-grown specimens having a length of about 10 cm. along the hinge-line. It differs also by the more even character of the striæ, and the absence of the large ribs which are so characteristic of Martin's species. From *Pr. corrugato-hemisphericus* Vaughan it differs by its transverse form and its elongated hinge-line. In the specimen figured there are also closely-set spine-bases along the hinge-line.

Horizon.—Characteristic of the Lower *Dibunophyllum* Sub-zone in the North-Western Province. The specimen figured is from this horizon in the Pennine District.

SPIRIFER PINSKEYENSIS, sp. nov. (Pl. LII, figs. 1 *a* & 1 *b*.)

Hinge-line straight, by far the greatest width of the shell. Beak small and depressed. Valves almost equally convex.

Pedicle-valve.—Sinus shallow, with flattened floor and three or four ribs; these may be faint and indistinguishable in the casts, but are distinctly larger than those on the rest of the shell. Surface ornamented with fine concentric lines and occasional indications of radial striæ on the ribs in the sinus. The ribs bounding the sinus frequently bifurcate at some distance from the beak, and are inclined to be raised above the general surface of the shell.

Brachial valve.—Mesial fold flat, scarcely elevated above the general surface of the shell, indistinct, usually divided near the beak to form two ribs which diverge considerably towards the anterior margin, each bifurcating once. The lateral ribs bordering the fold are frequently seen to bifurcate. The anterior margin of the fold is covered with conspicuous concentric growth-lines.

Remarks.—This species bears considerable resemblance to *Sp.* aff. *clathratus* (M'Coy) Vaughan.[2] It differs from Dr. Vaughan's figure of a typical specimen, given in vol. lxi (1905) of this Journal,[3] by its rather less transverse form; by the shallow and flattened nature of the sinus; and by the less numerous and coarser character of the ribs in the sinus.

Horizon and locality.—Pinskey Beds, underlying the Shap Conglomerate. Pinskey Gill, Ravenstonedale District.

[1] T. Davidson, 'Brit. Foss. Brachiop.' Monogr. Pal. Soc. vol. ii (1858–63) pl. xxxix, fig. 4.

[2] Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 125–26 & pl. ii, fig. 3.

[3] P. 300 & pl. xxvi, fig. 5.

Spirifer furcatus M'Coy.[1]

This small *Spirifer*, which occurs abundantly near the summit of the *Athyris-glabristria* Zone on Meathop Fell, in Docker Beck, and elsewhere, bears a very close resemblance to M'Coy's figure. It is a somewhat variable form, and does not always show the bifurcation of the ribs clearly at the anterior portion of the shell. In some specimens, apparently belonging to this species, the ribs are more numerous and the bifurcation takes place nearer the posterior margin.

This form approximates occasionally to *Sp. duplicicostatus*, under which name Davidson includes M'Coy's species; but, on the whole, it differs from the typical examples of that species in the following points:—

1. The subquadrate form of the shell.
2. The less numerous and coarser ribs. In the pedicle-valve there is a somewhat marked bifurcation about the third rib from the sinus.
3. The narrower character of the mesial fold, especially towards the anterior border, giving a more parallel and less divergent appearance to the ribbing.
4. The well-marked growth-lines towards the anterior margin of the shell: these are clearly shown in M'Coy's figure.

Horizon and localities.—Very characteristic of the band near the summit of the *Athyris-glabristria* Zone. It is doubtful whether it occurs outside this band in the North-Western Province. A few specimens met with at a slightly lower horizon in the Ravenstonedale District should perhaps be assigned to this form. Meathop Fell, Arnside District; Beck Head, Grange District; Elliscales, Furness District.

Seminula gregaria (M'Coy). (Pl. LI, fig. 5.)

The typical form of the Athyrid selected for the zonal index of the upper portion of the *Athyris-glabristria* Zone in the Shap and Ravenstonedale Districts is shown in Pl. LI, fig. 5. It appears to be identical with M'Coy's '*Atrypa gregaria*,' figured in his 'Carboniferous Limestone Fossils of Ireland' pl. xxii, fig. 18. With regard to its true generic affinities, very little information can be obtained from the occurrences of this species in the North-Western Province, as the specimens are there invariably dolomitized. Dr. Vaughan informs me that the species is probably a *Cryptonella*, but it cannot be definitely assigned to its proper genus, until better specimens, showing internal characters, are obtainable.

Seminula aff. ficoidea Vaughan. (Pl. LI, fig. 6.)

This form bears a close general resemblance to Dr. Vaughan's figure of *S. ficoidea*.[2] It appears, however, to differ from that species by its more swollen character; by its greater length of

[1] See F. M'Coy, 'Syn. Carb. Limest. Foss. Ireland' 1844, pl. xxii, fig. 12 & p. 131.
[2] Proc. Bristol Nat. Soc. n. s. vol. x (1903) pl. ii, fig. 1.

hinge-line, and more attenuated umbo in the pedicle-valve; and also by the absence of a well-marked fold and sinus.

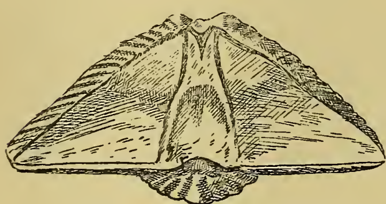
The occurrence of this form, so closely resembling the index-species of the *Seminula* Zone in the South-Western Province, at a much lower level in the North-Western Province is of considerable interest.

Horizon and locality.—*Athyris-glabristria* Zone (chiefly in the upper portion of this zone). The specimen figured is from the *Camarotœchia-proava* Band at the summit of the *Solenopora* Sub-zone, at Low Meathop, Arnside District.

Spiriferina laminosa M'Coy. (Pl. LI, figs. 7 *a*–7 *e* & text-fig. 7.)

The form figured here appears to belong to M'Coy's species; but his original figure is too poor for precise comparison, and the type-specimen is unfortunately not preserved in the Griffith Collection at Dublin, although search has been made for it. It is certainly not a *Syringothyris*, as specimens when rubbed down show only a single plate in the delthyrium of the pedicle-valve (text-fig. 7). The shell is characterized by the abundance of coarse punctations which are conspicuous along the hinge-line, as well as in other portions of the shell.

Fig. 7.—*Specimen of* Spiriferina laminosa, *showing the delthyrium of the pedicle-valve (rubbed down).*



[Twice the natural size.]

This form is very characteristic of the *Productus corrugato-hemisphericus* Zone in the Ravenstonedale District, being found abundantly both in the Ashfell Sandstone in the lower portion of the zone, and in the Bryozoa Band at the summit of the zone. The specimen figured is from the Lower *Pr. corrugato-hemisphericus* Zone near the summit of the Ashfell Sandstone, Ravenstonedale District.

Appendix I.

Description of the Teeth of Two New Species of Fishes from the Lower Carboniferous Rocks of the North-Western Province.

By A. Smith Woodward, LL.D., F.R.S., Sec.G.S.

Deltodus garwoodi, sp. nov. (Pl. LII, figs. 2, 3 *a*, & 3 *b*.)

Specific characters.—'Upper' dental plate narrow, triangular in shape, and scarcely curved; antero-lateral and postero-lateral borders nearly straight, the inner border bulging downwards in its anterior half. Antero-lateral half of the coronal face raised into a prominent round ridge, which is partly subdivided by transverse constrictions into a few large rounded bosses; postero-lateral half flattened, curving a little upwards at the postero-lateral border.

Remarks.—This species is known only by two satisfactorily preserved 'upper' dental plates and a few fragments. The type-specimen (B.M. P 10335) measures 12 mm. in width at its inner border, while the second specimen is somewhat larger. In the former five distinct bosses are seen on the rounded antero-lateral ridge, and there would probably be a sixth at the apex, which is broken away. In both cases the coronal face is much abraded, so that the punctations of the dentine, below the original surface, are conspicuous; but in the larger specimen there are still traces of sigmoidally-curved lines extending from the grooves between the antero-lateral border: these suggest that the dental plate results from the fusion of *Helodus*-shaped teeth in which the coronal eminence occupied the anterior half.

D. garwoodi, which is named after its discoverer, differs from all other known species of the genus in the coarse beading of the antero-lateral eminence of its dental plate, the relative evenness of its postero-lateral half, and the slightness of its curvature. A fragment from the St. Louis Limestone of Illinois, which has been referred to *D. intermedius*,[1] perhaps approaches it most closely.

Horizon and localities.—*Solenopora* Sub-zone. *Archæocidaris* Bed, Shap Abbey, Shap; and *Vaughania-cleistoporoides* Band, Stone Gill, Ravenstonedale.

COCHLIODUS VIRGATUS, sp. nov. (Pl. LII, figs. 4 *a* & 4 *b*.)

Specific characters. — Anterior dental plate scalene-triangular in shape; its sharp oblique coronal ridge divides the surface into two equal areas, of which the postero-lateral is smooth and slopes gradually downwards to the border, while the antero-lateral is strongly ridged, with a tendency to the branching of at least one ridge. Postero-lateral border slightly crimped.

Remarks.—The anterior dental plate of *Cochliodus* often exhibits a tendency to bear radiating ridges on its antero-lateral extensions, but the new tooth is unique in the strength of this ridging. The specimen described also differs from all other known teeth of *Cochliodus*; but it resembles *Psephodus*, in the crimping of at least part of the border.

Horizon and locality.— *Vaughania-cleistoporoides* Band, *Solenopora* Sub-zone. Stone Gill, Ravenstonedale.

[1] A. H. Worthen & O. St. John, Geol. Surv. Illinois, vol. vii, Geol. & Pal. (1883) pl. ix, fig. 15.

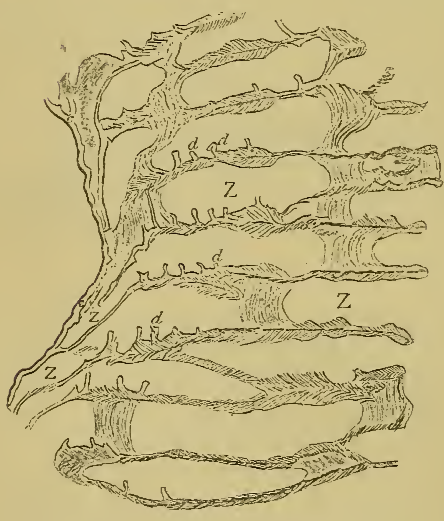
Appendix II.

Description of some New Forms of Trepostomatous Bryozoa from the Lower Carboniferous Rocks of the North-Western Province. By Madeline Munro, B.Sc.

Stenophragma, gen. nov.

Zoarium ramose or irregular, lobate and folded; branches generally hollow and lined by an epizoarium; zoœcia of varying size, the largest sometimes occupying distinct monticules at the surface; periodical thickening of the walls in the mature region well marked in many species; diaphragms present in the mature region, incomplete and very narrow, only attached to the proximal walls; acanthopores present or absent; no mesopores, but cells much smaller than the average are observed occasionally.

Fig. 8.—*Longitudinal section of a branch of* Stenophragma lobatum, *consisting of only one layer, showing strong epizoarium* (e), *zoœcia* (z), *diaphragms* (d), *in the mature region, and the characters of the walls.* × *about 20 diameters.*



[Two of the diaphragms in the above figure are wrongly shown open at the tip.]

Stenophragma lobatum, gen. et sp. nov. (Figs. 8–10.)

Zoarium composed of one to three layers, each having a thickness of 1 to 2·5 mm., epizoarium strong and wrinkled; branches hollow, irregularly lobate or folded, having a diameter of from 5 to 20 mm.; zoœcial apertures usually polygonal, sometimes subcircular; three to four ordinary zoœcia occupy 1 mm.; monticules quite conspicuous, each occupied by eight or more zoœcia nearly half as broad again as the rest, the centres of these groups being at distances of 4 to 5 mm. from one another. Zoœcial tubes thin-walled and oblique at first, then making an angle of about 120° they proceed directly to the surface, the walls at the same time becoming much thicker and the tubes broader; the walls are periodically constricted. The numerous narrow crescentic diaphragms arise at very constant levels in neighbouring zoœcia, and always from what were the

Fig. 9.—*Tangential section of* Stenophragma lobatum : *showing the polygonal and rounded outlines of the zoœcia* (z), *many of which are furnished with narrow diaphragms* (d); *also great variation in the thickness of the walls.* × *about 20 diameters.*

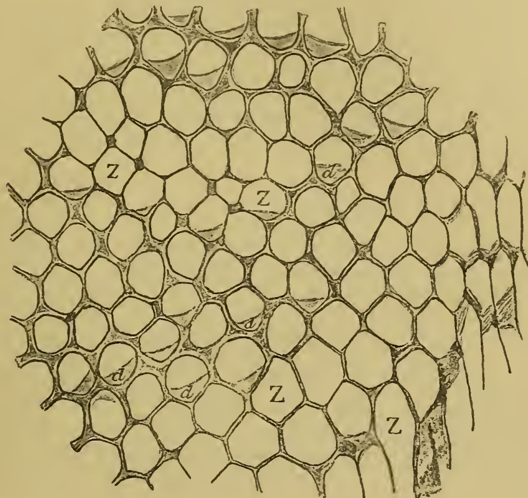
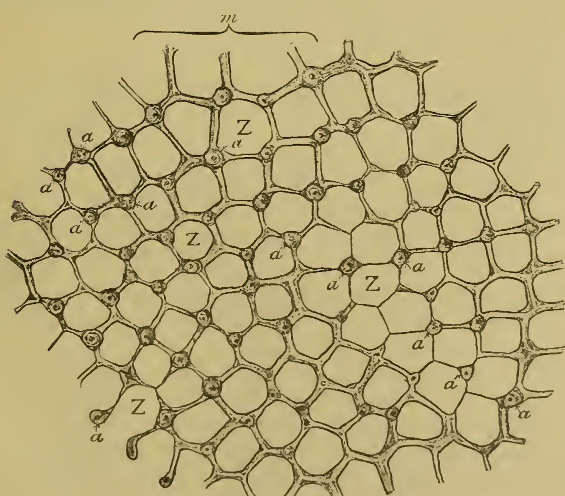


Fig. 10.—*Tangential section of* Stenophragma lobatum, *showing the distribution of the numerous acanthopores* (a), *and passing through a portion of a monticule* (m). × *about 20 diameters.*



proximal or lower walls of the zooecial tubes (assuming, as seems probable, that the branches were erect); most of the diaphragms are curved inwards and even back towards the lower walls; usually they are thickened along the inner margin: they never extend more than a third of the way across the zooecial tubes.

The divisional line between adjoining zooecia, as seen in section, is rarely well-marked, and the laminated structure of the walls is clearly seen in longitudinal sections. Many, but not all, of the junction-angles are occupied by strong acanthopores; these in well-preserved specimens appear as blunt spines at the surface.

Horizon and locality.—*Solenopora* Sub-zone. Ravenstonedale.

STENOPHRAGMA GRANDYENSE, sp. nov.

The genus *Stenophragma* is further represented by a single large and well-preserved specimen from Grandy Quarry, near Shap. This specimen, consisting of a hollow cylindrical branch, differs conspicuously from those constituting the species just described in the absence of acanthopores, the larger size of the zooecia, the much greater thickness of their walls in the mature region, and the circular or oval outlines of the zooecia, as seen in tangential sections. The periodical constrictions of the wall in the peripheral region are much more marked though less numerous; the diaphragms are somewhat thicker, and gently curved towards the epizoarium throughout their width, tapering slightly at the inner margin. The divisional lines between adjoining zooecia are frequently occupied by a crowded but usually single series of small dark spots, many of which (when magnified) present the appearance of minute tubuli, running parallel with the length of the zooecial tubes.

In all other characters this specimen is essentially similar to those from Ravenstonedale, and the name *Stenophragma grandyense* is suggested for its reception.

Other specimens from Humphrey Head and Great Rundal Beck (Upper *Dibunophyllum* Sub-zone in both localities) appear to be referable to the same species. Unfortunately, the material available is scarce, and the immature region is crushed in parts; however, all the sections show a close resemblance, both in structure and in dimensions, to *St. grandyense*. The excellent preservation of one of the specimens from Humphrey Head probably accounts for the fact that it is only in sections of this one that acanthopores can be observed; they are few in number and irregularly distributed, occurring singly at some of the junction-angles which are not occupied by a cluster of dark spots.

A solitary, but large and well-preserved specimen from Ashfell, near the summit of the Gastropod Beds, will probably necessitate the foundation of an additional new species for its reception.

This consists of part of a long hollow cylindrical branch having a diameter of 12 mm. The zoarium varies in thickness from 2 mm. to 4·5 mm., and is lined by a strong wrinkled epizoarium;

the immature region is very narrow, but not constant in extent. The zoœcia are large, though not uniform in size: about thirty occupy 1 cm.; the largest occur in groups, and originally they may have constituted monticules at the surface, but this is somewhat worn; the apertures are polygonal. Cells with apertures much smaller than the average occur occasionally, and especially among the largest zoœcia. The moniliform thickening of the walls is very pronounced, occurring at frequent but variable distances throughout the peripheral region, though at constant levels in all parts of the zoarium. Diaphragms are few, very narrow, often thickened along the inner edge; almost invariably one occurs at the point where the zoœcial walls become thickened, and bend outwards to proceed directly to the surface. Acanthopores of moderate size occur singly at many of the junction-angles.

This specimen is further characterized by the possession of numerous structures of an unusual kind, which may prove to be mesopores. They appear to have been cut off from the zoœcial cavities by outgrowths from the zoœcial walls; they occur singly and in small clusters at many of the junction-angles.

The genus *Stenophragma* closely resembles *Anisotrypa*, Ulrich, and *Tabulipora*, Young, in many characters; but it differs from both, in having narrow crescentic diaphragms attached only to the proximal portion of the circumference of the zoœcial walls, instead of centrally perforated diaphragms.

It seems advisable to alter one sentence in the description of the family Batostomellidæ, Ulrich, to read thus:—

> 'diaphragms in the peripheral region often centrally perforated or merely crescentic,'

in order that the genus may be included in it.

[As these notes are passing through the press we learn from the Geological Survey Memoir on the 'British Carboniferous Trepostomata,' by Dr. G. W. Lee, issued on May 12th, 1912, that other new species, agreeing in all essential characters with those described above, have been placed in the genus *Tabulipora* Young, in Section B, founded for their reception, since they differ from the typical species of the genus as originally founded, in that

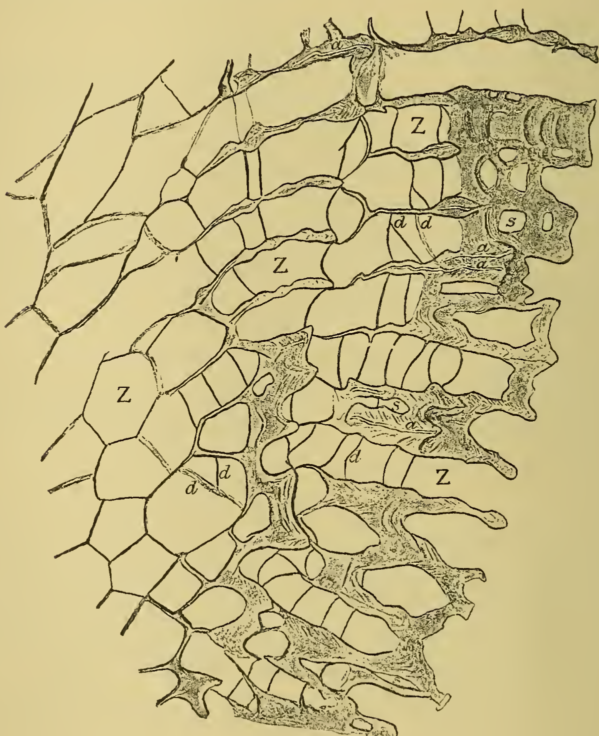
> 'the perforation of the tabulæ occupies a lateral position, distal in relation to the general direction of growth.'

In other words, the diaphragms are attached to the proximal or lower walls of the zoœcia.]

Stenopora compacta, sp. nov. (Figs. 11 & 12, pp. 578–79.)

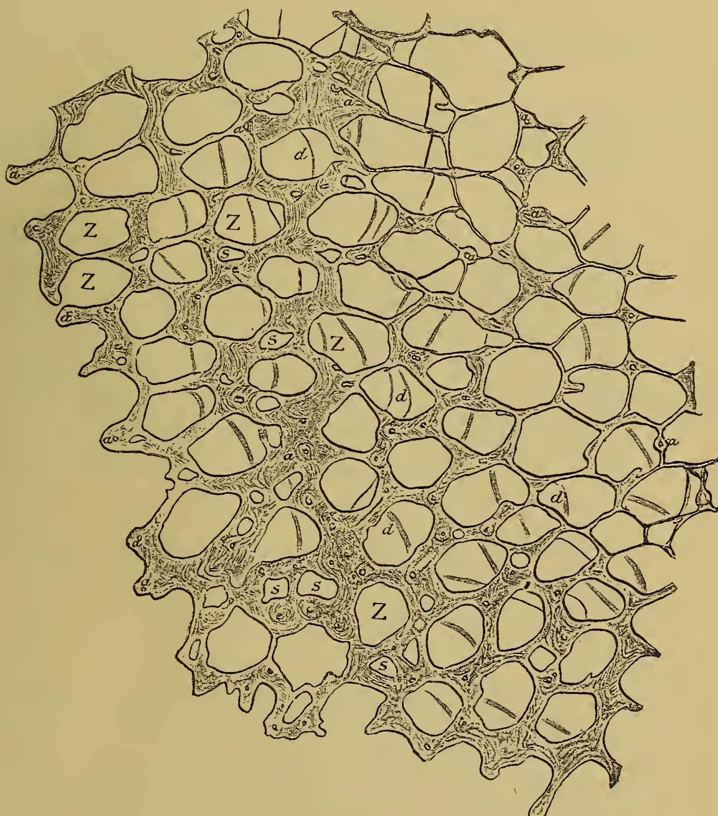
Zoarium ramose; branches solid, robust, often 8 mm. in diameter; frequently dichotomizing, the branches thus formed only slightly narrower than the main branch; many-layered, those layers which are fully developed having a thickness of 2 mm. in the mature region. Zoœcia prismatic and thin-walled in the axial region, diverging gently from an imaginary central axis to open directly at the surface; usually, eight to ten zoœcia occupy 5 mm. in all parts of the zoarium; apertures rounded and large; walls

Fig. 11.—*Longitudinal section of a branch of* Stenopora compacta, *sp. nov., composed of two layers; showing zoœcia* (z) *traversed by complete diaphragms* (d), *small cells, possibly mesopores* (s), *acanthopores* (a), *and the characters of the walls in the mature and the immature regions.* × *about 20 diameters. (From the Bryozoa Band, Weather Hill, Shap District.)*



unequally thickened in the mature region, but seldom sharply constricted. The zoœcia are traversed by thin, complete diaphragms, which are rare in the axial region but numerous in the mature zone, seldom being separated by distances greater than their own diameter; the majority are straight and horizontal, but some are very oblique, others curved, and often an oblique and an horizontal one appear to coalesce or have a common origin on one side. Small cells, often irregularly moniliform and without diaphragms, occur singly at many of the junction-angles. Acanthopores few, the majority small and inconspicuous. In those parts of the zoaria where the mature region is very narrow, the zoœcia often open

Fig. 12.—*Tangential section through the mature region of* Stenopora compacta, *showing the sub-polygonal and rounded outlines of the zoœcia* (z), *small cells, possibly mesopores* (s), *acanthopores* (a), *and marked variation in the thickness of the walls.* × *about 20 diameters.*



[The diaphragms should be shown attached to the zoœcial walls at all points.]

obliquely at the surface, and small cells (which may be mesopores) are not seen.

Horizon and localities.—Bryozoa Band, top of the *Nemato-phyllum-minus* Sub-zone; Roman Fell, Weather Hill, and Orton Knott. The best-developed examples are from Weather Hill, but the greatest number are from Roman Fell.

EXPLANATION OF PLATES XLIV–LVI.

Plate XLIV (facing p. 486).

Fig. 1. Shap-Abbey Cliff, *Solenopora* Sub-zone. (The figure points to the Lower *Solenopora* Band ; the *Proava* Band lies at the top of the cliff.)

2. Halton Green, Arnside District. Knoll-reef breccia (D_2-D_3). (See p. 515.)

Plate XLV (facing p. 512).

Fig. 1. Trowbarrow Quarry, Silverdale, showing the vertical beds of D_1.

2. Middlebarrow Quarry, Silverdale, showing the thrust-plane in D_1.

Plate XLVI (facing p. 518).

Fig. 1. Fold in the *Thysanophyllum* Band, Hall-Head Hall, Kendal.

2. Pseudobreccia and 'Stick Bed,' Lower *Dibunophyllum* Sub-zone, Chapel Island, Furness. (See p. 533.)

Plate XLVII.

Fig. 1. Transverse section of *Solenopora garwoodi* (MS. Hinde), from the *Solenopora* Sub-zone. Stone Gill, Ravenstonedale District. × 40. (See p. 459 ; also Pl. XLIX, fig. 1.)

2. A section of a typical calcareous alga from the Algal Layer, at the base of the *Seminula-gregaria* Sub-zone. Near Wath, Shap District. × 40. (See p. 462.)

3. Section of a 'spotted' bed, showing the arrangement of the sand-grains round a dark calcareous nucleus, from the Lower *Dibunophyllum* Sub-zone. Great Rundal Beck, Pennine District. × 12. (See p. 476.)

4. Section of porcellanous rock showing *Calcispheræ*, etc., from the Bryozoa Band. Lyvennet Beck, Shap District. × 45. Inset: *Calcisphera* cf. *fimbriata* Williamson. (See p. 474.)

Plate XLVIII.

Fig. 1 *a*. *Carruthersella compacta*, gen. et sp. nov. Natural size. *Seminula-gregaria* Sub-zone. Meathop, Arnside District. (See p. 555.)

1 *b*. The same. × 3.

1 *c*. Section through the base of the cup from the same specimen, showing the structure of the central area and the outer zone of vesicular tissue. × 2.

1 *d*. The same. Longitudinal section. × 3.

Figs. 2 *a*–2 *c*. *Lophophyllum meathopense*, sp. nov. Serial sections. Natural size. *Seminula-gregaria* Sub-zone. Meathop. (See p. 557.)

Fig. 2 *d*. *L. meathopense*. Another specimen. Natural size.

2 *e*. Longitudinal section of the same, natural size.

Figs. 3 *a* & 3 *b*. *Carcinophyllum simplex*, sp. nov. Natural size. Serial sections. *Seminula-gregaria* Sub-zone. Meathop. (See p. 556.)

Fig. 3 *c*. *C. simplex*. Another specimen. Natural size. Marton, Furness District.

4 *a*. *C. simplex*. Natural size. Section through the cup of a large specimen. *Seminula-gregaria* Sub-zone. Meathop.

4 *b*. Longitudinal section of the same, natural size.

5 *a*. *Lophophyllum vesiculosum*, sp. nov. Natural size. *Seminula-gregaria* Sub-zone. Meathop. (See p. 559.)

5 *b*. Longitudinal section of the same.

Figs. 6 *a* & 6 *b*. *Campophyllum ciliatum*, sp. nov. Serial sections, natural size. *Seminula-gregaria* Sub-zone. Meathop. (See p. 561.)

Fig. 6 *c*. Longitudinal section of the same, natural size.

7. *Vaughania cleistoporoides*, gen. et sp. nov. Natural size. *Solenopora* Sub-zone. Ravenstonedale District. (See p. 564.)

Plate XLIX.

(All the figures are of the natural size.)

Fig. 1. *Solenopora garwoodi* MS. Hinde. Lower *Athyris-glabristria* Zone. Shap-Abbey Cliff. (See p. 459.)

2 *a*. *Thysanophyllum pseudovermiculare* (M'Coy). Natural size. Showing the mode of budding. Underbarrow Road, Kendal District. (See p. 562.)

Figs. 2 *b* & 2 *c*. Horizontal sections of the same. Rosgill, Shap District.

Fig. 2 *d*. Longitudinal section of the same.

3. *Caninia subibicina* M'Coy. Horizontal section, natural size. From M'Coy's type-specimen in the Sedgwick Museum, Cambridge. *Michelinia* Zone, Kendal District. (See p. 561.)

4. *Zaphrentis konincki*, forma *kentensis* nov. *Michelinia* Zone. Gascow, Furness District. (See p. 561.)

Figs. 5 *a* & 5 *b*. *Lophophyllum fragile*, sp. nov. *Michelinia* Zone. Arnside Shore, Arnside District. (See p. 558.)

Plate L.

(All figures are of the natural size.)

Fig. 1. *Clisiophyllum multiseptatum*, sp. nov. Large specimen, from the *Cl.-multiseptatum* Band, *Michelinia* Zone. Gascow, Furness District. (See p. 560.)

Figs. 2 & 3. *Cl. multiseptatum*. Younger specimen. Arnside District.

Fig. 4 *a*. *Cl. multiseptatum*. Another specimen, showing the thickened septa.

4 *b*. Longitudinal section of the same.

5. *Cyathophyllum multilamellatum* (M'Coy). Section of type-specimen in the Sedgwick Museum, Cambridge, from Arnside. (See p. 562.)

6. *C. multilamellatum*. *Michelinia* Zone. Arnside.

7. *C. multilamellatum*. Another specimen. Same locality.

Figs. 8 *a* & 8 *b*. *Diphyphyllum* aff. *lateseptatum* M'Coy. Base of the *Productus-corrugato-hemisphericus* Zone. Blackstone Point, Arnside. (See p. 563.)

9 *a* & 9 *b*. *Lophophyllum ashfellense*, sp. nov. Ashfell Sandstone, Ravenstonedale. (See p. 559.)

Plate LI.

(Figures 1–7 are of the natural size.)

Figs. 1 *a*–1 *c*. *Camarotœchia proava* Phill. *Camarotœchia-proava* Band. *Solenopora* Sub-zone. Ravenstonedale District. (See p. 567.)

Figs. 2 *a* & 2 *b*. *Rhynchonella (Pugnax) fawcettensis*, sp. nov. *Productus globosus* Band. *Seminula-gregaria* Sub-zone. Shap District. (See p. 568.)

Figs. 3 *a* & 3 *b*. *Productus rotundus*, sp. nov. Base of the *Seminula-gregaria* Sub-zone. Shap District. (See p. 569.)

Figs. 4 *a* & 4 *b*. *Productus globosus*, sp. nov. Base of the *Seminula-gregaria* Sub-zone. Shap District. (See p. 568.)

Fig. 5. *Seminula gregaria* M'Coy. *S.-gregaria* Sub-zone. Shap District. (See p. 571.)

Fig. 6. *Seminula* aff. *ficoidea* Vaughan. *Solenopora* Sub-zone. Meathop. (See p. 571.)

Figs. 7 *a*–7 *e*. *Spiriferina laminosa* M'Coy. Lower *Productus-corrugato-hemisphericus* Zone. Ashfell Sandstone, Ravenstonedale District. (See p. 572.)

Fig. 8. *Productus* cf. *maximus* M'Coy. Lower *Dibunophyllum* Sub-zone. Long Fell, Pennine District. About two-thirds of the natural size. (See p. 570.)

Plate LII.

(All figures are of the natural size.)

Figs. 1 *a* & 1 *b*. *Spirifer pinskeyensis*, sp. nov. From below the Shap Basement Conglomerate, Pinskey Gill, Ravenstonedale District. (See p. 570.)

Fig. 2. *Deltodus garwoodi*, sp. nov. *Solenopora* Sub-zone (*Vaughania-cleistoporoides* Band). Stone Gill, Ravenstonedale District. (See p. 572.)

Figs. 3 *a* & 3 *b*. *Deltodus garwoodi*. Same horizon. Shap-Abbey Cliff, Shap District.

Figs. 4 *a* & 4 *b*. *Cochliodus virgatus*, sp. nov. *Solenopora* Sub-zone (*Vaughania-cleistoporoides* Band). Stone Gill, Ravenstonedale District. (See p. 573.)

Plate LIII.

Geological map illustrating the Lower Carboniferous rocks of the Shap and Ravenstonedale Districts, on the scale of 1 inch to the mile, or 1 : 63,360.

Plate LIV.

Geological map illustrating the Lower Carboniferous rocks of the Kendal, Kirkby Lonsdale, Arnside, and eastern portion of the Grange Districts, on the scale of 1 inch to the mile, or 1 : 63,360.

Plate LV.

Geological map illustrating the Lower Carboniferous rocks of the Furness and western portion of the Grange Districts, on the scale of 1 inch to the mile, or 1 : 63,360.

Plate LVI.

Fig. 1. Section across the Shap District. Scales: horizontal, 6 inches = 1 mile; vertical, 1 inch = 850 feet.

2. Section across the Ravenstonedale District. Scales, the same as fig. 1.

3. Generalized section across the Furness, Grange, and North Kendal Districts. Horizontal scale: 1 inch = 1 mile; vertical scale: 1 inch = 850 feet.

Discussion.

Dr. Marr said that he had been over much of the ground with the Author, and desired to express his admiration of the thorough way in which the work had been done. The fact that towards the end of his investigations the Author was able to view a section which he had not previously visited, and, after a very brief inspection, could state what was to be found there, was a proof of the accuracy of the work. The speaker was interested in the beds at Pinskey Gill. According to the Geological Survey map, the conglomerate apparently overlying the *Spirifera*-bearing beds was the 'Basal Conglomerate' faulted into that place. The Author suggested a different interpretation: the Devonian age of those beds was suggested, but not stated. It need not be assumed that because no Devonian strata had hitherto been recorded in the area, they must necessarily be absent. Lastly, the speaker called attention to the old view that the Lake District was an island in Lower Carboniferous times; he thought that the evidence brought forward in the paper was against that view.

Dr. Vaughan congratulated the Author on so successful a termination to his protracted labours, on the thoroughness of his work, and on the well-balanced presentation of the many facts of interest. The sequence in and above the '*Michelinia* Bed' of Arnside and above the '*pseudovermiculare* bed' of Brigsteer, near Kendal, appeared to agree exactly with the sequence from C_2 through S and D in the type-Province. Considering the very small total thickness from the base of the '*pseudovermiculare* bed' to the base of S_1 at Brigsteer; and remembering also that white oolite, similar to that above the bed, occurred at the top of C_2, not only at many points of the South-Western Province, but also in Belgium and Northern France, it seemed unlikely that the '*pseudovermiculare* bed' itself could lie beneath C_2. Below this bed, at Brigsteer, occurred no great thickness of dolomite, but the Author had presented a very different picture of his type-sections at Ravenstonedale and Shap. Here there was some 1200 feet of more or less dolomitic rock—rivalling the Grande Dolomie of Namur—from which, by dint of oft-repeated attacks, he had obtained a most valuable series of brachiopods. Lastly, in regard to the '*Spirifer-pinskeyensis* Beds,' a further scrap of evidence favouring the suggestion made by the Author that these beds were Devonian, was the fact that Spirifers possessing a similar type of ribbing, combined with the peculiar mesial fold, were common only in Devonian rocks (compare *Sp. oweni* Hall and *Sp. granulosus* Conrad—both from the Hamilton Beds of North America). It might therefore be that, at Ravenstonedale, deposits were only interrupted from the latest Devonian to early *Zaphrentis* time: at Brigsteer the gap was greater.

Mr. R. G. Carruthers remarked on the great interest of this important paper. Not the least interesting of the many points raised lay in the instance cited of a transgression of faunal across lithic lines, as shown by the relationship of the *Michelinia* Beds to the Ashfell Sandstone. Correlation with standard areas was, to some extent difficult, owing to the difference of faunal facies. Nevertheless, such a fact was of great interest to the evolutionist, as it gave hope that in this northern tract gaps might be filled in the life-history of certain gentes, of which hitherto we possessed very imperfect knowledge.

The assignment of the lowest beds to horizon γ was supported by the statement that the *Zaphrentis-konincki* Bed lay some 1200 feet above this base. There were strong reasons for considering that this species was, genetically, short-lived, and the assemblage found in Ravenstonedale was of practically the same evolutionary standard as that found in C_2 of the South-Western Province.

Mr. J. Allen Howe welcomed the paper, and said that he was particularly struck with the evidence that the Author had obtained of the important development of algæ; he was strongly of opinion that this group of organisms had often played a large part in the formation of some of the Carboniferous limestones: its significance had been rather overlooked.

The small fold between undisturbed beds briefly described by the Author was a very interesting feature, about which he (the speaker) would be glad to learn more. He was acquainted with what appeared to be similar cases in the limestones of Pendle Hill, and near Ashford in Derbyshire.

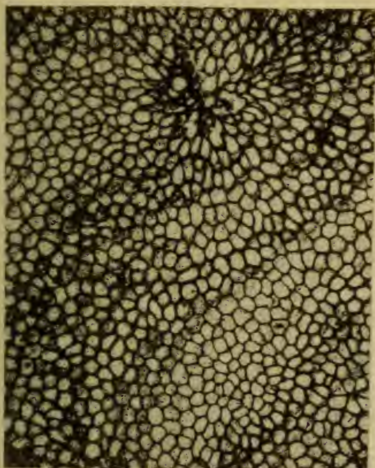
That the spotting in the 'spotted' limestone was in some way connected with the presence of sand-grains was new to the speaker; in all the examples that he had examined, from South and North Wales, Derbyshire, and elsewhere, he had not observed any associated sand-grains.

It was with great diffidence that he said a word about zonal fossils, but he could not help feeling that it would have been more convenient if the zonal forms adopted had been the same as those established in the South-Western region. Quite possibly this was not practicable, if so it was a matter of considerable interest; still, the practice of selection of locally abundant fossils as zone-indicators would tend to obscure the facts of correlation for the ordinary student.

Mr. Cosmo Johns remarked on the value and interest of the paper, and said that he was in general agreement with the Author. He was particularly pleased with the value attached to the bands, chiefly faunal, as marking definite horizons. Of the great value of these distinctive bands in field-work there could be no question, provided that they were not used beyond the area where their value had been established. He would also agree with the Author in considering the dolomitization of the lower limestone-beds as being contemporaneous: their restriction to definite horizons was so clear that it would invalidate any other conclusion. He further agreed with the Author that beds of Tournaisian age, that was, lower than the C_2S level which forms the logical base to the Viséan, occur in Ravenstonedale. He would, however, differ from the Author in suggesting probable equivalents with the zonal divisions made by Dr. Vaughan in the South-Western Province and in Belgium. The beds with *Cyrtina septosa*, a maximum of *Cyathopyllum murchisoni*, and characterized by the pseudo-breccia, would, in the Yoredale country and South Wales, come in at the base of D_1 and not at the top. The division of the whole succession into a series with and a series without *Lithostrotion* was hardly precise enough, and a definite division into Tournaisian and Viséan would appear to be necessary. If this were done, the line would be drawn below and not above the *Michelinia-megastoma* level, and might even include the beds with *Thysanophyllum pseudovermiculare*, below which the most marked lithological change seemed to occur.

The transgression of the faunal lines across the lithological lines in the short distance from Ravenstonedale to Shap, as mentioned by the Author, was so startling that comment must be reserved until the whole of the evidence had been published. It was possible that a complication had been introduced into the reading of the structure of the Shap-Ravenstonedale area by assuming that the whole of the Carboniferous rocks were laid down over what is now the Lake-

1.

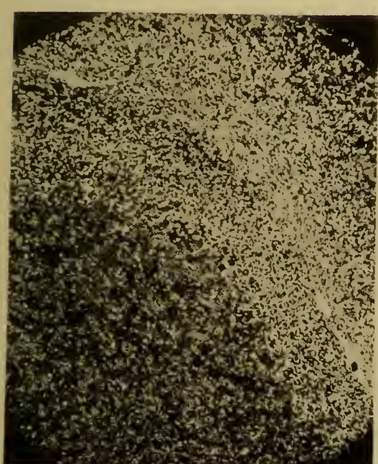


×40.

2.

×40.

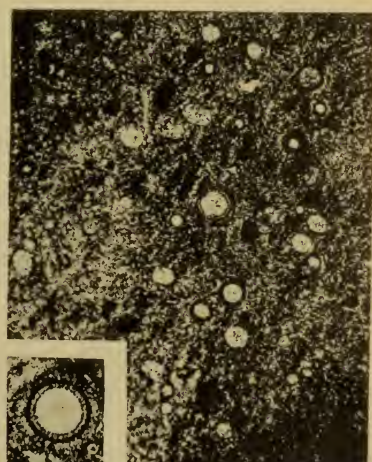
3.



×12.

4.

×90.

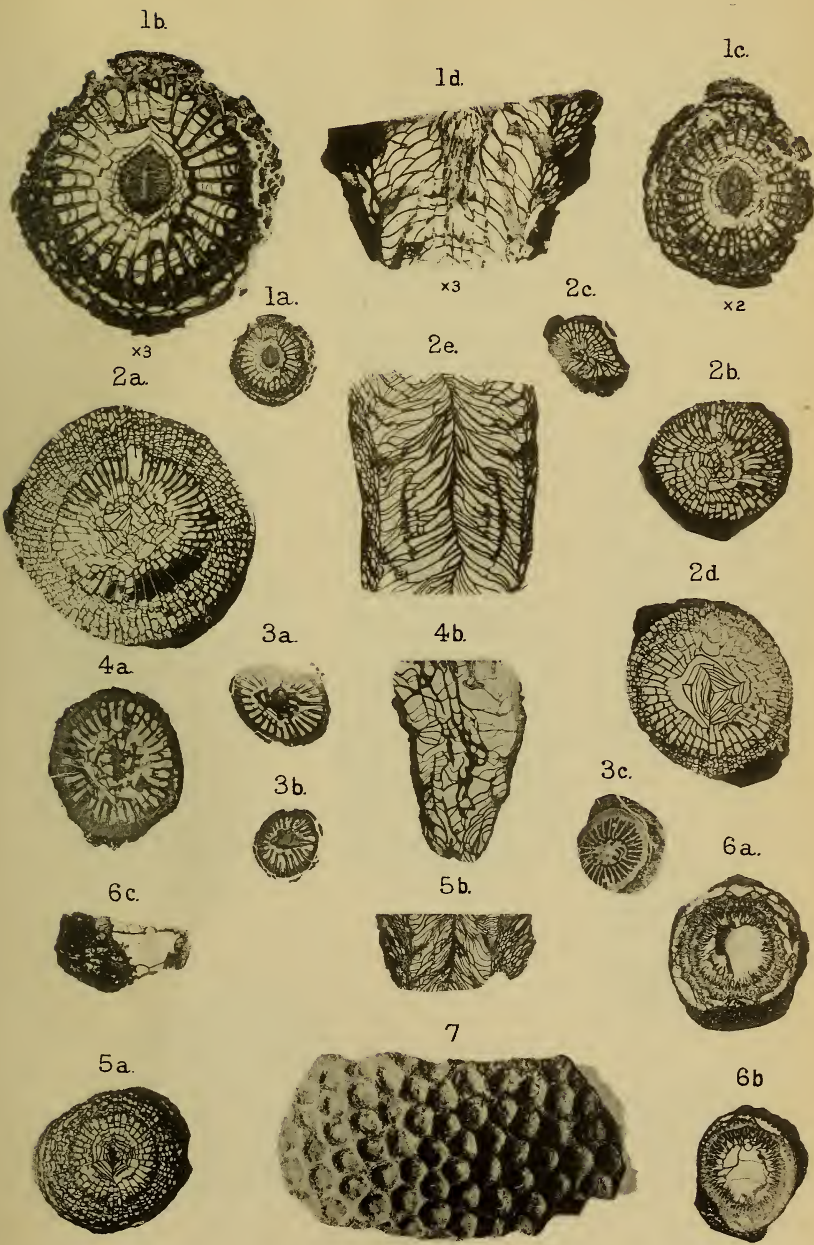


×45

E. J. G., Photo.

Bemrose, Collo., Derby

SECTIONS OF FOSSILS AND ROCKS
FROM THE CARBONIFEROUS LIMESTONE SERIES.



E.J.G., Photo.

Bemrose, Collo., Derby

CARBONIFEROUS LIMESTONE CORALS.

1.

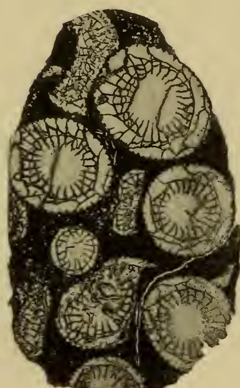
3.

4.

2a.

2d.

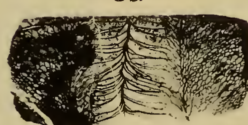
2b.



2c.

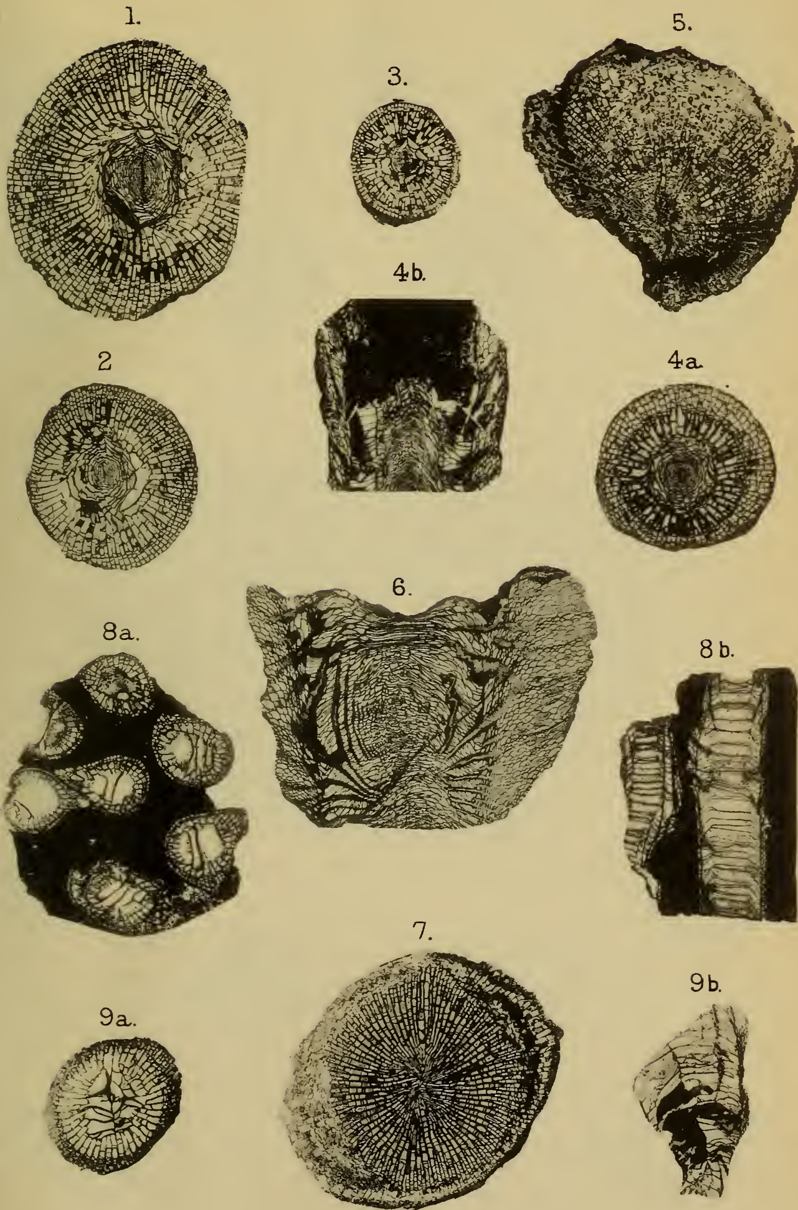
5a.

5b.



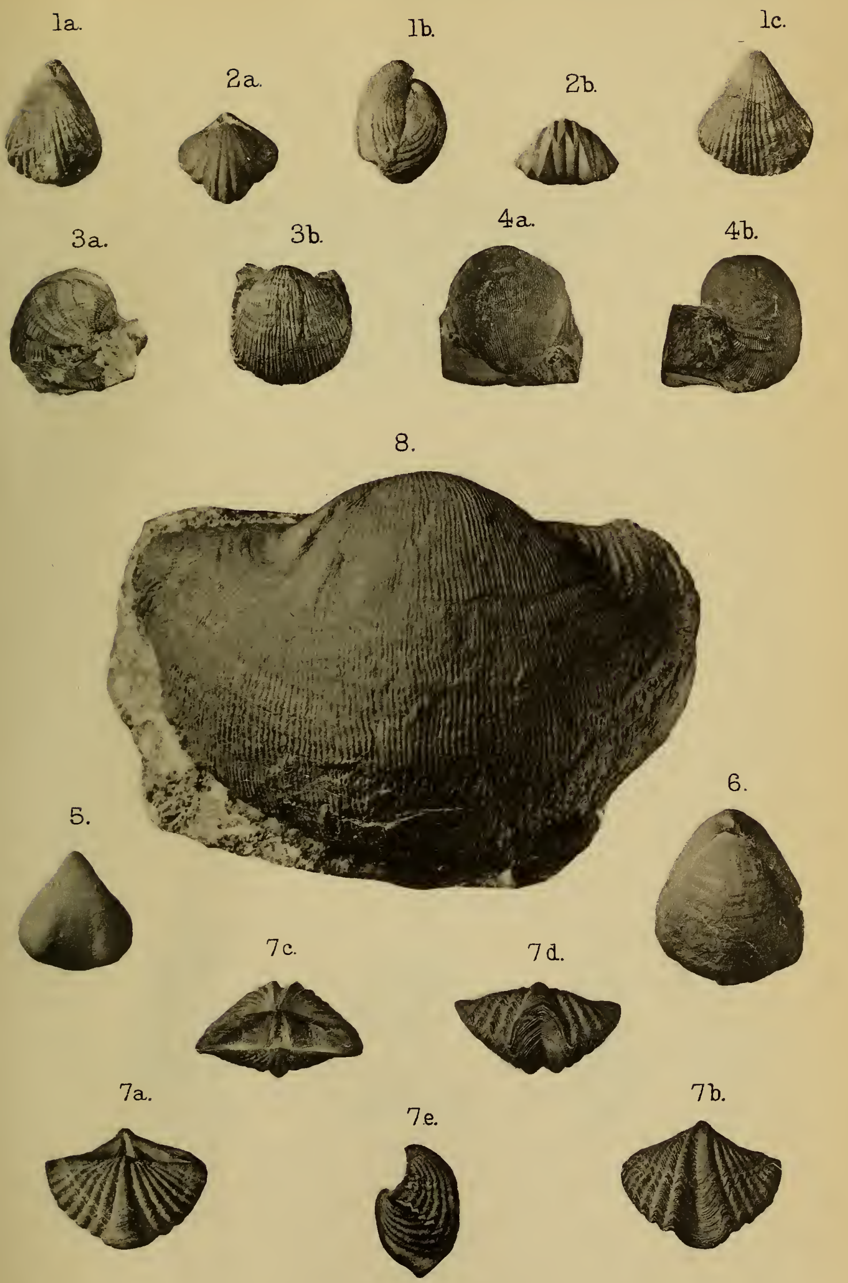
E.J. G. & J. W. Tutcher, Photo. Bemrose, Collo., Derby.

CARBONIFEROUS LIMESTONE CORALS.



E.J.C, Photo. Bemrose, Collo., Derby.

CARBONIFEROUS LIMESTONE CORALS.

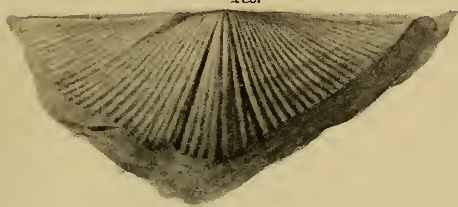


J. W. Tutcher, Photo.

Bemrose, Collo., Derby.

CARBONIFEROUS LIMESTONE BRACHIOPODS.

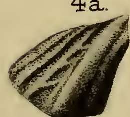
1a.



1b.

2.

4a.



4b.

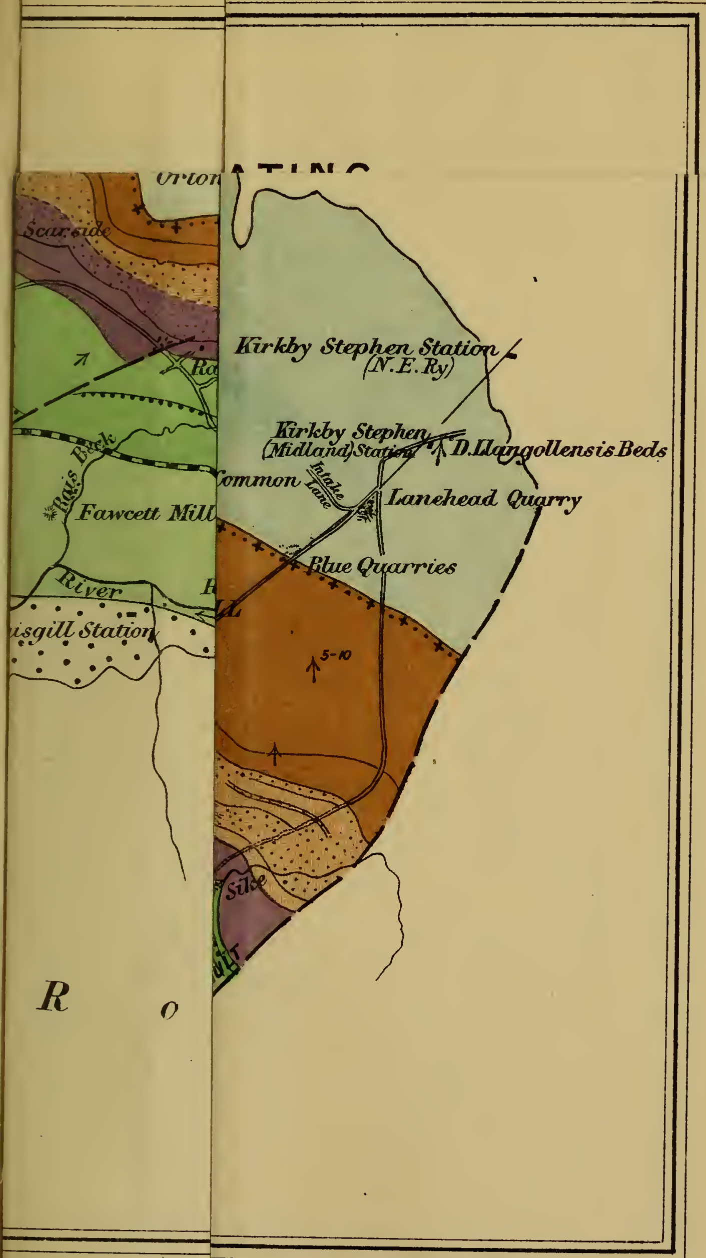
3a.

3b.

G.M. Woodward, del.

Bemrose. Collo., Derby.

SPIRIFER, DELTODUS, AND COCHLIODUS.



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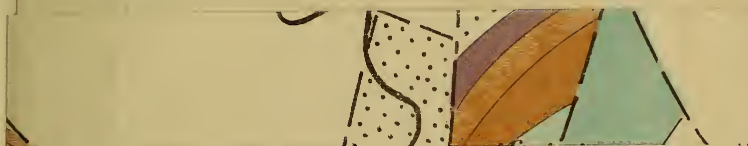
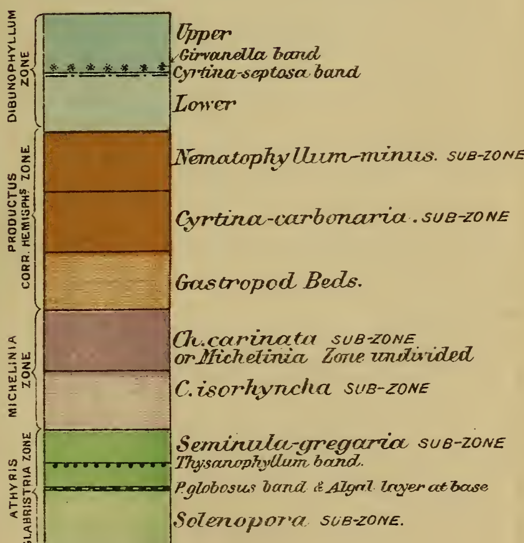
Quart. Journ. Geol. Soc. Vol. LXVIII, Pl. LIV.



INDEX OF COLOURS



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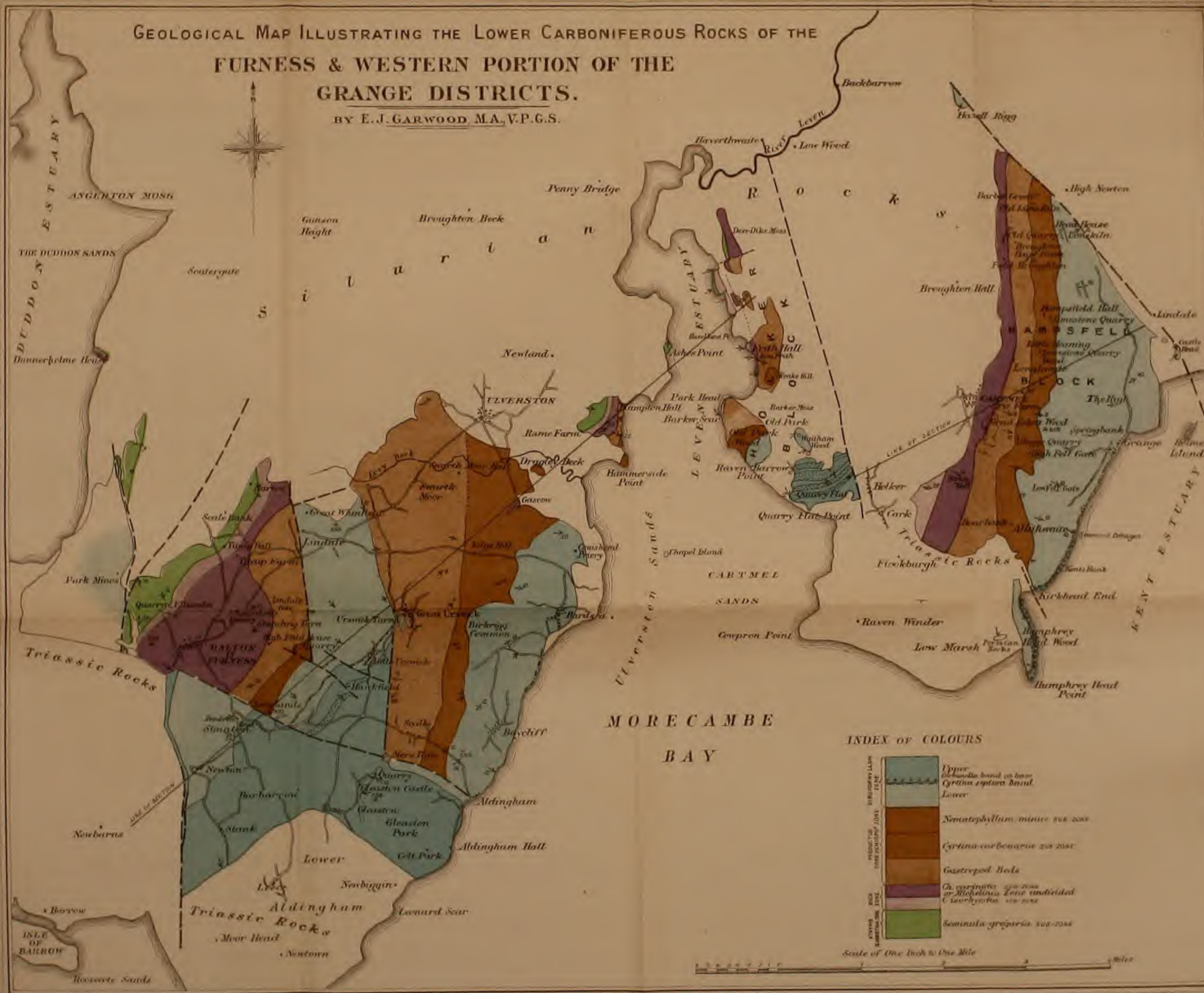
GEOLOGICAL MAP ILLUSTRATING THE LOWER CARBONIFEROUS ROCKS OF THE
KENDAL, KIRKBY LONSDALE, ARNSIDE & EASTERN PORTION OF THE GRANGE DISTRICTS
BY E. J. GARWOOD M.A., V.P.G.S.
Scale of One Inch to One Mile
(The small arrows indicate dips)
INDEX OF COLOURS
Upper
Lower
Nematophyllum-minus sub-zone
Cyrtina-carbonaria sub-zone
Gastropod Beds
C. isorhyncha sub-zone
Seminula-gregaria sub-zone
Solenopora sub-zone
Silurian Rocks
Upper Carboniferous Rocks
MORECAMBE BAY
KENDAL
KIRKBY LONSDALE
BURTON IN KENDAL
MILNTHORPE SANDS
WHITBARROW BLOCK
YEWBARROW BLOCK
LINE OF SECTION
BEDS VERTICAL
River Lune
River Kent
Milnthorpe
Arnside
Silverdale Station
Bolton-le-Sands
Halton
Whittington
Tunstall
Priest Hutton
Over Kellet
Nether Kellet
Holme
Beetham
Heversham
Levens Hall
Sizergh Hall
Oxenholme Junction
Grayrigg
Otter Bank
Hallhead Farm


GEOLOGICAL MAP ILLUSTRATING THE LOWER CARBONIFEROUS ROCKS OF THE
FURNESS & WESTERN PORTION OF THE
GRANGE DISTRICTS.
BY E. J. GARWOOD, M.A., V.P.G.S.
Silurian
Rocks
Triassic Rocks
MORECAMBE
BAY
DUDDON ESTUARY
THE DUDDON SANDS
ANGERTON MOSS
LEVEN ESTUARY
KENT ESTUARY
Ulverston Sands
CARTMEL
SANDS
ULVERSTON
Penny Bridge
Broughton Beck
Newland
Great Urswick
Dalton Furness
Aldingham
Newbiggin
Leonard Scar
Moor Head
Newtown
ISLE OF BARROW
Barrow
Newbarns
Bardsea
Baycliff
Chapel Island
Conypron Point
Raven Winder
Low Marsh
Flookburgh
Cark
Holker
Quarry Flat Point
Humphrey Head Point
Kirkhead End
Grange
Lindale
Broughton Hall
Backbarrow
Low Wood
Haverthwaite
High Newton
Hazel Rigg
Holme Island
HAMPSFELL BLOCK
HOLKER BLOCK
LINE OF SECTION
INDEX OF COLOURS
Upper
Orionastraea band at base
Cyrtina septosa band
Lower
Nematophyllum minus sub-zone
Cyrtina carbonaria sub-zone
Gastropod Beds
Ch. carinata sub-zone or Michelinia Zone undivided
C. isorhyncha sub-zone
Seminula gregaria sub-zone
Scale of One Inch to One Mile
Miles

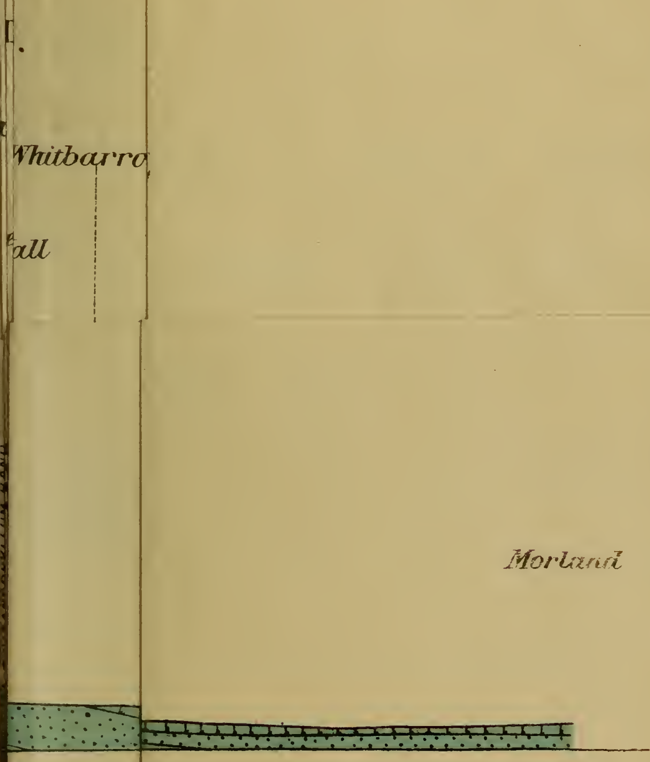


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Fig. 3. — GENERALIZED SECTION ACROSS THE FURNESS, GRANGE, AND NORTH KENDAL DISTRICTS.

Fig. 2. — SECTION ACROSS THE RAVENSTONEDALE DISTRICT.

Fig. 1. — SECTION ACROSS THE SHAP DISTRICT.

Note. — The beds in the above Sections are geologically coloured as in the Maps, Pls. LIII–LV.

Vertical and Horizontal Scale

District dome, as suggested by Dr. Marr. He (the speaker) thought that the evidence pointed to the upper zones having successively overlapped the lower, and that later movements had brought the portion nearest the Dent Fault within the range of denuding influences to a greater extent than the portion towards the north-west, so that the lowest beds were exposed near Ravenstonedale.

The suggestion that the Pinskey-Gill Beds might be of Devonian age added to the difficulty of interpreting the geological history of the area. Rocks of Tournaisian age were present; the red conglomerate could best be correlated with the Upper Old Red of Scotland, and yet Devonian rocks were suggested in Pinskey Gill. It would certainly be most useful if the exact position of the red conglomerate, below the bridge of Pinskey Gill, in the sequence could be determined.

Dr. Ivor Thomas considered that the correlation of the *pinskeyensis* beds with the Hamilton Group of North America, as suggested by one of the previous speakers, was very unsafe. The fossils hitherto found in the former were insufficient to warrant even an attribution of Devonian age. The correlation of the *Cleistopora* Beds with the Chemung Group by the same speaker was also somewhat startling, since there appeared to be no justification for it whatever on palæontological grounds.

The palæontology of the district under discussion was exceptionally interesting. Several of the characteristic fossils, such as *Camarotœchia proava*, *Seminula gregaria*, *Productus globosus*, etc., were so far unknown in the South-Western Province; while the occurrence of forms such as *Vaughania cleistoporoides* and other interesting corals afforded ample opportunity for important researches.

Mr. E. E. L. Dixon congratulated the Author, and was in complete accord with the conclusions, outlined in the abstract, as to the age of the dolomitization and silicification, and the conditions of deposition, that was, in lagoons, of the *Solenopora* Beds and the associated compact (amorphous-looking) limestones and dolomites. But, although the Author had succeeded in establishing a faunal succession for the North-West of England, and did not insist on the suggested correlation with the South-Western Province, the speaker asked whether the following alternative correlation of the beds referred by the Author to γC_1 had been considered.

The Sub-zone C_2, both in the South-Western Province and elsewhere (as, for instance, parts of Belgium), commenced with a peculiar shallow-water phase similar to the lagoon-deposits forming the *Solenopora* Sub-zone of the North-Western Province; at Rush (Co. Dublin) heavy conglomerates in C_2 also pointed to shallow-water conditions. Shallow water, therefore, was widespread in C_2 times, and might well have extended to the North-Western Province. Further, a γC_1 fauna such as that on which the Author relied in correlating the basal *Athyris-glabristria* Zone of the North-Western Province with γC_1 of the South-Western Province, had been found by Dr. Vaughan to continue in parts of the latter province into the lower part of C_2, in which sub-zone therefore, although it was mingled at first with a few newcomers, it changed to the true C_2 fauna—not at the base but a short distance above. Hence it seemed possible that the *Athyris-glabristria* Zone was no lower than the base of C_2 of the South-Western Province.

This possibility, which accorded with Dr. Vaughan's view that the *Thysanophyllum-pseudovermiculare* Band at the top of the *Athyris-glabristria* Zone should be placed well up in C_2, would become a strong probability were it certain (as the Author adduced evidence for believing) that the *Spirifer-pinskeyensis* Beds are separated from the overlying *A.-glabristria* Zone by the conglomerate exposed in Pinskey Gill. For the conglomerate, and the change in the character of sedimentation which it accompanied, would together point to an unconformity; and the beds below, although of uncertain age, were by consent either Upper Devonian or Tournaisian. As no break, apparently, was known to occur in the Upper Devonian-Tournaisian sequence, whereas in the South-Western Province the mid-Avonian unconformity existed in places at the top of the Tournaisian, and the Viséan (the base of which is C_2) transgressed across various lower horizons on to pre-Carboniferous rocks, an unconformity, if existent, at the transgressive base of the *Athyris-glabristria* Zone would probably be this mid-Avonian unconformity, and the zone itself, despite its Tournaisian aspect, would accordingly be correlative with the lower part of C_2. The *A.-glabristria* Zone was shown by its fauna to lie in or near C_1, but its exact position might, possibly, be best determined by a comparison of the earth-movements of Avonian time in the North-Western Province with those in other areas.

The AUTHOR thanked the Fellows for the cordial reception which they had given to his paper. In reply to Dr. Vaughan and Mr. Dixon, who referred to the age of the beds below those in which *Michelinia* occurred in the north, that was, from the *Thysanophyllum* Band downwards, he remarked that the succession which he had established in the north-west was essentially a local classification, and he did not wish to press unduly the correlation of the beds with those in the Bristol area which he had suggested in the last column of the table. He hoped that any value that the work might possess would be judged independently of such correlation; at the same time, he thought it improbable that the whole of the succession in the north could be included in C_2, and was inclined to think that a certain amount, at all events, of C_1 of the Bristol succession was represented by the lowest beds above the conglomerate in the Shap area. He would like to add that he had frequently consulted Dr. Vaughan with regard to the equivalents of these beds in the Bristol area, and he had always been under the impression that Dr. Vaughan agreed with the correlation suggested in the table. He did not quite understand Dr. Vaughan's present contention, that there was nothing older than C_2 of the Bristol area in the succession which he had described.

The Author thought that he had dealt in the paper itself with most of the other questions raised in the course of the discussion.

24. *On the* Geology *and* Palæontology *of the* Warwickshire Coalfield.

By Robert Douglass Vernon, B.A., B.Sc., F.G.S., Emmanuel College, Cambridge. (Read June 19th, 1912.)

[Plates LVII–LXI.]

Contents.

I. Introduction.

Warwickshire, the nearest of the Midland coalfields to London, with an annual output of coal exceeding 3,500,000 tons, is of considerable economic importance. The potential value of this coalfield is also very great, because within recent years the coal-producing area has been nearly doubled, and it is still rapidly extending.

During the preparation of the reports by the Royal Commission on Coal Supplies, both in 1871 and in 1905, great difficulty was experienced by the Commissioners in estimating the coal-resources of Warwickshire, because the geology of the coalfield, especially with regard to the relationship of the so-called 'Permian' to the Coal Measures, was not fully understood. Again, as recently as 1908, Dr. Walcot Gibson (08) [1] expressed the opinion that

'It would appear advisable, before making more ambitious attempts at development in the Triassic areas, to first determine the exact geological position and character of the so-called Permian.' (*Op. cit.* p. 189.)

It may be added that the current geological memoir and maps of the Warwickshire Coalfield were published more than fifty years ago; and further, until quite recently, there were no records of fossils from the Carboniferous rocks of the county. Thus, from the points of view of stratigraphy, of palæontology, and of economics, there was a clear need for research-work on this coalfield.

In 1909, on my election to a scholarship awarded by the Royal Commissioners for the Exhibition of 1851 'for research-work bearing upon industry,' I was enabled to begin this investigation, which has been prosecuted in the field and at the Sedgwick Museum, Cambridge, during the past three years.

[1] These numerals in parentheses refer to the corresponding numbers in the Bibliography, § VI, p. 636.

I wish to thank Prof. T. McKenny Hughes, F.R.S., and Prof. T. G. Bonney, F.R.S., for many helpful suggestions and for their valuable criticism of the manuscript. To Dr. E. A. Newell Arber I am especially indebted, not only for his constant advice, but also for the personal labour which he has undertaken in checking my determinations of the fossil plants recorded in this paper. I also wish to record my thanks to all those gentlemen who have permitted me to visit the collieries and clay-pits under their charge, and especially to Mr. Evans, of Coventry, for allowing me to examine the cores from several important borings for coal put down by the North Warwickshire Coal Company.[1] My friend Dr. L. Moysey, F.G.S., of Nottingham has kindly prepared most of the photographs, but a few are by Mr. Tams of Cambridge.

The sketch-map and vertical section which illustrate this paper (Pl. LXI) are based on the 1-inch maps of the Geological Survey mentioned below, and on my own mapping of a large part of the district on the 6-inch scale.

II. Historical Review.

A brief history of the literature relating to the Warwickshire Coalfield will now be given, in order to trace the development of the opinions which have been held by previous writers on the geology of this district.

Up to the close of the 18th century some account of the mineral waters of the county had been published, together with a few notes on the rocks. On William Smith's (15) Geological Map of England, published in 1815, the 'Millstone Grit,' the exposed Coal Measures and the red rocks separating the latter from the Lias are all clearly indicated. During the next forty years these red rocks are briefly mentioned by Buckland (19), Conybeare & Phillips (22), De La Beche (31), and by Murchison & Strickland (40). By all these authors the red rocks were regarded as New Red Sandstone, including under that term both the Keuper and certain underlying beds thought to be of Bunter age. The few fossils obtained during this period, which were described by Buckland (37) and Lloyd (50), were therefore considered to be Triassic fossils. It was not until 1855 that Sir Andrew Ramsay (55) and Mr. H. H. Howell (59) showed that the Bunter was absent from the greater part of Warwickshire, and that the beds in question should be relegated to the Permian. Subsequently, Prof. Hull (69) repeated Mr. Howell's description of these rocks, and referred to them as part of his Salopian type of Permian; and, in the absence of any definite palæontological evidence to the contrary, they have continued to be so regarded by subsequent authors.

The hard quartzites were originally mapped as Millstone Grit, and the indurated shales with diorites, which underlie the Productive Coal Measures and closely resemble them in lithological characters, as Lower Coal Measures. It was not until 1882 that

[1] The details of these boreholes cannot, for commercial reasons, be published in this paper.

Prof. Lapworth (82) was able to demonstrate, by the discovery of fossils in them, that these rocks were really of Cambrian age. Four years later, while mapping the boundary between the Cambrian and the Carboniferous for the new edition of the Geological Survey map, Sheet 63 S.W., Dr. Strahan (86) found that the junction between these two formations was marked by a bed of coarse pebbly sandstone, which forms, therefore, the base of the Coal Measures.

Until quite recently the Carboniferous rocks have attracted no special attention, so that Mr. Howell's memoir on the Coalfield has remained the standard paper on the Coal Measures of Warwickshire, and subsequent authors, such as Prof. Hull (05), Prof. Charles Lapworth (98) & (05), and Mr. T. C. Cantrill (05), have followed that work in their descriptions of the Coalfield. No other contribution of general importance has since been published; but there are a few papers of local interest, to which reference will be made in the following account.

The references to the literature on the Warwickshire Coalfield are collected in the Bibliography at the end of this paper.

III. Stratigraphy.

The Warwickshire Coalfield forms a roughly triangular tract in the north-eastern part of the county, the towns of Coventry, Nuneaton, and Tamworth being situated at the angles. The surface-area of rocks of Carboniferous age, including the additions necessitated by the present work, is about 60 square miles. But, in describing the measures, it will be necessary to include a much larger extent of country, particularly with regard to the underground extension of the Coal Measures beneath the cover of Permian and Triassic rocks which almost completely surrounds the exposed coalfield.

The whole of the district under consideration is contained within parts of the following 1-inch maps of the Geological Survey (Old Series):—Quarter-Sheets 62 N.E. & S.E.; 54 N.E.; 53 N.W.; and 63 N.W. & S.W.

The general structure of the coalfield is that of a shallow basin of Carboniferous rocks resting discordantly upon an irregular floor or basement of Cambrian age; on all sides it is faulted against, or covered unconformably by, the succeeding Permian and Triassic rocks.

The dominant structural features are the two parallel anticlines ranging north-west and south-east, which have ridged up the floor of the coalfield both on the east and on the west of the district. Not only has subsequent denudation removed the cover of Trias and Permian, but, along the crests of these anticlines, even the Carboniferous rocks have been stripped off, thus laying bare the Cambrian and Archæan rocks which form the pre-Carboniferous floor.

The main topographical features of the district are intimately related to this geological structure. Three distinct types of scenery can be distinguished. The most striking physical feature is caused by the broken anticline of hard Cambrian rocks forming the abrupt ridge from Nuneaton to Atherstone, which rises to 500 feet above sea-level. Within the basin the Carboniferous and Permian formations, consisting of alternating beds of soft marl and hard sandstone, give rise to a low, much dissected plateau, which, however, north of Meriden, on the line of the watershed that divides the basins of the Trent and Severn, rises to a height of 600 feet above the sea. Finally, the whole inlier of Palæozoic rocks is surrounded by the Trias, which gives rise to a third type of scenery, the broad undulating country forming the eastern part of the Midland plain.

Although this paper is concerned chiefly with the Carboniferous rocks, it is necessary to mention briefly the other formations, both above and below, which occur in the immediate neighbourhood. The following table embodies a synopsis of the various formations and groups of rocks, according to the new classification which it is proposed to establish on the evidence detailed in a later portion of this paper:—

Table of Formations.

Pleistocene and Recent.	Recent and post-Glacial	Alluvium and peat. River-gravels.
	Glacial[1]	Boulder-clays, sands, and gravels, with erratic blocks.
Trias.	Keuper	Red marls with thin sandstones. Soft red and white flags and marls.
	Bunter	Sandstones and conglomerates.
Permian.	Permian	Red sandstones, marls and breccias. Corley Conglomerates at the base.
Carboniferous.	Upper Coal Measures or Red Barren Coal Measures	Keele Beds.—Red sandstones and marls with three beds of *Spirorbis* Limestone. Haunchwood Sandstones.—Grey sandstones, marls, and shales with *Spirorbis* Limestones. Nuneaton Clays.—Red marls and clays containing Espley Rocks, local breccias, and a bed of *Spirorbis* Limestone.
	Middle Coal Measures or Productive Coal Measures	Grey shales, sandstones and underclays with numerous seams of coal and beds of ironstone.
Cambrian.	Stockingford Shales	Shales (with intrusive diorite).
	Hartshill Quartzite	Quartzite (with intrusive diorite).
Pre-Cambrian.	Caldecote Rocks	Sheets of breccia, tuffs, and grits of volcanic origin.

[1] The drift deposits are of no great thickness, except near Kenilworth and also south of Exhall, where clay, sand, and gravel occur up to 70 feet in thickness.

In Warwickshire the Carboniferous Limestone and the Millstone Grit are both completely absent, the lowest existing member of the Carboniferous formation being the Productive Coal Measures, which in the north of the coalfield do not exceed 700 feet in thickness and rapidly thin towards the south. On the other hand, there appears to be an exceptional development, both in thickness and in extent, of the so-called 'Permian' rocks as defined in the Geological Survey Memoir on the coalfield. In recent years, however, the work of Dr. R. Kidston (88–90), (05), Mr. T. C. Cantrill (95), and Dr. Walcot Gibson (01) has demonstrated that much of the Salopian Permian of the Midland counties of England was deposited in conformable sequence with the underlying Coal Measures, and not, as in the case of the Permian of the North of England, on the eroded edges of the Carboniferous strata. Thus great uncertainty prevails as to how much of the Salopian Permian is to be relegated to the Trias on the one hand, or to the Carboniferous on the other. It is one of the chief objects of this paper to determine the true age of the so-called 'Permian' rocks of Warwickshire, and to discover their stratigraphical relationship to the underlying Carboniferous rocks and to the overlying deposits of Triassic age. Further, I attempt on geological evidence to subdivide the Carboniferous rocks into groups, and from a study of the fossil flora to determine the age of the subdivisions.

The so-called 'Permian' formation of Warwickshire was established by Sir Andrew Ramsay (55), to include the lower portion of the 'New Red Sandstone' of previous observers. The chief evidence in favour of the Permian age of these rocks was their close resemblance in lithological characters to the Permian rocks which almost surround the South Staffordshire Coalfield, and like the latter they were proved directly to overlie the Productive Coal Measures. The presence of a supposed outlier of Permian between Polesworth and Glascote was regarded as a proof that these rocks were unconformable to the Coal Measures. Finally, the discovery near Exhall of fragments of a *Lepidodendron* and a Calamite, and the casts of a shell supposed to be allied to *Strophalosia*, was considered additional proof of the Permian age of these beds.

In the light of recent research this evidence appears to be anything but convincing. There can be little doubt as to the similarity between the Warwickshire 'Permian' and the 'Permian' of South Staffordshire; but it may be contended that at least the lower portion of these South Staffordshire rocks is now considered by Mr. T. C. Cantrill (95) and Dr. W. Gibson (01) to be of Carboniferous age, and to be the equivalent of the Keele Beds of North Staffordshire.

The supposed outlier of Permian is merely an ordinary Coal-Measure sandstone. With regard to the fossils mentioned above, as it is impossible to give specific names to such fragmentary and dubious specimens, the evidence adduced from them must be dismissed as inconclusive. There remains the question of the boundary between the Permian and the Carboniferous. As delineated on the

Geological Survey maps, this boundary is an arbitrary one, which coincides neither with any physiographic feature nor with any break in the stratigraphical succession of the beds. We may thus infer that the evidence for the Permian age of these rocks is exceedingly vague and inconclusive. From a study of these rocks in the field, I propose to show that the first important break in the stratigraphical succession occurs at the Corley Conglomerates (see p. 603), and that the underlying 1000 feet of rocks of so-called 'Permian' age are conformable to the Coal Measures, with which they must therefore be grouped. In confirmation of this view, I have been able to obtain fossil plants of Upper Coal-Measure age from these supposed Permian rocks.

The pre-Carboniferous Floor of the Coalfield.

The Coal Measures rest upon an irregular floor of Cambrian rocks, which is only known where it is exposed at the surface, or where it has been proved in deep borings. This floor, together with the overlying Coal Measures, has been elevated along three parallel lines which trend in a north-west to south-east direction. Portions of two of these old ridges are the anticlines of Nuneaton and Dosthill; but there is a third ridge in the neighbourhood of Market Bosworth, which is completely hidden beneath the Trias. The occurrence of a faulted anticline of Upper Coal Measures at Arley may indicate yet another fold in the pre-Carboniferous floor.

(A) The Coal Measures.

Basement conglomerate.—Resting unconformably on the Cambrian (Stockingford Shales) is the basement bed of the Coal Measures—a soft, coarse, false-bedded, ferruginous sandstone with quartz-pebbles. This rock, which was first noticed by Dr. Strahan (86), is of value in mapping the boundary between the Cambrian and Carboniferous formations near Merevale, where it makes a conspicuous feature, and at Dosthill. This conglomerate, as well as the succeeding strata of shales and fireclays, may be absent, so that the lowest seam of coal comes to rest directly upon the Cambrian.

Where the conglomerate is absent, or where there is no section, the junction is clearly indicated by the rising ground, at the points at which the Cambrian comes to the surface. The base of the Coal Measures has also been proved some distance away from the outcrop in certain of the colliery sinkings near Bedworth.

The grouping of the measures.—Between the basement conglomerate of the Coal Measures and the Corley Conglomerate at the base of the Permian, there is a vertical thickness of more than 2500 feet of Coal Measures. It is possible, on both lithological and palæontological evidence, to effect a twofold grouping of these rocks.

The lower subdivision, about 700 feet in thickness, includes all the chief seams of coal; the strata have a prevalent grey tint, and possess an abundant flora and fauna.

The upper subdivision, about 2000 feet thick, contains only a few, thin, impersistent seams of coal; its constituent strata have, on the whole, a prevalent red tint. This distinction in lithological character is accompanied by a remarkable absence of animal life, and by the occurrence of a limited but characteristic flora, very different from that of the lower subdivision.

These two subdivisions, the Productive Measures and the Barren Measures, are separately dealt with in the following description.

The Productive Coal Measures.—From base to summit the strata are made up of repeated alternations of sandstone, underclay, and shale, with beds of ironstone and coal-seams. The rocks fall naturally into a lower argillaceous series, which contains the workable seams of coal, and an upper arenaceous series,[1] which contains only a few thin seams. In lithological character these rocks show a general similarity to the Productive Measures of the other coalfields of the Midlands, but a few minor differences have been observed. The coals belong exclusively to the bituminous variety, steam-coals and cannel-coals being practically unrepresented. Locally some of these seams, more particularly the Thick Coal, contain numerous macrospores, which are found in a flattened state between the planes of bedding of the dull hard layers of the coal. Macrospores have also been obtained from the shales overlying the coal. In the Stockingford clay-pit fossil trees (*Sigillaria*) are not uncommon. They are found both erect and recumbent, being usually preserved as casts in ironstone, but sometimes as casts in shale. These casts attain a diameter of several feet, and are often accompanied by a thin layer of coal representing the bark. Sometimes such erect trees, often many feet long, may be observed to extend almost vertically across the beds of shale separating two seams of coal. In such cases it may be inferred that the time taken for the deposition of the strata separating the coal-seams must have been comparatively short.

Nodules and bands of clay-ironstone occur at several horizons, interstratified with the shales and sometimes even with the coals. The smaller symmetrical nodules are sometimes fossiliferous; while the large, irregular, septarian ironstones or 'big balls,' which frequently attain a diameter of 6 feet, are almost invariably barren. A peculiar form of oolitic ironstone or 'sphærosiderite,' composed of small spherules of siderite, frequently occurs in the fireclays and sometimes in the coal.

Underclays and sandstones are of common occurrence: the former tending to predominate in the south of the coalfield, and the latter in the north.

There is abundant proof, in the form of local breccias, 'washouts,' and local unconformities, that the deposition of the Coal

[1] Including the Four-Feet Sandstone (see vertical section, Pl. LXI).

Measures was not continuous, but that, at certain periods, sedimentation was interrupted by local elevation and contemporaneous erosion. In the measures above the Thick Coal, local breccias are not infrequent. These rocks consist of angular fragments of coal, ironstone, or shale, often several inches long, set in a matrix of coarse sandstone or of an extremely hard ganister-like sandstone. Fragments of plants, and casts in shale or ironstone of *Trigonocarpus*, as also large specimens of *Carbonicola*, may sometimes be found in these coal-breccias.

Extensive barren areas or 'wash-outs' affect some of the seams: especially the Ryder Coal at Kingsbury and Arley, and the Thick Coal at Exhall Colliery. An example of a local unconformity is seen in a clay-pit at Polesworth, where fireclays and coal-smuts dip at an angle of about 25° under nearly horizontal sandstones with a breccia at the base. A section of this clay-pit is appended:—

		Thickness in feet.
Horizontal	Massive ferruginous sandstones, which form the whole of Hermitage Hill west of Polesworth. At the base, ashy grit and a breccia of vein-quartz and felspathic quartzite	1
Dipping at 25°.	Fireclay with coal-smuts	8
	Yellow sandstone	6
	Fireclay and red mottled marl with sphærosiderite	10
	Coal-smuts } seen in well	1
	Fireclay } seen in well	1
	Total	27

The sandstones of Hermitage Hill are the Haunchwood Sandstones, while the beds in the clay-pit represent the uppermost beds of the Productive Measures; the unconformity thus appears to be related to the apparent absence of the Nuneaton Clays at this locality.

Coal-seams.—In the following general sections the more important coal-seams in each half of the coalfield are arranged in descending order, and a correlation of these seams is suggested:—

	South.	*North.*
Warwickshire Thick Coal.	Two-Yard Coal	Four-Feet Coal.
	Ryder Coal	Ryder Coal.
	Bare Coal	Bare Coal.
	Ell Coal.	....
	Slate Coal	Slate Coal.
	Seven-Feet Coal	Seven-Feet Coal.
	....	Double Coal.
	....	Bench Coal.

The Seven-Feet Coal appears to be the only seam which has been recognized individually throughout the coalfield. The Double and Bench Coals are not known in the extreme south of the coalfield; and in the extreme north, near Tamworth, it becomes impossible to identify the Ryder, Bare, and Slate Coals. The measures above the Seven-Feet Coal show a progressive thinning from the north to the south of the district; this is accompanied by a tendency of the seams to come together, until, south of Bedworth, the Two-Yard, Ryder, Bare, Ell, and Slate Coals unite to form the Warwickshire Thick Coal. This phenomenon is a striking illustration of the effects of an unequal rate of sedimentation in different parts of the basin of deposition: the ultimate cause being a differential movement in the area. The outcrop of these coal-seams can readily be made out over a large portion of the northern area by following the lines of old workings. At Polesworth a thick coal has been seen in a sewer-excavation in the main street. Three seams—the Four-Feet, Slate, and Seven-Feet Coals—crop out in the railway-cutting south of Polesworth Station; while farther south, near the river, three thin seams (representing the Bench Coal) may also be noted. The strata are much broken, and dip steeply westwards.

At Chapel End, near Hartshill, the outcrop of five seams of coal can still be seen in the old clay-pits which are now being used as a waste-tip for Stockingford Colliery; while in the south, at Chilvers Coton, two clay-pits have been opened up on the outcrop of the Thick Coal, so as to expose six or seven of its constituent seams. Measured sections of both of these clay-pits are given below. It is, unfortunately, impossible to identify any particular seam of coal; but the series of coals, as a whole, represents the Thick Coal.

Chilvers Coton Clay-pit, Nuneaton.

	Thickness in feet	inches.
Smut Measures	10	0
Coal	5	6
Fireclay and shale	12	0
{ Coal	2	0
{ Fireclay	4	0
{ Coal	1	0
{ Fireclay	1	0
{ Coal	1	6
Sandy shales and fireclay, with 'big balls' of ironstone. (Plant-bed in the lowest 3 feet.)	23	0
{ Coal	4	0
{ Fireclay, with black shale in the centre	2	6
{ Coal	1	9
Sandy shales and fireclay, with 'big balls' of ironstone. (Plant-bed at the base.)	16	0
Black coaly shale with spores	1	0
Coal	3	0
Fireclay and shales, with 'big balls' of ironstone	22	0
Coal	3	0
Sandy fireclay, shale, sandstones, and thin coal	12	0
Coal	3	0
Sandy fireclay	5	0
Coal	0	9
Fireclay	6	0
Total	140	0

Dip=21° westwards.

This clay-pit has yielded a rich flora; the plants are in an excellent state of preservation, and are abundant both as individuals and as species. The cones of *Calamites*, rare species of Sphenopterids, and macrospores of *Lepidostrobus* are all common in the lower of the two plant-beds indicated in the section.

STOCKINGFORD CLAY-PIT, NUNEATON. (Pl. LX, fig. 1.)

	Eastern end. Thickness in ft.	ins.	Western end. ft.	ins.
Coal .... about	5	0		
Measures .... about	10	0		
Coal .... about	3	0		
Measures (with hard current-bedded sandstones) .... about	20	0		
Coal	1	9		
Measures .... about	6	0		
⎧ Coal	6	0	5	0
⎪ Fireclay	3	0	3	0
⎨ Coal	1	0	1	6
⎪ Fireclay	0	6	0	3
⎩ Coal	1	6	1	6
Sandstones, sandy shales with 'big balls' of ironstone, and fireclay	15	0	12	0
Coal with thin dirt-partings (and macrospores)	3	0	⎧ coal 3 0 ⎨ fireclay 0 6 ⎩ coal 0 6	
Fireclay floor of coal, containing a 6-inch nodular band of ganister, sandy shales, and fireclay	10	0	10	0
⎧ Coal	4	6	4	6
⎨ Sandy shales (with 'big balls' of ironstone) and fireclay	22	0	4	0
⎩ Coal	1	0	2	0
Sandy shales (with 'big balls' of ironstone) and fireclay; 6 inches of black shales at the base. (Fossil trees occur.)	20	0	20	0
Coal (with spores)	3	0	3	0
Fireclay 18 inches thick; sandy shales and sandy fireclay with 'big balls' of ironstone...	12	0		

Dip = 30° to 45° westwards.

Within the basin, 2 miles away to the south-east, at a depth of about 500 yards, the Newdigate Colliery near Bedworth yields the following section of the Thick Coal, in which it will be seen that the partings that separate the various seams in the above-mentioned clay-pits have almost entirely thinned away:—

SECTION OF THE THICK COAL-SEAM,[1] NEWDIGATE COLLIERY.

	Description of Strata.	Thickness of Strata. Ft. ins.	Ft. ins.
Roof.	Shaly bind.		
Two-Yard Seam.	Coal, tops	1 3	
	Coal, hards	0 10	
	Coal, brights	2 3	
	Coal, slotters	1 8	6 0
	Dirt-parting	0 6	
Bare Seam.	Coal	2 0	2 0
	Stone	0 1	
Ryder Seam	Coal, windings	0 8	
	Coal, spires	1 1	
	Stone	0 4	
	Coal, spires	2 0	
	Coal, bottoms	2 0	5 9
	Dirt	0 4	
Ell Seam	Coal, black	2 5	
	Coal, spires	0 10	3 3
	Dirt	0 2	
Slate Seam.	Coal, three-quarter	1 6	
	Batt	0 1	
	Coal, bright	2 3	
	Coal, bottoms	2 7	6 4
Floor.	Clunch		
	Total	24 10	23 4 coal.

Above the Thick Coal there are about 300 feet of strata which, on palæobotanical evidence, must be placed in the Middle Coal Measures. These rocks, which include the Forty-Feet Sandstone (see vertical section, Pl. LXI), consist of extremely variable beds of strongly current-bedded sandstones and shales, with one or two thin coals, some fireclays, and certain peculiar breccias. Good exposures can be seen at Messrs. Stanley's No. 4 clay-pit at Stockingford; at Griff Clay-pit, Heath End, Chilvers Coton; and also in a clay-pit near Polesworth. Each of these clay-pits has yielded fossil plants—those from the first locality being partly petrified; while those from the second are impressions preserved in nodules of clay-ironstone.

Arrangement.—The accompanying map (Pl. LXI) shows that the outcrop of this subdivision consists of two narrow arms of unequal length, which meet in the northern portion of the coal-field. From the identity of the seams which form this double outcrop, it is evident that the Coal Measures lie in a broad shallow

[1] J. T. Browne (08) p. 503.

syncline pitching towards the south and having its longer axis in a north-and-south direction.

The strata dip steeply away from the eastern, northern, and a portion of the western boundary; but, towards the centre of the basin, they become almost horizontal. South of Polesworth, and east of the coal-outcrops, a subsidiary anticline causes the measures to roll over and dip eastwards into the boundary-fault. There is evidence of a similar faulted anticline beneath the Trias, at Brandon in the south.

The greater part of the syncline is concealed from view by the spread of Upper Coal Measures, Permian, and Trias, which come on successively towards the south.

The Barren or Upper Coal Measures.—The rocks of this group may be conveniently divided into three sub-groups, each of which possesses certain definite lithological features. Though somewhat variable in character and thickness, each sub-group can readily be traced throughout the greater part of the district.

Fossil plants are much more difficult to obtain from this group than from the Productive Measures—partly because the flora on this horizon, though sometimes rich in individuals, is poor in species; but largely because of the paucity of exposures in the Red Rock area.

The Nuneaton Clays.—This sub-group consists of a series of red and purple mottled marls and shales, often apparently unstratified. A thin *Spirorbis* Limestone; several beds of a peculiar green gritty sandstone or 'Espley Rock'; and, locally, a bed of hard green breccia made up of angular pebbles of red and green marl, of vein-quartz, and of ironstone, ranging up to 4 inches in length, are also characteristic of this sub-group. The breccia is best seen in the south; but the Espley Rocks become coarser, and their constituent fragments of green shale are more angular, in the north of the district at Whateley Clay-pit.

Both in the breccias and in the Espley Rocks are pebble-like pieces of ironstone, made up of a nucleus and concentric coats strongly suggestive of a decayed basic igneous rock.

The whole of the beds are extremely variable in thickness from place to place, but the sub-group averages about 100 feet. For this reason, and also because of the high dip of the beds, the Nuneaton Clays have a very narrow outcrop, which strikes roughly parallel to that of the coal-seams. To the north of Wilnecote the Nuneaton Clays are either very thin, or locally absent. Good exposures are to be seen on the west of the district at Cliff and Whateley, near Kingsbury, and again on the east at Stockingford and Nuneaton, where several extensive marl-pits have been opened out in these measures.

In order to illustrate the nature of the rocks, measured sections of two of these marl-pits are given below:—

SECTION IN THE HAUNCHWOOD BRICK COMPANY'S CLAY-PIT AT HEATH END, CHILVERS COTON.

		Thickness in feet.
	Soil, sand and pebbles	1
Haunchwood Sandstone.	Soft yellow sandstone	12
Nuneaton Clays.	Espley Rock	1
	Purple and grey clay	12
	Calcareous, laminated, cream-coloured shale.	4
	Yellow massive sandstone	4
	Red clay	4
	Calcareous, laminated, cream-coloured shale.	7
	Purple marl	9
	Grey marl	6
	Red marl	14
	Purple marl	9
	Fireclay	6
	Breccia in two beds, from 0 feet up to	8
	Measures } seen in the well	30
	Stone: ? Espley Rock } seen in the well	4
	Total	131

Dip=about 15° westwards.

In the foregoing section the junction of the Nuneaton Clays with the overlying sub-group of the Haunchwood Sandstones is clearly seen; the latter are well exposed in the adjoining cutting of the London & North-Western Railway (Griff Branch).

At Messrs. Stanley's adjacent brick-pit, at Griff, near Chilvers Coton, an impersistent band of ironstone, an inch thick, makes its appearance immediately above the breccia. Fossil plants have been obtained from this ironstone, and also from the purple shales and clays with which it is interbedded. These plants, although fragmentary, are very abundant; but they appear to consist exclusively of leaves of *Cordaites principalis* (Germar), together with Equisetaceous pith-casts.

The section of this pit is as follows:—

SECTION IN MESSRS. STANLEY'S BRICK-PIT AT GRIFF, NUNEATON.

		Thickness in feet.
Nuneaton Clays.	Red and yellow clay with drift-pebbles	3
	Laminated, calcareous, cream-coloured shale with ironstone nodules	5
	Thinly-bedded, yellow, micaceous sandstone	3
	Grey shales	8
	Red and green, unstratified, mottled marls	10
	Lumpy green gritty marl, ferruginous grit with pebbles of hæmatite, and green and purple shale containing a bed of ironstone 1 inch thick	8
	Hard green breccia with partings of green marl	5
	Fine-grained green sandstone or Espley Rock (seen in the well)	15
	Total	57

At the north-western end of the line of clay-pits in the Nuneaton Clays at Haunchwood, near Stockingford, there is an outcrop of a richly fossiliferous *Spirorbis* Limestone about 9 inches thick. In this limestone fishes occur, while ostracoda and *Spirorbis* are very abundant.

The Haunchwood Sandstones.[1]—The Nuneaton Clays pass gradually upwards into a series of pale-grey, micaceous, current-bedded sandstones, shales, and marls containing a few thin and impersistent coal-seams and *Spirorbis* Limestones. To this sub-group I apply the term 'Haunchwood Sandstones.'

The base of this sub-group has been taken at the uppermost bed of Espley Rock, where that is present; while its upper limit is clearly defined by a thick and persistent bed of *Spirorbis* Limestone.

In the north of the coalfield, where the Nuneaton Clays are locally absent, both the sandstones towards the top of the Productive Coal Measures and the Haunchwood Sandstones appear to be much thicker than in the south; and it is, therefore, difficult to distinguish the base of the Haunchwood Sandstones.

In the Nuneaton district the outcrop of the Haunchwood Sandstones is very narrow, on account of their high dip; but in the north, near Wilnecote, along the axis of the syncline the beds are almost horizontal, and cover a much wider area.

Being more resistant to denudation than the soft marls of the Nuneaton Clays these sandstones make sharp features in the field; this is well seen to the south of Wilnecote, and again between Merevale and Polesworth, where the sandstones have been quarried. At Stockingford the sandstone quarries on the Heath-End road provide good sections in these beds, which consist of soft, yellow, current-bedded, micaceous sandstone containing lumps and thin lenticles of green marl.

An uprise of the Haunchwood sub-group at Arley breaks the symmetry of the main syncline; this may possibly be caused by the fault which crosses the coalfield at this point.

Plant-remains are not infrequently found in the Haunchwood Sandstones; but, so friable and soft is the weathered rock, that it is impossible to collect satisfactory specimens. However, a number of plants were obtained in the shales from the cores of the Whitmore Park Boring, near Coventry; from a well-sinking at Griff, near Nuneaton: and also from a new pit at Biddles Wood, near Kingsbury.

The Keele Beds.—The strata of this sub-group consist of calcareous red and purple sandstones alternating with red marls, which contain three thin beds of *Spirorbis* Limestone and a number of hard lenticular bands of calcareous marly breccia. The breccias are lenticles composed exclusively of rounded pisolitic masses of red and yellow ferruginous marl (presumably of Keele age) set in an abundant matrix of crystalline calcite. Red is the

[1] These rocks are the chief source of the water-supply of the Nuneaton district; and, as the main water-bearing bed has an average thickness of 100 feet, it has received the local name of the Hundred-Foot Sandstone.

prevailing tint of these rocks; but this is diversified by a peculiar spotting[1] and veining with green which affects both the sandstones and the marls, and occurs most commonly either in the beds containing rain-prints and sun-cracks or else along joints and fissures. On the whole, the rocks are rather soft; but, throughout the group, very hard, thin, calcareous beds of sandstone occur, which towards the base are grey in colour and alternate with the red beds.

The Keele Beds occupy the whole of the area between the outcrop of a persistent bed of *Spirorbis* Limestone, which has been taken as the base of this sub-group, and the outcrop of Corley Conglomerate which forms the base of the Permian.

The most striking and characteristic feature of the Keele Beds is the occurrence therein of the *Spirorbis* Limestones described below. A thin bed of limestone containing *Spirorbis* has long been known to occur in the Warwickshire Coalfield; and, by means of the numerous old workings in it, Mr. H. H. Howell was able, fifty years ago, to lay down the line of outcrop on the Geological Survey maps. The position of this bed was supposed to be in the Productive Coal Measures at about 50 feet below the base of the Permian rocks. As the true relationship of the Carboniferous to the Permian was not at that time fully understood, there was a tendency to refer every exposure of limestone to the outcrop of one bed, and the finding of *Spirorbis* therein was regarded as sufficient confirmation of that opinion.

It has since been pointed out by the late Mr. C. Fox-Strangways (00) that, near Baxterley, there are apparently two beds of limestone; but it is not certain whether this double outcrop is caused by two distinct beds, or whether it is to be regarded as a repetition of the same bed by a fault or roll of the strata.

Mr. Howell's statement (1859, pp. 28, 29) as to the occurrence of a limestone near the Hall, Nether Whitacre, has recently been confirmed by Mr. T. C. Cantrill (09), who has also detected another isolated exposure of limestone, 5 miles farther south, at Maxstoke. Both these outcrops are by that author considered to be, not in the Coal Measures, but in the Permian.

During the re-survey for the purpose of this paper, conclusive evidence has been obtained to show that there are in the Upper Coal Measures of this area, not merely a single bed of limestone, but many different beds distributed throughout about 1500 feet of strata. Although these beds are so thin, being often only a few inches thick, and rarely exceeding 3 feet, four of them are somewhat persistent; but all are constant in lithological and palæontological characteristics.

An examination of hand-specimens shows the rocks to be hard limestones of very fine-grained texture, varying in colour from

[1] The green disc-like spots, which often have a black nucleus, are not confined to the Keele Beds; they are common in the Permian, and also in the red Keuper Marls near Leamington.

a pale grey to a dark slaty blue and sometimes to red, and frequently containing cavities filled with green marl; while specimens of *Spirorbis* may often be distinguished by the unaided eye. Under the microscope a large amount of argillaceous matter can be detected, particularly in the darker varieties, while careful search nearly always reveals the tests of ostracoda. A diligent examination of other beds (particularly the thin upper bed) has failed to reveal a single fossil. Indeed, there is reason to believe that some of these limestones are, in part, of inorganic origin, and that their formation may be largely the result of chemical precipitation. In describing the North Staffordshire examples, Ward (see Gibson, 05) proposed the term 'Entomostracan Limestone,' for those beds in which ostracoda abounded to the exclusion of *Spirorbis*; but, as ostracoda and *Spirorbis* almost invariably occur together, this distinction appears to be somewhat arbitrary.

Most of the *Spirorbis* Limestones, whether in the Nuneaton Clays, in the Haunchwood Sandstones, or in the Keele Beds, are merely impersistent lenticular bands. Only one bed can be proved to extend over the whole district; it is that laid down on the old Geological Survey maps, and, in this paper, is taken as the base of the Keele Beds. On the line of outcrop sections can still be seen near Biddles Wood, near Kingsbury; in the stream at Monk's-Park Wood, near Merevale; and again at Longford, near Coventry, where, at a depth of 75 feet, the limestone forms the floor of the Foleshill Clay-pit. This occurrence shows that the outcrop has, at this point, been placed too far to the east on the Geological Survey map. This bed was formerly worked at Arley, but no section is now visible there.

Within the basin this *Spirorbis* Limestone has been proved in the following colliery-shafts and boreholes :—

	Depths in feet.
Exhall Colliery, near Bedworth	340
Well-section near the Griff Clara Colliery, Nuneaton	60
Tunnel Colliery, Stockingford	286
Baddesley Colliery (Stratford Pit)	148
New sinking at Biddles Wood, near Kingsbury	250
Whitmore-Park Boring, near Coventry	1637
Keresley Boring	1413

At Baxterley a second bed of limestone crops out about 150 yards south-west of the main limestone, which was proved in the colliery-shaft at that place. In the south this bed is probably represented by a limestone which occurred in the Keresley Boring at a depth of 1306 feet—that is, 107 feet above the main limestone.

The third limestone is a nodular bed, from 2 to 6 inches thick, which crops out near Maxstoke, and again near Brook End and Nether Whitacre. This bed is possibly the equivalent of the limestone which occurs in the Keresley Boring at a depth of 499 feet (that is, 914 feet above the main *Spirorbis* Limestone), and of a similar thin limestone in the Whitmore-Park Boring at a depth of 855 feet (that is, 782 feet above the main *Spirorbis* Limestone).

Near Nuneaton there is a sandstone at the base of the Keele Beds which, being of some importance as a water-bearing rock, has received the local name of the 'Forty-Feet Sandstone' (see vertical section, Pl. LXI). It varies from 20 to 40 feet in thickness, and occurs at from 100 to 170 feet above the main *Spirorbis* Limestone.

In the Keele Beds fossil plants have been obtained from the new sinking at Keresley, and from the red marls immediately above the *Spirorbis* Limestone in the Foleshill Clay-pit. The most important plant is the characteristic Upper Coal-Measure species *Pecopteris polymorpha* Brongniart, which, together with *P. miltoni* (Artis), is not uncommon in one thin bed. Erect pith-casts of *Calamites* sp. also occur.

(B) The Permian.

In the foregoing pages it has been shown that more than half of the area of the so-called 'Permian' must be relegated to the Carboniferous; the remaining portion of these rocks (the Corley Conglomerates and the Kenilworth Sandstones) will now be considered.

The Corley Conglomerates.—In the Geological Survey Memoir no distinction is drawn between the Carboniferous breccias described above and the Corley Conglomerates, the lowest of which I regard as the base of the Permian. The chief difference between the breccias in the Keele Beds and these Permian conglomerates is that, while the former are composed exclusively of fragments of rocks (marls and sandstones, presumably of Upper Carboniferous age) similar to those with which the breccias are interbedded, the latter contain an abundance of pebbles derived from rocks foreign to the coalfield. And, further, the great bulk of these pebbles in the Corley Conglomerates are composed of rocks of Lower Carboniferous age. The presence of large numbers of rounded pebbles of Carboniferous Limestone in these beds suggests that, before this period, the continuous deposition of Coal-Measure sediments had ceased, and that a period of uplift and denudation had exposed certain areas of Carboniferous Limestone, thus providing the material from which the pebbles were formed.

The following section of one of the Corley Conglomerates, which was proved in the Whitmore-Park Boring, is intended to show the thickness and mode of occurrence of the bed:—

Corley Conglomerate.	*Thickness (feet).*	*Depth (feet).*
Conglomerate	13	597
Calcareous, current-bedded, red sandstone, red marl, and breccia	45	
Conglomerate	18	660

The upper bed of conglomerate is a hard massive rock, consisting of small rounded pebbles set in a matrix of red sandy marl. The lower bed of conglomerate is very similar, but is lighter in colour and somewhat harder; its constituent pebbles are rather larger, and the matrix is a coarse angular sand. In both the relative proportion of pebbles to matrix is large, the pebbles are not evenly bedded, and fragments of rounded red marl from the underlying Keele Series are not uncommon. In each case the rock is very calcareous. The pebbles have an average length of 1½ inches, but pebbles 3 inches long are quite common. Several kinds of rock are represented among these pebbles; arranged in the relative order of abundance they are:—Carboniferous Limestone, Carboniferous-Limestone chert, indurated and felspathic sandstones of Silurian age, quartzites, and vein-quartz.

In some of the conglomerates, especially the bed which crops out at Corley Rock and again in St. Joseph's Avenue, Radford, near Coventry, fossiliferous pebbles are not uncommon.[1]

The pebbles of Carboniferous Limestone yield various corals and crinoids; while, from the Silurian rocks, such fossils as the following have been obtained:—

Rhynchonella nucula Sow.	*Orthis* sp., cf. *lunata* (Sow.).
Rhynchonella davidsoni M'Coy.	*Cœlospira hemispherica* (Sow.).

The parent-rocks from which these Silurian pebbles were derived must, therefore, have been largely of Llandovery and Ludlow age. One of these Silurian pebbles, containing the last fossil mentioned above, is a hard green sandstone very similar to the May-Hill Sandstone.

The surface of the limestone pebbles, when unweathered, exhibits a multitude of small cavities evidently caused by the grains of sand that form the matrix of the rock, many of which still occupy the cavities. Other larger depressions mark the points of contact of adjacent pebbles. Such 'pitted' and 'impressed' pebbles are invariably found to be limestone; they are everywhere common. The ultimate cause of these pittings appears to be the great pressure experienced by the rock, which has caused a partial solution of the limestone at the points of contact.

The relative proportion of Carboniferous Limestone in the conglomerates from two widely-separated localities is shown below:—

	Whitmore-Park Boring.	*Outcrop at Maxstoke.*
Carboniferous Limestone and chert	71 per cent.	84 per cent.
Silurian and other rocks	29 ,,	16 ,,

The average percentage of Carboniferous-Limestone pebbles is thus about 75.

With the exception of a few rounded and subangular pebbles of quartzite and of vein-quartz of unknown age, the remainder of the pebbles consist exclusively of Silurian rocks.

In this connexion, it is of interest to note that Mr. Horace Brown (89) found that in the north, near Polesworth, the conglomerate contains only 9 per cent. of Carboniferous-Limestone

[1] A detailed account of the fossiliferous pebbles from these conglomerates will be given in a future paper.

pebbles. The parent-rock must not, therefore, be sought in the north, but rather to the south or west of the district.

At Corley Rock, 6 miles north-west of Coventry, an abrupt escarpment facing north-eastwards is formed by the hard red sandstones with thin beds of conglomerate in a marly matrix, which dip south-westwards. The conglomerates at this horizon appear to be continuous for a distance of about 10 miles.

From Corley the bed strikes south-eastwards to Radford, where it is seen in the Radford road; in the railway-cutting under the road; and in St. Joseph's Avenue, where it makes a distinct feature. Farther south the bed crosses the town of Coventry to Whitley Common, beyond which it disappears, being overlapped by the Lower Keuper Sandstone.

At Corley Rock the direction of strike changes from north-west to almost due west. The bed is seen in the sand-pits at Chapel Green and near Meriden; still farther west it is probably cut off by the boundary-fault.

Isolated patches of conglomerate occur at Exhall, Maxstoke, Arley, and Fillongley, and near Polesworth. At Arley two conglomerates crop out: one is seen in the Bourne Brook at Fillongley Lodge, and the other is well exposed in the railway-cutting at Arley Station. The latter exposure consists of 10 feet of massive false-bedded conglomerate in a red marly matrix which, about 50 yards westwards, passes laterally into a pebbly sandstone, and finally into a red marly sandstone devoid of pebbles. This conglomerate is not, therefore, a continuous bed, but only a lenticular mass which probably thins away in every direction.

At Hill Farm, Maxstoke, the boundary-fault brings a bed of conglomerate which dips eastwards at 15° alongside nearly horizontal Upper Keuper Marls; the course of the fault is a steep escarpment facing west.

It is necessary to add that, on the present evidence, the relationship of the isolated outcrops of conglomerate to the main bed at Corley is still uncertain. It is a question whether there is but one horizon of conglomerates, or whether there are two different horizons separated by some hundreds of feet of pebbleless sandstones and marls.

In the first case, the isolated patches of conglomerate are simply outliers of the main bed at Corley; and the presence of the conglomerates at a depth of 600 feet in the Whitmore-Park Boring, and of a thin bed 900 feet deep in the Foleshill-Road Boring, may be explained either by a strike-fault, or else by a local syncline striking south-eastwards about a mile north of Coventry.

In the second case, assuming the presence of two main beds of conglomerate, the Maxstoke, Arley, and Exhall conglomerates suggest an outcrop striking roughly parallel with that of the Coventry–Corley bed.

Each of these explanations requires the presence of some hundreds of feet of Permian in the neighbourhood of the two boreholes mentioned above. A few yards east of the Foleshill-Road Boring, Messrs. Webster's brick-pit shows a good section of the

Permian, which here consists of highly false-bedded, calcareous, red sandstones interbedded with red marls. On the weathered surfaces of the sandstones the casts of large stems, often several feet in length, of the Permian plant *Walchia imbricata* Schimper are not uncommon. A portion of one of these leafy branches is figured in Pl. LIX, fig. 10.

The presence of the conglomerate at Polesworth is important, as showing that originally these beds extended throughout and beyond this district, whence they have since been removed by denudation.

The occurrence of pebbles of Keele Sandstone, together with the abundance of the Carboniferous-Limestone pebbles described above, strongly suggests that the Corley Conglomerates are unconformable to the Keele Beds. The presence of such an unconformity is rendered more probable by the manner in which one bed of conglomerate strikes across the district, and above all by the occurrence of isolated patches of conglomerate apparently resting upon different horizons of the Keele Beds. The following particulars illustrate this fact:—

Whitmore-Park Boring, near Coventry.

Lowest Corley Conglomerate at 660 feet.
Main *Spirorbis* Limestone at 1637 feet (base of the Keele Beds).
The Keele Beds are, therefore, 977 feet thick.

Keresley Boring (445 feet above O.D.).

Corley Conglomerate exposed at Corley Rock (625 feet above O.D.) half a mile west of the borehole.
Main *Spirorbis* Limestone at 1413 feet (base of the Keele Beds).
Keele Beds 1413 feet thick.
At Corley Rock the Keele Beds would be about 1600 feet thick.

Exhall.

Corley Conglomerate crops out at about 300 feet above O.D.
Main *Spirorbis* Limestone, dipping westwards at about 7°, is exposed in the Foleshill Clay-pit.
Thickness of the Keele Beds=about 650 feet.

There can be little doubt, therefore, that the Corley Conglomerates are unconformable to the underlying Carboniferous rocks, and that they constitute the basal member of the succeeding Permian formation.

The Permian extends due southwards from the outcrop of the Corley Conglomerate to within 2 miles of Warwick, where it is unconformably overlain by Trias. At Spon End, Coventry, the general dip of the Corley Conglomerate, which crops out at Radford, is south-westwards at 4°.

The Kenilworth Sandstones.—In the Kenilworth Sandstones sections are very rare, but the nature of the beds can be made out in the clay-pits and old sandstone-quarries at Coundon and Allesley near Coventry, and at Kenilworth. The Whitmore-Park Boring, near Coventry, penetrated 660 feet of these rocks before reaching the Keele Beds.

These beds consist exclusively of calcareous red sandstones alternating with red marls, which are frequently spotted and veined with green. Red is the predominating colour, but the tint varies considerably from red to chocolate; while some beds are green, white, or even yellow. The rocks pass gradually from marls into sandstones, in which fine detrital mica is abundant. Rain-prints, sun-cracks, ripple-marks, and animal footprints are not uncommon. This evidence, together with the false bedding of the sandstones and the lenticular nature of the marls, suggests that these rocks are shallow-water deposits. The Kenilworth Sandstones are lithologically very similar to the underlying Keele Beds; but the characteristic *Spirorbis* Limestones of the latter are completely absent.

The general direction of dip is south-westerly: the formation may thus be expected to attain its greatest thickness near Warwick. But the prevalent false bedding renders it almost impossible to determine the true dip; and, in the absence of deep borings in the south, any estimate of the thickness of these rocks must be merely approximate. Fossils are extremely rare in the Permian: the following list includes all the known records:—

LIST OF FOSSILS FROM THE PERMIAN OF WARWICKSHIRE.

Species.	Locality.	Reference.	Horizon.
Breea entassoides[1]	Meriden.	Ramsay (55) p. 198 and footnote; also 'Geol. Warwick. Coalfield' Mem. Geol. Surv. p. 32.	Permian.
Caulerpites oblonga[1]	Meriden.	*Ibid.* p. 32.	Permian.
Caulerpites biangularis[1].	Meriden.	*Ibid.* p. 32.	Permian.
Caulerpites triangularis[1]	Meriden.	*Ibid.* p. 32.	Permian.
Calamites sp.[3]	Whitmore-Park Boring, 120 feet deep.	......	Permian.
Calamites sp.[2]	Exhall.	*Ibid.* p. 31.	(?) Permian.
Lepidodendron[2] sp.	Exhall.	*Ibid.* p. 31.	(?) Permian.
Sternbergia	Exhall.	Phillips, 'Geol. of Oxford' p. 96.	(?) Permian.
Dadoxylon[1 2 3]	Allesley.	Proc. Geol. Soc. vol. ii, no. 48, p. 439 (1837).	Permian.
Walchia hypnoides (Brongn.).	'Trias' of Warwickshire.	Morris (54) p. 24. [This record may perhaps refer to a Permian fossil, but no locality is given.]	(?) Permian.
Walchia imbricata[3] Schimper, & *Walchia* sp.	Messrs. Webster's clay-pit, Stoney-Stanton Road, Coventry.	......	Permian.
Strophalosia[2] ?	Exhall.	'Geol. Warwick. Coalfield' pp. 31–32.	Permian.
Dasyceps bucklandi[1] (Lloyd).	Near Kenilworth.	*Ibid.* pp. 52–56.	Permian.
Oxyodon britannicus[2] F. von Huene.	Near Kenilworth.	F. von Huene, Centralbl. f. Min. 1908, pp. 431–4.	Permian.
Maxillary bone of a fish ...	¾ mile north-west of Coventry.	Trans. Geol. Soc. ser. 2, vol. v, 1840, pl. xxviii, fig. 5, & p. 348.	(?) Permian.
Footprints[3]	Cherry Orchard Clay-pit, Kenilworth.	......	Permian.
Footprints[3]	Coundon-Road Clay-pit, Coventry.	......	Permian.

[1] Fossils marked thus are in the Warwick Museum.

[2] These fossils are in the Museum of Practical Geology, Jermyn Street, London: the plants being Nos. 1640, 1642–44, 1650, and 1653.

[3] In the author's collection, Sedgwick Museum, Cambridge.

We have seen that the rocks from which these fossils have been obtained unconformably overlie, and are younger than, the Keele Beds; and it will be shown on a subsequent page that they are themselves unconformably overlain by, and are older than, the Trias. The sediments in question may thus have been formed contemporaneously with the Permian of the North of England, or they may even be the English representatives of the Stephanian (Carboniferous) Series of the Continent.

The fossils in the foregoing list will now be considered, with the object of fixing the age of the rocks. In this connexion the animal footprints recorded above, as well as the 'bone of a fish' figured by Murchison & Strickland, are of little value, and may be omitted.

The fossil which Salter considered to be allied to *Strophalosia* is a badly-preserved cast in sandstone, the real nature of which appears to be very doubtful. There is reason to believe that this specimen is not a Permian fossil, but a derived shell (possibly of Silurian age) from the pebbles of the Corley Conglomerate, which is known to occur at Exhall.

Of more importance is the skull of *Dasyceps bucklandi* (Lloyd). In 1849 G. Lloyd (49) gave a brief description of 'a new species of *Labyrinthodon* from the New Red Sandstone of Warwickshire,' which he named *L. bucklandi*. No precise locality was cited; but the fossil was said to come from the Bunter Sandstone, near Kenilworth. By Mr. Howell (59) and Sir Andrew Ramsay (55) these rocks were placed in the Permian.

Huxley (59) pointed out that the fossil was generically distinct from any known Labyrinthodont; he, therefore, proposed for it the name *Dasyceps*. In the same year Huxley gave a detailed description, with two figures, of the skull of *Dasyceps*. Morris (54) mentions this fossil, and Phillips (71) and Miall (75) follow Huxley in their descriptions and figures. Recently Baron F. von Huene (10) has re-described and re-figured *Dasyceps*, which he considers to be most nearly related to *Cochliosaurus* and other genera of the Palæozoic family of Melosauridæ that are found in the Stephanian Gas-Coal of Bohemia. Baron von Huene (08) has also described a Pelycosaurian jaw from Kenilworth (now in the Museum of Practical Geology) as *Oxyodon britannicus* von Huene.

Unfortunately, neither of these species has yet been recorded elsewhere, and so they afford no definite evidence regarding the exact age of the beds from which they come.

The following fossils, which have never been figured or described, are of doubtful specific and generic value:—

Breea entassoides.	*Caulerpites biangularis.*
Caulerpites oblonga.	*Caulerpites triangularis.*

The *Calamites* and *Lepidodendron* mentioned in the list on p. 607 cannot be specifically identified.

With regard to *Dadoxylon*, longitudinal sections of the silicified wood from one of these tree-trunks from the Kenilworth Sandstones of Allesley (a portion of which is in the Sedgwick Museum, Cambridge) show that it possesses uniseriate bordered pits. The plant cannot therefore be referred, either to the Equisetales, or to the Lycopodiales; it appears to be coniferous wood of Cordaitean affinities. Fragments of such woods are common in the drift-gravels of the neighbourhood.

There remains the conifer *Walchia imbricata*, the only plant in the list that is of stratigraphical value. The genus *Walchia* is known from the Stephanian beds of the Continent—a series which is not known to occur in Britain. It has also been recorded from the Upper Coal Measures (Keele Beds) of both the North and the South Staffordshire Coalfields, in which it is exceedingly rare. *Walchia* is, however, a typical Permian plant, and it is only in beds of Permian age that it becomes common. The abundance of the plant in the Kenilworth Sandstones at this locality suggests that the rocks in question are Permian.

Until definite palæontological evidence to the contrary is forthcoming, the Corley Conglomerates and the Kenilworth Sandstones must be both regarded as of Permian age.

(C) The Base of the Trias.

The Trias of Warwickshire is not fully developed, two of the subdivisions being absent; a third is very thin, while a fourth dies out south-eastwards within the limits of the district. The following subdivisions are represented:—

Keuper..........	Upper Keuper Marls. Lower Keuper Sandstone.
Bunter..........	Bunter Pebble-Beds.

The relationship of the Trias to the older rocks is a matter of some importance, to which a brief reference will now be made. The accompanying map (Pl. LXI) shows clearly that the Trias is everywhere unconformable to the older rocks, and that its outcrop successively overlaps the Cambrian, the Carboniferous, and the Permian. In the north near Polesworth (where the Bunter is the lowest member of the Trias), east of the boundary-fault of the coalfield, a small area of Permian with Corley Conglomerate at the base is seen dipping east-north-eastwards at 30° under Bunter Pebble Beds which dip south-eastwards at 25°. The Pebble-Beds in turn dip beneath the Lower Keuper Sandstone, and the latter beneath the Upper Keuper Marls. The Bunter, which is well exposed in several quarries near Hoo Hill, is only about 250 feet thick. Farther south, near Atherstone and in Merevale Park, the Bunter is absent, so that the Lower Keuper becomes the basal member of the Trias. It is noteworthy that here, as at other places along the line where the Lower Keuper abuts against the older rocks, the base of the subdivision becomes very coarse and pebbly. At Nuneaton (Midland Company's Quarry and Tuttle Hill Quarry) the well-bedded brown sandstones and red marls of the Lower Keuper rest horizontally upon steeply-dipping Hartshill Quartzite. Farther south, at Wash Lane and again near Marston Jabet, the unconformable junction of the Lower Keuper with the Stockingford Shales may be seen in several old quarries. At each of the above-mentioned localities the junction is marked by a local breccia, which consists of large angular fragments of the underlying Cambrian rocks.

At Blackatree Farm, a quarter of a mile south-west of Wash-Lane Bridge, Nuneaton, a sand-pit and coal-shaft have proved the Coal Measures dipping steeply south-westwards under 12 feet of Lower Keuper Sandstone and red marl, which dip at 15° north-eastwards. Again, a number of collieries from Hawkesbury to Binley have proved that the horizontal Lower Keuper here rests upon Coal Measures dipping steeply westwards; and between Nuneaton and Coventry the Lower Keuper overlaps in turn each of the subdivisions of the Coal Measures. Near Willenhall Bridge, 2 miles south-east of Coventry, a well and boring for water gave the following section:—

		Thickness in feet	inches.
Alluvium.	Sand and clay	15	6
Lower Keuper.	White sandstone and red marl	42	0
	Conglomerate	4	0
Permian (Corley Conglomerates).	Red marl and red sandstone with pebbles...	41	6
	Conglomerate	12	0
	Red marl and red sandstone	44	0
	Conglomerate	1	6
	Red marl and red sandstone	38	6
	Conglomerate with 1 foot of red marl in the middle	5	0
	Red sandstone and red marl	46	0
	Total	250	0

The Permian was said to dip at about 15°, while the Lower Keuper was nearly horizontal. Still farther south, the latter rests upon higher horizons of the Permian until Warwick is reached.

The unconformity between the Trias and the Palæozoic rocks is thus one of the most conspicuous features in the geology of Warwickshire.

(D) Tectonics.

The following table embodies an account of the more important sinkings and borings in the southern part of the coalfield. It has been added, in order to illustrate the geological structure of that part of the district:—

IMPORTANT SINKINGS AND BORINGS IN THE WARWICKSHIRE COALFIELD.

Locality of Boring.	*Number on Map (Pl. LXI).*	*Height of surface above O.D.*	*Depth of Boring.*	*Formations passed through. Thickness in feet.*
Spring Pools	1	370	2009	Coal Measures to 2009.
Keresley	2	445	2173	Coal Measures to 2173.
Whitmore Park	3	340	2591	Permian ...... 660. Coal Measures 1931.
Foleshill	4	310	1055	Permian ...... 909. ? Keele Beds... 146.
Spon End	5	266	575	Permian ...... 190. ? Keele Beds... 385.
Whitley	6	230	250	Lower Keuper 46. Permian ...... 188½.
Tile Hill	7	350	693	Permian to 693.
Kenilworth	8	237	226½	Permian to 226½.
Leamington	9	......	346¼	Upper Keuper to 346¼.
Stoke	10	240	169	Upper Keuper 60. Lower Keuper 82. ? Keele Beds ... 27.
Brandon	11	270	366¼	Drift .... 21. Keuper .... 313. Coal Measures 32.
Weston	12	360	300	Upper Keuper to 300.
Burton Hastings	13	330	130	Lower Keuper 60. Cambrian ...... 70.
Nuneaton	14	210	123	Drift .... 27. Lower Keuper 81. Cambrian ...... 15.
Bedworth Charity Colliery	15	360	1029	Coal Measures 795. Cambrian ...... 234.
Lindley	16	300	660	Keuper to 660.

The structure of the coalfield is remarkably simple, especially in the northern portion, where the various subdivisions of the Coal Measures, and also the coal-seams, crop out symmetrically on each side of the syncline. In the south this symmetry is partly hidden by the pitch of the syncline, and by the unconformable cover of Permian and Trias, and partly destroyed by the western boundary-fault.

The proved faults within the coalfield are neither very great nor very numerous; but the western and eastern boundary-faults are important dislocations. The eastern boundary of the Palæozoic rocks is, in part, a fault which runs in a south-easterly direction from Shuttington by Polesworth and Atherstone to near Nuneaton. The amount of throw is unknown, but it decreases southwards and at Nuneaton, where the junction between the Trias and the older rocks is an unconformity and the fault is entirely in Trias, the displacement is probably quite small. On the upthrow side of the fault the Cambrian has been proved beneath the Lower Keuper at The White Stone, Burton Hastings (13), and at Nuneaton (14). On the downthrow side a boring at Lindley (16) has penetrated more than 600 feet of Keuper without reaching the base of the subdivision. Near Market Bosworth, 7 miles north-east of Nuneaton, a series of borings passed through the Trias into the Cambrian; and Mr. Horace Brown (89) has shown that this part of the Palæozoic floor forms a sub-Triassic anticline parallel with the Nuneaton ridge.

The western and north-western boundary-fault is probably the most important one; but at present there is no means of estimating the displacement, as the thickness of the strata is unknown. On this point the only evidence available is the King's-Heath Boring, near Birmingham, which ended in Keuper rocks at a depth of 1106 feet; also a boring farther north at Streetly, which proved about 1850 feet of red 'Permian' sandstones, marls, and conglomerates of unknown age beneath 50 feet of Bunter Pebble-Beds. South of the district, at Stratford-on-Avon, the base of the Keuper has not been reached at a depth of 800 feet. Nothing very definite can thus be affirmed concerning the southern portion of the county.

With regard to the age of the movements which have affected the coalfield, it is obvious that the main folding and faulting took place after the deposition of the Upper Coal Measures and before the Trias was laid down; but, whether it is of pre- or of post-Permian age is not so clear. The Permian has been proved unconformable to the Keele Beds, and so it is probable that the main folding was pre-Permian; but there has been subsequent upward movement of the old Palæozoic ridges along the same lines in post-Permian and also in post-Triassic times.

(E) Conclusion.

The Coal Measures of Warwickshire are merely the remnants of an extensive sheet which formerly overspread a wide area in the Midlands. With other existing portions of this sheet it is possible to institute a close comparison. In other words, the stratigraphical succession, lithological characters, and fossil contents of the Coal Measures of Warwickshire can be correlated with those of the other coalfields of the Midland counties, and more especially does this apply to the South Staffordshire Coalfield. Such a correlation is indicated in the appended table (p. 613).

In this connexion, it may be remarked that it is still a matter for speculation whether Upper Coal Measures were ever deposited over the Leicestershire area; but this does not affect the question of the correlation of the Middle Coal Measures. The Middle Coal

Table illustrating the Correlation of the Coalfields of the Midland Province.

		North Staffordshire.	Nottinghamshire.	Leicestershire.	South Staffordshire.	Warwickshire.
Cover:—		Trias.	Permian Magnesian Limestone.	Salopian Permian.	Salopian Permian.	Salopian Permian.
Subdivisions of the Westphalian Series.		Keele Beds. + 700 feet.	Keele Beds. + 188 feet.	Absent.	Keele Beds. + 800 feet.	Keele Beds. 1600 feet.
		Newcastle Beds. 300–350 feet.	Newcastle Beds. 91 feet.	Absent.	Newcastle Beds. 500 feet.	Haunchwood Sandstones. 300 feet.
		Etruria Marls. 800–1100 feet.	Etruria Marls. 283 feet.	Absent.	Etruria Marls. 600 to 1000 feet.	Nuneaton Clays. 100 feet.
		Blackband Group. 300–450 feet.	Absent.	Absent.	Absent.	Absent.
		Middle Coal Measures. 4000 feet.	Middle Coal Measures. 2000 feet.	Middle Coal Measures. + 1600 feet.	Middle Coal Measures. 500 to 2000 feet in the north.	Middle Coal Measures. 400 to 700 feet in the north.
		Lower Coal Measures. 1200 feet.	Lower Coal Measures. 1000 feet.	Lower Coal Measures. (?) 1000 feet.	Absent (except in the north).	Absent.
		Millstone Grits.	Millstone Grits. 1300 feet.	Millstone Grits. 50 feet.	Absent (except in the north).	Absent.
Avonian Series.		Limestone Shales and Carboniferous Limestone.	Limestone Shales and Carboniferous Limestone.	Limestone Shales and Carboniferous Limestone.	Absent (except in the north).	Absent.
Floor:—		(?)	(?)	Pre-Cambrian.	Silurian.	Cambrian.

Measures of Leicestershire are very similar to those of Warwickshire, and the resemblance extends even to minor points, such as the occurrence of certain coarse grits towards the summit of the group near Polesworth in Warwickshire, and also near Moira and Boothorpe in Leicestershire. One striking feature, which each of these coalfields has in common with the South Staffordshire Coalfield, is the occurrence of seams of coal of exceptional thickness formed by the union of several individual seams. From this and other evidence, it appears extremely probable that these separate areas of Coal Measures were formed under similar conditions in one general basin of deposition.

In North Staffordshire and in Nottinghamshire the Keele Beds are not fully developed, and the summit of the group is nowhere visible; while in South Staffordshire the top of the Keele Beds is also unknown. In Warwickshire, as a result of this work, it is now possible for the first time to demonstrate the exact upward limit of the Keele Beds. The Warwickshire Coalfield may thus be regarded as the typical area of development of the Upper Coal Measures of the Midland province, with which the incomplete sequence exposed in other coalfields can be compared.

The Southerly Attenuation and Overlap of the Carboniferous System.

One other fact of general interest clearly shown by this correlation-table (p. 613) is the remarkable attenuation of the consecutive subdivisions of the Carboniferous System, along a north-and-south line from Nottinghamshire through Leicestershire to Warwickshire, just as there is also an exactly similar attenuation on a parallel line farther west through the North and South Staffordshire Coalfields. Further, this attenuation is accompanied by the successive overlap of each subdivision upon the pre-Carboniferous floor of the district. This southerly attenuation and overlap of the Lower Carboniferous by the Upper Carboniferous, and also of the two lower subdivisions of the Upper Carboniferous, can be demonstrated; and it may be inferred that, in the unproved area south of Coventry, the Middle Coal Measures in turn thin away and are overlapped by the barren Upper Coal Measures. The southern margin of deposition of the Middle Coal Measures must have lain along an east-and-west line somewhere to the south of Coventry: therefore, we may conclude that the southern portion of the basin was not depressed until late Middle Coal-Measure times, and that the pre-Carboniferous floor had a general slope from south to north.

IV. Palæontology.

With the exception of a few plants in the museum of the Warwickshire Naturalists' Field-Club at Warwick, there appears to be no public collection of fossils from the coalfield. Records of fossils are equally scarce, and in the most recent account of the palæontology of the county by Mr. Lydekker (05) no Carboniferous fossils are mentioned. This branch of the subject had thus remained a virgin field for research, and in the following account I am concerned solely with the fossils which I have myself collected during the past three years. It is, however, necessary to add that, since this work was completed, a list of fossils from the Coal Measures of Warwickshire has been published.[1] These fossils, which were collected and identified by Mr. A. R. Horwood, are restricted to Middle Coal-Measure forms of plants and freshwater lamellibranchs, from the subdivisions of the Thick Coal worked in the collieries of the neighbourhood of Nuneaton.

Fossil horizons.—Each of the four subdivisions of the Coal Measures—the Productive Measures, the Nuneaton Clays, the Haunchwood Sandstones, and the Keele Beds—has yielded fossil plants, and from the Productive Measures an extensive fauna has been collected. Fossils have also been obtained from the Permian deposits (see p. 607).

In natural sections in the field, the rocks have invariably proved to be barren of fossils, or else to contain only indeterminable fragments. The whole of the flora and fauna about to be considered has therefore been obtained from artificial sections, such as clay-pits, colliery tip-heaps, and the cores from deep borings for coal.

The nomenclature of the seams of coal is still somewhat confused, and so it is extremely probable that, in some cases, the same seam has received distinct names at different collieries. As might perhaps have been expected, the various subdivisions of the Thick Coal—including the Four-Feet, Two-Yard, Ryder, Bare, Ell, and Slate Coals—were found to constitute one palæontological horizon, from which the greater part of the Middle Coal-Measure flora, together with most of the freshwater lamellibranchiata, has been obtained. It will be seen from Table II (p. 617) that most of the collieries work one or more of the divisions of the Thick Coal, together with one or more of the lower seams; and, as the resulting débris of shale is thrown on the waste-heaps, it naturally becomes mixed, so that it has not always been possible to refer each fossil to its exact horizon. In most cases, it is a question of distinguishing the débris of the Thick Coal from that of the Seven-Feet Coal; and, as the latter yields only a marine fauna, the problem of correlating fossils with the seams from which they come is considerably simplified.

The localities and stratigraphical horizons of each of the fossiliferous sections are stated in the following tables:—

[1] Rep. Brit. Assoc. (Portsmouth) 1911, p. 105.

For convenience of reference, the chief palæontological horizons may be summarized as follows:—

Horizon	Fossils
Permian (Kenilworth Sandstone)	Plant-bed.
Keele Beds	Plant-bed. Three limestones with *Spirorbis* and ostracoda.
Haunchwood Sandstones	Plant-bed. Limestones with *Spirorbis* and ostracoda.
Nuneaton Clays	Plant-bed. Limestone with fishes, *Spirorbis*, and ostracoda.
Upper Beds of Middle Coal Measures	Plant-bed.
Four-Feet Coal, Two-Yard Coal, Ryder Coal, Ell Coal, Slate Coal } Thick Coal	Plant-bed. Mussel-band. Fish-bed.
Seven-Feet Coal	Marine bed. Fish-bed.
Double Coal, Bench Coal	Plant-bed. Fish-bed.

FOSSILIFEROUS BEDS. TABLE I.

Locality.	*Horizon.*
Cherry Orchard Brick-pit, Kenilworth (8).[1]	Permian.
Coundon Road Brick-pit, Coventry (5).	Permian.
Messrs. Webster's brick-pit, Stoney-Stanton Road, Coventry (4).	Permian.
Foleshill Brick-pit, Longford, Coventry (to the south of 17).	Keele Beds (at the base). About 10 feet above the main *Spirorbis* Limestone.
New sinking at Keresley (2).	Keele Beds.
Stockingford Sand-pit, Heath-End Road, Stockingford, Nuneaton (immediately north of 41).	Haunchwood Sandstones.
Well-sinking near Griff Colliery, Clara Pit, at a depth of about 200 feet (22).	Haunchwood Sandstones.
New sinking at Biddles Wood, near Kingsbury (28).	Haunchwood Sandstones.
Whitmore-Park Boring, near Coventry, at a depth of 1670 feet (3).	Haunchwood Sandstones.
Messrs. Stanley's brick-pit, Chilvers Coton, Nuneaton (just north of 22).	Nuneaton Clays.
Griff Clay-pit, Chilvers Coton, Nuneaton (41).	Upper beds of Productive Measures.
Messrs. Stanley's No. 4 clay-pit, Arbury Road, Stockingford, Nuneaton.	Upper beds of Productive Measures.
Midland Stoneware Pipe Co.'s clay-pit, Tamworth Road, Polesworth.	Upper beds of Productive Measures.
Alvecote Clay-pit (33).	70 yards above the Four-Feet Coal.
Old clay-pit, near Two Gates, Wilnecote (to the south of 36).	Thick Coal.
Chilvers Coton Clay-pit, Heath End, Nuneaton (41).	Thick Coal.
Stockingford Clay-pit, Arbury Road, Nuneaton (north of 41).	Thick Coal.
Keresley Boring, near Coventry (2).	Immediately above the Thick Coal.

[1] The numerals in parentheses refer to boreholes and shafts marked on the map (Pl. LXI), near to which the fossiliferous localities are situated.

FOSSILIFEROUS BEDS. TABLE II.

Colliery.	*Horizon (Coal worked).*						
Alvecote (33)[1]					Seven Feet.	Double.	(Bench).[2]
Amington (34)					Seven Feet	Double.	Bench.
Ansley Hall (25)		Ryder.		Slate.			
Arley (26)		Ryder.		(Slate)			
Baddesley (27)		Ryder.					
Binley (20)	Two Yard.						
Birch Coppice No. 1[3] (31)					(Seven Feet)		
Charity (15)	Two Yard.	Ryder.		Slate.	(Seven Feet)		
Craven (19)			Ell.				
Exhall (17)	Two Yard.	Ryder.	Ell.	Slate.			
Glascote (35)		Ryder.			Seven Feet.	Double.	Bench.
Griff Clara (22)		Ryder.		Slate.	Seven Feet.		
Griff No. 4 (41)				Slate.			
Hall End (29)		Ryder.		Thin Ryder.	Seven Feet.		
Haunchwood (23)		Ryder.					
Hockley Hall[3] (38)					(Seven Feet)		(Bench)
Kingsbury (40)		Ryder.					
Newdigate (21)	Two Yard.			Slate.			
Nuneaton (23)		Ryder.		Slate.	Seven Feet.		
Pooley Hall (32)		(Ryder)			(Seven Feet)		Bench.
Peel No. 3 (36)						Double fireclay. Bottom fireclay.	Bench.
Tunnel (24)	Two Yard.	Ryder.		Slate.			
Stockingford (43)		Ryder.		Slate.	(Seven Feet)		
Valley (37)	Four Feet.				Seven Feet.	Double fireclay.	
Whateley (39)	Four Feet.						
Wyken (18)	Two Yard.	Ryder.	Ell.	Slate.			

[1] The numerals in parentheses refer to the collieries indicated on the map which accompanies this paper (Pl. LXI).

[2] Parentheses signify that the seam in question was not being worked at the time of my visit.

[3] Old disused pits, from which fossils have been obtained.

(A) The Fossil Flora.

The fossil plants from the Carboniferous rocks of the Warwickshire Coalfield are tabulated below[1]:—

Species.	Horizon.	Locality.
EQUISETALES.		
Calamites (Calamitina) göpperti Ettingshausen.	Above Thick Coal.	Griff Clay-pit.
	Ryder Coal.	Arley Colliery.
	Below Seven-Feet Coal.	Peel Colliery.
Calamites (Calamitina) varians Sternberg.	Above Thick Coal.	Griff Clay-pit.
	Ryder Coal.	Kingsbury Colliery.
Calamites (Calamitina) undulatus Sternberg.	Ryder Coal.	Arley Colliery.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Newdigate Colliery.
	Below Seven-Feet Coal.	Peel Colliery.
Calamites (Eucalamites) ramosus Artis.	Ryder Coal.	Arley Colliery.
	Thick Coal.	Griff Colliery, Clara Pit.
	Below Seven-Feet Coal.	Peel Colliery.
Calamites (Stylocalamites) approximatus Brongniart.	Thick Coal.	Newdigate Colliery.
Calamites (Stylocalamites) cisti Brongniart.	Above Thick Coal.	Messrs. Stanley's No. 4 clay-pit, Stockingford.
	Above Thick Coal.	Griff Clay-pit.
	Ryder Coal.	Kingsbury Colliery.
	Ryder Coal.	Arley Colliery.
	Thick Coal.	Stockingford Clay-pit.
	Thick Coal.	Tunnel Colliery.
Calamites (Stylocalamites) suckowi Brongniart.	Above Thick Coal.	Messrs. Stanley's No. 4 clay-pit, Stockingford.
	Above Thick Coal.	Griff Clay-pit.
	Ryder Coal.	Arley Colliery.
	Slate Coal.	Griff Colliery, No. 4 Pit.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Nuneaton Colliery.
	Thick Coal.	Stockingford Colliery.
	Thick Coal.	Tunnel Colliery.
	Thick Coal.	Stockingford Clay-pit.
Calamocladus equisetiformis (Schlotheim).	Above Thick Coal.	Messrs. Stanley's No. 4 clay-pit, Stockingford.
	Ryder Coal.	Arley Colliery.
Calamocladus charæformis (Sternberg).	Above Four-Feet Coal.	Alvecote Clay-pit.
	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Wyken Colliery.
	Below Bench Coal.	Amington Colliery.
	Below Bench Coal.	Peel Colliery.
Annularia stellata Schlotheim.	Haunchwood Sandstones.	New sinking at Biddles Wood, near Kingsbury.
Annularia radiata Brongniart.	Thick Coal.	Chilvers Coton Clay-pit.
	Below Seven-Feet Coal.	Alvecote Colliery.
	Bench Coal.	Pooley-Hall Colliery.
Annularia galioides (Lindley & Hutton).	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Newdigate Colliery.
Calamostachys germanica Weiss.	Thick Coal.	Chilvers Coton Clay-pit.
Calamostachys ludwigi Carruthers.	Thick Coal.	Chilvers Coton Clay-pit.
Calamostachys ramosa Weiss.	Thick Coal.	Chilvers Coton Clay-pit.

[1] The number of localities from which each species has been obtained gives some indication of the relative abundance of that species throughout the Coalfield.

Species.	Horizon.	Locality.
SPHENOPHYLLALES.		
Sphenophyllum cuneifolium (Sternberg).	Above Four-Feet Coal.	Alvecote Clay-pit.
	Ryder Coal.	Baddesley Colliery.
	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Stockingford Clay-pit.
	Thick Coal.	Nuneaton Colliery.
	Below Seven-Feet Coal.	Amington Colliery.
	Below Seven-Feet Coal.	Peel Colliery.
Sphenophyllum cuneifolium var. *saxifragæfolium* (Sternberg).	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Stockingford Clay-pit.
	Below Seven-Feet Coal.	Peel Colliery.
Sphenophyllum majus (Bronn).	Above Thick Coal.	Griff Clay-pit.
	Ryder Coal.	Baddesley Colliery.
Sphenophyllum myriophyllum Crépin.	Thick Coal.	Keresley Boring, at the depth of 2035 feet.
	Below Seven-Feet Coal.	Amington Colliery.
	Below Seven-Feet Coal.	Peel Colliery.
Sphenophyllum emarginatum Brongniart.	Haunchwood Sandstones.	Whitmore-Park Boring, at the depth of 1670 feet.
	Haunchwood Sandstones.	New sinking at Biddles Wood, near Kingsbury.
FILICALES and PTERIDOSPERMÆ.		
Alethopteris decurrens (Artis).	Thick Coal.	Newdigate Colliery.
	Thick Coal.	Wyken Colliery.
Alethopteris lonchitica (Schlotheim).	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Newdigate Colliery.
	Thick Coal.	Stockingford Clay-pit.
	Below Seven-Feet Coal.	Alvecote Colliery.
Dactylotheca plumosa (Artis).	Ryder Coal.	Baddesley Colliery.
Mariopteris muricata (Schlotheim).	Ryder Coal.	Kingsbury Colliery.
	Ryder Coal.	Arley Colliery.
	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Wyken Colliery.
Mariopteris latifolia (Brongniart).	Slate Coal.	Griff Colliery, No. 4 Pit.
	Thick Coal.	Nuneaton Colliery.
	Thick Coal.	Wyken Colliery.
Neuropteris impar (Weiss) ...	Ryder Coal.	Arley Colliery.
	Thick Coal.	Nuneaton Colliery.
	Thick Coal.	Newdigate Colliery.
Neuropteris gigantea Sternberg.	Above Thick Coal.	Griff Clay-pit.
	Ryder Coal.	Kingsbury Colliery.
	Slate Coal.	Griff Colliery, No. 4 Pit.
	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Binley Colliery.
	Thick Coal.	Newdigate Colliery.
	Thick Coal.	Nuneaton Colliery.
	Thick Coal.	Stockingford Colliery.
	Thick Coal.	Wyken Colliery.
	Thick Coal.	Stockingford Clay-pit.
Neuropteris heterophylla Brongniart.	Above Thick Coal.	Griff Clay-pit.
	Four-Feet Coal.	Valley Colliery.
	Ryder Coal.	Baddesley Colliery.
	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Newdigate Colliery.
	Thick Coal.	Nuneaton Colliery.
	Thick Coal.	Stockingford Clay-pit.

Species.	Horizon.	Locality.
Neuropteris obliqua (Brongniart).	Four-Feet Coal.	Valley Colliery.
	Ryder Coal.	Arley Colliery.
	Ryder Coal.	Baddesley Colliery.
	Ryder Coal.	Kingsbury Colliery.
	Slate Coal.	Griff Colliery, No. 4 Pit.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Newdigate Colliery.
	Thick Coal.	Nuneaton Colliery.
	Thick Coal.	Wyken Colliery.
	Below Seven-Feet Coal.	Amington Colliery.
Neuropteris rarinervis Bunbury.	Thick Coal.	Chilvers Coton Clay-pit.
	Haunchwood Sandstones.	Whitmore-Park Boring, at the depth of 1670 feet.
Neuropteris schlehani Stur ...	Thick Coal.	Chilvers Coton Clay-pit.
Neuropteris tenuifolia (Schlotheim).	Ryder Coal.	Arley Colliery.
	Thick Coal.	Nuneaton Colliery.
	Thick Coal.	Wyken Colliery.
Neuropteris scheuchzeri Hoffmann.	Haunchwood Sandstones.	Well-sinking near Griff Colliery, Clara Pit, at about 200 feet down.
	Ryder Coal.	Baddesley Colliery.
	Haunchwood Sandstones.	New sinking at Biddles Wood, near Kingsbury.
Neuropteris ovata Hoffmann.	Haunchwood Sandstones.	Well-sinking near Griff Colliery, Clara Pit, at about 200 feet down.
Pecopteris arborescens (Schlotheim).	Keele Beds.	Foleshill Clay-pit, near Coventry.
Pecopteris miltoni (Artis) ...	Haunchwood Sandstones.	Whitmore-Park Boring, at the depth of 1670 feet.
	Haunchwood Sandstones.	Well-sinking near Griff Colliery, Clara Pit, at about 200 feet down.
	Keele Beds.	Foleshill Clay-pit, near Coventry.
Pecopteris polymorpha Brongniart.	Keele Beds.	Foleshill Clay-pit, near Coventry.
Aphlebia crispa (Gutbier) ...	Ryder Coal.	Baddesley Colliery.
Crossotheca schatzlarensis (Stur).	Thick Coal.	Stockingford Clay-pit.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Chilvers Coton Clay-pit.
Sphenopteris sternbergi (Ettingshausen).	Ryder Coal.	Baddesley Colliery.
	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Stockingford Clay-pit.
Sphenopteris crepini (Stur) ...	Thick Coal.	Chilvers Coton Clay-pit.
Sphenopteris furcata Brongniart.	Thick Coal.	Stockingford Clay-pit.
Sphenopteris laurenti Andrae.	Thick Coal.	Chilvers Coton Clay-pit.
Sphenopteris obtusiloba Brongniart.	Ryder Coal.	Arley Colliery.
	Thick Coal.	Newdigate Colliery.
	Thick Coal.	Nuneaton Colliery.
Sphenopteris multifida Lindley & Hutton.	Thick Coal.	Chilvers Coton Clay-pit.
Sphenopteris dissecta Brongniart.	Thick Coal.	Stockingford Clay-pit.
Renaultia footneri (Marrat) ...	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Exhall Colliery.
	Thick Coal.	Newdigate Colliery.
Renaultia chærophylloides Brongniart.	Ryder Coal.	Arley Colliery.
Oligocarpia brongniarti Stur	Thick Coal.	Chilvers Coton Clay-pit.

Species.	Horizon.	Locality.
Zeilleria delicatula (Sternberg).	Thick Coal.	Chilvers Coton Clay-pit.
Lonchopteris bricei Brongniart	Thick Coal.	Wyken Colliery.
Odontopteris lindleyana Sternberg.	Haunchwood Sandstones.	New sinking at Biddles Wood, near Kingsbury.
LYCOPODIALES.		
Lepidodendron aculeatum Sternberg.	Ryder Coal.	Baddesley Colliery.
	Thick Coal.	Stockingford Colliery.
	Thick Coal.	Griff Colliery, Clara Pit.
	Below Seven-Feet Coal.	Peel Colliery.
Lepidodendron dichotomum Sternberg.	Ryder Coal.	Kingsbury Colliery.
Lepidodendron lycopodioides Sternberg.	Ryder Coal.	Baddesley Colliery.
	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Chilvers Coton Clay-pit.
	Thick Coal.	Stockingford Colliery.
	Below Seven-Feet Coal.	Peel Colliery.
Lepidodendron simile Kidston	Ryder Coal.	Arley Colliery.
Lepidodendron obovatum Sternberg.	Ryder Coal.	Kingsbury Colliery.
	Slate Coal.	Griff Colliery, No. 4 Pit.
	Thick Coal.	Griff Colliery, Clara Pit.
	Thick Coal.	Chilvers Coton Clay-pit.
	Below Seven-Feet Coal.	Amington Colliery.
Lepidodendron ophiurus Brongniart.	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Chilvers Coton Clay-pit.
Lepidodendron wortheni Lesquereux.	Ryder Coal.	Arley Colliery.
	Thick Coal.	Chilvers Coton Clay-pit.
Lepidophloios laricinus Sternberg.	Ryder Coal.	Baddesley Colliery.
	Below Seven-Feet Coal.	Amington Colliery.
Lepidophyllum intermedium Lindley & Hutton.	Haunchwood Sandstones.	New sinking at Biddles Wood, near Kingsbury.
Lepidophyllum brevifolium Lesquereux.	Thick Coal.	Chilvers Coton Clay-pit.
Lepidostrobus variabilis Lindley & Hutton.	Thick Coal.	Chilvers Coton Clay-pit.
Lepidostrobus sp., cf. *L. russelianus* Binney.	Thick Coal.	Chilvers Coton Clay-pit.
Sigillaria tessellata Brongniart.	Above Thick Coal.	Griff Clay-pit.
Sigillaria mamillaris Brongniart.	Thick Coal.	Chilvers Coton Clay-pit.
Sigillaria diploderma Corda.	Thick Coal.	Chilvers Coton Clay-pit.
Sigillaria elongata Brongniart	Thick Coal.	Nuneaton Colliery.
Sigillaria sp., cf. *S. davreuxi* Brongniart.	Ryder Coal.	Arley Colliery.
Sigillaria scutellata Brongniart.	Above Thick Coal.	Griff Clay-pit.
Asolanus camptotænia (Wood)	Haunchwood Sandstones.	New sinking at Biddles Wood, near Kingsbury.
Stigmaria ficoides (Sternberg).	At all horizons.	
Pinnularia sp.	Ryder Coal.	Kingsbury Colliery.
CORDAITALES.		
Cordaites borassifolius (Sternberg).	Above Thick Coal.	Griff Clay-pit.
	Ryder Coal.	Kingsbury Colliery.
	Thick Coal.	Nuneaton Colliery.
Cordaites principalis (Germar)	Above Thick Coal.	Griff Clay-pit.
	Haunchwood Sandstones.	New sinking at Biddles Wood, near Kingsbury.
	Nuneaton Clays.	Messrs. Stanley's clay-pit, Chilvers Coton.

Species.	Horizon.	Locality.
Artisia transversa (Artis)......	Above Thick Coal.	Messrs. Stanley's No. 4 clay-pit, Stockingford.
	Thick Coal.	Stockingford Colliery.
Cordaianthus pitcairniæ (Lindley & Hutton).	Below Seven-Feet Coal.	Amington Colliery.
Walchia sp.	Keele Beds.	New sinking at Keresley.
SEMINA INCERTÆ SEDIS.		
Trigonocarpus parkinsoni Brongniart.	Thick Coal.	Newdigate Colliery.
Samaropsis fluitans (Dawson).	Ryder Coal.	Tunnel Colliery.
Cardiocarpus cordai (Geinitz).	Ryder Coal.	Baddesley Colliery.
Cardiocarpus congruens Grand'Eury.	Thick Coal.	Chilvers Coton Clay-pit.
Carpolithes cf. *areolatus* (Boulay).	Thick Coal.	Stockingford Clay-pit.
Rhabdocarpus sulcatus (Presl).	Thick Coal.	Griff Colliery, Clara Pit.
Rhabdocarpus elongatus Kidston.	Thick Coal.	Newdigate Colliery.
	Thick Coal.	Chilvers Coton Clay-pit.
INCERTÆ SEDIS.		
Bark of unknown plant.	Ryder Coal.	Arley Colliery.

The Calamites from Warwickshire are of particular interest, because, in addition to the common mode of preservation as medullary casts, it is not unusual to find specimens preserved in the much rarer condition of casts of the external surface of the plant. Several examples of such external casts have been collected; they belong to the following three species:—

CALAMITES GŒPPERTI Ettingshausen. A specimen from the Ryder Coal at Arley Colliery shows two nodes, each furnished with a verticil of branch-scars; these are separated one from the other by six barren nodes, on one of which a solitary branch-scar is borne. A typical example of this species from above the Thick Coal in the Griff Clay-pit is figured in Pl. LVII, fig. 10.

CALAMITES RAMOSUS Artis. An external cast of this plant from the Thick Coal of the Griff Colliery, Clara Pit, has very rough internodes marked by longitudinal lines; and, in places where the coaly film has been stripped off, a meshwork of large rectangular cells may be seen.

CALAMITES SUCKOWI Brongniart. With some doubt I refer to this species an external cast of a Calamite from the Ryder Coal of Arley Colliery. The short, wide internodes are marked with large irregular, longitudinal cracks, and with fine regular striæ which run in the same direction. One node has a verticil of contiguous, circular branch-scars, each of which measures about 8 centimetres in diameter, and has a nipple-like central portion projecting above the surface of the plant.

The stems of Calamites are very common at all horizons in the Coal Measures, but the leaves (*Annularia*, Pl. LIX, fig. 4, and *Calamocladus*) are much rarer; while the fructifications (*Calamostachys* and *Palæostachya*, Pl. LVII, fig. 5) have only been seen at the Chilvers Coton Clay-pit.

Neuropteris gigantea Sternberg. Three varieties of this species have been collected. The typical form (Pl. LIX, fig. 3) is the only common one, but at Chilvers Coton Clay-pit it is accompanied by a variety with elongate pinnules. From the Stockingford Clay-pit a variety with unsymmetrical pinnules has been obtained.

Neuropteris schlehani Stur (Pl. LVIII, fig. 1). This plant has only been found at one locality, where several different varieties are common.

Neuropteris scheuchzeri Hoffmann (Pl. LIX, fig. 6). This species, together with *N. ovata* Hoffmann (Pl. LIX, fig. 5), is very abundant in the Haunchwood Sandstones at Griff, where the large and small cyclopteroid pinnules and the terminal pinnules from the frond all occur detached.

Sphenopteris multifida Lindley & Hutton.[1] The distinctive characters of this species (see Pl. LVIII, fig. 10) are somewhat obscure, as the type-specimen is lost; and the enlarged drawing given by Lindley & Hutton does not agree with their figure showing the plant of natural size, in that the acute character of the pointed pinnules appears to be exaggerated in the enlarged figure.

Lepidodendron. Many specimens of this genus, belonging to several species, have been obtained from the Thick Coal exposed in Chilvers Coton Clay-pit. The fossils are commonly preserved as casts of the exterior of the bark of the plant, but leafy branches, detached leaves (*Lepidophyllum*), cones (*Lepidostrobus*), and macrospores also occur, and the latter abound both in the shales and in the coal itself. A specimen of a cone containing macrospores is figured in Pl. LIX, fig. 1.

Bark of unknown plant (Pl. LVIII, fig. 4). This specimen appears to be the bark of a Lycopodiaceous plant somewhat similar to, but quite distinct from, *Bothrodendron*. Two leaf-scars are shown.

Sigillaria elongata Brongniart. The specimen figured in Pl. LVIII, fig. 8 is a small portion of the bark from a large tree. Such trees are common at the horizon of the Thick Coal.

[1] 'Fossil Flora' vol. ii (1833–35) p. 113 & pl. cxxiii.

Rhabdocarpus elongatus Kidston.[1] To this species is referred a seed (Pl. LVII, fig. 4) from Newdigate Colliery, which, though 10 mm. longer than the type figured by Dr. Kidston, closely agrees with the type in general shape and ornamentation.

The distribution, in the Upper Carboniferous of Britain, of the species which comprise the flora of the Productive Measures of Warwickshire, is as follows:—

Distribution of Upper Carboniferous Species which occur in the Productive Coal Measures of Warwickshire.

Species.	Upper Coal Measures.	Transition Series.	Middle Coal Measures.	Lower Coal Measures.
Equisetales.				
Calamites gœpperti Ett.	...	×	×	×
Calamites varians Sternb.	×	×	×	×
Calamites undulatus Sternb.	×	×	×	×
Calamites ramosus Artis	×	×	×	×
Calamites approximatus Brongn.	...	×	×	×
Calamites cisti Brongn.	×	×	×	×
Calamites suckowi Brongn.	×	×	×	×
Calamocladus charæformis (Sternb.)	...	×	×	...
Calamocladus equisetiformis (Schloth.)	×	×	×	×
Annularia radiata Brongn.	...	×	×	×
Annularia galioides (L. & H.)	...	...	×	×
Calamostachys germanica Weiss.	...	...	×	×
Calamostachys ramosa Weiss	...	...	×	×
Palæostachya ettingshauseni Kidston	...	...	×	...
Sphenophyllales.				
Sphenophyllum cuneifolium (Sternb.).	...	×	×	×
Sph. cuneifolium var. *saxifragæfolium* (Sternb.)	...	...	×	×
Sphenophyllum majus (Bronn)	×	...	×	×
Sphenophyllum myriophyllum Crépin.	...	...	×	×
Pteridosperms and Primofilices.				
Alethopteris decurrens (Artis)	×	?	×	×
Alethopteris lonchitica (Schloth.)	×	×	×	×
Dactylotheca plumosa (Artis)	×	×	×	×
Dactylotheca plumosa var. *dentata* (Brongn.)	×	...	×	...
Mariopteris muricáta (Schloth.)	×	×	×	×
Mariopteris latifolia (Brongn.)	...	...	×	×
Neuropteris impar (Weiss)	...	...	×	×
Neuropteris gigantea Sternb.	...	×	×	×
Neuropteris heterophylla Brongn.	×	×	×	×
Neuropteris obliqua (Brongn.)	...	×	×	×
Neuropteris rarinervis Bunb.	×	×	×	...
Neuropteris schlehani Stur	...	...	×	...
Neuropteris tenuifolia (Schloth.)	...	×	×	...
Aphlebia crispa (Gutbier)	×	×	×	...

[1] Trans. Geol. Soc. Glasg. vol. viii (1885–88) p. 70 & pl. iii, fig. 6.

Distribution of Upper Carboniferous Species (*continued*).

Species.	Upper Coal Measures.	Transition Series.	Middle Coal Measures.	Lower Coal Measures.
Crossotheca schatzlarensis (Stur) ...	...	...	×	...
Sphenopteris crepini (Stur)	...	...	×	...
Sphenopteris sternbergi (Ett.)	...	...	×	×
Sphenopteris furcata Brongn.	...	...	×	×
Sphenopteris laurenti Andrae	...	...	×	×
Sphenopteris obtusiloba Brongn.	...	×	×	×
Sphenopteris multifida L. & H.	...	...	×	...
Sphenopteris dissecta Brongn.	...	...	×	×
Renaultia footneri (Marrat)	...	...	×	×
Renaultia chærophylloides (Brongn.).	...	...	×	...
Oligocarpia brongniarti Stur	...	...	×	...
Zeilleria delicatula (Sternb.)	...	...	×	...
Lonchopteris bricei Brongn.	...	...	×	...
Lycopodiales.				
Lepidodendron aculeatum Sternb. ..	×	? ×	×	×
Lepidodendron dichotomum Sternb....	×	×	×	×
Lepidodendron lycopodioides Sternb.	...	? ×	×	×
Lepidodendron simile Kidston	...	...	×	×
Lepidodendron obovatum Sternb. ...	...	...	×	×
Lepidodendron ophiurus Brongn. ...	...	×	×	×
Lepidodendron wortheni Lesq.........	×	×	×	...
Lepidophloios laricinus Sternb.	...	×	×	...
Lepidophyllum brevifolium Lesq. ...	×	...	...	...
Lepidostrobus variabilis L. & H. ...	×	×	×	×
Lepidostrobus cf. *russelianus* Binney	...	...	×	...
Sigillaria tessellata Brongn.	...	×	×	×
Sigillaria elongata Brongn.	...	×	×	...
Sigillaria cf. *davreuxi* Brongn.	...	...	×	...
Sigillaria mamillaris Brongn..........	...	×	×	×
Sigillaria diploderma Corda...........	...	...	×	...
Sigillaria scutellata Brongn.	...	×	×	×
Stigmaria ficoides (Sternb.)	×	×	×	×
Cordaitales.				
Cordaites borassifolius (Sternb.)	×	×	×	×
Cordaites (?) principalis (Germ.) ...	...	×	×	×
Artisia transversa (Artis)	...	×	×	...
Cordaianthus pitcairniæ (L. & H.)...	...	...	×	×
Semina.				
Trigonocarpus parkinsoni Brongn....	...	×	×	×
Rhabdocarpus elongatus Kidst.	...	...	×	×
Rhabdocarpus sulcatus (Presl)	×	×	×	...
Samaropsis fluitans (Dawson)	×	×	×	...
Cardiocarpus cordai (Geinitz)	...	...	×	...
Cardiocarpus congruens Grand'Eury.	...	...	×	...
Carpolithes cf. *areolatus* (Boulay) ...	...	...	×	...

From the foregoing table it can be clearly seen that this is a typical Middle Coal-Measure Flora. It is distinguished from the flora of the Transition Series and the Upper Coal Measures by the fact that many of the species have never been recorded from these higher horizons. The majority of the species occur both in the Middle Coal Measures and in the Lower Coal Measures of Britain; but the presence of a number of plants, such as *Oligocarpia brongniarti*, *Zeilleria delicatula*, and *Lonchopteris bricei*, which are restricted to the Middle Coal Measures of Britain, at once differentiates the flora from that of the Lower Coal Measures.

It may perhaps be contended that a thin representative of the Lower Coal Measures might be present in the north of the Warwickshire Coalfield, where the thickness of Productive Coal Measures reaches its maximum. In this connexion the species tabulated below, which are from the two lowest seams—the Bench Coal and the Double Coal—towards the base of the Coal Measures (see vertical section, Pl. LXI), are of especial interest.

Distribution of Upper Carboniferous Species which occur in association with the Lowest Coals in the Warwickshire Coalfield.

Species.	Middle Coal Measures.	Lower Coal Measures.
Equisetales.		
Calamites ramosus Artis	×	×
Calamites varians Sternb.	×	×
Calamites undulatus Sternb.	×	×
Annularia radiata Brongn.	×	×
Calamocladus charæformis Sternb.	×	...
Sphenophyllales.		
Sphenophyllum cuneifolium Sternb.	×	×
Sph. cuneifolium var. *saxifragæfolium* (Sternb.)	×	×
Sphenophyllum myriophyllum Crépin	×	×
Pteridosperms and Primofilices.		
Alethopteris lonchitica (Schloth.)	×	×
Neuropteris obliqua Brongn.	×	×
Lycopodiales.		
Lepidodendron aculeatum Sternb.	×	×
Lepidodendron lycopodioides Sternb.	×	×
Lepidodendron obovatum Sternb.	×	×
Lepidophloios laricinus Sternb.	×	...
Cordaitales.		
Cordaianthus pitcairniæ (L. & H.)	×	×

From the presence in the foregoing list of *Lepidophloios laricinus* and *Calamocladus charæformis*, which are unknown from the Lower Coal Measures of Britain, it is concluded that in the Warwickshire Coalfield the Lower Coal Measures are entirely absent, and that the lowest palæobotanical horizon is that of the Middle Coal Measures.

On field evidence the arenaceous strata containing a few thin coals, which occur between the Thick Coal and the Nuneaton Clays, have been included in the Middle Coal Measures; while the Nuneaton Clays and the Haunchwood Sandstones, the latter being also an arenaceous series with one or more thin coals, have been placed with the Keele Beds in the Upper Coal Measures. We will now consider the palæontological evidence for this classification.

The range in time of the plants from the upper beds of the Productive Measures is recorded in the following table:—

Distribution of Upper Carboniferous Species which occur in the Upper Beds of the Productive Coal Measures of Warwickshire.

Species.	Upper Coal Measures.	Transition Series.	Middle Coal Measures.
Equisetales.			
Calamites gœpperti Ett.	...	×	×
Calamites varians Sternb.	×	×	×
Calamites cisti Brongn.	×	×	×
Calamites suckowi Brongn.	×	×	×
Calamocladus equisetiformis (Schloth.)	×	×	×
Sphenophyllales.			
Sphenophyllum majus (Bronn)	×	...	×
Pteridosperms and Primofilices.			
Neuropteris gigantea Sternb.	...	×	×
Neuropteris heterophylla Brongn.	×	×	×
Lycopodiales.			
Sigillaria tessellata Brongn.	...	×	×
Cordaitales.			
Cordaites borassifolius (Sternb.)	×	×	×
Cordaites principalis (Germ.)	...	×	×
Artisia transversa (Artis)	...	×	×

The absence of typical Upper Coal-Measure species and the abundance of *Neuropteris gigantea* are sufficient evidence to prove that the beds immediately above the Thick Coal, including the Four-Feet Sandstone, are Middle Coal Measures.

We may now conclude that the whole of the lower or productive division of the Coal Measures of Warwickshire, up to the base of the Nuneaton Clays, is of Middle Coal-Measure age.

The Upper or Barren Coal-Measures will next be considered. In the following table a list is given of the fossil plants which have been obtained from the Keele Beds, the Haunchwood Sandstones, and the Nuneaton Clays:—

Species.	Keele Beds.	Haunchwood Sandstones.	Nuneaton Clays.
Annularia stellata Schlotheim	...	×	...
Calamites sp.	×	...	...
Calamites sp.	...	...	×
Calamites sp.	...	×	...
Sphenophyllum emarginatum Brongn.	...	×	...
Neuropteris rarinervis Bunb.	...	×	...
Neuropteris scheuchzeri Hoffmann	...	×	...
Neuropteris ovata Hoffmann	...	×	...
Odontopteris lindleyana Sternberg	...	×	...
Pecopteris arborescens (Schloth.)	×	...	...
Pecopteris miltoni (Artis)	...	×	...
Pecopteris cf. *miltoni* (Artis)	×	...	...
Pecopteris miltoni var. *abbreviata* Brongn.	...	×	...
Pecopteris polymorpha Brongn.	×	...	...
Pecopteris sp. (villose condition)	...	×	...
Lepidophyllum intermedium L. & H.	...	×	...
Stigmaria ficoides (Sternb.)	...	×	...
Cordaites principalis (Germar)	...	...	×
Asolanus camptotænia Wood	...	×	...
Walchia sp.	×	...	...

The distribution of these plants in the Upper Coal Measures of Britain is indicated below:—

Distribution of the Upper Carboniferous Species which occur in the Upper Coal Measures of Warwickshire.

Species.	Upper Coal Measures.	Transi-tion Series.	Middle Coal Measures.	Lower Coal Measures.
Annularia stellata Schlotheim	×	×	...	...
Sphenophyllum emarginatum Brongn.	×	×	...	...
Neuropteris rarinervis Bunb.	×	×	×	...
Neuropteris scheuchzeri Hoffmann	×	×	×	...
Neuropteris ovata Hoffmann	×	×	...	...
Odontopteris lindleyana Sternberg	×	×	...	...
Pecopteris arborescens (Schloth.)	×	...	...	...
Pecopteris miltoni (Artis)	×	×	×	×
Pecopteris miltoni var. *abbreviata* Brongn.	×	×	×	×
Pecopteris polymorpha Brongn.	×	...	...	...
Stigmaria ficoides (Sternb.)	×	×	×	×
Cordaites principalis (Germar)	...	×	×	×
Lepidophyllum intermedium L. & H.	...	×	×	×
Asolanus camptotænia Wood	×	×	×	×

If we exclude from this list the variety of *Pecopteris miltoni* and the ubiquitous *Stigmaria ficoides*, there remain twelve species. Two of these range throughout, and two occur in the three uppermost divisions; while four species are restricted to the Upper Coal Measures and Transition Series, and two are only known to occur in the Upper Coal Measures. It is clear, therefore, that this is an Upper Coal-Measure flora. The abundance of *Pecopteris polymorpha* in the Keele Beds is evidence of their Upper Coal-Measure age.

In the Haunchwood Sandstones we have a mixture of forms. The Upper Coal-Measure species *P. polymorpha*, which is very rare at this horizon, occurs, together with an abundance of such typical Transition species as *Neuropteris scheuchzeri*, *N. ovata*, *N. rarinervis*, and *Sphenophyllum emarginatum*. The Haunchwood Sandstones must, therefore, be referred to the Transition Series, in which the red Nuneaton Clays may also be placed.

The striking contrast, between the rich flora of the Middle Coal Measures and the meagre flora of the Transition Series and the Upper Coal Measures, raises an important question with regard to the meaning of this difference. The partial extinction of the Middle Coal-Measure species of plants, and the incoming of the Upper Coal-Measure Pecopterids and Conifers (which are essentially Stephanian species ranging upwards into the Permian), appears to have taken place during the period of formation of the Nuneaton Clays. At the same time the abundant fauna of the Middle Coal Measures becomes reduced to a few species of fishes, ostracoda, and *Spirorbis*. We may expect such profound palæontological changes to have been accompanied by important changes in the lithological characters of the deposits then in course of formation, and, in fact, such is the case.

The Nuneaton Clays mark the appearance of the first red sediments among the grey rocks of the Coal Measures. In these red strata are found the first Espley Rocks and *Spirorbis* Limestones, while rocks foreign to the coalfield now become common as pebbles in the breccias. These breccias in the Nuneaton Clays suggest that a local unconformity may occur at this horizon, an opinion which receives some support from the fact that there is in Warwickshire no equivalent of the Black-Band Group of North Staffordshire. In conclusion, it may be affirmed that the horizon of the Nuneaton Clays marks the initiation of those continental conditions in the English Midlands which continued throughout Permian and Triassic times.

(B) The Fossil Fauna.

In addition to the fossil flora recorded above, the Middle Coal Measures have also yielded evidence of an extensive fauna. In this paper it is not proposed to describe these fossils in detail: it seems desirable, however, to refer briefly to them, not only on account of the extreme rarity of some of the species, but also because the fauna as a whole may be expected to provide further evidence regarding the age of the beds. The collection includes fishes, crustacea, and mollusca.

Two distinct faunas, which never commingle, are represented; one of these appears to be marine, and the other is of freshwater habitat.

The freshwater lamellibranchiata.—A large number of shells have been obtained, chiefly from the roof of the Thick Coal or from the uppermost subdivision of that seam, the Two-Yard or Four-Feet Coal. The following general section of the strata forming the roof of this coal shows the mode of occurrence of the shells:—

(3) Rock. (A hard grey sandstone.)
(2) Grey sandy shale, with small nodules of ironstone.
(1) Black laminated carbonaceous shale.
Two-Yard Coal.

The black shale (1) is a prolific horizon for the genus *Carbonicola*—indeed, so abundant are these fossils in the shale and so constantly does this 'mussel-band' occur at this horizon throughout the coalfield, that it may be used as an index for the identification of the coal. Shells of this genus also occur, but more sparingly in the grey shales (2) and in the nodules of ironstone contained therein. But, while the specimens from the latter bed appear in the form of internal casts in ironstone and are generally very small, those from the former have the periostracum preserved and are usually much larger and apparently more robust. This fossil horizon has been detected at the following nine collieries:—

Colliery.	*Horizon.*	*Colliery.*	*Horizon.*
Arley	Ryder Coal.	Nuneaton	Thick Coal.
Baddesley	Ryder Coal.	Stockingford ...	Thick Coal.
Binley	Thick Coal.	Tunnel............	Thick Coal.
Kingsbury	Ryder Coal.	Wyken	Thick Coal.
Newdigate	Thick Coal.		

The fossils which have been obtained from the foregoing localities are recorded in the following list:—

Species.	Occurrence.
Carbonicola aquilina (Sow.).	Constant throughout the coalfield.
Carbonicola similis (Brown).	Kingsbury Colliery.
Carbonicola obtusa Hind.	Kingsbury Colliery; Tunnel Colliery.
Carbonicola turgida (Brown).	Binley Colliery; Tunnel Colliery.
Naiadites carinata (Sow.).	Arley Colliery; Griff Clara Colliery; Tunnel Colliery.
Anthracomya williamsoni (Brown).	Kingsbury Colliery; Baddesley Colliery.

It is noteworthy that in this list of freshwater lamellibranchiata there is a complete absence of those forms, such as *Carbonicola robusta*, which in other coalfields are restricted to the Lower Coal Measures. And, further, all the species recorded above are common Middle Coal-Measure fossils. This suggests that the Productive Coal Measures must be of Middle Coal-Measure age—a conclusion which agrees with that arrived at from a study of the fossil flora.

The marine fauna.—The bulk of the Coal-Measure sediments of this coalfield were undoubtedly laid down in fresh water, and the abundant remains of a terrestrial flora which they contain indicate the proximity of land throughout the time that elapsed during the deposition of the beds. But, during one period, the subsidence was of such an extent that the sea invaded the area, and the deposits thus formed contain marine forms of animal life.

This marine bed occurs in the roof of the Seven-Feet Coal; it consists of dark-blue shale, containing hard ovoid nodules of clay-ironstone. Fossils are found both in the shale and in the ironstone; but in the former they are usually crushed flat, while in the latter uncrushed specimens may sometimes be found. The marine shale, which contains a large amount of pyrite disseminated through it, has a characteristic mode of weathering quite different from that of ordinary non-marine Coal-Measure shales; and this is accompanied by the formation of selenite, which usually occurs as radiating masses of crystals. The ironstones are but little affected by exposure to the atmosphere, and thus it has been possible to collect fossiliferous nodules from the waste-tips of collieries which have been abandoned for at least 30 years. The marine horizon has been found at the following seven collieries:—

Valley Colliery.	Pooley-Hall Colliery.
Glascote Colliery.	Alvecote Colliery.
Amington Colliery.	Hockley-Hall Old Pit (abandoned).

Birch Coppice, No. 1 Pit (abandoned).

The marine bed thus appears to be invariably present immediately above the Seven-Feet Coal, throughout the whole of the northern portion of the coalfield.[1]

In the south, at Blackatree Farm, near Wash-Lane Bridge, Nuneaton, an old trial-shaft sunk on the outcrop of the Thick Coal yielded a small amount of dark-blue shale containing fish-remains and *Lingula mytiloides* Sow. As this shale comes from the bottom of the shaft, some distance below the Thick Coal, it is probably from the Seven-Feet Coal marine bed. The fossils from this stratum are tabulated in the following list:—

[1] Another marine bed may be present above the Thick Coal, but on this point palæontological evidence is still incomplete.

List of Fossils from the Marine Bed in the Roof of the Seven-Feet Coal.

Species.	Birch-Coppice Old Pit.	Amington Colliery.	Glascote Colliery.	Valley Colliery.	Hockley-Hall Old Pit.	Pooley-Hall Colliery.	Alvecote Colliery.
Annelida.							
Spirorbis sp.	×	×	×	×	×	×	×
Brachiopoda.							
Lingula mytiloides Sow.	×	×	×	×	×	×	×
Orbiculoidea sp.	...	...	...	...	...	...	×
Lamellibranchiata.							
Aviculopecten gentilis Sow.	×	...	...	...	...	...	...
Pterinopecten papyraceus (Sow.).	×	×	×	×	×	×	×
Myalina compressa Hind	×	×	×	×	×	×	×
Myalina cf. *flemingi* M'Coy	...	...	...	...	...	×	...
Nucula undulata Phillips	...	×	...	...	...	...	...
Nucula sp.	×	×	×	...	...	×	...
Schizodus sp.	...	...	...	...	...	×	...
Pteronites, sp. nov.	...	...	...	...	...	×	...

In addition to the fossils in the above list, ostracoda occur at each locality, and from Hockley-Hall Pit a few badly-preserved specimens of gasteropoda have been obtained.

The list shows that apparently the cephalopoda are entirely absent, and that the lamellibranchiata predominate over the brachiopoda. Three of the species in this bed are exceedingly common; they are:—*Lingula mytiloides* (Sow.), *Pterinopecten papyraceus* Sow., and *Myalina compressa* Hind. The first two are also abundant in the marine beds of other coalfields; but *M. compressa*, which is the characteristic fossil of this bed, is not common in other areas.

The fossil figured in Pl. LX, fig. 6 is an internal cast of a shell, to which is attached a specimen of *Lingula mytiloides* Sow., but the latter is not shown in the photograph. Dr. Wheelton Hind considers the shell to be a freshwater *Carbonicola*, which has been washed into the marine bed.

Fossil fishes.—At least three fish-bearing beds have been detected in the Middle Coal Measures, and their position in the sequence is shown below:—

1. Thick Coal (and its constituent seams: the Ryder Coal and the Slate Coal).
2. Seven-Feet Coal. (Fish-band in the Marine Bed.)
3. { Double and Bench Coals.

1. From the first horizon the following species have been obtained:—

Species.	Horizon.	Locality.
Megalichthys hibberti Agassiz. (Teeth.)	Thick Coal.	Nuneaton Colliery.
Rhizodopsis sauroides Willm. (Scales.)	Slate Coal. Thick Coal.	Griff No. 4 Pit. Newdigate Colliery.
Elonichthys sp.	Thick Coal.	Newdigate Colliery.
Diplodus sp.	Four-Feet Coal.	Valley Colliery.

Indeterminable fragments of fishes were also found in small nodules of clay-ironstone from this horizon at the Tunnel, Binley, and Kingsbury Collieries.

2. From the Marine Bed only two genera have been obtained:—

Elonichthys sp. (Scales.)	Glascote Colliery. Birch Coppice, No. 1 Pit.
Megalichthys hibberti Agassiz. (Scales.)	Amington Colliery.
Megalichthys sp. (Teeth.)	Glascote Colliery.

3. The following occurred in a carbonaceous shale from the Double and Bench Coals at Pooley-Hall Colliery:—

Megalichthys hibberti Agassiz. (Scales and teeth.)
Rhizodopsis sauroides Willm. (Scales.)
Platysomus parvulus Young. (Scales.)
Acanthodes wardi Egerton. (Fin-spines.)
Cœlacanthus elegans Newb. (Scales.)
Elonichthys sp. (Scales.)

This horizon was seen at Amington Colliery, where the fish-remains are found, in association with *Carbonicola*, *Spirorbis*, and ostracoda, in a black shale said to come from the Double Coal.

It is interesting to notice the varied habitat of these ubiquitous organisms, *Spirorbis* and ostracoda. They occur in the Middle Coal Measures associated with freshwater shells, such as *Carbonicola* and its allies; but they are equally common in the marine shales, where the shells of *Pterinopecten* are frequently covered with the casts of *Spirorbis*. In the upper beds of the Productive Measures, where mollusca appear to be absent, *Spirorbis* is found adherent to the stems of *Calamites gœpperti*. These fossils are still more abundant in the Upper Coal Measures, but they appear to be restricted to the *Spirorbis* Limestones. The *Spirorbis* Limestone in the Nuneaton Clays is crowded with *Spirorbis* and ostracoda: they are common in the limestones in the Haunchwood Sandstones and persist into the Keele Beds; but they finally die out in the thin and almost unfossiliferous limestone near the top of the Keele Beds.

Finally, the following fossils are mentioned in this brief summary of the fauna, because of their great rarity:—

Species.	Horizon.	Locality.
Arthropoda.		
Arthropleura armata (Jordan). (Pl. LX, fig. 11.)	Ryder Coal.	Baddesley Colliery.
Eurypterus sp.	Thick Coal.	Newdigate Colliery.
Anthrapalæmon sp. (Pl. LX, fig. 7.)	Seven-Feet Coal. Marine Bed.	Amington Colliery.
Leaia leidyi var. *salteriana* Jones	Haunchwood Sandstones.	New pit at Biddles Wood, near Kingsbury.
Incertæ sedis.		
Vetacapsula cooperi Mackie & Crocker. (Pl. LX, fig. 3.)	Thick Coal.	Chilvers Coton Clay-pit.

In addition to its intrinsic interest, this fossil fauna, and more especially the marine fauna, may be expected to prove of considerable value in distinguishing definite positions in the Coal-Measure sequence, for which purpose only the coal-seams are at present available.

V. General Conclusions.

The detailed description of the rocks and of their organic contents being now completed, it will be convenient to summarize the chief facts, which will be best understood from the appended table (p. 635).

The general conclusions of this paper may be summarized as follows:—

1. On stratigraphical and palæontological evidence it is shown that a large area of rocks in Warwickshire, previously mapped as Permian, is really of Carboniferous age.

2. The Carboniferous rocks are subdivided into groups which, on palæobotanical evidence, are proved to belong to the following three horizons of the Westphalian Series:—

Upper Coal Measures.
Transition Measures.
Middle Coal Measures.

And the Lower Coal Measures are found to be absent.

3. The fossil flora of the Middle Coal Measures, the Transition Measures, and the Upper Coal Measures is discussed, and a brief account is given of the freshwater and marine faunas of the Middle Coal Measures.

4. The Carboniferous rocks of Warwickshire are correlated with those of the other coalfields of the Midland province, and it can thus be demonstrated that there is a marked southward attenuation and overlap of each of the subdivisions of the Carboniferous System.

5. Some account of the Permian and the Trias is given, in order to make clear the unconformable relationship of the Permian to the Carboniferous on the one hand, and that of the Trias to the whole of the Palæozoic rocks of the district on the other.

SYNOPSIS OF THE CARBONIFEROUS AND PERMIAN FORMATIONS OF WARWICKSHIRE.

Name.	*Characters.*	*Chief Fossils.*	*Thickness.*
PERMIAN.	Calcareous, false-bedded red sandstones and lenticular red marls spotted with green; with two horizons of limestone conglomerates, the lowest of which forms the base.	*Walchia* sp. *Walchia imbricata* Schimper. *Calamites* sp. *Dasyceps bucklandi* (Lloyd). *Oxyodon britannicus* von Huene.	? 1000 feet.
KEELE BEDS.	Red and purple sandstones and marls, with marly breccias and, towards the base, beds of grey sandstone. Three thin beds of *Spirorbis* Limestone, the lowest (and thickest) of which is taken as the base.	*Walchia* sp. *Pecopteris polymorpha* Brongn. *Pecopteris arborescens* Schloth. *Pecopteris miltoni* (Artis). *Spirorbis.* Ostracoda.	1000 to 1500 feet.
HAUNCHWOOD SANDSTONES.	Grey sandstones and shales, with thin coals and *Spirorbis* Limestones; some red mottled marls towards the top.	*Annularia stellata* Schlotheim. *Neuropteris ovata* Hoffmann. *Neuropteris scheuchzeri* Hoffm. *Neuropteris rarinervis* Bunb. *Pecopteris miltoni* (Artis). *Sphenophyllum emarginatum* Brongn. *Leaia leidyi* var. *salteriana* Jones.	300 to 450 feet.
NUNEATON CLAYS.	Red and purple mottled marls and clays, with thin Espley Rocks, a *Spirorbis* Limestone, and local breccias.	*Cordaites principalis* (Germar). *Calamites* sp. *Spirorbis.* Ostracoda. Fish-remains undetermined.	80 to 150 feet.
MIDDLE COAL MEASURES.	Grey sandstones, shales, and underclays, with thick coal-seams and beds of ironstone. Sandstones and breccias towards the top, which thicken northwards. An impersistent conglomerate forms the base.	*Neuropteris schlehani* Stur. *Zeilleria delicatula* (Sternb.). *Sigillaria elongata* Brongn. *Lingula mytiloides* Sow. *Myalina compressa* Hind. *Pterinopecten papyraceus* (Sow.). *Carbonicola aquilina* (Sow.). *Anthracomya williamsoni* (Brown). *Naiadites carinata* (Sow.). *Megalichthys hibberti* Agassiz. *Rhizodopsis sauroides* Willm. *Acanthodes wardi* Egerton.	400 in the south to 700 in the north.

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EXPLANATION OF PLATES LVII–LXI.

[All figures of fossils are of the natural size, except where otherwise stated.]

Plate LVII.

Fig. 1. *Sphenophyllum majus* (Bronn). Ryder Coal, Baddesley Colliery.
2. *Sphenopteris laurenti* Andrae. Thick Coal, Chilvers Coton Clay-pit.
3. *Calamites (Calamitina) undulatus* (Sternberg). Thick Coal, Newdigate Colliery.
4. *Rhabdocarpus elongatus* Kidston. Thick Coal, Newdigate Colliery. (See p. 624.)
5. *Calamostachys ramosa* Weiss. Thick Coal, Chilvers Coton Clay-pit.
6. *Sigillaria tessellata* Brongniart. Upper beds of Productive Measures, Griff Clay-pit, near Nuneaton.
7. *Lepidodendron simile* Kidston. Ryder Coal, Arley Colliery.
8. *Lonchopteris bricei* Brongniart. Thick Coal, Wyken Colliery. $\times \frac{6}{5}$.
9. *Neuropteris* cf. *scheuchzeri* Hoffmann. Ryder Coal, Baddesley Colliery. $\times \frac{2}{3}$.
10. *Calamites (Calamitina) gœpperti* Ettingshausen. Upper beds of Productive Measures, Griff Clay-pit, near Nuneaton. $\times \frac{3}{4}$. (See p. 622.)

Plate LVIII.

Fig. 1. *Neuropteris schlehani* Stur. Thick Coal, Chilvers Coton Clay-pit. $\times \frac{4}{3}$. (See p. 623.)
2. *Sphenopteris crepini* (Stur). Thick Coal, Chilvers Coton Clay-pit.
3. *Sphenopteris sternbergi* (Ettingshausen). Thick Coal, Chilvers Coton Clay-pit. $\times \frac{6}{5}$.
4. Bark of unknown plant. Ryder Coal, Arley Colliery. (See p. 623.)
5. *Sphenopteris sternbergi* (Ettingshausen). Ryder Coal, Baddesley Colliery.
6. *Zeilleria delicatula* (Sternberg). Thick Coal, Chilvers Coton Clay-pit.
7. *Cardiocarpus cordai* (Geinitz). Ryder Coal, Baddesley Colliery. $\times \frac{4}{5}$.
8. *Sigillaria elongata* Brongniart. Thick Coal, Nuneaton Colliery. (See p. 623.)
9. *Sigillaria diploderma* Corda. Thick Coal, Chilvers Coton Clay-pit.
10. *Sphenopteris multifida* Lindley & Hutton. Thick Coal, Chilvers Coton Clay-pit. $\times \frac{3}{2}$. (See p. 623.)

Plate LIX.

Fig. 1. *Lepidostrobus* cf. *russelianus* Binney. Thick Coal, Chilvers Coton Clay-pit. $\times \frac{6}{5}$. (See p. 623.)
2. *Cordaianthus pitcairniæ* (Lindley & Hutton). Below Seven-Feet Coal, Amington Colliery. $\times \frac{3}{2}$.
3. *Neuropteris gigantea* Sternberg. Thick Coal, Newdigate Colliery. (See p. 623.)
4. *Annularia galioides* (Lindley & Hutton). Thick Coal, Chilvers Coton Clay-pit.
5. *Neuropteris* cf. *ovata* Hoffmann. Hauncliwood Sandstones, well-sinking at Griff Colliery, Clara Pit. (See p. 623.)

Fig. 6. *Neuropteris scheuchzeri* Hoffmann. Haunchwood Sandstones, well-sinking at Griff Colliery, Clara Pit. × $\frac{3}{4}$. (See p. 623.)
7. *Sphenopteris laurenti* Andrae. Thick Coal, Chilvers Coton Clay-pit. × $\frac{4}{5}$.
8. *Pecopteris polymorpha* Brongniart. Keele Beds, Foleshill Clay-pit, Longford, Coventry. × 2.
9. *Pecopteris* sp. Haunchwood Sandstones, Whitmore-Park Boring, near Coventry. × $\frac{5}{3}$.
10. *Walchia imbricata* Schimper. Permian, Messrs. Webster's Clay-pit, Stoney-Stanton Road, Coventry. × $\frac{1}{2}$. (See p. 606.)

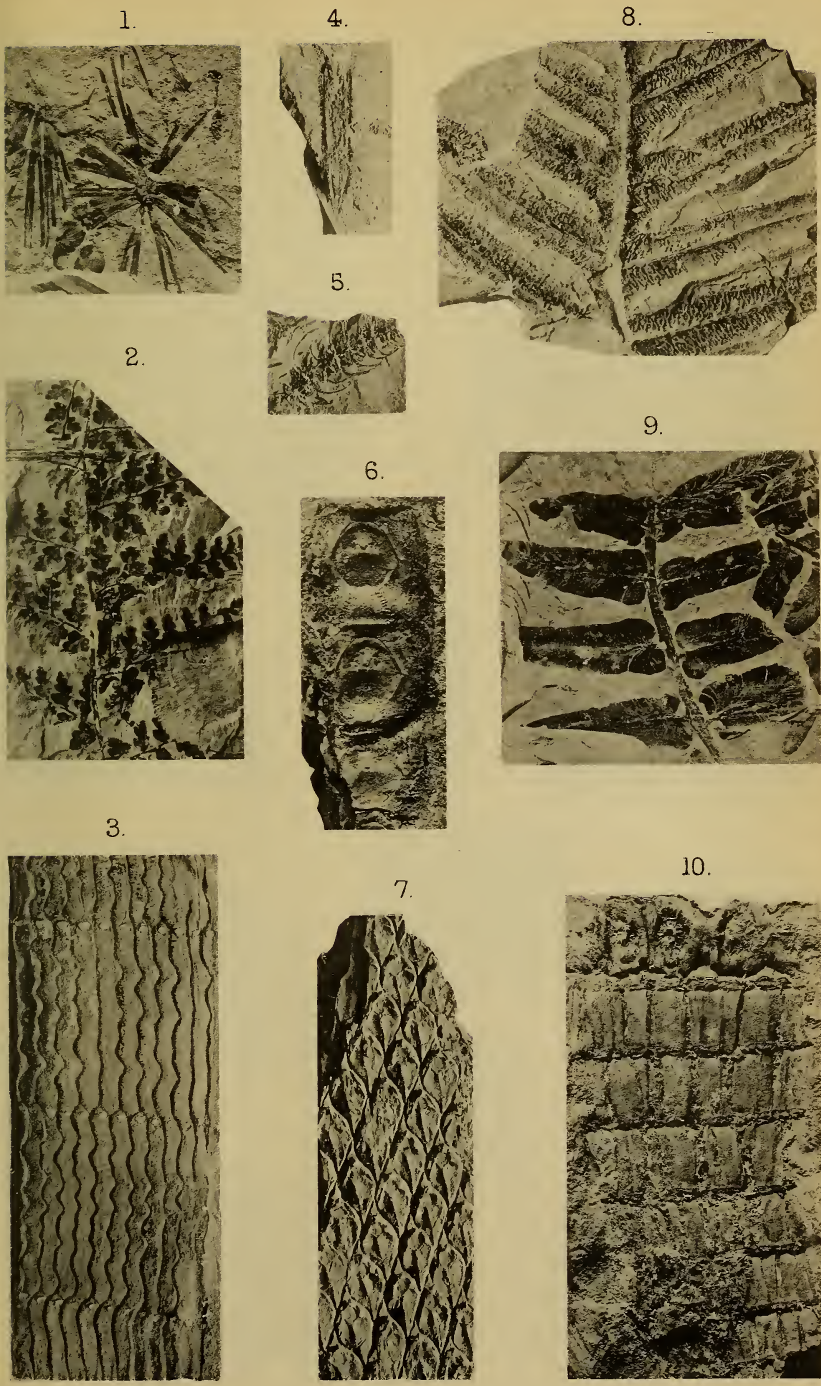
Plate LX.

Fig. 1. The 'Stockingford Clay-Pit,' showing the constituent seams of the Thick Coal (Messrs. Stanley's clay-pit, Arbury Road, Nuneaton).
2. *Carbonicola turgida* (Brown). Ryder Coal, Kingsbury Colliery. × $\frac{3}{4}$.
3. *Vetacapsula cooperi* Mackie & Crocker. Thick Coal, Chilvers Coton Clay-pit. × 2. (See p. 634.)
4. *Anthracomya* sp. Glascote Colliery. × $\frac{3}{4}$.
5. *Nucula undulata* Phillips. Seven-Feet Coal, Marine Bed, Amington Colliery. × $\frac{3}{4}$.
6. *Carbonicola* sp. Seven-Feet Coal, Marine Bed, Pooley-Hall Colliery. × $\frac{3}{4}$. (See p. 632.)
7. *Anthrapalæmon* sp. Seven-Feet Coal, Marine Bed, Amington Colliery. (See p. 634.)
8. *Carbonicola aquilina* (Sow.). Thick Coal, Newdigate Colliery. × $\frac{3}{4}$.
9. *Myalina compressa* Hind. Seven-Feet Coal, Marine Bed, Glascote Colliery. × $\frac{3}{4}$.
10. *M. compressa* Hind. Seven-Feet Coal, Marine Bed, Birch-Coppice Old Pit. × $\frac{3}{4}$.
11. *Arthropleura armata* (Jordan). Ryder Coal, Baddesley Colliery. × $\frac{4}{5}$. (See p. 634.)

Plate LXI.

Geological sketch-map of the Warwickshire Coalfield, on the scale of 2 miles to the inch, or 1 : 126,720.

[For the Discussion, see p. 681.]



Bemrose, Collo., Derby.

WARWICKSHIRE COAL-MEASURE PLANTS.

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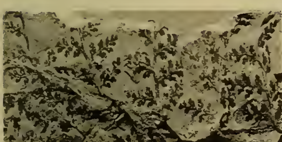

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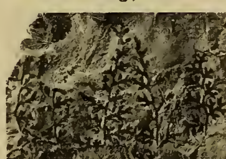

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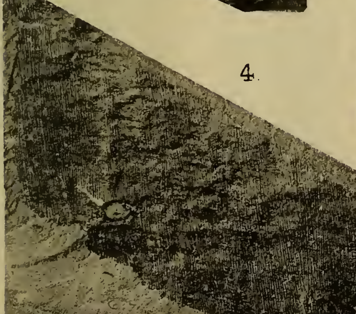

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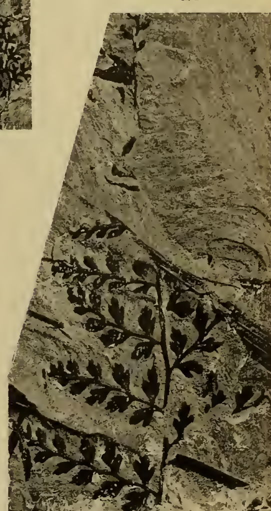
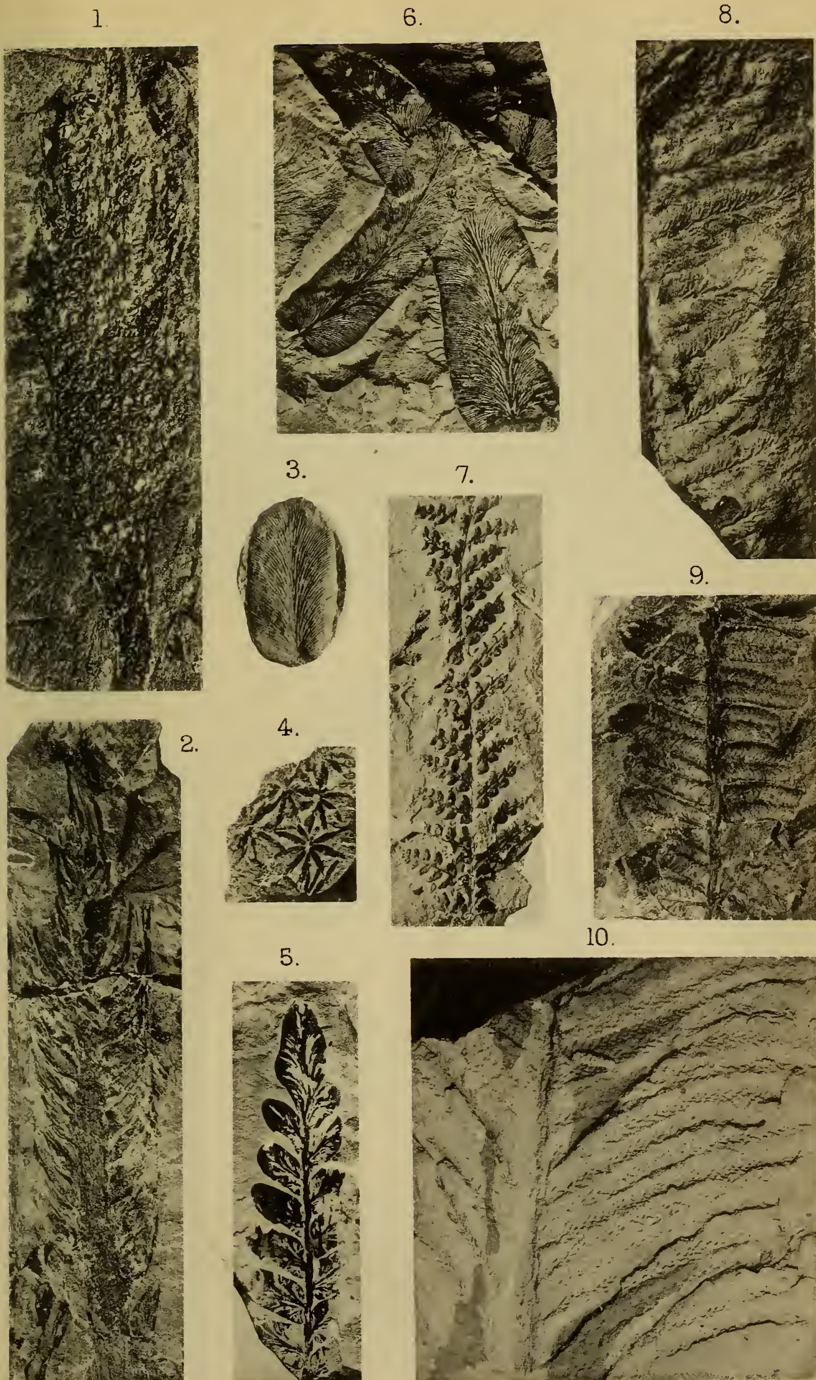


Bemrose, Collo., Derby.

WARWICKSHIRE COAL-MEASURE PLANTS.



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COAL-MEASURE AND PERMIAN PLANTS FROM WARWICKSHIRE.

Fig. 1.— View of Stockingford Clay-Pit, showing the Thick Coal.

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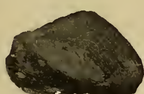

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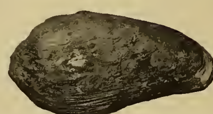

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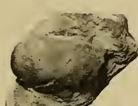

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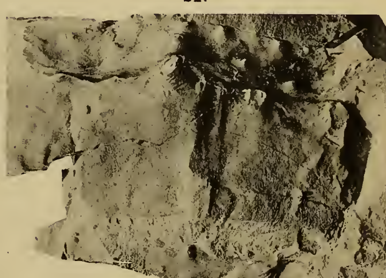

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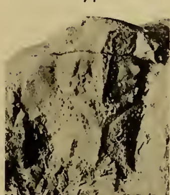

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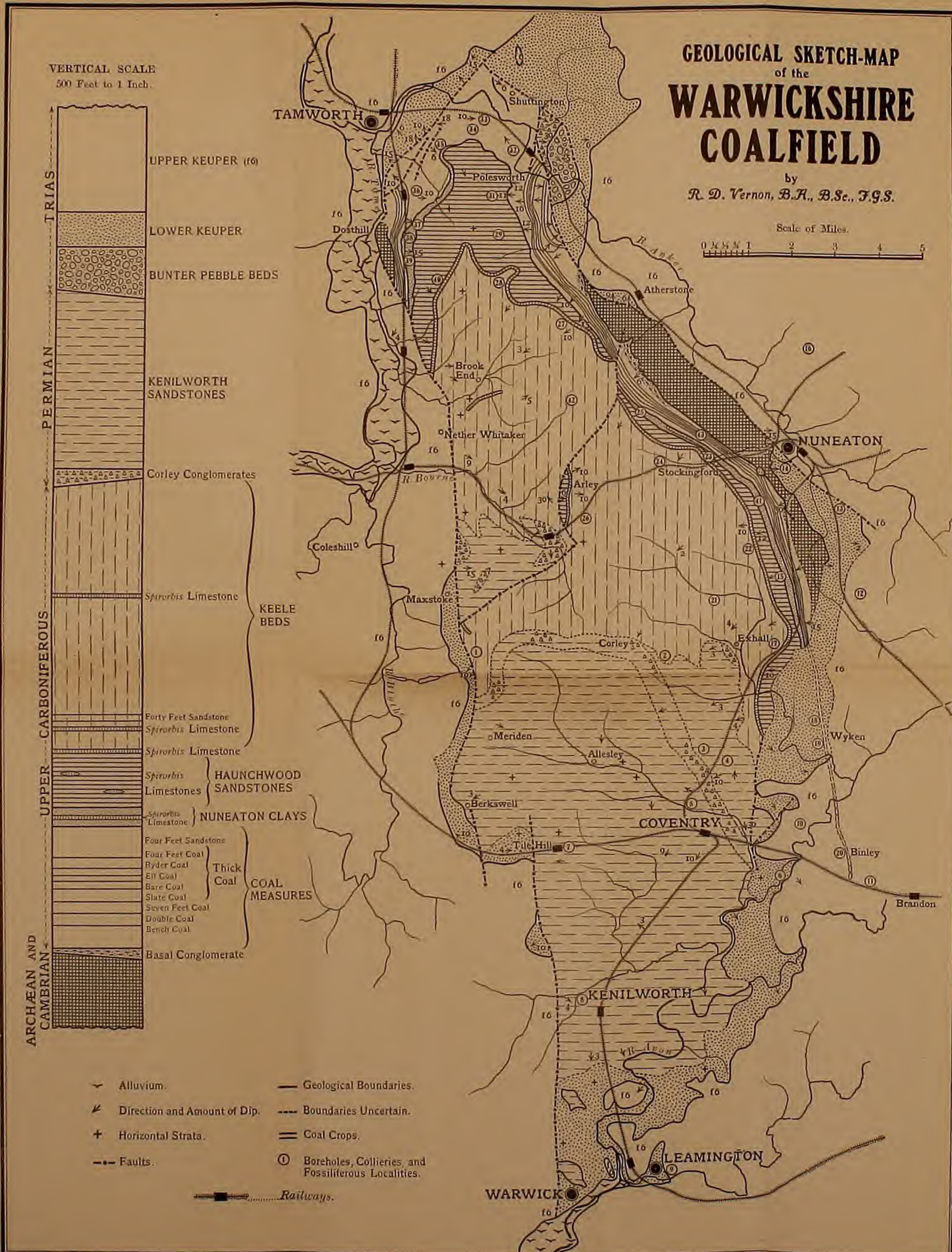
Figs. 2–11.— Warwickshire Coal-Measure Fossils.


GEOLOGICAL SKETCH-MAP
of the
WARWICKSHIRE
COALFIELD
by
R. D. Vernon, B.A., B.Sc., F.G.S.
Scale of Miles.
VERTICAL SCALE
500 Feet to 1 Inch.
TRIAS
PERMIAN
UPPER CARBONIFEROUS
ARCHÆAN AND CAMBRIAN
UPPER KEUPER (16)
LOWER KEUPER
BUNTER PEBBLE BEDS
KENILWORTH SANDSTONES
Corley Conglomerates
Spirorbis Limestone
KEELE BEDS
Forty Feet Sandstone
Spirorbis Limestone
Spirorbis Limestone
Spirorbis Limestones
HAUNCHWOOD SANDSTONES
Spirorbis Limestone
NUNEATON CLAYS
Four Feet Sandstone
Four Feet Coal
Ryder Coal
Ell Coal
Bare Coal
Slate Coal
Thick Coal
Seven Feet Coal
Double Coal
Bench Coal
COAL MEASURES
Basal Conglomerate
Alluvium.
Direction and Amount of Dip.
Horizontal Strata.
Faults.
Geological Boundaries.
Boundaries Uncertain.
Coal Crops.
Boreholes, Collieries, and Fossiliferous Localities.
Railways.
TAMWORTH
Shuttington
Polesworth
Dosthill
Atherstone
Brook End
Nether Whitaker
NUNEATON
R. Bourne
R. Anker
Arley
Stockingford
Coleshill
Maxstoke
Corley
Exhall
Meriden
Allesley
Wyken
Berkswell
COVENTRY
Tile Hill
Binley
Brandon
KENILWORTH
R. Avon
LEAMINGTON
WARWICK

25. *On the* Discovery *of a* Fossil-bearing Horizon *in the* 'Permian' Rocks *of* Hamstead Quarries, *near* Birmingham.

By Walter Henry Hardaker, B.Sc.(Vict.), M.Sc.(B'ham). (Communicated by Prof. Charles Lapworth, LL.D., F.R.S., F.G.S. Read June 19th, 1912.)

Contents.

I. Introduction.

(1) The Hamstead Locality.

Near the village of Hamstead, 4 miles north-west of the centre of the city of Birmingham, the shafts of the Hamstead Colliery are sunk in the broad outcrop of Midland Red Rocks which fringe the south-eastern edge of the South Staffordshire Coalfield, and are classed and coloured upon the original maps of H.M. Geological Survey as 'Permian.' The colliery-shafts are carried down through the lower rocks of this so-called 'Permian' into productive Coal Measures below, which are the underground continuation of those of the visible South Staffordshire Coalfield, the well-known 'Thick Coal' itself being worked in this colliery.

The red rocks cut through in the colliery-shafts between the surface of the country and the grey productive Coal Measures below are collectively referred to in the present paper—for the sake of convenience—under the title of the Hamstead Colliery Series.

The strata of the Colliery Series rise to the outcrop west of the colliery for a distance of about 2 miles, until they are cut off by the well-known Eastern Boundary-Fault of the South Staffordshire Coalfield, which there limits the 'Permian' outcrop in the western direction.

A short distance east of the colliery, the eastern limit of the 'Permian' outcrop is reached, and is succeeded by the outcrop of the Trias.

In the narrow band of 'Permian' ground which intervenes between the colliery and the Triassic boundary-line, the local remainder of the so-called 'Permian' crops out. Its strata follow conformably upon those of the Hamstead-Colliery Series, and are overlain unconformably eastwards by the basement-beds of the Trias. This higher Permian Series is excavated in several local quarries, and will be referred to throughout the present paper as the Hamstead-Quarry Series. Excavated in this outcrop of the Hamstead-Quarry Series, about a quarter of a mile east of the Hamstead shafts, are the extensive marl-quarries or brick-clay pits of Messrs. Turner & Hadley.

About two years ago, I noticed excellently-preserved fossil rain-prints and sun-cracks on the surface of the loose blocks of stone in these quarries. This prompted me to make a careful detailed examination and study of the so-called 'Permian' of the locality and of the surrounding country, resulting in my discovery of many fossils in one of the component divisions of these so-called 'Permian' rocks, in the fixation of the place of this division in the order of the successive local divisions previously accepted, and inferentially in the determination of the true geological age of the fossil-bearing division as compared with the divisions of the typical Permian System of Central Europe.

The object of the present paper is to give a summary of my work and its results.

(2) Previous Research and Opinion.

(*a*) Stratigraphical.—The Midland formations, hitherto collectively coloured as Permian upon geological maps of the South Staffordshire Coalfield and its surroundings, were first described in some detail by Sir Roderick Murchison in his famous 'Silurian System' (1839). He noted (pp. 54–55) the presence of a lower group of

'Sandstones and grits chiefly of a red colour, sometimes argillaceous, very frequently calcareous, associated with deep brown-red shales and marls, occasionally spotted green. . . . Towards the base many fragments of impressions of plants appear in beds of sandstone, which graduate into other and lower strata, containing thin seams of coal, from which there is a conformable descending passage into the true Carboniferous System.'

This group he termed Lower New Red Sandstone or Lower Permian, and regarded it as the equivalent of the Rothliegende of Germany. This Lower Permian he found to be succeeded by a second group containing calcareous conglomerates which, he asserts (*op. cit.* p. 46), 'there can be no hesitation in referring to the age of the Magnesian Limestone' of the North-East of England and to the Zechstein or Upper Permian of the Continent. The bedded nature of the associated 'trappean' breccias of the Clent Hills was not recognized by him, but they are described as trap erupted after the consolidation of the Carboniferous deposits (p. 496).

In the Enville area he described the highest Permian sandstones as graduating upwards into the succeeding New Red Sandstone or Trias (*op. supra cit.* p. 58).

Sir Andrew Ramsay [1] subsequently showed that the Breccias were 'truly sedimentary and rudely stratified,' and had a definite and constant horizon in the Permian succession. In his typical area, that around Enville, the succession is thus given (*op. cit.* p. 188):—

PERMIAN	Sandstone and red marls.
	Coarse breccias.
	Sandstones and red marls, containing two beds of calcareous conglomerate.

In the Clent district, at the southern extremity of the South Staffordshire Coalfield his sequence, again in ascending order, is (*op. cit.* p. 190):—

PERMIAN	Breccia 450 feet.
	Alternations of red marl and sandstone, with two calcareous bands.

J. B. Jukes,[2] in his classic memoir on the South Staffordshire Coalfield, practically adopts Ramsay's arrangement of these rocks, but notes that there are three beds of calcareous conglomerate in South Staffordshire. He gives it as his opinion that the Lower Permian lies unconformably upon the Carboniferous (p. 136).

Prof. E. Hull,[3] who mapped much of the ground covered by these rocks, proposed the name of 'Salopian' for the special type of

[1] 'On the Occurrence of Angular, Subangular, Polished & Striated Fragments & Boulders in the Permian Breccia of Shropshire, Worcestershire, &c.' Q. J. G. S. vol. xi (1855) p. 186.

[2] 'The South Staffordshire Coalfield' Mem. Geol. Surv. 1859.

[3] 'The Triassic & Permian Rocks of the Midland Counties of England' Mem. Geol. Surv. 1869.

Permian rocks occurring in this part of the Midlands (*op. cit.* p. 11), and regrouped these as follows (p. 13):—

PERMIAN of the Enville area.	Upper series, of red and purple sandstones and marls. Middle series, of calcareous conglomerates below and breccias above. Lower series, of red and purple sandstones and marls.

He also pointed out that

'the highest beds of the Permian series in this district [South Staffordshire] are those of trappoid breccia.' (*Op. cit.* p. 18.)

He considered the whole of his 'Salopian' Permian to be of the same geological age as the Rothliegende.

Very little further advance in our stratigraphical knowledge of these rocks was made until 1899, when Mr. W. Wickham King[1] published his valuable paper on the subject. His arrangement of the South Staffordshire Permian is the following (*op. cit.* pp. 111 *et seqq.*):—

Upper division:—Breccias interbedded with red sandstones and marls.

Middle division:—Calcareous conglomerates and sandstones, interbedded with marls and soft sandstones.

Lower division:—Red sandstones and marls.

His middle division was subdivided into six sub-groups, and his upper into two sub-groups. All these groups were described by him in detail, and followed by him on the eastern side of the South Staffordshire Coalfield as far north as Handsworth, to a point about 3 miles south of the area described in the present paper.

(*b*) Palaeontological.—In none of the above-mentioned papers is the true Permian age of any of the members of the 'Salopian' Permian that occur in the Midlands questioned. But the discovery and identification of a few plants of Carboniferous types at Hamstead[2] and elsewhere in the lower members of the so-called 'Permian'; the discovery of thin coal-seams and *Spirorbis* Limestone in corresponding members near Enville[3]; and the further discovery that certain red rocks originally mapped as Permian in North Staffordshire must now be properly classed as Upper Coal Measures,[4] have all thrown grave doubts upon the ascription of the whole of this massive Midland Red-Rock Series to the Permian System, as developed on the Continent of Europe.

[1] 'The Permian Conglomerates of the Lower Severn Basin' Q. J. G. S. vol. lv (1899) p. 97.

[2] R. Kidston, 'On the Fossil Flora of the Staffordshire Coalfields. Pt. i—Plants collected during the Sinking of the Shaft of the Hamstead Colliery' Trans. Roy. Soc. Edinb. vol. xxxv (1888) p. 317.

[3] T. C. Cantrill, 'On the Occurrence of *Spirorbis* Limestone & Thin Coals in the so-called "Permian" Rocks of Wyre Forest' Q. J. G. S. vol. li (1895) p. 528.

[4] Walcot Gibson, 'The Geology of the North Staffordshire Coalfields' Mem. Geol. Surv. 1905.

Indeed, it may be safely asserted that, at the present time, the geological age of the Midland so-called 'Permian,' considered as a whole, and also the age of its lithological divisions are matters which are by no means settled, and every new discovery among them may prove of some service.

Hitherto, almost the only fossils detected in the strata of the South Staffordshire 'Permian' are plants, and those but few in number and of long range. On the other hand, most of the fossils described in the present paper are the relics of animal life, and the species identifiable among them appear to be comparatively restricted in their geological range on the Continent of Europe and elsewhere, and therefore are of definite value in fixing the approximate age of the Midland strata in which they occur.

II. Detailed Description of the Rocks and Rock-Formations of the Hamstead-Quarry Series.

(1) The Hamstead Fossil-bearing Quarry.

All the fossils obtained by myself were collected from the Hamstead Marl-Quarry of Messrs. Turner & Hadley. These fossils include plant-impressions, well-preserved footprints, and trails of amphibia and crustacea, worm-burrows, and the like; rain-prints, sun-cracks, and ripple-markings.

By far the most important, from the geological point of view, are the footprints of Amphibia, which can be identified as belonging to certain specific forms long since described and named from typical geological horizons in the strata of the Continent of Europe.

A second quarry, known as the Old Quarry, has, up to the present, yielded no fossils.

The quarries above mentioned are two in number, and their position with relation to the Hamstead Colliery-shaft on the west, and to the outcrop of the Bunter Pebble-Beds which cover up the 'Permian' strata on the east, is shown in the accompanying geological sketch-map (fig. 1, p. 644), which I have worked out in a personal survey of the ground.

The strata laid bare in the quarries, and the majority of those which crop out between Hamstead Colliery and the base of the Bunter on the east, constitute the Hamstead-Quarry Series as previously defined (p. 640). The following description of that Series has been partly drawn from the strata laid bare in these quarries, and partly from surface exposures upon the ground.

All the 'Permian' strata in the Hamstead area dip regularly at a small angle (3° to 4°) south-eastwards. In consequence, the oldest beds lie in the west of the district, while continuously newer beds supervene as we pass in an easterly direction.

The first or larger quarry, which is known as the New Quarry, occupies over an acre in superficial extent, and varies in depth

Fig. 1. Map of the Permian Rocks of Hamstead.

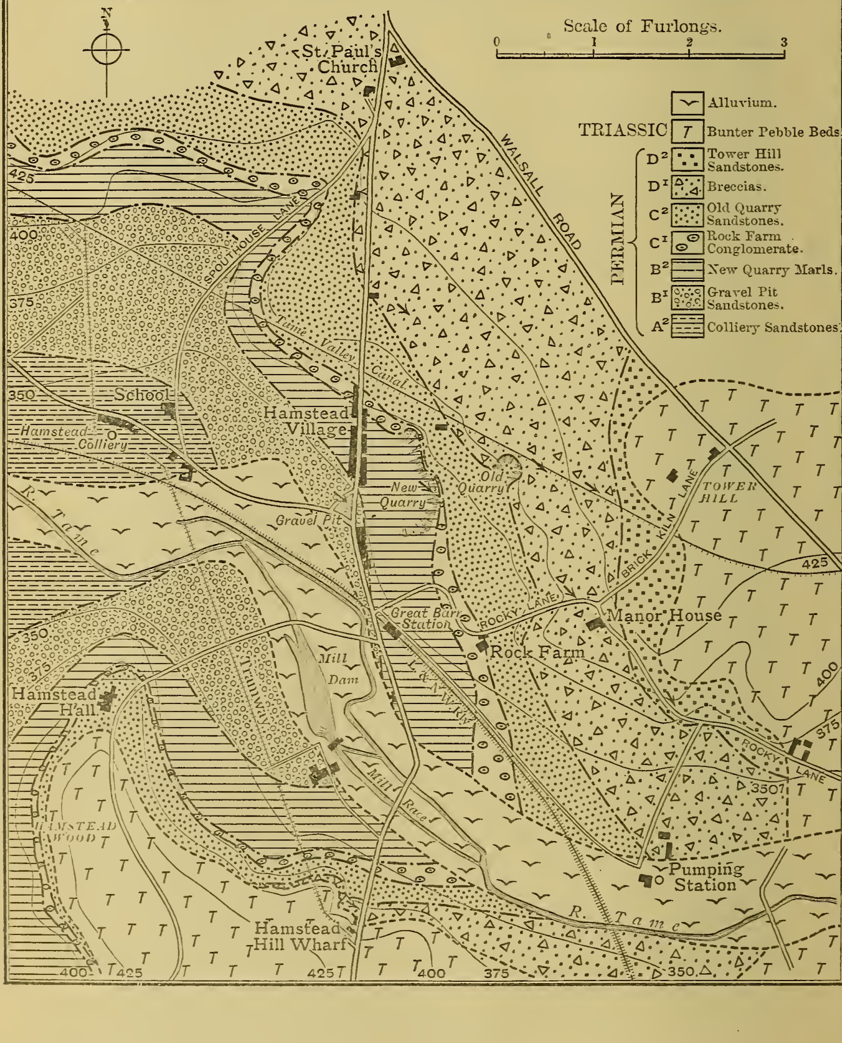


Fig. 2.—*Section of the New Quarry, Hamstead.* (*Scales: horizontal, 1 inch = 90 feet; vertical, 1 inch = 45 feet.*)

[1 = Sandstones and marls. 2 = Rock-Farm Conglomerate. 3 = Old-Quarry Sandstone.]

from 20 to 50 feet. The second or Old Quarry is relatively smaller and shallower, and lies about 100 yards to the north-east of the first. Both are excavated in the outcrop of the so-called 'Permian' rocks.

The strata of the New Quarry are dominantly purple marls (rarely green), often obscurely bedded, alternating irregularly with massive sheets and flaggy layers of red (and green) calcareous sandstones. Many of the sandstone layers are inconstant in character and lenticular in shape, with an undulating and irregular surface. Near the top of the succession of strata seen in the sides of the quarry is a bed of massive conglomerate, which varies in thickness from place to place, and lies at times with local unconformity upon the beds beneath.

The rocks in the Old Quarry are practically all sandstones, of more or less massive type in the lower beds, but flaggy in the upper layers.

All the fossils, without exception, have been obtained from the New Quarry, of which I append (fig. 2) a measured section. Those collected *in situ* were found in relief on the under surfaces of the sandstone beds. By far the larger proportion, however, were collected from the loose blocks in the quarry; but a careful comparison of the blocks has enabled me to identify them with the actual layers in the quarry from which they must have been derived.

(2) Divisions, Lithology, and Sequence of the Hamstead-Quarry Series.

The following ascending succession in the Quarry Series is observed:—

A_2. The Colliery-Sandstone Sub-group (20 feet).—Immediately east of Hamstead Colliery we meet with about 20 feet of soft sandstones and marls; they are not, however, well exposed in the neighbourhood. Surface-indications point to the absence from them of pebbly beds, but to the presence of a considerable portion of marl.

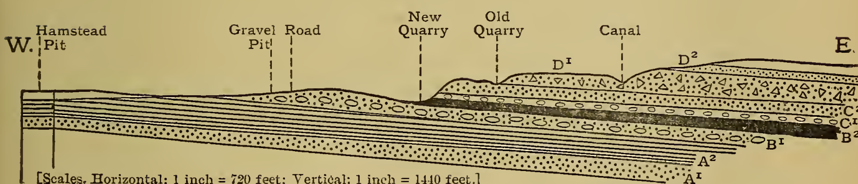
B_1. The Gravel-pit Sandstone and Conglomerate Sub-group (40 feet).—A rather harder band of calcareous sandstones—some of them conglomeratic—succeeds. The pebbles are principally Carboniferous Limestone and chert. In thickness these calcareous sandstones, with their included pebbly layers, are estimated to measure about 40 feet. They are exposed in the gravel-pit at the southern end of the main street of Hamstead village, and may therefore be called the Gravel-pit Sandstone Sub-group. In the quarry itself about 6 feet of fine conglomerate with small fragments of yellow and brownish-red Mountain Limestone and chert is well shown. The same group of sandstone rocks has been bored through by Messrs. Turner & Hadley in the New Quarry farther east, where it forms the floor of the principal seam of marl, now worked for brick-making. A thickness of 36 feet of hard calcareous sandstones, some of them pebbly, was met with in a boring in the floor of the quarry.

B_2. The New-Quarry Marl Sub-group (25 feet).—All the members of this succeeding group are well exposed in the face of the New Quarry. At the base are 6 to 13 feet of marl, with lenticular beds of sandstone. In these sandy layers, some of the fossils to be described later were found. A sandstone of freestone type, apparently unfossiliferous, appears above the marly beds. The thickness of this sandstone varies considerably, but it is, on the average, about 10 feet at the southern end of the quarry. At the northern end of the quarry this bed dies out by passing laterally into marl, which is replaced at a slightly higher horizon by another seam of sandstone that thickens northwards. Above these sandstones the strata, as will be seen in fig. 2 (p. 645), are very variable. In the northern part they consist of thinly-bedded marly sandstones, which disappear southwards in a number of tongues of sandstone, wedging into the marls there found. Still farther south, these sandy marls are cut off with a local unconformity by beds of lenticular sandstone containing a few thin beds of marl. Most of the fossils obtained from the quarry were derived from these thinly-bedded sandy layers. In thickness these average 10 feet.

C_1. The Rock-Farm Conglomerate Sub-group (5 feet).—This sub-group, which receives its name from Rock Farm near the Quarry, is seen to be about 5 feet thick in the New Quarry itself. It is there a pronounced conglomerate, with well-rounded and sometimes discoidal pebbles. It rests upon an uneven and denuded surface of the strata of the underlying sub-group, and where these have been most deeply eroded, the conglomerate attains its greatest thickness. The pebbles are mainly limestones (Silurian and Carboniferous), usually pink or yellow in colour, but there are also pebbles of yellow and red Carboniferous chert, grey quartzite, vein-quartz, grits of Carboniferous type, and hornstone.

C_2. The Old-Quarry Sandstone Sub-group (20 feet).—Above the conglomerate just described a massive sandstone is seen in the New Quarry at its northern end. The same sandstone is more fully exposed in the Old Quarry, somewhat farther east, and may therefore be conveniently denominated the 'Old Quarry Sandstone.' Its lower layers make a good building-stone. They are hard calcareous sandstones, with chips of yellow and red limestone

Fig. 3.—*Horizontal section from Hamstead Colliery eastwards to the Trias.*



and chert. Upwards they pass into thinly-bedded softer sandstones. The thickness of this group is about 20 feet.

From the Old Quarry the succession is continued along the canal-cutting and along Rocky Lane. Its details are as follows:—

D_1. The Manor-House Breccia and Sandstone Sub-group (70 feet).—In this group are a number of thin beds of breccia and brecciated sandstones, alternating with layers of pebbleless sandstone. The following is the ascending order of the strata, No. 1 being the lowest:—

1. Brecciated sandstones—coarse above and below, 10 feet.
2. Flaggy sandstones, without pebbles, 4 feet.
3. Brecciated sandstone, with two bands of coarse angular fragments 7 feet.

4. Soft flaggy sandstone, 2 feet.
5. Breccia 6 feet thick, resting upon an uneven surface of No. 4. It is false-bedded. The fragments are considerably larger than those of Beds 1 or 3, and include many small blocks of fossiliferous Silurian sandstone.
6. Sandy marl, 3 feet.
7. Conglomerate of large well-rounded pebbles, 5 feet.
8. Sandstone without pebbles, 5 feet.
9. Subangular breccia. Varying in thickness from 9 feet to 11 feet 6 inches. (In the strata numbered 5, 7, and 9, fragments of fossiliferous Silurian—probably Llandovery—sandstones occur. They become more numerous as we pass from 5 to 9, while the proportion of Carboniferous Limestone and chert diminishes. The fossiliferous fragments of sandstone are accompanied by those of other sandstones of a dark red colour and micaceous. A peculiar green quartzite, Lower Permian sandstone, and vein-quartz also are common.)
10. Sandstone without pebbles, 2 feet.
11. Brecciated sandstone, 10 feet. The rock-fragments included are small.
12. False-bedded sandstone, 2 feet.
13. Brecciated sandstone, with coarse breccia near the top, 5 feet.

D_2. The Tower-Hill Sandstone Sub-group (22 feet).—This sub-group consists of 22 feet of sandstones (in which pebbles are rare), with two thin seams of marl. These rocks crop out at the eastern end of the canal-cutting at Tower Hill, and are also well exposed in Rocky Lane.

Above this last division in the canal-cutting the Bunter Pebble-Beds are found to succeed unconformably. In Rocky Lane the Tower Hill Sub-group is also followed eastwards by Triassic pebble-beds, but there is room for the suspicion that the usual unconformity is here accompanied by a fault.

The harder beds of the local 'Permian' sub-groups described above are marked by terraces, and the beds of marl met with in the lower part of the sequence are marked by flatter tracts of ground.

The most distinct of the minor terraces is that produced by the Rock-Farm Conglomerate. The rocks forming the Breccia Sub-group, however, give rise to the most marked surface-features of the series. They generally form relatively high ground; and a sudden rise of the surface indicates in each case the approach to their outcrop. This sudden change of slope is very noticeable in going eastwards along Rocky Lane near the Manor House, and at the western end of the canal-cutting.

III. Comparison and Correlation of the Hamstead 'Permian' with the rest of the general 'Permian' Succession bordering the South Staffordshire Coalfield.

(1) Relations of the Hamstead-Quarry Series and the Hamstead-Colliery Series to the Coal-bearing Strata below.

The Permian rocks described above, cropping out in the area east of the Hamstead Colliery-shaft, and constituting the Hamstead-Quarry Series, may be summarized in descending order as follows:—

	Thickness in feet.
7. The Tower-Hill Sandstone Sub-group—fine sandstone with some marl	22
6. The Manor-House Breccia and Sandstone Sub-group—breccias usually subangular, interbedded with sandstones	70
5. The Old-Quarry Sandstone Sub-group—calcareous sandstone	20
4. The Rock-Farm Conglomerate Sub-group—calcareous conglomerate and sandstone	5
3. The New-Quarry Marl Sub-group—fine-grained sandstones and marls	25
2. The Gravel-pit Sandstone and Conglomerate Sub-group—calcareous sandstone and conglomerate	40
1. The Colliery-Sandstone Sub-group—soft sandstones and marls	20
Total	202

The surface-arrangement of these sub-groups is shown in the map (fig. 1) on p. 644.

The Hamstead-Quarry Series, as has been already pointed out, follows immediately upon the strata pierced in the Hamstead Colliery-shaft. This shaft-section has already been broadly described by Messrs. F. G. Meachem & H. Insley,[1] and in greater detail by Dr. R. Kidston, Mr. F. G. Meachem,[2] and Mr. T. C. Cantrill.

I have to thank the owners of the Colliery for according me the privilege of personally studying the detailed section of the strata sunk through in the Hamstead shaft. This section, drawn to a large scale, is kept at the colliery, and fig. 4 (p. 652) is a careful reproduction of it, from the surface down to a depth of 1024 feet, that is, 845 feet above the Thick Coal-seam. The section is here published with the permission of the Manager of the Colliery

[1] 'Notes on the Rocks between the Thick Coal & the Trias North of Birmingham & the Old South Staffordshire Coalfield' Rep. Brit. Assoc. (Birmingham, 1886) 1887, p. 626.

[2] 'The Search for Coal over the Eastern Boundary-fault of the South Staffordshire Coalfield, with especial reference to the Sinking at Hamstead Colliery & the Working of the Thick Coal-Seam' Trans. Fed. Inst. Min. Eng. vol. viii (1894–95) p. 401.

Company. The shaft itself is 1900 feet deep. The rocks of the lower portion, from 1900 to 1024 feet, are, as all investigators agree, of Carboniferous age, and contain the well-known Thick Coal and other seams of the South Staffordshire Coalfield. From 1024 feet up to the surface the beds consist chiefly of red sandstones and marls, and have been generally assigned to the Permian System. By some, however, they have been claimed as Upper Coal Measures, and the matter must still be regarded as unsettled.

That most of the higher beds of the Hamstead Colliery-shaft belong to the so-called 'Permian' rock-succession of the district, coloured as such in the first edition of the maps and sections of H.M. Geological Survey, has long been acknowledged; and the acknowledgment may be presumed to carry with it the general admission that the officers of the Survey are correct in colouring the outcrops of the Hamstead Quarry beds as belonging to the same succession. But it is most desirable that an attempt should in this place be made to fix, if possible, the exact place of both the Hamstead-Colliery Series and the Hamstead-Quarry Series in the ascending order of the divisions already recognized in the so-called 'Permian' rocks of South Staffordshire. Our present interest is mainly with the Quarry Series and their fossils; but, in order to fix the exact position of the Quarry Series in the Permian succession of the Midlands, it is desirable to make some observations on the Permian succession of the borders of the South Staffordshire Coalfield in general, and on the upper divisions of that succession in particular.

(2). The Clent and Enville 'Permian' Succession, and its three Divisions.

The typical so-called 'Permian' rocks of the borders of the South Staffordshire Coalfield may perhaps be said to be the red strata of the Clent district, which commence almost immediately above a band of *Spirorbis* Limestone there met with in the highest layers of the Halesowen Sandstone Group (Carboniferous). According to Mr. W. Wickham King, the Permian rocks are there divisible into three groups, namely:—

(*c*) Upper Division including breccias interbedded with red sandstones and marls. Localities[1]: Walton Hill, etc.

(*b*) Middle Division, including calcareous cornstone bands and sandstones, interbedded with marls and soft sandstones. Localities[1]: St. Kenelms, etc.

(*a*) Lower Division of red sandstones and marls. Localities[1]: Hunnington, etc.

He attempted no subdivision of his Lower Permian in the paper already cited, but he carefully subdivided his Middle and Upper divisions of the South Staffordshire 'Permian' as follows[2]:—

[1] Typical localities, the names of which were supplied to me by Prof. Lapworth.

[2] Q. J. G. S. vol. lv (1899) p. 108, table i.

UPPER PERMIAN or Breccia Group.	D	D_2.	Marls with intercalated breccia-bands.
		D_1.	Trappoid breccia and breccia-sandstone.
MIDDLE PERMIAN or Calcareous Conglomerate Group.	C	C_2.	Marls.
		C_1.	Calcareous zone.
	B	B_2.	Soft red and mottled sandstones and marls.
		B_1.	Calcareous zone.
	A	A_2.	Soft sandstones and marls.
		A_1.	Calcareous zone.

If we accept the above arrangement, it becomes at once evident that the descending succession of the lithological sub-groups in the Hamstead area, as worked out by myself and described by me in the preceding pages of the present paper, falls quite naturally into Mr. Wickham King's scheme.

The Quarry Series of Hamstead belongs in part to his Upper Permian division (Walton) and in part to his Middle Permian (St. Kenelms), the line of division between the two occurring at the base of the Manor-House Breccia.

The 70 feet of breccia and sandstones of the Manor-House Breccia and Sandstone Sub-group at Hamstead are evidently the representatives of Mr. King's division D_1; while the 22 feet of the Tower-Hill Sandstone Sub-group are the representatives of the rocks of his sub-group of sandstone and marls, D_2.

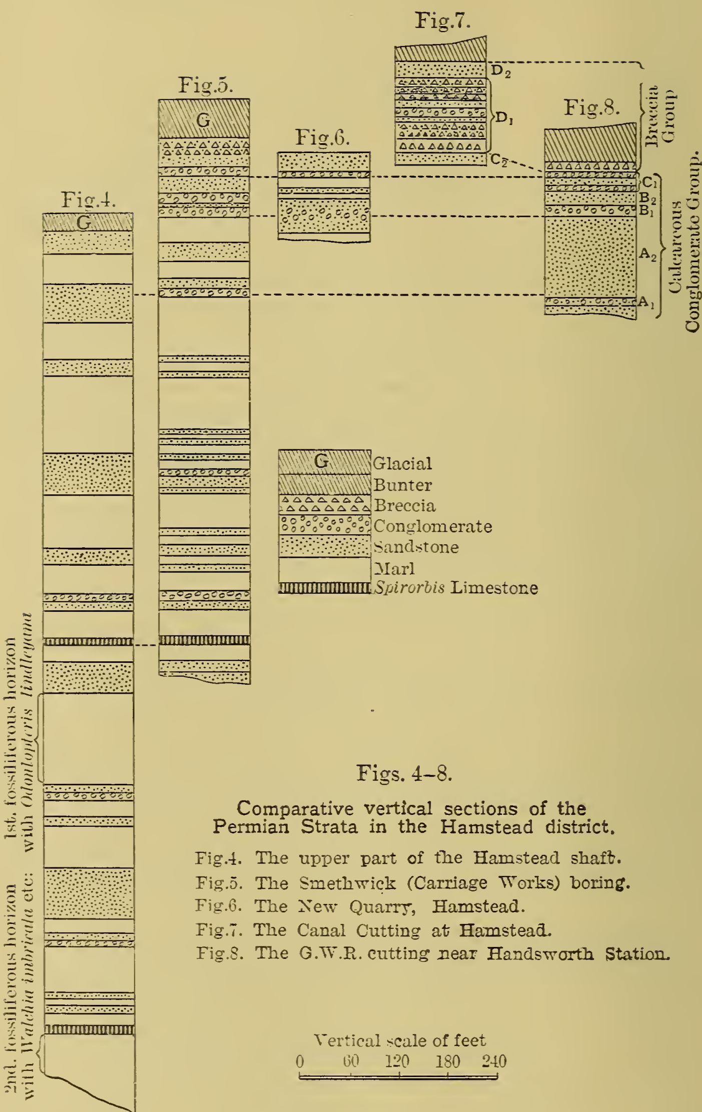
Below the Manor-House Breccias, the Old Quarry Sandstones answer to C_2, and the Rock-Farm Conglomerate, met with in the face of the New Quarry, to C_1. The rocks beneath this conglomerate and down to the base of the quarry (that is, the New-Quarry Marl Sub-group) belong to the subdivision B_2.

The calcareous sandstone and conglomerate of the floor of the quarry (namely, the Gravel-pit Sandstone and Conglomerate Sub-group, which is at an horizon slightly above that of the top beds of the Hamstead Shaft), correspond to Mr. King's subdivision B_1.

My own personal observation of the Hamstead strata extended only to the actual site of the Hamstead Shaft; but a study of the Hamstead Colliery-shaft section, as drawn up at the time of its sinking, makes it evident that in the higher parts of the shaft the uppermost beds (from the surface down to $86\frac{1}{2}$ feet) are merely the downward continuation of the lowest beds of the Quarry Series, and must therefore, as a whole, be correlated with Mr. Wickham King's sub-group A_2.

In his paper already cited, that writer traces his three divisions of the ‘Permian’ throughout the region, from the Clent Hills round the south-eastern corner of the South Staffordshire Coalfield as far as the line of the Great Western Railway, west of Handsworth station, and distant but 3 miles south-west from Hamstead. A section of the ‘Permian’ rocks met with in the railway-cutting west of Handsworth Station is summarized by Mr. King in his paper. The detailed sequence, as worked out by him, is shown in the first column of the table on p. 654, and in fig. 8, p. 652.

Valuable evidence to support this correlation, and to continue it downwards into the rocks of the Hamstead Shaft itself, has been afforded by the study of a detailed section of a boring, made in



Figs. 4–8.

Comparative vertical sections of the Permian Strata in the Hamstead district.

Fig.4. The upper part of the Hamstead shaft.
Fig.5. The Smethwick (Carriage Works) boring.
Fig.6. The New Quarry, Hamstead.
Fig.7. The Canal Cutting at Hamstead.
Fig.8. The G.W.R. cutting near Handsworth Station.

1910 at their Smethwick works by the Birmingham Railway Carriage & Wagon Co., who have kindly furnished me with particulars of the strata passed through, and given me permission to make use of them.

(3) The 'Permian' Succession of Smethwick and Handsworth.

The Smethwick boring which I have studied lies very slightly north of the section in the railway-cutting of which the details were given by Mr. King, and a few yards west of the outcrop of calcareous conglomerate shown crossing the cutting on the Geological Survey maps. The upper strata (to 204 feet) of this Smethwick boring agree almost exactly with those of the adjoining railway-cutting. Below 204 feet from the surface the Lower (so-called) 'Permian' is entered. A depth of 650 feet was attained in the boring. At a depth of 620 feet a bed of *Spirorbis* Limestone, which probably answers to the upper bed of limestone—at 579 feet—in the Hamstead Shaft, was pierced. Above this horizon in the Smethwick boring the strata are chiefly red sandstones and marls, and in this respect agree almost exactly in their relative thickness and composition, as will be seen in the appended vertical sections (p. 652), where the Carriage-Works section (fig. 5) is paralleled with that of Hamstead Colliery (fig. 4).

In the upper layers the 43 feet of sandstone, from $88\frac{1}{2}$ to $131\frac{1}{2}$ feet, in the Hamstead Shaft are on an horizon corresponding to that of conglomerate A_1 of the Smethwick Carriage-Works boring. It is true that this conglomerate A_1 is not present as such in the Hamstead Shaft; but it is doubtless represented by the calcareous sandstone shown in the Hamstead-Shaft section at $88\frac{1}{2}$ feet. As will be seen by the comparative sections, the Smethwick boring pierces higher beds than those of the uppermost strata of the Hamstead Colliery-shaft. Thus the second conglomerate of the boring corresponds exactly to the sandstone and conglomerate beds which form the floor of the New Quarry or, in other words, the Gravel-pit Sandstone Sub-group of the Hamstead area. The uppermost conglomerate of the Smethwick boring is evidently the bed of conglomerate (Rock-Farm Conglomerate) which is met with 25 feet higher in the face of the same quarry. They are thus respectively equivalent to Mr. Wickham King's stages B_1 and C_1.

(4) Summary.

From the comparisons adduced in the foregoing paragraph it is evident that:—

1. The highest 92 feet of the Hamstead-Quarry Series belong to Mr. Wickham King's Upper Breccia division of the general Permian succession in the districts bordering the South Staffordshire Coalfield.

2. The lower 210 feet belong to his Middle Permian (or Calcareous Conglomerate) division.

The highest 115 feet of strata below the 16½ feet of Glacial deposits pierced in the Hamstead Colliery-shaft also belong to Mr. King's Middle Permian division. The base of that author's Middle Permian is thus at a depth of 131½ feet in the Hamstead Shaft.

3. The following table summarizes the detailed correlation of the strata.

Great Western Railway Cutting.			Smethwick Boring.	Hamstead Area.
Bunter Pebble-Beds.			Glacial Deposits.	Bunter Pebble-Beds.
Breccia Group of W. W. King.	D_2	Sandstone (absent)	D_2 absent.	The Tower-Hill Sandstone Sub-group—sandstones and thin marls (22 feet).
	D_1	Breccia (20 feet).	D_1 Sandstone with angular fragments (33 feet).	The Manor-House Breccia and Sandstone Sub-group—breccia and sandstone (70 feet).
Calcareous Conglomerate Group of W. W. King.	C_2	Sandstone (absent).	C_2	The Old-Quarry Sandstone Sub-group—sandstone (20 feet).
	C_1	Fine calcareous conglomerate 4 feet. Calcareous red sandstone 15 feet. Fine calcareous conglomerate 5 feet. (24 feet.)	C_1 Conglomerate (9 feet).	The Rock-Farm Conglomerate Sub-group—conglomerate with large pebbles (5 feet).
	B_2	Sandstone (20 feet).	B_2 Sandstone and marl (29 feet).	The New-Quarry Farm Sub-group—sandstone and marl (25 feet).
	B_1	Conglomerate (12 feet).	B_1 Conglomerate (12 feet).	The Gravel-pit Sandstone and Conglomerate Sub-group—calcareous sandstone and conglomerate (40 feet).
	A_2	Soft sandstone, with some marls (100 feet)?	A_2 Soft sandstone and marls (79 feet).	The Colliery-Sandstone Sub-group (above shaft) 20 feet. 72 feet of soft sandstone and marl (in shaft) to 88½ feet.[1]
	A_1	Calcareous sandstone (10 feet).	A_1 Fine conglomerate with grey sandstone (8 feet).	Calcareous sandstone of the Hamstead Shaft (43 feet).

[1] 16½ feet of Glacial deposits are included.

IV. Detailed Description of the recently-discovered Fossils of the Hamstead-Quarry Series, and Comparison of these Fossils with similar Fossils elsewhere in Britain and abroad.

(1) The Identifiable Species and Varieties.

All the fossils that I discovered were obtained from the New Quarry, but the four sub-groups of the strata present in the Quarry are not all fossiliferous. The majority of the fossils found were procured from the second sub-group (the New-Quarry Marls), and the remainder from the Old-Quarry Sandstone Sub-group. The two sub-groups of the Gravel-pit Sandstone and the Rock-Farm Conglomerate are barren of fossils.

The organisms include plants, tracks of amphibia and crustacea, and worm-burrows. All the animals and plants represented by the fossils are of terrestrial habit, and no sign of marine life has been found. Most of the specimens occur in relief on the under surfaces of sandstones in places where those surfaces rest on a marly base, and thus they are casts of the original markings. Very rarely, however, the actual impression or mould is met with. In such cases the moulds occur on the upper surfaces of fine-grained marly sandstones.

The fossil plants of the quarry are chiefly in the form of impressions, occurring either on the surface or between the laminæ of similar fine-grained argillaceous sandstones. Occasionally they are met with in coarse sandstones—usually red or purple in colour, but sometimes green.

The beds of marl in the quarries and elsewhere, so far as my investigations have gone, are barren.

The fossils capable of more or less satisfactory identification are enumerated in the following list:—

PLANTÆ.	Coniferæ ...	*Walchia* [*W. piniformis* Schloth., *W. imbricata* (Schimper)]. *Cordaites* [*Artisia* Sternberg].
AMPHIBIA or REPTILIA	Footprints ...	1. *Ichnium sphærodactylum* Pabst. 1*a*. *Ichniotherium cottæ* Pohlig. 1*b*. *Ichnium sphærodactylum* (*minimum*) Pabst. =*Ichniotherium cottæ* (*minus*) Pohlig. 2. *Ichnium pachydactylum* Pabst. 2*a*. *Ichnium pachydactylum* (*minus*) Pabst. 2*b*. *Ichnium pachydactylum* (*ungulatum*) Pabst. =*Ichnium brachydactylum* Geinitz. 3. *Ichnium brachydactylum* Pabst. 4. *Ichnium dolichodactylum* Pabst. 5. *Ichnium gampsodactylum* Pabst. =*Saurichnites lacertoides* Geinitz. 5*a*. *Ichnium gampsodactylum* (*minus*) Pabst. 6. *Ichnium acrodactylum* (?) Pabst.
ARTHROPODA	Insecta	Wing of insect.
	Crustacea ...	Tracks of three species. Casts of entomostraca.
VERMES		Worm-burrows and castings.

As respects the bearing of the Hamstead fossils on the question of the age and correlation of the containing rocks, we may confine our attention to the fossil plants and the fossil footprints.

(2) The Plants.

Plants in a specifically identifiable condition are rare. Most of those found were obtained from layers of fine-grained red sandstone, immediately under the bed of conglomerate near the top of the face of Turner & Hadley's New Quarry; but a few specimens of *Walchia* (doubtfully referable to *W. piniformis*) were found in the massive sandstones above the conglomerate. The genera noted are *Walchia* and *Artisia*. Specimens of *Walchia* are fairly common. Even in the specimens which are not generically identifiable, and have come under my notice, there is nothing referable to a fern or fern-like plant.

Walchia piniformis (Schlotheim). (Fig. 9.)

Fig. 9.—*Twig of* Walchia piniformis *(natural size).*

Three examples of this species have been identified. One of these is figured here. The leaves are 5 mm. long, and are unusually thick and markedly keeled.

In Britain *W. piniformis* is recorded only from the Langley-Green boring[1] made through the same type of rocks as those at Hamstead Colliery. The Langley-Green locality is distant 4½ miles southwest from Hamstead. The actual horizon at which the fossil was found is not stated.

Abroad, *W. piniformis* is perhaps the commonest fossil of the Lower Permian (Autunian) of France and the Lower Permian (Rothliegende) of Germany.[2] In France[3] and Italy[4] it is recorded also from the highest Upper Carboniferous (Stephanian) rocks, and in Germany from the higher beds of the Ottweiler Series or the Upper Carboniferous of the Saarbrücken Coalfield.[5]

It is, however, both in France and in Germany, a rare fossil in Upper Carboniferous rocks.

Walchia imbricata Schimper.

This species is rather commoner than the former, or is at least better preserved, and several specimens referable to this species

[1] W. Gibson, 'On the Search for Coal beneath the Red Rocks of the Midland Counties' Summary of Progress, Geol. Surv. for 1905 (1906) p. 173.

[2] W. Pabst, 'Die Tierfährten in dem Rotliegenden Deutschlands' Nov. Act. Acad. Cæs. Leop.-Carol. vol. lxxxix (1908) p. 338.

[3] E. Roche, Bull. Soc. Géol. France, ser. 3, vol. ix (1880) p. 79.

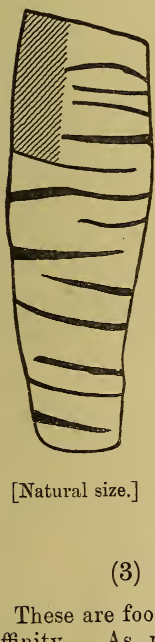
[4] A. de Lapparent, 'Traité de Géologie' 5th ed. vol. ii (1906) pp. 953 & 963.

[5] C. E. Weiss, 'Fossile Flora der jüngsten Steinkohlenformation & des Rothliegenden im Saar-Rhein-Gebiete' vol. i (1869) p. 6.

have been secured. The stems are thin, and closely set with leaves about 2 mm. long. Occasionally, certain of the upper layers of fine-grained sandstone under the conglomerate contain this species in abundance, so that some of the rock-laminæ are covered with a confused matting of impressions. Of the actual carbonaceous substance of the plant nothing is left: all the specimens (like those of *W. piniformis*) are replacements by very fine sand.

An allied form, quoted as *W. hypnoides (?)*, has been found at a depth of 850 feet in the Claverley boring, on the eastern border of the neighbouring Forest-of-Wyre Coalfield, and 15 miles west of Hamstead. The containing strata are assigned by Dr. Gibson to the Keele Group or Upper Carboniferous. On the Continent the species *W. imbricata* occurs in the Saarbrücken Coal-field in the Upper Carboniferous rocks, but only in the Ottweiler or very highest division of that system. It is a common and characteristic fossil of the Rothliegende of Germany, but it is not recorded from France. Possibly, it is by French geologists included under the broader specific name of *W. piniformis*.

Fig. 10.—*Cast of pith-cavity of* Cordaites.



[Natural size.]

CORDAITES (ARTISIA). (Fig. 10.)

A single cast of the pith-cavity of a plant was found in fairly coarse red sandstone. As similar casts have been met with elsewhere, and interpreted to be the result of the infilling with sediment of the stem of *Cordaites*, we may safely presume the presence of that genus in these rocks. The Hamstead specimen is $2\frac{1}{4}$ inches long, and about 1 inch broad.

(3) Footprints of Amphibia or Reptilia.

These are footprints made by creatures of amphibian or reptilian affinity. As might naturally be expected, the footprints vary both in size and in shape. The same foot would, of course, leave different markings under different conditions, dependent upon the consistency of the ground, upon the rate of progress of the animal, etc. Further, after the impression had been made, it became liable to distortion by desiccation and compression. It has been found possible, however, to group the Hamstead fossil footprints into a number of types, each type in all probability having been made by a different species of animal. The majority of the animals leaving these footprints were distinctly plantigrade, and in walking impressed the whole of the foot from front to heel. A few of the animals, however, appear to have been digitigrade.

These latter made contact with the ground mainly by the toes, so that merely impressions of the toes and of the balls at the base of the toes are displayed.

Footprints of amphibia and reptilia have long been known from the Rothliegende of Germany. Fortunately for our present purpose, many of these have been described and figured in detail by Prof. W. Pabst in his great monograph—'Die Tierfährten in dem Rotliegenden Deutschlands,' published in 1908 (Nov. Act. Acad. Cæs. Leop.-Carol. vol. lxxxix, pp. 315–481 & pls. i–xxxv).

In the descriptions and figures of the Hamstead footprints given in the present paper, I have adopted throughout the descriptive terms and special plan of measurement originated by Prof. Pabst. In the final column of each table, which I have devoted to a single Hamstead type, I have inserted the corresponding measurements from Prof. Pabst's table of that Continental type of species which appears to be identical with the Hamstead form, or to be its nearest ally.

I have numbered the Hamstead types from H_1 to H_6. The footprints of types 1, 2, 3, and 4 are shorter, or at any rate not markedly longer than they are broad; whereas those numbered H_5 and H^6 are distinctly longer than they are broad.

The measurements given in the tables refer to:—

1. Length of footprint.—From the end of the longest toe to the heel.
2. Width of footprint.—From tip to tip of the outside toes.
3. Length of toes.—The toes are numbered 1 to 5, in which 1 corresponds in position to the human thumb, and thus appears on the inside of the track. In cases where the left and right sides of the track are not both present on the specimen the shortest outside toe is regarded as No. 1.
4. 'Track-measurement' I [Pabst].—From the centre of a fore footprint to the centre of the next print of the hind foot behind it. The arbitrary assumption is here made that, as in the tracks of modern salamanders, the fore footprint is slightly in front of the hind footprints which immediately followed it in time. The impression of the hind foot is usually also slightly the larger of the two.
5. 'Track-measurement' II [Pabst].—From centre to centre of a fore footprint and the next hind footprint before it in the track. This measurement is generally greater than track-measurement I.
6. Length of stride.—The distance between two successive appearances of the same foot in the track. This is approximately equal to the sum of track-measurements I & II.
7. Width of track.—The distance between the line of tracks made by the feet on the left side of the animal and that made by the feet on the right side. In footprint reliefs the footprints on the right side of the forward stepping track are those made by the left foot of the animal and *vice versâ*.

Descriptions of the six Hamstead Types.

None of these forms have been met with in the Carboniferous rocks of Britain or of the Continent of Europe, but forms somewhat similar to H_1 (*Ichnium sphærodactylum*) and H_5 (*Ichnium gampsodactylum*) have been recorded from the Coal Measures of America.

From rocks of acknowledged Permian age, however, either in Britain or upon the Continent of Europe, all the Hamstead forms—or, at all events, closely-allied forms or varieties—have been cited.

Type H_1. ICHNIUM SPHÆRODACTYLUM Pabst. Of this type there are nineteen specimens in relief (casts) and one specimen as an impression. (See figs. 11 & 12, p. 661.)

The footprints included in type H_1 are characterized by the impression of a broad and massive ball, and show a distinct heel. The width of the footprint exceeds the length. There are five toes, with blunt ends, which often leave rounded impressions. The toes vary considerably in their spacing, sometimes being widely spread open, at other times close together. Most commonly the 2nd, 3rd, and 4th toes are close, with the 1st and 5th toes well separated from them and occasionally bent a little back towards the heel. Sometimes the 1st and 5th toes have left no impression. The toes turn, to some extent, towards the middle of the track, especially so in prints of the forefoot. The prints of the fore feet are always smaller than those of the hind feet, and show toes proportionately shorter. Sometimes distinct markings indicate the places of the joints of the toes; and, more rarely, fainter markings afford distinct evidence of a wrinkling of the skin of the foot. The first toe of both feet is the shortest, and the 4th the longest. Track-measurement I is always distinctly smaller than track-measurement II.

Measurements.	H [main type].			ICHNIUM SPHÆRODACTYLUM (Rothliegende).
	Minimum.	*Maximum.*	*Average.*	*Average.*
Fore foot:	cms.	cms.	cms.	cms.
Length	6·0	10·0	7·7	9·0
Breadth	7·5	11·9	9·5	10·2
1st toe	not present	1·5	1·0	2·1 (often absent)
2nd toe	1·0	2·8	2·0	2·8
3rd toe	1·5	3·4	2·7	3·4
4th toe	1·8	4·0	3·1	4·3
5th toe	1·0	2·5	2·1	2·6
Hind foot:				
Length	8·5	12·5	9·7	10·2
Breadth	9·0	13·0	11·0	11·0
1st toe	0·5	1·6	1·2	2·6
2nd toe	1·2	3·2	2·1	3·4
3rd toe	2·0	4·6	3·0	4·2
4th toe	2·5	5·0	3·8	5·3
5th toe	not present	4·0	2·5	3·4
Track-measurement I	8	14	11	13
Track-measurement II	16	25	19	22
Width of track	12	17	14	18

Sub-Type H_{1a}. Variation of main type. ICHNIOTHERIUM COTTÆ Pohlig. One specimen in relief (cast). (See fig. 13, p. 662.)

The length of the footprints is 13 cms., and the breadth 16·5 cms. The outlines of the toes are not shown, but the toe-tips are represented as a semicircle of elevations at some distance (5 cms.) in front of another mound representing the ball of the foot. There are no indications of claws.

	H_{1a}.	ICHNIOTHERIUM COTTÆ.	
		Maximum.	*Average of the four measured specimens.*
	cms.	cms.	cms.
Length	13	14	11·6
Breadth ...	16·5	16	12·7

Sub-Type H_{1b}. ICHNIUM SPHÆRODACTYLUM (MINIMUM) Pabst. Six specimens: five in relief.

The footprints are smaller than those of H_1, but resemble them in other respects. The last of the Hamstead forms included in the following table of measurements is like a small H_{1a}, in that only toe-tips and indications of the ball of the foot are preserved.

Measurements.	H_{1b}.						ICHNIUM SPHÆRODACTYLUM (MINIMUM).
Fore foot:	cms.	cms.	cms.	cms.	cms.	cms.	cms.
Length	...	1·8	2·3	1·0	0·4	3·0	2·5
Breadth	1·6	1·8	2·3	1·0	0·5	3·5	2·5
1st toe	...	...	0·4	...	...	...	0·8
2nd toe	0·4	0·5	0·6	...	..	...	1·2
3rd toe	0·6	0·6	0·9	...	...	...	1·5
4th toe	0·7	0·7	1·2	...	...	...	1·8
5th toe	...	0·5	0·8	...	...	...	0·8
Hind foot:							
Length	2·4	2·2	2·6	1·2	0·4	3·6	3·2
Breadth	2·5	2·6	2·8	1·0 ?	0·4	4·0	3·2
1st toe	0·4	...	...	...	...	...	0·9
2nd toe	0·6	0·5	0·9	...	...	...	1·5
3rd toe	0·9	0·6	1·2	...	...	...	2·0
4th toe	1·1	0·6	1·2	...	...	...	2·2
5th toe	0·8	0·5	0·8	...	...	...	1·1
Track-measurement I ...	0·2	2·5	0·4	1·8	...	...	2·8
Track-measurement II ...	...	...	7·5	4·3	...	...	10·0
Width of track	4·2	...	5·0	3·5	...	6·0	5·0

The Hamstead form H_1 (fig. 11, p. 661) I hold to be identical with *Ichnium sphærodactylum* (fig. 12), from the Middle and Upper

Rothliegende of Thuringia, and also from the Rothliegende of Silesia, Bohemia, and Moravia. The description of the Hamstead type H_1, given on p. 659, will answer equally well for that of the German species.

Comparative measurements of the English and Continental examples have been tabulated above. Except as regards the smaller average size of the Hamstead specimens, it will be noticed that the two series of measurements agree very closely. Owing possibly to the greater average hardness of the ground on which the Hamstead species trod at the time of the making of the impressions,

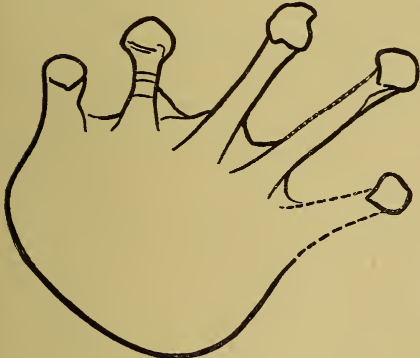


Fig. 11.—*Hamstead form of* Ichnium sphærodactylum *(half of the natural size).*

Fig. 12.—Ichnium sphærodactylum *from Tambach (half of the natural size).*

the first toe of each foot has left a smaller impression than in the German forms, and thus the measurements of our H_1 are relatively slightly the smaller. Besides this, the only difference between the Hamstead and German forms is in the breadth of the hind foot, which is proportionately the larger in the Hamstead specimens. As this measurement is determined by taking the distance apart of the tips of the outstretched toes on the inside and outside of the foot, and as a number of the Hamstead specimens have their toes widely stretched, this latter fact may account for the difference.

Footprints allied to the Hamstead form H_1, but not identical with it, are recorded from the Carboniferous rocks of America. These are named *Baropus lentus* and *Themaropus heterodactylus.*

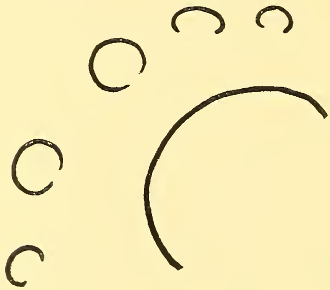
Baropus lentus Marsh,[1] from the Coal Measures of Kansas, shows a certain resemblance to the Hamstead form H_1. But that

[1] O. C. Marsh, 'Footprints of Vertebrates in the Coal Measures of Kansas' Amer. Journ. Sci. ser. 3, vol. xlviii (1894) pp. 81–84, & Geol. Mag. dec. 4, vol. i (1894) pp. 337–39.

B. lentus is not identical with the Hamstead species is shown by the much greater overlapping of the fore and hind footprints in

Fig. 14.—Ichniotherium cottæ *from Friedrichroda (a fifth of the natural size).*

Fig. 13.—*Type* H_{1a} *from Hamstead (half of the natural size).*



the former, and by the pointed character of the heel. A less important difference is the fact that, more rarely than in the Hamstead form, the whole of the five toes are impressed.

Thenaropus heterodactylus King[1] was found in the Coal Measures of Pennsylvania. Especially in the spacing of the feet in the tracks this form is like that of the Hamstead type H_1. The shape of the footprint, however, serves to separate this American species from the British form. Further, the toe-impressions in the former are much longer proportionately. The first toe is also more distinctly marked and longer.

From the British rocks of the Lower Permian—Penrith Sandstone—near Penrith were obtained the footprints modelled by G. Varty Smith. The description of the footprint noted by him as Cast 1 agrees with our description of the Hamstead form H_1. No figure of the Penrith footprint or of the cast is, however, given in Mr. Smith's paper.[2]

Sub-Type H_{1a}. ICHNIOTHERIUM COTTÆ Pohlig. (See also p. 660.)

Specimens precisely similar in character to that of H_{1a} are recorded in Prof. Pabst's memoir from the Rothliegende (Upper and Middle) of Thuringia, and from the Rothliegende of Silesia, Bohemia, and Moravia. The Hamstead specimen (fig. 13, p. 662) seems to me to be an imperfectly-impressed footprint of type H_1. The Continental analogue of H_{1a} is termed *Ichniotherium cottæ* (fig. 14). No footprints at all like H_{1a} are known from other Permian strata or from Carboniferous rocks.

Sub-Type H_{1b}. ICHNIUM SPHÆRODACTYLUM (MINIMUM) Pabst = *Ichniotherium cottæ* (*minus*) Pohlig. (See also p. 660.)

Sub-Type H_{1b} I consider to be the same as Pabst's *Ichnium sphærodactylum* (*minimum*), which occurs in the Middle and Upper Rothliegende of Thuringia. Both H_{1b} and *I. sphærodactylum* (*minimum*) are footprints with a broad ball. The width of the foot exceeds the length. There are five short toes with conspicuously semispherical endings, without any mark of a claw. The measurements of H_1 also agree in general with those of its German analogue (see p. 660); but the toe-prints in the Hamstead specimens are considerably the shorter, possibly due to a greater hardness of the ground at the time when the impressions were made. That this supposition is the correct one is rendered more probable by the rarer occurrence in the prints of H_{1b} of the first toe, which naturally bore least of the weight of the animal.

Type H_2. ICHNIUM PACHYDACTYLUM Pabst. Nine specimens in relief. (See figs. 15 & 16, p. 665.)

The footprints included here show a broad ball. There were five toes, although frequently only three or four are visible. These toes are thick, and their ends are obtusely rounded. The fourth

[1] A. T. King, 'Description of Fossil Footmarks found in the Carboniferous Series in Westmoreland County, Pennsylvania' Amer. Journ. Sci. vol. xlviii (1845) pp. 343–52 & vol. xlix (1845) p. 216.

[2] G. Varty Smith, 'On further Discoveries of the Footprints of Vertebrate Animals in the Lower New Red Sandstone of Penrith' Q. J. G. S. vol. xl (1884) p. 479.

is the longest, and the first the shortest. The first is the one which is most frequently absent in the cast. The toes are turned somewhat towards the inside of the track. The fore footprint is smaller than that of the hind foot. The breadth of all the footprints exceeds their length.

Measurements.	H_2.			I. PACHYDACTYLUM Pabst. Rothliegende.
	Minimum.	*Maximum.*	*Average.*	*Average.*
Fore foot:	cms.	cms.	cms.	cms.
Length	3·5	4·5	4·2	4·2
Breadth	4·5	6·0	5·2	5·3
1st toe	...	...	...	1·0
2nd toe	0·5	1·2	1·0	1·5
3rd toe	1·0	1·8	1·5	1·6
4th toe	1·1	1·8	1·3	1·8
5th toe	0·6	1·2	1·0	1·2
Hind foot:				
Length	4·0	7·0	5·0	5·5
Breadth	5·0	7·5	5·8	5·7
1st toe	0·5	1·0	0·8	1·2
2nd toe	1·0	1·5	1·2	1·5
3rd toe	1·0	1·6	1·4	1·8
4th toe	1·5	2·0	1·8	2·4
5th toe	1·0	1·3	1·2	1·5
Track-measurement I ...	3·5	12 ?	9·6 ?	5·7
Track-measurement II ...	10	26 ?	18·6 ?	15
Width of track	10	12	11	10·4

Sub-Type H_{2a}. ICHNIUM PACHYDACTYLUM (MINUS) Pabst. One specimen in relief. (See also pp. 665–66.)

The specimen shows small footprints of the same characters as H_2, but smaller. They are 0·8 cm. long, and of about the same width.

Sub-Type H_{2b}. ICHNIUM PACHYDACTYLUM (UNGULATUM) Pabst= *Saurichnites leisnerianus* (Geinitz). Four specimens, three in relief (casts): one as a mould. (See figs. 17 & 18, p. 666.)

The footprints of H_{2b} in some cases possess a broad ball with short, thick, and blunt-ended toes. These are five in number, but usually four only are shown in the print. In this case the ball of the foot then resembles the whole footprint of H_2. In others the ball of the foot is not indicated. In all cases, however, a semicircle of claw-markings with five or fewer claws is present. This semicircle, when the ball of the foot is represented in the impression, precedes it in the track by about 2 cms. The footprints are wider than they are long. The length of three of the footprints is from 4 to 5 cms., and the width from 5 to 6 cms. The toes vary from 1 to 2 cms. in length. Track-measurement I=12 cms., and track-measurement II=14 cms. The fourth example of this type is considerably smaller than the others. It shows no ball in the centre of the footprint, but a semicircle of claw-impressions curved and slightly pointed. The toe-tips or claw-markings are respectively ·3, ·5, ·6, ·8, and ·3 cm. long. The breadth is 1·3 cm.; the length is not determinable. Track-measurement I=1 cm.; track-measurement II=2 cms.; width of track = 2 cms.

The footprints classed as H_2 (fig. 15, below) are considered to have been made by the animals of the same species as those of *Ichnium pachydactylum* (fig. 16), which has been recorded by Prof. Pabst from the Middle Rothliegende of Thuringia and from the Rothliegende of Silesia, Bohemia, and Moravia. No other similar footprints from the Permian areas or from Carboniferous rocks are known to me.

Fig. 15.—H_2 *from Hamstead (half of the natural size).*

Fig. 16.—Ichnium pachydactylum *from Friedrichroda (half the natural size).*

The description of the Hamstead form Type H_2 (pp. 663–64) will apply equally well to Pabst's *I. pachydactylum.* As in the Hamstead specimens of H_1, the toes of the British specimens of H_2 have left shorter impressions than those of their representatives from the German Rothliegende. The first toe on the foot is not shown on the fore foot of any Hamstead specimen, while it is often absent from the hind-foot impression. Comparative measurements of the Hamstead and Rothliegende specimens are tabulated on p. 664. Track-measurements I and II appear only very doubtfully on the Hamstead specimens. If my reading of them be correct, they are larger than the similar measurements in the German *I. pachydactylum.*

Sub-Type H_{2a}. Ichnium pachydactylum (minus) Pabst.

These appear to be the footprints of a young form of H_2, and may be, therefore, compared with *I. pachydactylum* (*minus*). On the

Continent specimens are recorded from the Silesian and Moravian Rothliegende.

Sub-Type H_{2b}. ICHNIUM PACHYDACTYLUM (UNGULATUM) Pabst = *Saurichnites leisnerianus* Geinitz.[1] (See also p. 664.)

Footprints similar to Sub-type H_{2b} (fig. 17) are known only from the Rothliegende of Silesia and Moravia. They have been named

Fig. 17.—H_{2b} *from Hamstead (half of the natural size).*

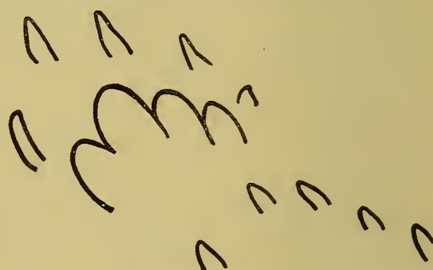
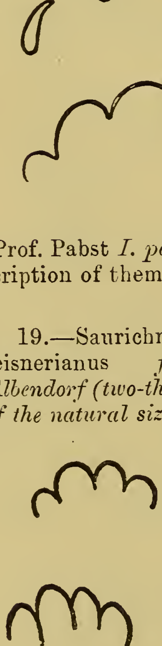


Fig. 18.—Ichnium pachydactylum (ungulatum) *from Albendorf (half of the natural size).*

by Prof. Pabst *I. pachydactylum* (*ungulatum*) (figs. 18 & 19). His description of them in his memoir is as follows:—

Fig. 19.—Saurichnites leisnerianus *from Albendorf (two-thirds of the natural size).*



'Footprints five-toed. Toes short, conspicuously broad, and thick-set, with claws measuring over 2 inches in length, which have left their distinct marks about 1·5 cm. before the ends of the toes in the footprints. The fourth toe is the longest. Each foot has a broad ball with rounded, weak, bluntly-marked ends. The width of the foot is from 1 to 1·5 cm. greater than their length.'

In every particular in the above description there is strict agreement between the Hamstead examples of H_{2b} and Prof. Pabst's species; hence I feel no hesitation in classing the Hamstead type H_{2b} as *I. pachydactylum* (*ungulatum*).

Type H_3. ICHNIUM BRACHYDACTYLUM (Pabst). One specimen in relief (cast). (See figs. 20 & 21, p. 667.)

H_3 includes footprints with five toes, and with a somewhat massively developed ball. The toes are short, weak, thickened somewhat towards the tips, yet with the ends sharp. The fourth is the longest. The length of the footprint is about equal to the width. The print of the fore foot is only slightly smaller than that of the hind foot. The fore footprint in the specimen is not clearly marked, and cannot be accurately measured.

[1] H. B. Geinitz, 'Beiträge zur Kenntniss der organischen Ueberreste in der Dyas, &c.' Neues Jahrb. für Min. 1863, p. 389.

Measurements.	H_3.		ICHNIUM BRACHYDACTYLUM. Rothliegende
Hind foot:	cms.	cms.	cms.
Length	1·3	3·0	3·5
Breadth	1·4	3·3	3·7
1st toe	0·3	0·7	1·5
2nd toe	0·5	1·4	1·7
3rd toe	0·7	1·7	1·9
4th toe	0·8	2·8	2·0
5th toe	0·4	1·4	1·5
Track-measurement I	1·5	3·3	3·5
Track-measurement II	4·0	10·3	8·0
Width of track	2·5?	6·0	5·5

Fig. 20.—H_3 *from Hamstead (half of the natural size).*

Fig. 21.—Ichnium brachydactylum *from Kalna (about half of the natural size).*

Type H_3 (fig. 20) = *Ichnium brachydactylum* Pabst, from the Middle and Upper Rothliegende of Thuringia and the Rothliegende of Bohemia (fig. 21). No footprints similar to this type are known

Fig. 22.—H_4 *from Hamstead (natural size).*

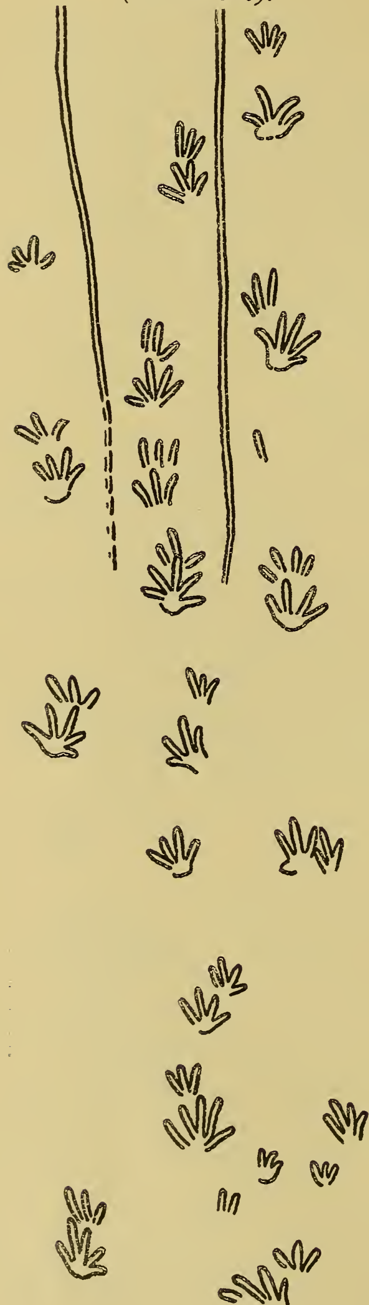


Fig. 23.—Ichnium dolichodactylum *from Tambach (half of the natural size).*

from Carboniferous rocks or from any other Permian areas. The Hamstead specimen is rather less than half the size of the two German specimens described and figured by Prof. Pabst. With the exception of this general difference in size, there is no distinction between the two series of measurements of the British and German examples, and the description given by Prof. Pabst of his *I. brachydactylum* answers to H_3 practically in every particular.

Type H_4. ICHNIUM DOLICHODACTYLUM Pabst. One specimen (a cast). (See figs. 22 & 23, p. 668.)

The single specimen shows a connected track of small footprints with feebly impressed ball, five long and outstretched toes on the hind foot. Their tips are blunt. The fore foot is overstepped by the hind foot, so that the fore footprint is smaller and not so well preserved as the hind one. In no case are more than four toes visible in the fore footprints. The toes are straight, but do not taper regularly from the base as in H_3. The fifth toe diverges considerably from the line of track, whereas the others point up the track in nearly parallel directions. The length of the footprint is about equal to the width.

Measurements.	H_4.	ICHNIUM DOLICHODACTYLUM Pabst. Rothliegende.
Fore foot:	cms.	cms.
Length	0·6	1·3
Breadth	0·6	1·4
1st toe	...	0·5
2nd toe	0·3	0·6
3rd toe	0·3	0·8
4th toe	0·4	1·0
5th toe	0·3	0·6
Hind foot:		
Length	1·0	1·9
Breadth	1·0	2·0
1st toe	0·3	0·6
2nd toe	0·4	0·7
3rd toe	0·5	1·0
4th toe	0·5	1·1
5th toe	0·4	0·8
Track-measurement I	0·4	2·0
Track-measurement II	1·6	5·5
Width of track	1·8	2·5

Type H_4 (fig. 22) is paralleled here with *Ichnium dolichodactylum* (fig. 23). Prof. Pabst records his *I. dolichodactylum* from the Upper Rothliegende of Thuringia, from which only one specimen was obtained. His description of it is as follows :—

'Each footprint with feebly developed ball and five long, weak, straight, outstretched toes, club swelling, but reducing again in size at the ends. No claw. The first four toes narrowly grown together: the fifth toe separated from them. The fourth toe is the longest, the first the shortest. The length of the footprint greater than the width. The footprints of the fore foot shorter than those of the hind foot; gait alternating with partial overlap of the hind and fore footprints.'

Except that in the Hamstead forms of H_4 the toe-tips appear to be blunt, Prof. Pabst's description applies almost exactly to the Hamstead specimen; but the first toe is absent from the fore foot of the Hamstead specimen, and the footprints are only about half the size of those described by Prof. Pabst as his *Ichnium dolichodactylum*; and the track-measurements I & II in H_4 are also proportionately smaller than in the German forms.

Type H_5. ICHNIUM GAMPSODACTYLUM Pabst = *Saurichnites lacertoides* Geinitz. Four specimens, A to D, in relief (casts).

The footprints of this type possess a feebly developed ball (sometimes not shown at all on the fossil), with five long curved and clawed toes, of which only four or even three are usually preserved. One of the toes, the fifth, generally is widely separated from the rest, and may be turned back in the track. The toe most often absent from the impression is No. 1. The hind footprint sometimes overlaps that of the fore foot, which is in consequence less easily measurable, with regard both to the ball and to the toes. The fore foot is the smaller. In its impression, the outstretched toe, the fifth, is never indicated. The length of the footprint is distinctly greater than the width. (See figs. 24 & 25, p. 671.)

Measurements.	H_5.				H_{5a}.			
	A.	B.	C.	D.	ICHNIUM GAMPSODACTYLUM (average).	D. (Small footprint.)	ICHNIUM GAMPSODACTYLUM (minimum).	
Fore foot:	cm.	cm.	cm.	cm.	cms.	cms.	cms.	cms.
Length	...	...	...	...	...	...	...	...
Breadth	...	...	...	...	...	...	...	...
1st toe	...	...	...	...	...	...	0·5	0·5
2nd toe	...	...	...	...	1·4 (may be absent)	0·5	0·7	0·8
3rd toe	...	...	...	...	2·0	0·8	1·0	1·1
4th toe	...	...	...	...	3·0	1·0	1·5	1·5
5th toe	. .	...	...	...	...	...	...	0·7
Hind foot:								
Length	5·0	3·8	...	5·0	4·9	1·8	2·8	...
Breadth	4·0	3·0	...	3·0	4·9	1·7	2·0	..
1st toe	...	0·7	...	...	1·3 (may be absent)	0·3	0·5	...
2nd toe	1·5	1·0	...	1·0& 1·0	1·9	0·6	0·8	0·6
3rd toe	3·7	1·8	...	1·5& 2·0	3·0	0·8	1·0	1·0
4th toe	4·0	2·2	...	2·5& 3·0	3·9	1·3	1·7	1·4
5th toe	3·0	1·8	...	3·0& 1·0	2·1	...	0·6	0·5
Track-measurement I	...	...	1·5	3·5	3·2	1·5	...	2·5
Track-measurement II	...	...	4·5	4·0	7·5	4·5	8·3	3·3
Width of track	...	...	5·5	...	7·2	3·0	5·0	4·0

In specimen D the fore foot is shown, but is so badly outlined as to debar accurate measurement. On the same specimen is a series of smaller footprints of the same type, referred to as H_{5a}, which may be compared with *Ichnium gampsodactylum* (*minus*).

The Middle Coal Measures of Kansas have furnished us with a footprint similar to, but not identical with, the Hamstead specimens of this type. It is described and figured by Marsh as *Dromopus agilis*. In both the Hamstead and American forms there are five slender curved and clawed toes indicated on the impression left by the hind foot, and four usually on the fore foot; the first toe spreads very much from the line of track, and the hind foot somewhat oversteps the fore foot. The principal points of difference between the two forms are: (*a*) the claws of *Dromopus agilis* appear to have been the longer and sharper; (*b*) the hinder part of the foot is not impressed in H_5, but is clearly outlined in the other;

Fig. 24.—H_5 *from Hamstead (natural size).*

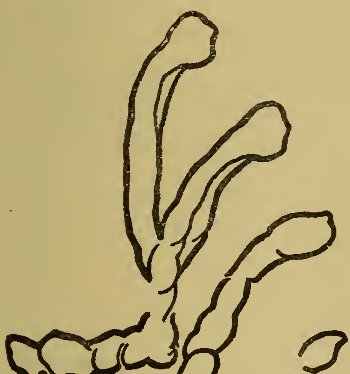
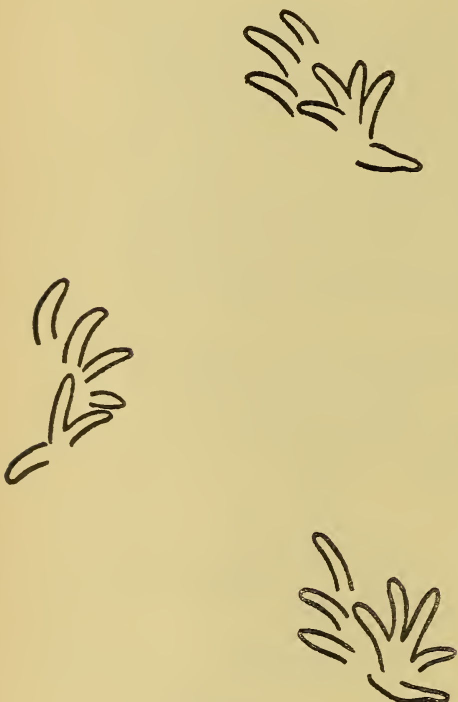


Fig. 25.—Ichnium gampsodactylum *from Albendorf (two-thirds of the natural size).*

(*c*) the general appearance of the footprint and the straighter and more distinctly impressed toe-prints in the American specimen suggest that the animal making these impressions was stronger and heavier than the one forming footprints of the type H_5. Dr. G. Hickling figures a similar footprint from the Permian sandstone in the neighbourhood of Penrith: it is a single small footprint with five slender and curved toes, and appears to agree exactly with the footprints of Type H_5 (fig. 24) and with *Ichnium gampsodactylum* (fig. 25). Footprints of animals probably identical

Fig. 26.—H_5 *from Hamstead (natural size).*

Fig. 27.—Ichnium gampsodactylum (minus) *from Albendorf (four-fifths of the natural size).*



with those of this Hamstead type H_5 occur commonly in the Middle and Upper Rothliegende of Thuringia and in the Rothliegende of Moravia, Bohemia, and Silesia. The Hamstead specimens of H_5 have furnished no measurable fore footprints, but the hind footprints show a very close resemblance to those described by Prof. Pabst as *Ichnium gampsodactylum.* The sole difference between the Hamstead and the German forms is the more frequent absence in H_5 of the print of the first toe, which is only shown on one specimen, and then but 0·7 cm. long; whereas the average length of this toe-print in the German *I. gampsodactylum* is 1·3 cm. It must be noted that there is no indication of this toe, on two out of the eight measured German specimens. The description of H_5 given on p. 670 accords in all respects with that given by Prof. Pabst of *I. gampsodactylum.*

Sub-Type H_{5a}. ICHNIUM GAMPSODACTYLUM (MINUS) Pabst.

The footprints in type H_{5a} (fig. 26, p. 672) appear to agree almost exactly with the small footprints of *I. gampsodactylum* separated by Prof. Pabst to form the subspecies *minus* (fig. 27). In type H_5 no fore footprint was clearly defined, but in H_{5a} both hind foot and fore foot are well shown, and in both the resemblance to the German form is very plain. It is to be noted, however, that the first toe of the fore foot and the fifth toe of the hind foot are absent from the Hamstead impressions, although present on some of the German specimens. The Continental specimens are derived from the Middle and Upper Rothliegende of Thuringia, and from the Rothliegende of Silesia, Bohemia, and Moravia.

Dr. G. Hickling[1] figures and describes a footprint from Penrith, collected by Mr. G. Varty Smith, which resembles closely the Hamstead type H_5 (*Ichnium gampsodactylum*).

Type H_6. Compare ICHNIUM ACRODACTYLUM (MINUS) Pabst. Two specimens (casts). (See fig. 28, p. 674.)

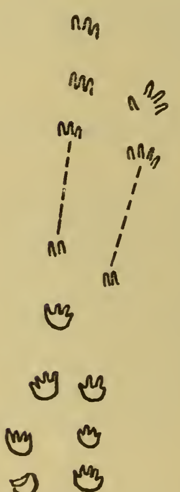
The specimens show tiny footprints, which are longer than they are broad. The ball of the foot is long and has a distinct heel. Five toes are indicated, which are long and taper gradually to a point. Each is straight throughout. The fifth toe diverges most from the line of the other four, which run closely side by side. The first is the shortest, and the third and fourth are the longest. In the connected track shown on one of the specimens, the fore and hind feet are not clearly distinguishable, owing to their close approximation in size and to the fact that track-measurement I is practically equal to track-measurement II. The gait is not alternating, but opposite.

[1] 'British Permian Footprints' Proc. Manch. Lit. & Phil. Soc. vol. liii (1909) no. 22, p. 1.

Measurements.	H_6.		ICHNIUM ACRODACTYLUM Pabst.
Fore foot:	cm.	cm.	cms.
Length	0·4	0·6	8·0
Breadth	0·5	0·7	6·3
1st toe	...	0·2	2·5
2nd toe	...	0·3	3·0
3rd toe	...	0·4	3·5
4th toe	...	0·4	4·5
5th toe	...	0·3	3·3
Hind foot:			
Length	0·4	0·65	0·9
Breadth	0·5	0·75	0·7
1st toe	...	0·2	0·4
2nd toe	...	0·3	4·5
3rd toe	...	0·4	4·5
4th toe	...	0·4	5·5
5th toe	...	0·3	3·5
Track-measurement I	about 1 cm. each.		13·5
Track-measurement II			17·5
Width of track	1·3		18·0

Type H_6 is distinguished from the other Hamstead types, the fore and hind feet of which are markedly unequal in size and their gait alternate, by a close approximation in size of the feet and a non-alternate but opposite gait. The footprints are also evenly spaced in the track (see fig. 28).

Fig. 28.—*Type* H_6 *from Hamstead (natural size).*



In these respects they agree with footprints from the Upper Rothliegende of Thuringia, named by Prof. Pabst *Ichnium acrodactylum.* These specimens show footprints far larger than those of H_6; but there is a general agreement in shape, relative size, and spacing of the feet. Pabst's description of his species is as follows:—

'Single footprints, with long narrow ball with distinctly marked heel. Five-toed. The toes long, conical, each tapering, and protected by a claw. The fifth toe spread out, the fourth the longest, the first the shortest. The length of the footprint about 2 cms. greater than its width. The fore footprints rather smaller than those of the hind feet. Gait not alternating.' (*Op. cit.* pp. 433–34.)

In the Hamstead specimen I can see no indication of a claw being present; but the description in other respects will answer for the two. The resemblance in shape, equality in size of the footprints of the fore and hind feet, and in particular the unique opposite and equally spaced-out gait, lead me to class this type with *I. acrodactylum*, despite the great disparity in size. The comparison between the measurements does not give a very close analogy; but this may be due to the fact that, owing to the small size of the footprints—length = 0·7 cm.—it has not been found possible to measure the length of the toes with sufficient accuracy.

The track of the tail of the animal, it may be mentioned, is present in the Hamstead specimen.

(4) Tracks of Animals other than Amphibia.

The tracks described in the foregoing pages include all those that can, with more or less certainty, be referred to those of amphibia or reptilia. They include, however, by no means the whole of the tracks shown on the surfaces of the sandstone beds, or even the majority of them: for the largest proportion of tracks present are of a different character, and have rather the appearance of having been made by some kind of arthropod, probably

Fig. 29.—*Tracks of crustacea from Hamstead (half of the natural size).*

crustacean. The commonest of these tracks was evidently made by a creature, each of whose feet ended in a claw or a sharp point. Every successive footstep made a separate and isolated depression in the soft muddy material, now represented by the marl-layers. Each of these depressions became subsequently filled up with sand, so that the tracks are now shown as casts on the under surfaces of the alternating sandstone beds. There are two parallel rows of these elevations in each separate track, one representing the impressions of the right, the other the left feet of the animal. Behind each cast of the claw-print of each foot is a depression on the face of the sandstone which is doubtless the mould of the little mound of mud or clay scraped backwards with each footstep by the creature in its forward march (see fig. 29, p. 675).

More rarely, specimens showing the actual impression of the claws are met with. Probably more than one species of crustacean is represented: for, besides the variation in the distance between individual footprints and the variation in the width of the track (such variation being likely because of the different ages and sizes of individuals of the same species), one finds that some differ so much in the relative proportions of the width of the track and the spacings of the markings as to render them almost certainly the work of animals of different species.

A large number of these tracks have come under my notice. They appear to fall into three groups, which I consider were made by as many different species. In each group are large and small examples, which I interpret as those made by mature and immature individuals. The following seem to be the average measurements of each group:—

Group A.

The impressions of the claws in this group appear from careful measurements to be opposite one another across the track. The width from tip to tip of the opposed claw-markings is 1·5 to 1·6 cm., and across the inside 0·9 to 1·0 cm. The distance between individual footprints in the same file is 0·4 cm.—varying from 0·3 to 0·55 cm.

Group B.

In this group are tracks made by a larger species of crustacean. The width across the outside of the track is 3 cms., whilst that across the inside of the track is 2·3 cms. The average distance between two successive footprints is 0·53 cm. They vary widely, however, from 0·2 to 0·7 cm. The claw-prints do not appear to pair across the track, and thus may be described as alternigrade.

Group C.

In these, the smallest type of crustacean footprint noticed at Hamstead, some of the legs were either shorter or were applied in walking more perpendicularly to the ground than the others, for a series of markings on the inside of the track is found, in which the claw-prints are shorter and often more bluntly ended than those on each side of them on the outside of the track. The width across the outside of the track is 1·0 cm., the width across the inside 0·5 to 0·7 cm. The distance between successive imprints on the same side varies from 0·1 to 0·4 cm., but is on an average 0·27 cm.

On the same surfaces as the last-noticed tracks are often straight line-markings, sometimes parallel to the tracks, but frequently crossing them at a small angle. Although the general direction of these parallel lines approximates to those made by the clawed animal, yet there is no certain indication of their organic origin. Very light bodies moved by water or by the wind along the muddy surfaces would make such lines.

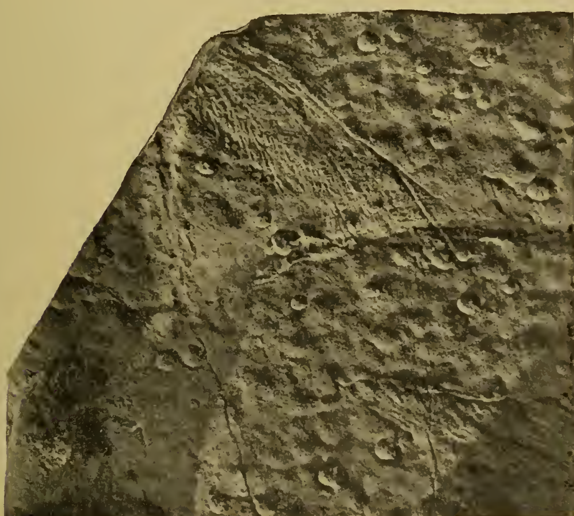
Other markings may be referred to worms. These worm-markings take the form sometimes of meandering tracks in sandstone, often almost along the planes of bedding, but they may be oblique to it; at other times they are vertical. In the latter case, heaps of castings are usual on the upper side of the sandstones containing the worm-burrows.

(5) Impressions other than Tracks or Footprints.

These include a cast in relief of a fish, the impression of an insect-wing, and casts of entomostraca (?). None of these show any trace of the organic substance of the fossil, and are all badly preserved.

The insect-wing occurs on the surface of a slab of red sandstone, which shows also some well-preserved rain-prints and a pair of casts of amphibian footprints. The wing, which is incomplete at the proximal end, measures 5·3 cms. in length, and 2 cms.

Fig. 30.—*Insect-wing (?), etc. from Hamstead (half of the natural size).*



in breadth. As one cannot be absolutely certain of the organic origin of the marking, I merely give a figure of the specimen (fig. 30). On the same slab, near the first, is a second marking of somewhat similar character, and disconnected from it. The 'nervures' in this marking are almost obliterated.

The markings interpreted as entomostracan casts are usually found on the nether surfaces of beds of sandstone, in what were once hollows of the underlying beds. The casts are concave on the one side, convex on the other, and have rounded ends. The length of one type is 1 mm., and its breadth 0·2 mm. Others are 2 mm. long and 1 mm. broad.

(6) Markings of Inorganic Origin.

Markings of undoubtedly inorganic origin, such as ripple-marks, rain-prints, and desiccation-cracks, are all very common, distinct, and abundant in the Hamstead rocks.

Of more doubtful origin are certain interesting circular marks, flame-shaped markings, and series of parallel lines. Some of the last-named mimic *Equisetum*.

(7) Table I, showing the Local Range of the Fossils of the Hamstead-Quarry Series.

Table I embodies the names and vertical distribution of the various fossil forms which I have discovered in the Hamstead Quarry Series.

TABLE I.	Gravel-Pit Sandstone & Conglom. Sub-group $=B_1$ of King.	New-Quarry Sandstone & Marl Sub-group $=B_2$.	Rock-Farm Conglomerate $=C_1$.	Old-Quarry Sandstone $=C_2$.	Manor-House Breccia & Sandstone Sub-group $=D_1$.
PLANTÆ.					
Walchia piniformis	—	×	—	×	—
Walchia imbricata	—	×	—	—	—
Artisia	—	×	—	—	—
ANIMALIA.					
H_1 = *Ichnium sphærodactylum*	—	×	—	—	—
H_{1a} = *Ichniotherium cottæ*	—	×	—	—	—
H_{1b} = *Ichnium sphærodactylum (minimum)* or *Ichniotherium cottæ (minus)*	—	×	—	—	—
H_2 = *Ichnium pachydactylum*	—	×	—	—	—
H_{2a} = *Ichnium pachydactylum (minus)*	—	×	—	—	—
H_{2b} = *Ichnium pachydactylum (ungulatum)* or *Saurichnites leisnerianus*	—	×	—	—	—
H_3 = *Ichnium brachydactylum*	—	×	—	—	—
H_4 = *Ichnium dolichodactylum*	—	×	—	—	—
H_5 = *Ichnium gampsodactylum* = *Saurichnites lacertoides*	—	×	—	—	—
H_{5a} = *Ichnium gampsodactylum (minus)*	—	×	—	—	—
H_6 = *Ichnium acrodactylum (?)*	—	×	—	—	—

V. GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF THE FOSSILS OF THE HAMSTEAD-QUARRY SERIES.

(1) General Distribution.

Table II (p. 679) summarizes the geological and geographical distribution of the foregoing (or nearly allied forms) in other parts of Britain and in Germany, France, and America.

Table II.	Carboniferous.								Permian.										
	Britain.		Germany.		France.		America.		Britain.		Germany.					France.			America.
	Middle or grey Productive Coal Measures.	Upper Coal Measures.	Middle Coal Measures. Westphalian.	Upper Coal Measures. Ottweiler & Saarbruckian.	Middle Coal Measures.	Upper Coal Measures. Stephanian.	Middle Coal Measures.	Upper Coal Measures.	Lower Permian Sandstones of Penrith, Dumfries, &c.	Upper Permian Magnesian Limestone Series.	Rothliegende of Thurignia. L.	M.	Upp.	Rothliegende of Silesia, Moravia, & Bohemia.	Zechstein or Upper Permian.	L.	M.	Upp.	'Permian.'
Plantæ.																			
Walchia piniformis	—	×	—	×	—	×	—	—	—	—	×	×	×	×	—	×	×	×	—
Walchia imbricata	—	×	—	×	—	—	—	—	—	—	—	×	—	×	—	—	—	—	—
Artisia (Sternbergia)	×	×	—	×	—	×	—	—	—	—	×	×	×	×	—	×	×	×	—
Animalia.																			
H_1. *Ichnium sphærodactylum*	—	—	—	—	—	—	× ?	—	× ?	—	—	×	×	×	—	—	—	—	—
H_{1a}. *Ichniotherium cottæ*	—	—	—	—	—	—	—	—	—	—	—	×	×	×	—	—	—	—	—
H_{1b}. *Ichnium sphærodactylum (minimum)*	—	—	—	—	—	—	—	—	—	—	—	×	×	—	—	—	—	—	—
H_2. *Ichnium pachydactylum*	—	—	—	—	—	—	—	—	—	—	—	×	—	×	—	—	—	—	—
H_{2a}. *Ichnium pachydactylum (minus)*	—	—	—	—	—	—	—	—	—	—	—	×	—	×	—	—	—	—	—
H_{2b}. *Ichnium pachydactylum (ungulatum)*	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—
H_3. *Ichnium brachydactylum*	—	—	—	—	—	—	—	—	—	—	—	×	×	×	—	—	—	—	—
H_4. *Ichnium dolichodactylum*	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—
H_5. *Ichnium gampsodactylum*	—	—	—	—	—	—	× ?	—	× ?	—	—	×	×	×	—	—	—	—	—
H_{5a}. *Ichnium gampsodactylum (minus)*	—	—	—	—	—	—	—	—	—	—	—	×	—	×	—	—	—	—	—
H_6. *Ichnium acrodactylum*	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—
Number of species recorded	1	3	0	3	0	2	2 ?	0	2 ?	0	2	11	9	11	0	2	2	2	0

(2) Summary and Conclusion.

(*a*) Plantæ.—Thus, so far as our present information respecting the range of these Hamstead-Quarry Series species of plants enables us to judge, the three species are common to the Upper Carboniferous and to the acknowledged Permian of other areas, either in Britain or abroad. It might, however, be here pointed out that, while *Walchia piniformis* and *W. imbricata* are rarities both in England and on the Continent in the Upper Carboniferous flora (in which the majority of the flora consists of ferns and fern-like plants), and there always preponderate in number of specimens over *Walchia*, in the Continental Lower Permian, on the other hand, these special types and other conifers form the majority of the flora, and individual specimens of *Walchia* are very abundant, while ferns and their allies are comparatively rare. Now, at Hamstead (although numerous specimens referable to *Walchia* have been discovered) no indication of fern or fern-like plants has been found. The plants found at Hamstead show, therefore, that the containing rocks have a closer affinity to the Continental Lower Permian than to the Continental Upper Carboniferous.

(*b*) Animalia.—The number of recognizable so-called species or main types of animals represented by footprints in the Hamstead-Quarry Group amounts to six, to which must be added five varieties or sub-types.

Two only of these, namely, H_1 (*Ichnium sphærodactylum*) and H_5 (*I. gampsodactylum*), have apparently hitherto been found in British deposits of acknowledged Permian age. H_1 and H_5 occur doubtfully in the Lower Permian strata of Penrith or Dumfries. None of the Hamstead forms have been met with in the Carboniferous rocks of Britain or the Continent; but forms somewhat similar to H_1 and H_5 have been recorded from the Middle Coal Measures of America.

All the amphibian forms of the Hamstead-Quarry Series (in all eleven species and subspecies) have been quoted from the Lower Permian (Rothliegende) of Germany. Eight forms (H_1, H_{1a}, H_{1b}, H_2, H_{2a}, H_3, H_5, H_{5a}) are common to the Hamstead-Quarry Series and the Middle Rothliegende of Thuringia, and seven (H_1, H_{1a}, H_{1b}, H_3, H_4, H_5, H_6?) to the Hamstead-Quarry Series and the Upper Rothliegende of the same region. The Rothliegende strata of Silesia, Moravia, and Bohemia have also afforded eight of these eleven common forms: namely, H_1, H_{1a}, H_2, H_{2a}, H_{2b}, H_3, H_5, and H_{5a}.

As the Hamstead-Quarry forms of amphibian footprints include ten, or possibly eleven (out of the total of seventeen) types and sub-types of footprints hitherto discovered in the whole Rothliegende of Germany, it would appear beyond question that the amphibian fauna of the Hamstead-Quarry Series must be paralleled with that of the German Rothliegende.

Conclusion.—Combining all the palæontological evidence hitherto obtained, namely that afforded by the species and varieties of the plants, and that afforded by the species and varieties of the animals, I hold that it may be safely inferred that the Hamstead-Quarry Series is the representative in geological time of a part of the Rothliegende of Germany and its equivalents in other countries—that is to say, the Hamstead-Quarry Series must in future be definitely regarded as of Lower Permian age. As this Quarry Series includes the upper part of Mr. Wickham King's Middle Permian, namely his Conglomerate and Sandstone Group, it appears probable that the whole of this group may be of true Lower Permian age.

I have to thank Prof. Lapworth for continued encouragement during the whole of this research.

Discussion on the two foregoing Papers.

Prof. C. Lapworth wrote :—

'I consider the Geological Society to be exceedingly fortunate in having before its members on the same evening two papers, both of which have a most important bearing upon the vexed and difficult question of the true limits of the so-called "Permian" red rocks of the Midlands. Both in the South Staffordshire area dealt with in Mr. Hardaker's paper, and in the Warwickshire area covered more or less by Mr. Vernon in his paper, the so-called "Permian" rocks apparently graduate upwards conformably from undoubted Carboniferous deposits with highly profitable coal-seams. The discoveries of Mr. Cantrill in the west, and Dr. Gibson in the north, prove that Upper Coal-Measure conditions continued at all events into the lower divisions of these red rocks, and even in composition and coloration the Midland Permian has much in common lithologically with the true Upper Coal Measures; while, as Dr. Kidston and Mr. Meachem have shown, the lowest members of the so-called "Midland Permian" afford fossils which are distinctly of the type of those of the Upper Coal Measures.

'Now that Mr. Hardaker has so successfully worked out, almost bed by bed, a complete descending succession of strata from his highest Permian zone down into the Thick Coal-seam of South Staffordshire; and that the various recent borings in search of coal through Warwickshire have made known the descending succession, almost bed by bed, from the higher zones of the so-called 'Permian" of Warwickshire down into the Hawkesbury Thick Coal and its equivalents: it is plain that (if Mr. Hardaker's identification of the fossils discovered by him in the hitherto barren Midland Permian is eventually confirmed by palæontologists) British geologists may now for the first time feel some assurance that the solution of the chief of the Permian problems of the Midlands is almost within sight, and may anticipate that such a solution will have the usual effect of justifying and at the same time harmonizing the differing views of previous observers.'

Dr. Walcot Gibson remarked that, as several borings and sinkings for coal through the red rocks of Warwickshire were in progress, the very interesting results obtained by the Authors of these two papers should stimulate local geologists to obtain further evidence on an important and hitherto unsolved problem. The 'Lower Permian' of Prof. Hull and Mr. Wickham King was everywhere in the Midlands conformable to the Coal Measures, and contained Carboniferous plants. In the Claverley Boring situated near Enville, which is the typical area of the Salopian Permian, all the plants, of which some specimens were exhibited by the Director of the Geological Survey, are Carboniferous forms; and one of them (*Neuropteris heterophylla*) is a characteristic Middle Coal-Measure species. He would ask Mr. Vernon to state on what evidence he based the unconformity between the limestone-conglomerate series with Permian fossils and the underlying Keele Beds with Carboniferous plants.

Baron F. Nopcsa commented on the fact that one of the footprints described by Mr. Hardaker seemed to indicate an animal having a lizard-like body, and he suggested that such footprints might be produced by a *Proterosaurus*-like reptile. If such were the case, it would point to a Permian age for the rocks under consideration.

Dr. C. A. Matley mentioned that his investigations of the Keuper rocks of Warwickshire had brought him to the western edge of the ground shown on Mr. Vernon's map, and enquired whether that Author had been able to confirm the position of the lines shown on the Geological Survey map as separating the Permian from the Trias. The speaker had not found the western boundary always well-defined, while the boundary-fault seemed, at Maxstoke Priory, to be farther west than the Geological Survey map indicated. He also enquired as to the nature and horizon of the silicified tree-stems found in the Permian at Allesley, examples of which, with the woody structure beautifully preserved, he had found in the glacial drift of the Keuper Marl country to the south-west.

The President (Dr. A. Strahan) agreed with the opinion expressed by previous speakers, that a considerable advance had been made by the Authors towards determining the limit between Permian and Carboniferous, and in thus removing what had long been a blot upon British geology. From his own recollection of the ground, he believed that there was a continuous and conformable sequence from the lowest Coal Measures of Warwickshire up into the Keele Beds. He, therefore, asked for some further details respecting the section in which the Haunchwood Sandstone was said to rest unconformably upon upturned Middle Coal Measures.

Mr. Vernon, in reply, pointed out that the unconformity at the base of the Permian was inferred from the fact that 75 per cent. of the pebbles in the Corley Conglomerates consist of Carboniferous Limestone. Further, the lowest beds of the Corley Conglomerates can be shown to rest upon different horizons of the Keele Beds: thus, near Exhall, the Keele Beds are only about 650 feet thick, but near Coventry, in the borehole at Whitmore Park they reach 977 feet, while in the Keresley borehole they attain a thickness of 1413 feet.

In answer to Dr. Matley, he stated that the silicified plants from Allesley occur in the Permian, and are probably allied to *Cordaites*.

With regard to the boundary-faults, the western fault near Maxstoke brings the Corley Conglomerates which dip eastwards at 15° against nearly horizontal Keuper Marls. He thought that the importance of the western boundary-fault near Nuneaton had been much exaggerated.

In reply to the point raised by the President, Mr. Vernon said that, although the subdivisions of the Upper Coal Measures are conformable, near Polesworth the Nuneaton Clays are locally absent, and so the nearly horizontal Haunchwood Sandstones come to rest upon Middle Coal Measures which have a westerly dip.

Mr. Hardaker stated that the footprints and plants described in his paper had been obtained from one quarry only, and that was in the Permian rocks of Hamstead.

Nothing is known as to the line of separation between the Upper Carboniferous and the Permian rocks in the Hamstead area. An unconformity accompanied by a bed of conglomerate occurs in the shaft at Hamstead Colliery at a depth of 802 feet; but this cannot be taken as the boundary between Carboniferous and Permian, for the Carboniferous plant *Odontopteris lindleyana* occurs at a depth of 729 feet, or 73 feet above the conglomerate. Above this there is strict conformity, and yet at the surface true Lower Permian rocks are found. Perhaps, under the circumstances, the best line of separation would be at the base of the Calcareous Conglomerate of Mr. Wickham King.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXVIII.

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PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1911-1912.

November 8th, 1911.

Prof. W. W. Watts, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On the Interglacial Gravel-Beds of the Isle of Wight and the South of England, and the Conditions of their Formation.' By Prof. Edward Hull, M.A., LL.D., F.R.S., F.G.S.

2. 'The Gopeng Beds of Kinta (Federated Malay States).' By John Brooke Scrivenor, M.A., F.G.S.

The following lantern-slides, specimens, etc. were exhibited :—

Lantern-slides, exhibited by Prof. E. Hull, M.A., LL.D., F.R.S., F.G.S., in illustration of his paper.

Granite-boulder from the Tekka-Linie Road Mine, Gopeng; also a series of photographs of the Gopeng district, exhibited by J. B. Scrivenor, M.A., F.G.S., in illustration of his paper.

Meteoric stone which fell on June 29th, 1911, near El-Nakbla-el-Baharra, 25 miles east of Alexandria (Egypt). Exhibited by Dr. G. T. Prior, M.A., F.G.S., on behalf of Dr. W. F. Hume, F.G.S., Director of the Geological Survey of Egypt.

November 22nd, 1911.

Prof. W. W. WATTS, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

Frederic Garnett Clarke, F.R.G.S., 15 Kensington Court Gardens, W., was elected a Fellow of the Society; and Prof. Baron Gerard Jakob de Geer, Stockholms Högskola, Stockholm, was elected a Foreign Member of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Petrological Notes on Guernsey, Herm, Sark, and Alderney.' By Prof. T. G. Bonney, Sc.D., LL.D., F.R.S., F.G.S., and the Rev. Edwin Hill, M.A., F.G.S.

2. 'The Evolution of *Inoceramus* in the Cretaceous Period.' By Henry Woods, M.A., F.G.S.

The following specimens and lantern-slides were exhibited:—

Rock-specimens and microscope-sections exhibited by Prof. T. G. Bonney, Sc.D., LL.D., F.R.S., F.G.S., and by the Rev. E. Hill, M.A., F.G.S., in illustration of their paper.

Lantern-slides exhibited by H. Woods, M.A., F.G.S., in illustration of his paper.

December 6th, 1911.

Prof. W. W. WATTS, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

George Debayo Agbebi, B.Sc., Lagos (West Africa); Henry Auty, 39 Kenbourne Road, Sharrow, Sheffield; Fredrick James Barnes, Glenthorne, Weymouth (Dorset); Robert George Alexander Bullerwell, M.Sc., Balgonie House, Maddison Street, Blyth (Northumberland); Arthur Croom-Johnson, J.P., Fox Elms, Robinswood Hill, near Gloucester; Hem Chandra Das-Gupta, M.A., Demonstrator in Geology in the Presidency College, Calcutta (India); Dr. G. Delépine, Professor of Geology in the Catholic University of Lille, 60 Boulevard Vauban, Lille (France); Dr. Franz Herzberg, 11 Rüsterstrasse, Frankfurt am Main (Germany); Douglas Leighton, 108 St. Julian's Farm Road, West Norwood, S.E.; Richard Roy Lewer, c/o Mower & Co., P.O. Box 42, Rangoon (Burma);

Frederick William Linck, Roydene, The Drive, Sidcup (Kent); Alexander Gordon Macdonald, B.E., Inspector of Mines, Federated Malay States, c/o the Institution of Mining & Metallurgy, Salisbury House, E.C.; Baidya Nath Saha, M.A., 1 Kumartuli Street, Calcutta (India); Ernest William Terrey, Darren Park, Pontypridd (South Wales); and Robert Charles Wallace, M.A., B.Sc., Ph.D., Lecturer in Geology & Mineralogy, University of Manitoba, Winnipeg (Canada), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Faulted Inlier of Carboniferous Limestone at Upper Vobster (Somerset).' By Thomas Franklin Sibly, D.Sc., F.G.S.

2. 'Geology of a Part of Costa Rica.' By James Romanes, M.A., F.G.S.

The following specimens and lantern-slides were exhibited:—

Specimens of Carboniferous rocks, microscope-sections and lantern-slides, exhibited by Dr. T. F. Sibly, F.G.S., in illustration of his paper.

Specimens of rocks from Costa Rica and lantern-slides, exhibited by J. Romanes, M.A., F.G.S., in illustration of his paper.

December 20th, 1911.

Prof. W. W. Watts, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

The Rev. Christopher Cecil Fowler, Corringham Vicarage, Gainsborough (Lincolnshire); and Albert Gilligan, B.A., University Lecturer in Geology, Craigholme, Horsforth, near Leeds, were elected Fellows of the Society; Dr. Armin Baltzer, Professor of Geology in the University of Berne (Switzerland); and Dr. Emmanuel de Margerie, Paris, were elected Foreign Members of the Society; also Prof. Charles Depéret, Lyons; and Prof. Arvid Gustaf Högbom, Upsala, were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The President, in announcing the decease of Sir Joseph Dalton Hooker, O.M., at the age of 94, drew attention to the long connexion of that illustrious man of science with the Society, of which he was elected a Fellow no less than 65 years ago, in 1846; and stated that the Council had passed a resolution of condolence and sympathy, which had been forwarded to Lady Hooker.

The President announced that Fellows were requested to send in to the Secretary, so as to reach him not later than January 9th, 1912, the Names of any Fellows whom they might desire to see placed on the Council.

The following communications were read :—

1. 'The Glacial Sections round Sudbury (Suffolk).' By the Rev. Edwin Hill, M.A., F.G.S.

2. 'The Ordovician and Silurian Rocks of the Kilbride Peninsula (Mayo).' By Charles Irving Gardiner, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S.

The following specimens, lantern-slides, and maps were exhibited :—

Fossils, rocks, rock-sections, and lantern-slides, exhibited by C. I. Gardiner, M.A., F.G.S., and Prof. S. H. Reynolds, M.A., F.G.S., in illustration of their paper.

Carte Géologique Internationale de l'Europe, 1 : 1,500,000, Sheets D I, E V–VII, and F V–VII, 1911, presented by the International Geological Commission.

Carte Géologique Détaillée du Bassin Houiller du Donetz, 1 : 42,000, Sheets VII 25, & VII 26, 1911, presented by the Imperial Geological Committee of Russia.

January 10th, 1912.

Prof. W. W. Watts, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following Fellows of the Society, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: James Vincent Elsden, D.Sc., and John William Evans, D.Sc., LL.B.

The following communication was read :—

'On a Late Glacial Stage in the Valley of the River Lea, subsequent to the Epoch of River-Drift Man.' By S. Hazzledine Warren, F.G.S. With Reports on the Flowering Plants, by Francis J. Lewis, M.Sc., F.L.S.; on the Mosses, by H. N. Dixon, M.A., F.L.S.;

on the Mollusca, by Alfred Santer Kennard, F.G.S., & Bernard Barham Woodward, F.L.S., F.G.S.; on the Coleoptera, by C. O. Waterhouse, I.S.O., F.E.S.; on the Entomostraca, by D. J. Scourfield, F.R.M.S.; and on the Microscopic Examination of the Sandy Residue, by George Macdonald Davies, F.G.S.

Remains of mammoth, horse, beetles, mollusca, and moss from the Arctic Bed of the Lea Valley and Palæolithic implements from the high-level terraces, were exhibited by S. H. Warren, F.G.S., in illustration of his paper.

January 24th, 1912.

Prof. W. W. Watts, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

David Farr Davies, New Crosslands, near Llanelly; Walter Thomas Davies, B.Sc., 115 Station Road, Old Hill (Staffordshire); Arthur Holmes, B.Sc., A.R.C.S., Assistant Demonstrator in Geology at the Royal College of Science, 34 Edith Grove, Chelsea, S.W.; George Howell, 23 Crowhurst Road, Brixton, S.W.; the Rev. Eric Marfleet Ingamells, B.A., Orroroo (South Australia); Henry Robert Knipe, F.L.S., 9 Linden Park, Tunbridge Wells; Ben Lightfoot, B.A., Geological Surveyor, Bulawayo (Rhodesia); Gerald Meyrick Part, Scholar of Trinity College, Cambridge; Henry Drummond Staniar, 105 Market Street, Manchester; Edward James Wayland, 56 Richmond Road, Barnsbury, N.; and J. Malcolm Whitehouse, M.Inst.M.E., 'Tranode,' Leyton Avenue, Mansfield, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Upper Keuper (or Arden) Sandstone Group and Associated Rocks of Warwickshire.' By Charles Alfred Matley, D.Sc., F.G.S.

The following specimens were exhibited:—

Specimens from the Upper Keuper (or Arden) Sandstone Group and Associated Rocks of Warwickshire, exhibited by Dr. C. A. Matley, F.G.S., in illustration of his paper.

Also a series of specimens from the same district, exhibited by L. J. Wills, M.A., F.G.S., and W. Campbell Smith, B.A., F.G.S.

February 7th, 1912.

Prof. W. W. Watts, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

Charles F. Garratt, Ashley House, Calthorpe Road, Edgbaston, Birmingham; L. William Jones, 112 Alexander Road, Acocks Green, Birmingham; John Roberts, 22 Cartwright Gardens, St. Pancras, W.C.; George Slater, Instructor in Geology, Ipswich Technical School, 4 Ruskin Road, Ipswich; and Joshua Thomas, 22 Cartwright Gardens, St. Pancras, W.C., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'On an Inlier of Longmyndian and Cambrian at Pedwardine (Herefordshire).' By Arthur Hubert Cox, M.Sc., Ph.D., F.G.S.

The following specimens and slides were exhibited:—

Rocks, fossils, and microscope-slides, exhibited by Dr. A. H. Cox, M.Sc., F.G.S., in illustration of his paper.

Specimens from a new island formed off the coast of Trinidad (British West Indies) in November, 1911, exhibited by C. B. C. Storey, M.A., F.L.S., F.G.S.

Specimens erupted in September, 1911, from a so-called 'mud-volcano' at Cedros (South-Western Trinidad); also specimens from the new island formed off the coast of Trinidad in November, 1911, exhibited by Dr. G. T. Prior, M.A., F.G.S.

ANNUAL GENERAL MEETING.

February 16th, 1912.

Prof. W. W. Watts, Sc.D., LL.D., M.Sc., F.R.S., President, in the Chair.

Report of the Council for 1911.

During the year 1911, 48 new Fellows were elected into the Society, the same number as were elected during the previous year. Nevertheless, a slight decrease in the total number of Fellows has to be recorded. Of the 48 Fellows elected in 1911, 35 paid their Admission Fees before the end of the year. Of the Fellows who had been elected in the previous year, 12 paid their Admission Fees in 1911, making the total accession of new Fellows during the year under review amount to 47.

Deducting from this number a loss of 52 Fellows (20 by death, 17 by resignation, and 15 by removal from the List, under Bye-Laws, Sect. VI, Art. 5), it will be seen that there is a decrease in the Number of Fellows of 5 (as compared with an increase of 5 in 1910 and of 11 in 1909).

The total Number of Fellows is therefore now 1294, made up as follows: Compounders, 248 (4 less than in 1910); Contributing Fellows, 1024 (1 less than in 1910); and Non-contributing Fellows, 22 (the same as in 1910).

Turning to the Lists of Foreign Members and Foreign Correspondents, the Council recall with regret the loss during the past year of Dr. E. Dupont, Dr. A. Michel Lévy, and Dr. C. A. White, Foreign Members; as also of Prof. G. Stefanescu and Dr. A. E. Törnebohm, Foreign Correspondents. The vacancies in the list of Foreign Members were filled up by the election of Baron G. de Geer, Prof. A. Baltzer, and Dr. E. de Margerie; two vacancies in the List of Foreign Correspondents were filled by the election of Prof. C. Depéret and Prof. A. G. Högbom, but there still remained three vacancies in the List of Foreign Correspondents at the end of the year.

With regard to the Income and Expenditure of the Society during 1911, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £352 19*s*. 2*d*. brought forward from the previous year, and £100, the amount of the Hannah Bequest) amounted to £3029 19*s*. 11*d*., being £35 6*s*. 1*d*. less than the estimated Income. On the other hand, the total Expenditure during the same year amounted to £3007 7*s*. 3*d*., being £56 10*s*. 9*d*. less than the estimated Expenditure for the year, and £22 12*s*. 8*d*. less than the actual Receipts: the year closing with a Balance in hand of £375 11*s*. 10*d*. (excluding the Hannah Bequest).

The question of the transference of the collections in the Society's Museum, to which reference was made in the previous Annual

Report, was finally considered at a Special General Meeting of the Fellows, held on June 14th, 1911. The result of that Meeting, as also the full text of the resolutions submitted thereat by the Council, appears on p. cii of the Proceedings for 1911 (vol. lxvii of the Quarterly Journal). The space formerly occupied by the collections of rocks and fossils has been fitted up as an extension of the Library. This work was carried out mainly during the summer recess, after the authorities of the Natural History Museum and of the Museum of Practical Geology had removed the specimens respectively allotted to those Institutions. The ultimate total cost of the alterations is expected to amount approximately to £230.

The Office of Works has removed from the cabinets the specimen-drawers which belonged to the Government, while those in the gallery belonging to the Society have been purchased by various Fellows, in response to the notice sent out simultaneously with one of the Abstracts of Proceedings. The demand was greater than perhaps could have been foreseen, and in the allotment to the various applicants every endeavour was used to make the distribution as widespread as possible. The Council are of opinion that the Society is greatly indebted to the Treasurer, for the continuous personal supervision which he gave to all the arrangements connected with this matter and with the fitting-up of the Library extension. The Society's thanks are also due to Dr. G. J. Hinde, Mr. H. W. Monckton, and Dr. J. J. H. Teall, who, although not serving on the Council at the time, freely gave their services to the Museum Committee.

The Council appointed a Special Committee to consider the partial re-arrangement of the books consequent on this extension, and availed themselves of the services on that Committee of Dr. F. A. Bather, Mr. F. W. Rudler, and Mr. C. Davies Sherborn. It is hoped that the recommendations made by the Special Library Committee will facilitate the use already largely made of the Library by the Fellows. This re-arrangement will necessarily involve a considerable amount of labour, and some little time must elapse before it can be regarded as complete.

The Council have to announce the completion of Vol. LXVII and the commencement of Vol. LXVIII of the Society's Journal.

The ninth Award from the Daniel-Pidgeon Trust Fund was made on March 8th, 1911, to Mr. Tressilian Charles Nicholas, B.A., Trinity College, Cambridge, who proposed to investigate the relations of the older rocks in the Lleyn Peninsula (Carnarvonshire).

The following Awards of Medals and Funds have also been made by the Council:—

The Wollaston Medal is awarded to Dr. Lazarus Fletcher, in recognition of his 'researches concerning the Mineral Structure of the Earth,' especially in connexion with the study of crystalline forms and crystal optics.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Prof. Louis Dollo, in recognition of his invaluable contributions to Geological Science, more especially in connexion with Vertebrate Palæontology.

The Lyell Medal, together with a sum of Twenty-Five Pounds from the Lyell Geological Fund, is awarded to Mr. Philip Lake, as an acknowledgment of his contributions to the knowledge of the Lower Palæozoic rocks and their fauna.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Charles Irving Gardiner, in recognition of the value of his investigations among the Ordovician and Silurian rocks of Ireland.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Dr. Arthur Morley Davies, in acknowledgment of his researches among the Mesozoic rocks of Buckinghamshire.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. Arthur Richard Dwerryhouse, in recognition of his contributions to the knowledge of the Glacial Phenomena of the North of England and of the igneous rocks of Eskdale.

A second moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Robert Heron Rastall, in acknowledgment of his contributions to Petrography, especially in connexion with the igneous and metamorphic rocks of the Lake District and other areas.

It has been decided not to award the Prestwich Medal this year, but to devote the accumulated proceeds of the Fund to the special purpose of the Society's Library, in accordance with the terms of the will of the late Sir Joseph Prestwich.

Report of the Library Committee for 1911.

The Committee have pleasure in stating that the Additions made to the Society's Library during the past twelve months have maintained, both in number and in importance, the standard of previous years.

During the year 1911, the Library received by Donation 227 Volumes of separately published Works, 382 Pamphlets, 49 detached Parts of Works; as also 345 Volumes and 55 detached Parts of Serial Publications, and 25 Volumes of Weekly Periodicals.

The total number of accessions to the Library by Donation is thus found to amount to 597 Volumes, 382 Pamphlets, and 104 detached Parts. Moreover, 164 Sheets of Geological Maps were presented to the Library, including 28 Sheets received from the Geological Survey of England and Wales, and 7 Sheets from that of Scotland; 12 Sheets from the Geological Survey of Japan; 7 Sheets from the Geological Survey of Sweden; 4 Sheets from the Royal Hungarian Geological Institute; 3 Sheets from the Geological Survey of the Cape of Good Hope and 2 Sheets from that of the Transvaal; Prof. Lugeon's Geological Map of the High Alps between the Lizerne and the Kander; and Prof. Credner's Geological Index-Map of the Kingdom of Saxony; also 7 Sheets of the International Geological Map of Europe.

Among the Books and Pamphlets mentioned in the preceding paragraph, especial attention may be directed to the following works:—the third volume of 'La Face de la Terre,' by E. Suess, translated by Dr. E. de Margerie; Prof. J. P. Iddings's 'Rock Minerals'; the second edition of Prof. Judd's 'Student's Lyell'; the second part of Prof. E. Kayser's 'Lehrbuch der Geologie' (4th edition); Sir Henry Miers's 'Growth of a Crystal'; Dr. J. V. Elsden's 'Principles of Chemical Geology'; Prof. J. Walther's 'Lehrbuch der Geologie von Deutschland'; the fourth volume of Prof. A. Lacroix's 'Minéralogie de la France & de ses Colonies'; Dr. J. D. Falconer's 'Geology & Geography of Northern Nigeria'; Mr. E. A. N. Arber's 'Coast Scenery of North Devon,' and the same author's 'Natural History of Coal'; Mr. H. B. Woodward's 'History of Geology'; Mr. E. W. Small's 'Geology of Skomer, etc.'; Mr. G. B. Pritchard's 'Geology of Melbourne'; Mr. F. W. Harmer's 'Glacial Geology of Norfolk & Suffolk'; Dr. A. Salée's monograph of the Genus *Caninia*; the first part of Prof. L. Cayeux's work on the pisolitic iron-ores of France; the fourth part of Mr. F. J. Lewis's monograph of 'The Plant-Remains in the Scottish Peat-Mosses'; Mr. N. D. Cochrane's 'Report on the Rocks of Vitilevu and Vanualevu (Fiji)'; and Prof. L. Duparc's monograph on the Platinum-bearing Deposits of the Ural Mountains. The Geological Survey Memoirs on the Country near Sidmouth & Lyme Regis, on the Country around Padstow & Camelford, on the Water-Supply of Sussex, on the Neighbourhood of Edinburgh, on the Glasgow District, on East Lothian, on Colonsay & Oronsay, on Glenelg, Lochalsh, &c., as also the Catalogue of Photographs of Geological Subjects in the Geological Survey Office at Edinburgh, were received. In addition, numerous publications were received from the Departments of Mines and Geological Survey Departments of Canada, Ontario, British Columbia, of the Cape of Good Hope and the Transvaal, of the various States of the Australian Commonwealth, and of the Dominion of New Zealand; also from the Geological Survey Departments of India, Mysore, Egypt, the Sudan, Belgium, Holland, Italy, Portugal, Bohemia, Hungary, Russia, and Norway; from the United States Geological Survey, and from the independent State Surveys of Alabama, Illinois, Iowa, New York, Ohio, and Oklahoma. A large series of Colonial Reports was presented by the Under Secretary of State for the Colonies; and Prof. H. F. Osborn sent a collection of reprints of his own memoirs and papers, numbering about a hundred.

The Books and Maps enumerated in the foregoing paragraphs were the gift of 161 Government Departments and other Public

Bodies; of 186 Societies and Editors of Periodicals; and of 140 Personal Donors.

The Purchases, made on the recommendation of the standing Library Committee, included 35 Volumes and 9 detached Parts of separately published Works; 86 Volumes and 14 detached Parts of Works published serially; and 7 Sheets of Geological Maps.

The Expenditure upon the Library during the year under review was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased	87	15	6
Binding of Books and Mounting of Maps ..	122	9	6
Total..........	£210	5	0

Mr. C. Davies Sherborn reports, on the progress which has been made with the Card Catalogue of the Library, as follows:—

'I hope by the middle of 1912 to have accumulated all the author material up to date (except the years 1884–1893). This will then be put away in the cabinets, and the editing of the mass will commence in 1913.'

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review:—

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Anglo-Egyptian Sudan.—Geological Survey. Khartum.
Argentina.—Ministerio de Agricultura. Buenos Aires.
Australia (S.), etc. *See* South Australia, *etc.*
Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
Bavaria.—Königliches Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique, Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
——. Service Géologique de Belgique. Brussels.
Bergens Museum. Bergen.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham, University of.
Bohemia.—Naturwissenschaftliche Landesdurchforschung. Prague.
——. Royal Museum of Natural History. Prague.
Bristol.—Public Library.
British Columbia.—Department of Mines. Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
Bucarest.—Museului de Geologia și de Paleontologia.
Buenos Aires.—Museo Nacional de Buenos Aires.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).

Camborne.—Mining School.
Cambridge (Mass.).—Museum of Comparative Zoology in Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
——, High Commissioner for. London.
Cape of Good Hope.—Department of Agriculture (Geological Commission). Cape Town.
——. South African Museum. Cape Town.
Chicago.—'Field' Columbian Museum.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Cracow.—Academy of Sciences.
Denmark.—Commission for Ledelsen af de Geologiske & Geographiske Undersögelser i Grönland. Copenhagen.
——. Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère de la Guerre. Paris.
——. Ministère des Colonies. Paris.
——. Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Geneva, University of.
Georgia.—Geological Survey. Atlanta (Ga.).
Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle an der Saale.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. India Office. London.
Holland.—Departement van Kolonien. The Hague.
——. Rijksopsporing van Delfstoffen. The Hague.
Hull.—Municipal Museum.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois State Geological Survey. Urbana (Ill.).
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
——. Surveyor-General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Italy.—Reale Comitato Geologico. Rome.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Jassy, University of.
Kansas.—University Geological Survey. Lawrence (Kan.).
Kingston (Canada).—Queen's College.
Klausenburg (Koloszvár).—Provincial Museum & Library.
Leeds, University of.
London.—City of London College.
——. Imperial College of Science & Technology.
——. Imperial Institute.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academía de Ciencias Exactas, Físicas & Naturales.
Magdeburg.—Museum für Natur- und Heimatkunde.
Maryland.—Geological Survey. Baltimore (Md.).
Melbourne (Victoria).—National Museum.
Mexico.—Instituto Geológico. Mexico City.
Michigan College of Mines. Houghton (Mich.).
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Missouri.—Bureau of Geology & Mines. Rolla (Mo.).
Montana University. Missoula (Mont.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
Nancy.—Académie de Stanislas.

Naples.—Accademia delle Scienze.
Natal.—Department of Mines. Pietermaritzburg.
——. Geological Survey. Pietermaritzburg.
——. Government Museum. Pietermaritzburg.
New Jersey.—Geological Survey. Trentham (N.J.).
New South Wales, Agent-General for. London.
——. Department of Mines & Agriculture. Sydney.
——. Geological Survey. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington.
——. Geological Survey. Wellington.
Norway.—Norges Geologiske Undersökelse. Christiania.
Nova Scotia.—Department of Mines. Halifax.
Ohio Geological Survey. Columbus (Ohio).
Oklahoma Geological Survey. Norman (Okla.).
Ontario.—Bureau of Mines. Toronto.
Padua.—Reale Accademia di Scienze, Lettere & Arti.
——. University.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Pisa, Royal University of.
Portici.—Reale Scuola Superiore di Agricoltura.
Portugal.—Commissão dos Trabalhos Geologicos. Lisbon.
Prussia.—Königliches Ministerium für Handel & Gewerbe. Berlin.
——. Königliche Preussische Geologische Landesanstalt. Berlin.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth.—School of Mines.
Rhodesia.—Chamber of Mines. Bulawayo.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Rumania.—Geological Survey. Bucarest.
Russia.—Comité Géologique. St. Petersburg.
——. Musée Géologique Pierre le Grand. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
São Paulo (Brazil).—Commissão Geographica & Geologica. São Paulo City.
——. Secretaria da Agricultura, Commercio & Obras Publicas. São Paulo City.
Sarawak Museum.
Sedgwick Museum, Cambridge.
South Africa.—Department of Mines of the Cape of Good Hope.
South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tokio.—Imperial University.
——. College of Science.
Transvaal.—Geological Survey. Pretoria.
——. Mines Department. Pretoria.
Turin.—Reale Accademia delle Scienze.
United States.—Department of Agriculture. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, Royal University of.
Victoria (Austral.), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
Washington, State of (U.S.A.).—Geological Survey. Olympic (Wash.).

West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).
Western Australia, Agent-General for. London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).
Yale University Museum (Peabody Museum). Geological Department. New Haven (Conn.).

II. Societies and Editors.

Acireale.—Accademia di Scienze, Lettere & Arti.
Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Alnwick.—Berwickshire Naturalists' Club.
Aylesbury.—Architectural & Archæological Society for the County of Buckingham.
Basel.—Naturforschende Gesellschaft.
Bath.—Natural History & Antiquarian Field-Club.
Belgrade.—Servian Geological Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. 'Zeitschrift für Praktische Geologie.'
Berne.—Schweizerische Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.) Society of Natural History.
——. American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brooklyn (N.Y.) Institute of Arts & Sciences.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.
——. Société Royale Zoologique & Malacologique de Belgique.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Científica Argentina.
Bulawayo.—Rhodesian Scientific Association.
Caen.—Société Linnéenne de Normandie.
Calcutta.—Asiatic Society of Bengal.
——. 'Indian Engineering.'
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
——. South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chambéry.—Société d'Histoire Naturelle de Savoie.
Chicago.—'Journal of Geology.'
Christiania.—'Nyt Magazin for Naturvidenskaberne.'
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—'Colorado College Studies.'
Croydon Natural History & Scientific Society.
Denver.—Colorado Scientific Society.
Dijon.—Académie des Sciences, Arts & Belles-Lettres.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat (Jurjew).—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft.
——. Verein für Erdkunde.
Edinburgh.—Geological Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Fribourg.—Société Fribourgeoise des Sciences Naturelles.
Geneva.—Société de Physique & d'Histoire Naturelle.

Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Scientific Association.
Hanau.—Wetterauische Gesellschaft für Gesammte Naturkunde.
Havre.—Société Géologique de Normandie.
Helsingfors.—Société Géographique de Finlande.
Hereford.—Woolhope Naturalists' Field-Club.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaft.
Hertford.—Hertfordshire Natural History Society.
Hull Geological Society.
Indianapolis (Ind.).—Indiana Academy of Science.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence (Kan.).—'Kansas University Bulletin.'
Leeds.—Geological Association.
——. Philosophical & Literary Society.
——. Yorkshire Geological Society.
Leicester Literary & Philosophical Society.
Leipzig.—'Zeitschrift für Krystallographie & Mineralogie.'
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences.
Lille.—Société Géologique du Nord.
Lima.—'Revista de Ciencias.'
Lisbon.—Sociedade de Geographia.
——. Société Portugaise des Sciences Naturelles.
Liverpool Geological Society.
——. Literary & Philosophical Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Journal.'
——. 'Nature.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Ray Society.
——. 'Records of the London & West-Country Chamber of Mines.'
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Biblical Archæology.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies)
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological & Mining Society.
——. Literary & Philosophical Society.

Manila.—'Philippine Journal of Science.'
Melbourne (Victoria).—Australasian Institute of Mining Engineers.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Moscow.—Société Impériale des Naturalistes.
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
New Haven (Conn.).—Academy of Arts and Sciences.
——. 'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Oporto.—Academia Polytecnica. [Coimbra.]
Ottawa.—Royal Society of Canada.
Paris.—Commission Française des Glaciers.
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Portland Society of Natural History. Portland (Maine).
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Academy of Science.
——. Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
——. Société Scientifique du Chili.
São Paulo (Brazil).—Sociedade Scientifica.
Scranton (Pa.).—'Mines & Minerals.'
St. John (N.B.).—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Oberrheinischer Geologischer Verein.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Swansea.—Royal Institution of South Wales.
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—'Beiträge zur Paläontologie & Geologie Œsterreich-Ungarns & des Orients.'
——. 'Berg- & Hüttenmännisches Jahrbuch.'
——. Geologische Gesellschaft.
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Philosophical Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
Worcester.—Worcestershire Naturalists' Club.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Ameghino, F.
Andrews, E. C.
Arber, E. A. N.
Arshinov, V.

Baldwin-Wiseman, W. R.
Baldwin, W.
Barker, T. V.
Barringer, D. M.
Bather, F. A.
Beadnell, H. J. L.
Bolton, H.
Breton, L.
Brydone, R. M.
Burton, F. M.

Carez, L.
Carruthers, R. G.
Carus-Wilson, C.
Cayeux, L.
Chaix-Dubois, E.
Chamberlin, T. C.
Chapman, F.
Choffat, P.
Crema, C.

Dal Piaz, G.
Déchy, M. von.
Dewey, H.
Ditmas, F. I. L.
Dollé, L.
Drake, H. C.
Drygalski, E. von.
Dunlop, A.
Dunn, E. J.
Duparc, L.

Elsden, J. V.
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Fabiani, R.
Falconer, J. D.
Ferrar, H. T.
Finlayson, A. M.
Flett, J. S.
Fraipont, C.

Gerth, H.
Gosselet, J.
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Griffith, C.

Haanel, E.
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Hague, A.
Halle, T. G.
Handlirsch, A.
Harger, H. S.
Harmer, F. W.
Hermann, F.
Heron-Allen, E.
Higgins, D. F.
Holtz, H. C.
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Horwood, C. B.
Hume, W. F.

Jackson, J. W.
Judd, J. W.

Kayser, E.
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Lacroix, A.
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Laney, F. B.
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Lewis, F. J.
Lobley, J. L.
Lœwinson-Lessing, F.
Lohest, M.
Lowe, H. J.
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Lukashevich, I.
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Macnair, P.
Margerie, E. de.
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Matley, C. A.
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Miller, W. G.
Monckton, H. W.

Nathorst, A. G.
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Nopcsa, Baron F.
Nordenskjöld, J.

Osborn, H. F.
Oswald, F.

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Pogue, J. E.
Pritchard, G. B.

Rastall, R. H.
Reed, F. R. C.
Reeds, C. A.
Reusch, H.
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Romero, A. A.

Sacco, F.
Salée, A.
Salter, A. E.
Sauvage, H. E.
Sawyer, A. R.
Schardt, H.
Schmidt, R. R.
Schuchert, C.
Seward, A. C.
Shone, W.
Small, W.
Smith, B.
Spencer, J. W.
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Stevenson, J. J.
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Strahan, A.
Suess, E.

Termier, P.
Thiele, E. O.
Thompson, B.
Tilton, J. L.
Tœrnquist, S. L.
Toni, A. de.
Twenhofel, W. H.
Tyrrell, G. W.
Tyrrell, J. B.

Uhlig, V.

Walther, J.
Warren, S. H.
Whitaker, W.
Wieland, G. R.
Wilckens, O.
Williston, S. W.
Wiman, C.
Wittich, E.
Woods, H.
Woodward, H. B.

Zeiller, R.
Zimmerman, M.

COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE CLOSE OF THE YEARS 1910 AND 1911.

	Dec. 31st, 1910.		Dec. 31st, 1911.
Compounders	252	......	248
Contributing Fellows	1025	......	1024
Non-Contributing Fellows	22	......	22
	1299		1294
Foreign Members	40	......	40
Foreign Correspondents	40	......	37
	1379		1371

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1910 and 1911.

Number of Compounders, Contributing and Non-Contributing Fellows, December 31st, 1910		1299
Add Fellows elected during the former year and paid in 1911		12
Add Fellows elected and paid in 1911		35
		1346
Deduct Compounders deceased	8	
Contributing Fellows deceased	13	
Contributing Fellows resigned	16	
Contributing Fellows removed	15	
		52
		1294
Number of Foreign Members and Foreign Correspondents, December 31st, 1910	80	
Deduct Foreign Members and Foreign Correspondents deceased	5	
	75	
Add Foreign Correspondents elected	2	
		77
		1371

Deceased Fellows.

Compounders (8).

Braby, F.
Brigg, Sir John.
Byles, R. H.
Emmons, S. F.
Hooker, Sir John D.
Hovenden, F.
Roberts, Dr. R. D.
Shone, W.

Resident and other Contributing Fellows (13).

Barnes, W. D.
Coke, G. E.
Cole, Rev. E. M.
Daniell, J. R.
Eunson, J.
Farrer, Sir William J.
Gullan, Rev. J. T. C.
Jones, Prof. T. R.
Kendal-Bushe, Col. C. K.
Lawrence, H. L.
Longbottom, A.
Story-Maskelyne, Dr. N.
White, W.

Fellows Resigned (16).

Bebbington, J. T.
Bose, P. N.
Brewer, G. W. S.
Clay, S.
Coe, F. E.
Corbin, H. B.
Davies, E. H.
Gordon, J. C.
Harris, G. W.
Krausé, F. M.
Morris, W.
Murdoch, T.
Rooper, F. E.
Spencer, W.
Thomson, F. R.
Veitch, W. Y.

Fellows Removed (15).

Burr, W. T. G.
Davies, W. A. T.
Dixon, A. E.
Duncan, E. A.
Hargreaves, T. S.
Kelly, J.
Lake, H. W.
Lawford, G. M.
Lawson, J. C. E.
Majumdar, P. K.
Maxwell, W.
Meredith, W. L.
Payne, E.
Ridge, W. S.
Sambasiva-Iyer, V.

The following Personages were elected Foreign Members during the year 1911:—

Prof. Armin Baltzer, of Berne.

Prof. Baron Gerard Jakob de Geer, of Stockholm.

M. Emmanuel de Margerie, of Paris.

The following Personages were elected Foreign Correspondents during the year 1911:—

Prof. Arvid Gustaf Högbom, of Upsala.

Prof. Charles Depéret, of Lyons.

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 Prof. W. W. Watts, retiring from the office of President.

That the thanks of the Society be given to Dr. C. W. Andrews, Mr. Alfred Harker, and Prof. W. J. Sollas, retiring from the office of Vice-President.

That the thanks of the Society be given to Prof. E. J. Garwood, retiring from the office of Secretary.

That the thanks of the Society be given to Dr. A. Strahan, retiring from the office of Treasurer.

That the thanks of the Society be given to Mr. G. Barrow, Mr. Alfred Harker, Dr. J. S. Flett, Prof. S. H. Reynolds, and Prof. W. J. Sollas, retiring from the Council.

After the Balloting-Glasses had been 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 AND COUNCIL.—1912.

PRESIDENT.

Aubrey Strahan, Sc.D., F.R.S.

VICE-PRESIDENTS.

Prof. Edmund Johnston Garwood, M.A.
John Edward Marr, Sc.D., F.R.S.
Richard Dixon Oldham, F.R.S.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.

SECRETARIES.

Arthur Smith Woodward, LL.D., F.R.S., F.L.S.
Herbert Henry Thomas, M.A., B.Sc.

FOREIGN SECRETARY.

Sir Archibald Geikie, K.C.B., D.C.L., LL.D., Sc.D., Pres.R.S.

TREASURER.

Bedford McNeill, Assoc.R.S.M.

COUNCIL.

Henry A. Allen.
Tempest Anderson, M.D., D.Sc.
Charles William Andrews, B.A., D.Sc., F.R.S.
Henry Howe Arnold-Bemrose, J.P., Sc.D.
Prof. Thomas George Bonney, Sc.D., LL.D., F.R.S.
Prof. William S. Boulton, B.Sc.
James Vincent Elsden, D.Sc.
John William Evans, D.Sc., LL.B.
Prof. Edmund J. Garwood, M.A.
Sir Archibald Geikie, K.C.B., D.C.L., LL.D., Sc.D., Pres.R.S.
Robert Stansfield Herries, M.A.
Herbert Lapworth, D.Sc., M.Inst.C.E.
Bedford McNeill, Assoc.R.S.M.
John Edward Marr, Sc.D., F.R.S.
Richard Dixon Oldham, F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.
Clement Reid, F.R.S., F.L.S.
Aubrey Strahan, Sc.D., F.R.S.
Herbert Henry Thomas, M.A., B.Sc.
Arthur Vaughan, M.A., D.Sc.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.
Rev. Henry Hoyte Winwood, M.A.
Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1911.

Date of Election.

1877. Prof. Eduard Suess, *Vienna.*
1880. Geheimrath Prof. Ferdinand Zirkel, *Leipzig.*
1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
1885. Prof. Jules Gosselet, *Lille.*
1886. Prof. Gustav Tschermak, *Vienna.*
1890. Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg.*
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brögger, *Christiania.*
1893. M. Auguste Michel-Lévy, *Paris.* (*Deceased.*)
1893. Prof. Alfred Gabriel Nathorst, *Stockholm.*
1894. Prof. George J. Brush, *New Haven, Conn.* (*U.S.A.*). (*Deceased.*)
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1895. Dr. Grove Karl Gilbert, *Washington, D.C.* (*U.S.A.*).
1896. Prof. Albert Heim, *Zürich.*
1897. Dr. Anton Fritsch, *Prague.*
1897. Dr. Hans Reusch, *Christiania.*
1898. Geheimrath Prof. Hermann Credner, *Leipzig.*
1898. Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899. Prof. Emanuel Kayser, *Marburg.*
1899. M. Ernest Van den Broeck, *Brussels.*
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul von Groth, *Munich.*
1900. Dr. Sven Leonhard Törnquist, *Lund.*
1901. M. Alexander Petrovich Karpinsky, *St. Petersburg.*
1901. Prof. Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Joseph Paxson Iddings, *Brinklow, Maryland* (*U.S.A.*).
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905. Prof. Louis Dollo, *Brussels.*
1905. Prof. August Rothpletz, *Munich.*
1906. Prof. Count Hermann zu Solms-Laubach, *Strasburg.*
1907. Hofrath Dr. Emil Ernst August Tietze, *Vienna.*
1907. Commendatore Prof. Arturo Issel, *Genoa.*
1908. Prof. Bundjirô Kôtô, *Tokyo.*
1908. Dr. Feodor Černyšev, *St. Petersburg.*
1909. Prof. Johan H. L. Vogt, *Christiania.*
1909. Prof. René Zeiller, *Paris.*
1911. Prof. Armin Baltzer, *Berne.*
1911. Prof. Baron Gerard Jakob de Geer, *Stockholm.*
1911. M. Emmanuel de Margerie, *Paris.*

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1911.

Date of Election.

1874. Prof. Igino Cocchi, *Florence.*
1879. Dr. H. Émile Sauvage, *Boulogne-sur-Mer.*
1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Weimar.*
1893. Prof. Aléxis P. Pavlow, *Moscow.*
1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. Dr. Francisco P. Moreno, *La Plata.*
1895. Prof. Constantin de Kroustchoff, *St. Petersburg.* (*Deceased.*)
1896. Prof. Johannes Walther, *Halle an der Saale.*
1898. Dr. Marcellin Boule, *Paris.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Berlin.*
1899. Prof. Franz Lœwinson-Lessing, *St. Petersburg.*
1899. M. Michel F. Mourlon, *Brussels.*
1900. Prof. Ernst Koken, *Tübingen.*
1900. Prof. Federico Sacco, *Turin.*
1901. Prof. Friedrich Johann Becke, *Vienna.*
1902. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1902. Prof. Samuel Wendell Williston, *Chicago, Ill.* (*U.S.A.*).
1904. Dr. William Bullock Clark, *Baltimore* (*U.S.A.*).
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *East Las Vegas, New Mexico* (*U.S.A.*).
1904. Dr. Henry S. Washington, *Locust, N.J.* (*U.S.A.*).
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1906. Dr. Jakob Johannes Sederholm, *Helsingfors.*
1908. Prof. Hans Schardt, *Veytaux, near Montreux.*
1909. Dr. Daniel de Cortázar, *Madrid.*
1909. Prof. Maurice Lugeon, *Lausanne.*
1909. Prof. Ralph S. Tarr, *Ithaca, N.Y.* (*U.S.A.*). (*Deceased.*)
1910. Prof. François Alphonse Forel. *Lausanne.*
1910. Dr. A. E. Törnebohm. *Strengnös.* (*Deceased.*)
1911. Prof. Arvid Gustaf Högbom, *Upsala.*
1911. Prof. Charles Depéret, *Lyons.*

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., ETC.

'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. Gideon A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. Hugh Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron Leopold von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. The Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. The Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. The 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 Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. William Thomas Blanford.
1884. Prof. Albert Jean Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Descloizeaux.
1887. Mr. John Whitaker Hulke.
1888. Mr. Henry B. Medlicott.
1889. Prof. Thomas George Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John Wesley Judd.
1892. Baron F. von Richthofen.
1893. Prof. Nevil Story Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Dr. Grove Karl Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.
1903. Prof. Heinrich Rosenbusch.
1904. Prof. Albert Heim.
1905. Dr. J. J. Harris Teall.
1906. Dr. Henry Woodward.
1907. Prof. William J. Sollas.
1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William Berryman Scott.
1911. Prof. Waldemar Christofer Brögger.
1912. Dr. Lazarus Fletcher.

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. Gideon A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. 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. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. Samuel P. Woodward.
1855. { Dr. G. Sandberger. / Dr. F. Sandberger. }
1856. Prof. G. P. Deshayes.
1857. Dr. Samuel P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. / Mr. W. K. Parker. }
1861. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Dr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John Wesley Judd.
1874. Dr. Henri Nyst.
1875. Prof. Louis C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. Robert Etheridge, jun.
1878. Prof. William J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay H. Traquair.
1882. Dr. George Jennings Hinde.
1883. Prof. John Milne.
1884. Mr. Edwin Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Dr. Benjamin Neeve Peach.
1888. Dr. John Horne.
1889. Dr. A. Smith Woodward.
1890. Mr. William A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville Adelbert Derby.
1893. Mr. John George Goodchild.
1894. Dr. Aubrey Strahan.
1895. Prof. William W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis Arthur Bather.
1898. Prof. Edmund J. Garwood.
1899. Prof. John B. Harrison.
1900. Dr. George Thurland Prior.
1901. Dr. Arthur Walton Rowe.
1902. Mr. Leonard James Spencer.
1903. Mr. L. L. Belinfante.
1904. Miss Ethel M. R. Wood.
1905. Dr. H. H. Arnold-Bemrose.
1906. Dr. Finlay Lorimer Kitchin.
1907. Dr. Arthur Vaughan.
1908. Mr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS 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 enquiries 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.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. The Rev. W. B. Clarke.
1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brögger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Dr. Benjamin Neeve Peach. Dr. John Horne.
1900. Baron A. E. Nordenskiöld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.
1905. Mr. Edward John Dunn.
1906. Mr. Charles T. Clough.
1907. Mr. Alfred Harker.
1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur Philemon Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. Mr. Alfred Bell. / Prof. Ralph Tate.
1875. Prof. H. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Dr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith John Williams.
1894. Mr. George Barrow.
1895. Prof. Albert Charles Seward.
1896. Mr. Philip Lake.
1897. Mr. Sydney S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Sir Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.
1905. Prof. Herbert L. Bowman.
1906. Dr. Herbert Lapworth.
1907. Dr. Felix Oswald.
1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS 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 cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and 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 may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. Arthur S. Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Dr. John Edward Marr.
1901. Dr. Ramsay H. Traquair.
1902. { Prof. Anton Fritsch. / Mr. Richard Lydekker. }
1903. Mr. Frederick W. Rudler.
1904. Prof. Alfred G. Nathorst.
1905. Dr. Hans Reusch.
1906. Prof. Frank Dawson Adams.
1907. Dr. Joseph F. Whiteaves.
1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather. / Dr. Arthur Walton Rowe. }
1912. Mr. Philip Lake.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. Prof. Louis Dollo.
1890. Mr. Charles D. Sherborn.
1891. Dr. C. I. Forsyth Major.
1891. Mr. George W. Lamplugh.
1892. Prof. John Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Prof. Percy Fry Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John William Evans.
1901. Mr. Alexander McHenry.
1902. Dr. Wheelton Hind.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.
1905. Dr. E. A. Newell Arber.
1905. Dr. Walcot Gibson.
1906. Mr. William G. Fearnsides.
1906. Mr. Richard H. Solly.
1907. Mr. T. Crosbee Cantrill.
1907. Mr. Thomas Sheppard.
1908. Dr. Thomas Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Mr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Dr. Charles Gilbert Cullis.
1912. Dr. Arthur Richard Dwerryhouse.
1912. Mr. Robert Heron Rastall.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

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. Prof. Othniel Charles Marsh.
1879. Prof. Edward Drinker Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Dr. J. J. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William J. Sollas.
1895. Dr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.
1907. Dr. Arthur W. Rogers.
1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.
1906. Mr. William Whitaker.
1909. Lady Evans.

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.'

1879. Purchase of Microscope.
1881. Purchase of Microscope-Lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Dr. Theodore T. Groom.
1902. Mr. William M. Hutchings.
1904. Mr. Hugh John Ll. Beadnell.
1906. Mr. Henry C. Beasley.
1908. Contribution to the Fund for securing the Preservation of the Sarsen-Stones on Marlborough Downs, known as 'The Grey Wethers.'
1911. Mr. John Frederick Norman Green.

AWARDS OF THE PROCEEDS OF THE 'DANIEL PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1903. Prof. Ernest Willington Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.
1906. Miss Helen Drew.
1907. Miss Ida L. Slater.
1908. Mr. James A. Douglas.
1909. Dr. Alexander Moncrieff Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian Charles Nicholas.
1912. Mr. Otway H. Little.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				140	0	0
Arrears of Admission-Fees	81	18	0			
Admission-Fees, 1912	200	12	0			
				282	10	0
Arrears of Annual Contributions	126	0	0			
Annual Contributions, 1912, from Resident and Non-Resident Fellows	1900	0	0			
Annual Contributions in advance	70	0	0			
				2096	0	0
Sale of the Quarterly Journal, including Longmans' Account	......			150	0	0
Sale of other Publications	......			10	0	0
Miscellaneous Receipts	......			10	0	0
Interest on Deposit-Account	......			10	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock	8	0	0			
				351	16	0
				£3050	6	0

[NOTE.—The accumulated interest on the Sorby and Hudleston Bequests, which will amount on December 31st, 1912, to £205 18*s.* 4*d.*, is not included in the above estimate of Income expected.]

the Year 1912.

EXPENDITURE ESTIMATED.

	£ s. d.	£ s. d.
House-Expenditure:		
Taxes	15 0	
Fire-Insurance and other Insurance	16 0 0	
Electric Lighting and Maintenance	45 0 0	
Gas	20 0 0	
Fuel	35 0 0	
Furniture and Repairs	40 0 0	
House-Repairs and Maintenance	40 0 0	
Annual Cleaning	25 0 0	
Washing and Sundry Expenses	30 0 0	
Tea at Meetings	20 0 0	
		271 15 0
Salaries and Wages, etc.:		
Assistant-Secretary	375 0 0	
,, half Premium Life-Insurance	10 15 0	
Assistant-Librarian	150 0 0	
Assistant-Clerk	150 0 0	
Junior Assistant	54 0 0	
House-Porter and Upper Housemaid	94 0 0	
Under Housemaid	49 18 0	
Charwoman and Occasional Assistance	14 0 0	
Accountants' Fee	10 10 0	
		908 3 0
Office-Expenditure:		
Stationery	30 0 0	
Miscellaneous Printing, etc.	60 0 0	
Postages and Sundry Expenses	75 0 0	
		165 0 0
Library (Books and Binding)		250 0 0
Library Catalogue:		
Cards	40 0 0	
Compilation	50 0 0	
		90 0 0
Publications:		
Quarterly Journal, including Commission on Sale	950 0 0	
Postage on Journal, Addressing, etc.	100 0 0	
Record of Geological Literature	150 0 0	
Abstracts of Proceedings, including Postage	105 0 0	
List of Fellows	40 0 0	
		1345 0 0
		3029 18 0
Estimated excess of Income over Expenditure		20 8 0
		£3050 6 0

AUBREY STRAHAN, *Treasurer.*

January 31st, 1912.

[Note.—The cost of the necessary alterations, and of the furniture and fittings for the extension of the Library, involving an expenditure during 1912 of about £170 is not included in the above estimate.]

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1911	423	8	2			
,, Balance in the hands of the Clerk at January 1st, 1911	29	11	0			
				452	19	2
,, Compositions				140	0	0
,, Admission-Fees:						
Arrears	75	12	0			
Current	220	10	0			
				296	2	0
,, Arrears of Annual Contributions	121	18	0			
,, Annual Contributions for 1911:—						
Resident Fellows	1879	8	0			
Non-Resident Fellow	1	11	6			
,, Annual Contributions in advance	60	18	0			
				2063	15	6
,, Publications:						
Sale of Quarterly Journal:*						
,, Vols. i to lxvi (less Commission £10 3*s*. 6*d*.)	100	16	10			
,, Vol. lxvii (less Commission £2 16*s*. 7*d*.)	48	19	4			
				149	16	2
,, Other Publications (less Commission)				8	18	0
,, Miscellaneous Receipts				3	3	0
,, Repayment of Income-Tax (1 year)				20	16	10
,, Interest on Deposit-Account				16	2	5
,, Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock	70	12	8			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	14	2	6			
£2250 London & North-Western Railway 4 per cent. Preference Stock	84	15	0			
£2800 London & South-Western Railway 4 per cent. Preference Stock	105	9	4			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	48	15	6			
£267 6*s*. 7*d*. Natal 3 per cent. Stock	7	11	0			
				331	6	0
				£3482	19	1

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales, etc. £61 4 0

Special Funds.

Hudleston Bequest.

£1000 Canada 3½ % Stock.

	£	s.	d.
To Balance bt. forward...	32	19	2
,, Dividends (less Inc. Tax)	32	19	2
,, Repaym. of Inc. Tax...	2	0	10
By Balance to next Acct..	67	19	2

Sorby Bequest.

£1000 Canada 3½ % Stock.

	£	s.	d.
To Balance bt. forward ...	32	19	2
,, Dividends (less Inc. Tax)	32	19	2
,, Repaym. of Inc. Tax...	2	0	10
By Balance to next Acct..	67	19	2

Year ended December 31st, 1911.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire-Insurance and other Insurance	16	3	5			
Electric Lighting and Maintenance	38	4	5			
Gas	17	9	0			
Fuel	39	8	0			
Furniture and Repairs (less Sale £3 10*s*. 0*d*.)	42	18	5			
House-Repairs and Maintenance	17	1	10			
Annual Cleaning	14	13	11			
Washing and Sundry Expenses	30	14	9			
Tea at Meetings	19	7	4			
Coronation Decorations	10	10	0			
				247	6	1
,, Salaries and Wages:						
Assistant-Secretary	375	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	150	0	0			
Junior Assistant	46	16	0			
House-Porter and Upper Housemaid	92	5	8			
Under Housemaid	48	14	8			
Charwoman and Occasional Assistance	14	5	0			
Accountants' Fee	10	10	0			
				898	6	4
,, Office-Expenditure:						
Stationery	30	1	1			
Miscellaneous Printing	63	9	10			
Postages and Sundry Expenses	63	6	5			
				156	17	4
,, Library (Books and Binding)				210	5	0
,, Extension of Library (cost of Carpet and Tables)				90	13	3
,, Library-Catalogue:						
Cards	40	2	6			
Compilation	50	0	0			
				90	2	6
,, Publications:						
Quarterly Journal, Vol. lxvii, Paper, Printing, and Illustrations	878	5	10			
Postage on Journal, Addressing, etc.	110	18	5			
Record of Geological Literature	164	1	10			
Abstracts, including Postage	102	17	8			
List of Fellows and Charter & Bye-Laws	57	13	0			
				1313	16	9
,, Balance in the hands of the Bankers at December 31st, 1911	464	2	8			
,, Balance in the hands of the Clerk at December 31st, 1911	11	9	2			
				475	11	10
				£3482	19	1

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

J. VINCENT ELSDEN, } *Auditors.*
JOHN W. EVANS, }

AUBREY STRAHAN, *Treasurer.*

January 31st, 1912.

Statements of Trust-Funds: December 31st, 1911.

‘Wollaston Donation Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911	32	3	10	By Cost of Medal	10	10	0
„ Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	6	2	„ Award from the Balance of the Fund	21	13	10
„ Repayment of Income-Tax (1 year)	1	17	6	„ Balance at the Bankers' at December 31st, 1911	32	3	8
	£64	7	6		£64	7	6

‘Murchison Geological Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911	21	1	10	By Award to the Medallist	10	10	0
„ Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	37	13	8	„ Award from the Balance of the Fund	29	8	8
„ Repayment of Income-Tax (1 year)	2	6	8	„ Balance at the Bankers' at December 31st, 1911	21	3	6
	£61	2	2		£61	2	2

‘Lyell Geological Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911	53	12	10	By Award to the Medallists	50	0	0
„ Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	66	5	0	„ First Award from the Balance of the Fund	20	4	1
„ Repayment of Income-Tax (1 year)	4	2	0	„ Balance at the Bankers' at December 31st, 1911	53	15	9
	£123	19	10		£123	19	10

‘Barlow-Jameson Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911	55	7	3	By Award	25	0	0
„ Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock	13	4	6	„ Balance at the Bankers' at December 31st, 1911	44	8	1
„ Repayment of Income-Tax (1 year)		16	4				

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911	9	11	8	By Cost of Medal	12	11	0
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	18	8	,, Balance at the Bankers' at December 31st, 1911	3	6	8
,, Repayment of Income-Tax (1 year)................		7	4				
	£15	17	8		£15	17	8

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911	35	6	10	By Grants	2	2	0
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock...............	3	18	8	,, Balance at the Bankers' at December 31st, 1911	37	8	6
,, Repayment of Income-Tax (1 year)................		5	0				
	£39	10	6		£39	10	6

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911.........	65	6	9	By Balance at the Bankers' at December 31st, 1911......	86	6	5
,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock.....................	19	15	4				
,, Repayment of Income-Tax (1 year)	1	4	4				
	£86	6	5		£86	6	5

'Daniel Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1911	16	3	5	By Award	30	11	4
,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	28	15	10	,, Balance at the Bankers' at December 31st, 1911	16	3	7
,, Repayment of Income-Tax (1 year)	1	15	8				
	£46	14	11		£46	14	11

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

AUBREY STRAHAN, *Treasurer.*
January 31st, 1912.

J. VINCENT ELSDEN, }
JOHN W. EVANS, } *Auditors.*

Statement relating to the Society's Property :

December 31st, 1911.

	£ s. d.	£ s. d.
Balance in the Bankers' hands, December 31st, 1911 :		
On Current Account	464 2 8	
Balance in the Clerk's hands, December 31st, 1911	11 9 2	
		475 11 10
Due from Messrs. Longmans & Co., on account of Quarterly Journal, Vol. LXVII, etc.	61 4 0	
Arrears of Admission-Fees	81 18 0	
Arrears of Annual Contributions	261 11 0	
		404 13 0
		£880 4 10
Funded Property, at cost price :—		
£2500 India 3 per cent. Stock	2623 19 0	
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502 15 3	
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898 10 6	
£2800 London & South-Western Railway 4 per cent. Preference Stock	3607 7 6	
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	1850 19 6	
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250 0 0	
£2000 Canada 3½ per cent. Stock	1982 11 0	
		13,716 2 9

[*N.B.—The above amount does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications. The value of the Funded Property of the Society, at the prices ruling at the close of business on December 31st, 1911, amounted to £11,262 11s. 0d.*]

AUBREY STRAHAN, *Treasurer.*

January 31st, 1912.

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Dr. Lazarus Fletcher, F.R.S., the President addressed him as follows:—

Dr. Fletcher,—

In the long list of distinguished men who have received from the Geological Society the Wollaston Medal, whether struck in palladium or in gold, there are not only many geologists of great eminence for their studies in other branches of the science, but a preponderance of those whom the donor doubtless had more particularly in mind in founding his Medal 'to promote researches concerning the mineral structure of the earth.' The list does not contain the names of many pure mineralogists, but in asking you to accept the Medal this year the Council has desired to place you in company with Bischof, Naumann, Dana, von Hauer, Des-cloizeaux, Story-Maskelyne, and von Groth. Succeeding in the Keepership of the Mineralogical Department of the British Museum to the real founder of that Department, and the one who made it an expression of the best side of mineralogical science, you impressed your own personality upon it, and left it more valuable, more useful, more representative, more simple. The last was no light task, and it required, in a mathematician of such high culture and ability, an extraordinary and very unusual type of intellect to write an introduction to the study of minerals, and to arrange a collection to illustrate it, without the use of a single mathematical expression; and yet to produce a book which is at once intelligible to the museum visitor, a scientific guide to the student, and a joy to the professed mineralogist. If this were all it would be a great achievement, but you have done as much for the study of rocks and even of meteorites. And all the time you have been engaged in research of a most painstaking and minutely accurate character on the constitution of meteorites and of certain obscure and rare minerals, leaving, with characteristic unselfishness, the more attractive problems to your colleagues. If we add to this your theoretic work on the effect of heat on crystals, your elegant treatment of crystallographic optics, culminating in the conception of the optical indicatrix, your fastidious and dainty choice of expression in order to eliminate the slightest trace of ambiguity from your descriptive work, and, finally, your steadfast devotion to the well-being of the Mineralogical Society, with which you have been so closely identified, we have a record of devotion to your science and duty which has, to the delight of your friends, been worthily crowned by your appointment to the Directorship of our great National Museum of Natural History.

I ask you to accept the Wollaston Medal, not for the sake of yourself and your work alone, but as a token of acknowledgment by the Science of Geology of part of her debt to the science which you so worthily represent in our country.

Dr. FLETCHER replied in the following words:—

Mr. PRESIDENT,—

I thank the Council very heartily for the distinction that has been conferred upon me by the award of this medal, given more especially, I am told, for my researches in connexion with crystalline forms and crystal optics.

Each recipient of the Wollaston Medal must have heard with a thrill of pleasure the news that such a compliment had been paid to him by his fellow-workers; but doubtless the pleasure has been especially great to the crystallographers, for they cannot but have felt that crystallographic researches deemed worthy of such recognition must have brought some additional honour, however slight, to the memory of the many-sided Wollaston, who, by his invention of the reflective goniometer, had first made possible the measurement of crystalline forms with astronomical precision.

As regards crystal optics, the subject is too abstruse to appeal to the popular imagination. But, for the mathematician at least, there is wonderful beauty in the thought that, for every biaxal crystal, notwithstanding all our uncertainties relative to the luminiferous ether, to each point on an ellipsoid there corresponds a single ray of light, with three physical characters—namely, the direction and velocity of transmission and the plane of polarization—all definitely and simply related to the geometrical characters of the ellipsoid at that point. I may mention that it was some time after the perception of this relationship before I could convince myself of its truth; for it seemed that, after the harvest that had been gathered from the wave-surface by Fresnel, Sir William Hamilton, MacCullagh, Sylvester and others, nothing was left for the gleaner, and that the relationship, if true, would have been discovered long ago.

It may be not without interest if I add that the direction of my work in life has been much influenced by two Wollaston Medallists, Prof. P. von Groth and the late Prof. Maskelyne. In the year 1876, when I was Demonstrator in Physics for Prof. Clifton at Oxford, I saw a new book lying on his study table: it was Groth's 'Physikalische Kristallographie,' then just published. I was so much interested in scanning its pages that I ordered a copy, and read it slowly and carefully at my leisure. Prof. Clifton mentioned my interest in crystals to his Oxford colleague, that enthusiastic crystallographer, Prof. Maskelyne, and I was invited to call at the British Museum; the visit had for result a brief official connexion with him in the Mineral Department, and, what was still more important, a long-continued friendship that ended only with his life thirty-four years later. To both of them I am thus under a heavy debt of gratitude.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Prof. Louis Dollo, F.M.G.S., addressing him as follows:—

Prof. Dollo,—

The Council have awarded you the Murchison Medal in recognition of the importance of your numerous contributions to our knowledge of Vertebrate Palæontology. Twenty-three years ago they encouraged your early work by the award of the Lyell Fund, and since that time the Society has continued to follow your researches with interest, enrolling you first as a Foreign Correspondent and then as a Foreign Member. The promise of your earliest publications on the Wealden Reptiles of Bernissart has been fulfilled in your later papers on the Cretaceous Mosasaurians and various other vertebrate fossils; and your philosophical insight has illumined many difficult problems which other authors found obscure. I need only refer to your interesting essays on the evolution of the Dipnoan Fishes, on the auditory apparatus of Mosasaurians and Ichthyosaurians, and on the feet of Marsupials, which are classics in modern palæontological literature. Your demonstration of the principle of 'irreversibility' in organic evolution has led to important conclusions which are now generally appreciated; and your treatise on ethological palæontology has opened the eyes of observers to the evidences of correlation between structure and function which may be observed in several classes of fossil animals. Your papers never fail to embody suggestions which are stimulating and conducive to new points of view.

Prof. DOLLO, in reply, said:—

Monsieur le PRÉSIDENT,—

Permettez-moi d'exprimer mes sentiments de profonde reconnaissance à la Société géologique de Londres pour le grand honneur qu'elle veut bien me faire en me décernant la Médaille de Murchison.

Il y a près d'un quart de siècle déjà, votre Société eut la bonté d'encourager mes premiers travaux, en m'attribuant le Fonds Lyell: c'était le temps des Iguanodons et des Mosasaures.

Depuis, sans jamais cesser de m'occuper des Reptiles fossiles, j'ai été amené à aborder de multiples problèmes de Paléontologie éthologique, et, même, tout récemment, il me fut donné, à cette occasion, de faire une incursion dans le Monde silurien. La grande ombre de Murchison a accueilli ma hardiesse avec indulgence, puisque je puis, aujourd'hui, vous assurer de ma gratitude, en recevant la Médaille fondée par cet illustre Géologue.

Mais je n'en ai pas fini avec les Reptiles fossiles de la Belgique, dont, prochainement, je suis heureux de pouvoir vous l'annoncer, le Musée de Bruxelles exposera une importante série nouvelle, provenant des Terrains éocène, oligocène et miocène, notamment un squelette gigantesque, presque complet, de l'*Eosphargis gigas*, découvert d'abord en Angleterre.

Et, maintenant, commencent à arriver les Reptiles fossiles du Congo, encore très fragmentaires, mais pourtant caractéristiques, dont j'ai pu signaler les premiers restes à l'Académie royale de Belgique, au début de cette année.

Après trente ans de carrière, une tâche considérable se dresse donc encore devant moi: en cette occurrence, la Médaille de Murchison sera un stimulant précieux, qui me soutiendra dans mes efforts, et c'est pourquoi je vous en remercie.

Award of the Lyell Medal.

In presenting the Lyell Medal to Philip Lake, M.A., the President addressed him as follows:—

Mr. Lake,—

As an old friend of many years' standing, I regard it as a great privilege to hand you the Lyell Medal which the Council has awarded to you, as to one who 'has deserved well of the Science.' But your work has been so many-sided, that it is not easy to choose that on which to lay the chief emphasis. You have dealt with the stratigraphy and tectonics of the older Palæozoic rocks in those more difficult regions which have been left by other observers till last, as in the Dee Valley and about Cader Idris. You have treated of the petrology and the structural relations of both interbedded and intrusive igneous rocks, and in doing so have carried down our knowledge of igneous activity well into the Cambrian Period. You have utilized your knowledge of the structure and relations of the rocks, and the superficial deposits resting upon them, to form a theory as to the history of the Dee and of Bala Lake, and have applied this theory to the general drainage-system of North Wales. And last, but far from least, you have done much to elucidate the structure and classification of certain forms of trilobites, more especially *Acidaspis*, and are now engaged upon an elaborate monograph, part of which is already published, on the Cambrian Trilobites, a work the need for which has long been felt by workers among the older rocks in this country. Your services to Geology do not end here, for by your teaching and organization you have contributed much to the study of geology and geography in Cambridge and its vicinity; while by your translation and adaptation of Kayser's 'Comparative Geology,' and the publication, in conjunction with Mr. Rastall, of your Textbook, you have placed the students of stratigraphical geology deeply in your debt.

Mr. Lake, in reply, said:

Mr. President,—

I am deeply sensible of the honour that the Council has conferred upon me by the award of the Lyell Medal.

It is an especial pleasure to find in the list of former recipients the names of two of those to whom I am most indebted for my geological training—Prof. Hughes and Dr. Marr.

But I do not forget that it is to Prof. Lebour, one of the Murchison Medallists, that I owe my first introduction to geology. Without his guidance and help I should never have become a geologist, nor should I ever have come under the influence of Cambridge.

Circumstances have seldom permitted me to devote undivided attention to the study of our science, and my geological work has suffered accordingly. It is encouraging to find that it has not altogether failed, and I still hope in the future more fully to justify the award for which I now thank the Council.

Award from the Wollaston Donation Fund.

In presenting the Balance of the Proceeds of the Wollaston Donation Fund to Charles Irving Gardiner, M.A., the President addressed him in the following words :—

Mr. Gardiner,—

The vacation times of a man so strenuously occupied as yourself are very precious to him, and it is a compliment to the fascination exercised by scientific research, and especially by the pursuit of geological investigation, that you willingly give up so much of your holidays to field-work in your chosen science. Mainly in association with Professor Reynolds, you have patiently and unweariedly carried out your steadfast programme, which I am glad to think was suggested to you by myself, of increasing our knowledge of the older Palæozoic rocks of Ireland. Beginning at Kildare, you passed thence by way of Lambay to Portraine, at each stage throwing new light on the succession, and at the last-named locality unravelled the different types of conglomerates, which in that neighbourhood have been produced by earth-movement. Shifting your operations to the south, you elucidated the succession of Silurian rocks in that region and the unusual association of contemporaneous igneous rocks with them. Then you proceeded to Mayo and Galway, dealing with the areas of Tourmakeady, Lough Nafooey, and Glensaul in turn; and, judging by your latest paper, you seem to have been as successful in this exceedingly difficult ground as in the simpler areas previously dealt with. The Council, in awarding you the Balance of the Proceeds of the Wollaston Fund, does so, not only in recognition of good work done, but in confidence that you will carry on equally good work in the future.

Award from the Murchison Geological Fund.

The President then presented the Balance of the Proceeds of the Murchison Geological Fund to Dr. Arthur Morley Davies, addressing him as follows:—

Dr. Morley Davies,—

It is recognized by your friends and colleagues that the original work which you have completed has been accomplished under singular difficulties and in the stress of a very busy life. You have been specially attracted by the series of anomalous deposits, which in various parts of Buckinghamshire and the vicinity come between the Oxford Clay and the Chalk, and several members of the sequence have been elucidated by your careful and detailed stratigraphical and palæontological research. You have collected many of these results, and combined them with other information, in your clear and concise summary of the Geology of Buckinghamshire published in 'Geology in the Field.' You have spent much thought and industry on the preparation of a tectonic map of the British Isles, a work long needed by Geologists, and one which we hope will shortly see the light. You have sympathies also with the geographic side of science, as testified by your work on the 'Geography of the British Isles,' your admirable little volume on the Geography of Buckinghamshire, and a number of papers dealing with such subjects as lie on the borderland between history and geography. You will perhaps also allow me to express here my very warm appreciation of the great value of your work as a colleague at the Imperial College of Science and Technology, and it is this which makes it an exceptionally pleasant duty for me to hand you the Balance of the Murchison Fund during my last year of office.

Awards from the Lyell Geological Fund.

In presenting a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Dr. Arthur Richard Dwerryhouse, the President addressed him as follows:—

Dr. Dwerryhouse,—

When, as Secretary of the Society, it was my duty to read the manuscript of your paper on the Glaciation of the Valleys of the

Tees and other northern rivers, I got the impression that it was a model of scientific exposition, an opinion confirmed when I saw it in print. But this represents only a part of the service that you have rendered to the Glacial Geology of the North and Midlands of England and of the North of Ireland. In each locality you have discovered something new and something throwing fresh light upon the conditions that prevailed during the Glacial Epoch. But you have also been able to pursue enquiries along other lines; for instance, the circulation of underground waters, the origin of caves, and the weathering of rocks; while in your Presidential addresses to the Liverpool Geological Society you have dealt with far larger geological problems. As a contributor to the 'Glacialists' Magazine,' as Secretary for several years of Section C of the British Association, and as a member of the Committee on Erratic Blocks, you have discharged other duties to your Science. In your papers on the Eskdale Granite and its metamorphism, you have approached a difficult petrographical problem, and made an important contribution to its solution. Finally, your recent work on geological maps will be of great help in educating students to deal in the laboratory with geological problems which they will have later to face in the field. I have the pleasure to hand you a moiety of the Balance of the Proceeds of the Lyell Geological Fund.

The President then presented the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to Robert Heron Rastall, M.A., addressing him as follows:—

Mr. Rastall,—

It is fitting that both authors of so novel and important a work as 'Lake and Rastall's Textbook' should receive awards from the Geological Society on the same occasion. In making this award, however, the Council had in mind not only that work, but the labour which you have for many years devoted to your Science in original research. You have been attracted most strongly by petrographical problems, as is indicated by your contributions to Dr. Hatch's work on that subject, and by your papers on the igneous rocks of Buttermere and Ennerdale, on the inclusions in the Mount-Sorrel granite, on the Skiddaw granite, on the rocks surrounding the Kimberley diamond pipes, and on the dedolomitization of marble at Port Shepstone. One might perhaps even venture to think that your chief interest in the Cambridgeshire boulders was aroused by the numerous rock-types which are thus to be found scattered over a country not otherwise rich in problems of the more solid geology, were it not for your contribution on the Cambridge district to 'Geology in the Field.' You have not neglected other sides of the Science, for your paper on the Dogger of Blea Wyke and that on the Ingletonian Series are important contributions to our detailed knowledge of the position and character of these strata. Your latest paper has dealt with your observations in South Africa, and involves, not only an important elucidation of the tectonics of the area, but, if its conclusions are accepted by South African geologists, a new reading of the relations of the strata there. It is my pleasant duty to hand to you the Balance of the Proceeds of the Lyell Fund.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,
Prof. WILLIAM WHITEHEAD WATTS, Sc.D., LL.D., M.Sc., F.R.S.

The Geological Society has unfortunately lost by death during the past year no less than two of its Foreign Members and two Foreign Correspondents. These are: M. E. Dupont, M. A. Michel-Lévy, Prof. G. Stefanescu, and Dr. A. E. Törnebohm. Dr. Charles Abiathar White, also a Foreign Member, died in 1910, but news of his death did not reach us in that year. The Society has also to mourn the loss of twenty-seven Fellows, including four who have served on the Council: Sir Joseph Hooker, a Fellow since 1846; Prof. T. Rupert Jones, who joined the Society in 1852; Prof. Nevil Story-Maskelyne, who had been on the roll since 1854; and George Maw, whose entry dates to 1864. The names of the other Fellows deceased are: G. Attwood (1872), Warren Delabere Barnes (1902), F. Braby (1864), Sir John Brigg, M.P. (1875), Robert Henry Byles (1895), G. E. Coke (1901), the Rev. E. M. Cole (1889), John Rule Daniell (1891), S. F. Emmons (1874), John Eunson (1878), Sir William James Farrer (1878), Charles J. Fauvel (1909), Rev. J. T. Campbell Gullan (1873), Joseph Richard Haines (1898), Frederick Hovenden (1876), Colonel Charles Kendal-Bushe (1896), Henry Lakin Lawrence (1891), A. Longbottom (1909), John Nevin (1894), Dr. R. D. Roberts (1875), William Shone (1874), G. P. Wall (1862), and William White (1894). Some account of the lives and work of these deceased Fellows is given below, where it has been possible to obtain the necessary information. For the notice of M. Michel-Lévy, I am indebted to Dr. J. S. Flett; for that of Sir Joseph Hooker, to Prof. J. W. Judd; for that of Prof. T. Rupert Jones, to Dr. A. Smith Woodward; for that on George Attwood, to Prof. T. G. Bonney; while Dr. Walcot Gibson has been good enough to furnish the short memoir of Mr. Coke, and Dr. Falconer that of Mr. Longbottom. The notice of Prof. C. A. White is taken largely from 'Science,' and that of Prof. Story-Maskelyne mainly from the 'Mineralogical Magazine.'

By the death of AUGUSTE MICHEL-LÉVY on September 21st, 1911, the French geological world has lost one of its most distinguished ornaments. For more than forty years he had been engaged in active geological research, and had figured prominently both as an official geologist and as an investigator. He was born on August 17th, 1844, and as the son of an eminent Parisian physician he was from the first placed in surroundings calculated to stimulate his extraordinary mental powers and his love of science. He was educated at the École Polytechnique and at the École des Mines, at both of which he distinguished himself. At the age of 23 he became a member of the Corps des Mines, to which body he belonged until the close of his life.

In 1887, on the retirement of Jacquot, Michel-Lévy succeeded to the Directorship of the Service de la Carte Géologique, a post for which he was eminently fitted, both by his personal influence and his great intellectual capacity. Since that date he has superintended the issue of 150 sheets of the geological map of France (1 : 80,000), and the cartographical excellence of that great publication is in no small measure due to the taste and judgment with which he edited it. He was an indefatiguable field-worker, never so happy as when engaged in surveying in Auvergne, in Morvan, or the Western Alps, and eleven sheets of the French map were wholly or partly completed by him. His field-work led to the preparation of some important monographs, of which one of the smallest, that on the Granite of Flammanville, because of the theoretical questions which it raised and the discussions which it provoked, is perhaps the best known.

But it was as a theoretical Mineralogist and as a Petrographer that he earned his best right to lasting fame. The 'Minéralogie Micrographique,' which he produced along with Fouqué in 1879, though not so much consulted as it was at one time, cannot be denied a position among the great pioneer works of Petrology. All the characteristics of his mind were exemplified in this book: mathematical skill, conciseness and lucidity of expression, complete mastery of the subject within the bounds which he had set himself, and consummate artistic taste in the graphic illustration of his work.

Two other books, of which he was joint author, the 'Minéraux des Roches' (with Prof. A. Lacroix), published in 1888, and the 'Synthèse des Minéraux des Roches' (with Prof. Fouqué), published in 1882, showed his remarkable powers both as an experimental scientist and as a theoretical mineralogist. Much work has been done in both these subjects since that day, but it is very largely a development along the lines laid down by Michel-Lévy in these books, and, in the broad sketch of the subject which he traced out, hardly anything has proved to be inaccurate or of secondary importance. The bent of his mind towards the theoretical problems of optical mineralogy was further exemplified by his work on the Felspars, which is the most widely used of all his books. The French school of mineralogists, including Mallard and Descloizeaux, had always excelled in this department, and Michel-Lévy as a petrographer adapted and completed the application of their work to the study of the minerals of rocks. It is principally owing to his work and to that of Fouqué that we are now in possession of means of determining even the smallest felspars in a rock-slide with great precision; and the elegance of his methods is a delight to every modern petrographer.

At no period did he do much descriptive petrography, and his principal contribution to the systematics of the science is embodied in his 'Structure et Classification des Roches Éruptives' (1889). As the recognized leader of the French school he laid down principles of classification in that work which are still regarded as authoritative in France, although, owing to the present uncertain state of rock-classification in general, they can hardly be accepted as final.

He was the recipient of many honours from scientific men, both in his own country and abroad. This Society elected him a Foreign Correspondent in 1889 and a Foreign Member in 1893. In 1892 he was made President of the Geological Society of France, and in 1887 he received the Prix Viquesnel of that Society. A man of singular courtesy, he was exceedingly helpful to all young geologists, and especially to the members of the Service de la Carte Géologique, who were devotedly attached to him. For several years he had not added to the list of his published works, but it is understood that he was engaged in editing for publication the lectures which he delivered to the Collège de France. His health, formerly robust, had failed of recent years, but to the last he continued to take a great interest both in his scientific and in his administrative work.

[J. S. F.]

Monsieur Édouard Dupont, Honorary Director of the Royal Museum of Natural History in Brussels, was born on January 31st, 1841, and died on March 31st, 1911, aged seventy years. He was elected a Foreign Correspondent of the Geological Society in 1879 and a Foreign Member in 1897. His earliest work to which he frequently returned later in his life, concerned the

Carboniferous Limestones, and this work apparently introduced him to the study of the Belgian caves, the human relics contained in them, the classification of the periods of human art, and, later, to the study of the Quaternary deposits of his country. On these subjects he published a work dealing with the Stone Age in the vicinity of Dinant-sur-Meuse. He also made important contributions to our knowledge of the Belgian Devonian, and was associated with M. Mourlon in the preparation of a general map of the country. He wrote an essay on this map, and also on the Belgian part of the International Congress Map of Europe. In 1887, he wrote on the living and post-Pliocene mollusca of the Congo. As Director of the Royal Museum, M. Dupont was chiefly interested in the skeletons of Iguanodon, mainly from Bernissart, which were mounted under his superintendence. Of these he wrote an account as a guide to the Museum Collection.

Charles Abiathar White, elected a Foreign Correspondent in 1893 and a Foreign Member in 1899, was born on January 26th, 1826, and died on June 29th, 1910, in his eighty-fifth year. His earliest published work dates from 1861, and in the two following years he assisted James Hall in palæontological work for New York State. He was appointed State Geologist of Iowa in 1866, and conducted that Survey until 1870, being responsible for the issue of an important series of Reports. His work at this period was chiefly concerned with glacial deposits and with palæontological questions. In 1867 he was appointed Professor of Natural History in the Iowa State University, and continued to hold this post until 1873, when he passed to a similar position in Maine. In the following year, he undertook the publication of the invertebrate palæontology of the Survey of the country West of the Hundredth Meridian. He joined the United States Geological Survey of the Territories in 1876, was appointed Curator of Palæontology in the U.S. National Museum in 1879, and Geologist on the Geological Survey of the United States in 1882, a post that he held for ten years, in the course of which he also executed palæontological work for the National Museum of Brazil. The degree of LL.D. was conferred upon him by his old University of Iowa in 1893. A long list of his papers is published in Bulletin 30 of the United States National Museum; and this shows that he wrote on very many of the branches of geology, and in the course of his work described a vast number of species of Invertebrata.

Gregorio Stefanescu, who was elected a Foreign Correspondent of this Society in 1899, had occupied for many years the Chair of Geology in the University of Bucarest. He may be said to have initiated the official Geological Survey of Rumania, a department which has of recent years greatly extended its activities. He described the fossil Dinotheria discovered in his native country, and being enthusiastically desirous of spreading the knowledge of the science among his countrymen, he published in 1890 an elementary text-book of geology in the Rumanian language.

The great merit of the work of Prof. Alfred Elis Törnebohm was recognized by the Geological Society, in his election as a Foreign Correspondent in 1910, but he unfortunately died on April 21st, 1911, in his 73rd year, before being elected a Foreign Member. He was born on October 16th, 1838. At the Tekniska Högskola of Stockholm he devoted himself to Chemistry and Physics, and so laid the foundation for his future career. He joined the Geological Survey of Sweden in 1859, and between that date and 1873 he published several maps, chiefly delineating Archæan, Cambrian, and Silurian rocks, which in places appeared to be conformably overlain by mica-schists, gneisses, etc., in a manner not unlike the similar rocks in the North-West Highlands. Leaving the Survey in 1873, he travelled in Central Europe, and spent some time in studying with Zirkel at Leipzig. A year or two after his return he was appointed Professor of Mineralogy and Geology at the Tekniska Högskola at Stockholm, and he continued to hold that office till appointed in 1897 Director of the Swedish Geological Survey, a post which he resigned in 1907. During this time he published petrographical papers and made an exhaustive study of Portland cement, working at the subject on petrographical lines. Other economic work accomplished by him had relation to several of the great fields of iron- and copper-ore, like those of Dannemora, Taberg, Atvideberg-Bersbo, and Pitkäranta. He published also a map of Central Sweden, a memoir on the outlines of the geology of Central Scandinavia, and a wall-map of Northern Europe.

Growing dissatisfied with the results of his earlier survey of the Highlands of Scandinavia, he spent many years between 1868 and 1888 in re-traversing his old ground in all directions, working very hard, and enduring no small privations. At the end of his investigation he had arrived at the conclusion that the gneisses and schists, which overlie the Cambrian and Silurian rocks, have been thrust into their present position, in the same way as the Moine Schists have been overthrust in the Scottish Highlands.

He further applied his thrust theory to the entire extent of the Mountain Range, conclusions which, though not so warmly welcomed on the Norwegian side of the national boundary, have been widely accepted on the Swedish side. After leaving the Survey he lived a very retired life, and it was a considerable disappointment to many of those attending the International Geological Congress in Sweden in 1910 that Prof. Törnebohm was unable, from his feeble health, to take a very active part in that Congress or in the field-excursions to the Highlands which he loved and served so well.

By the death of the venerable Sir Joseph Dalton Hooker, our Society not only loses perhaps its oldest Fellow and one whose name has, with a single exception, longest occupied a place on its roll, but there disappears from our midst the last survivor of that illustrious band of our Fellows—Lyell, Darwin, and Hooker—whose joint labours resulted in establishing the doctrines of Continuity and Evolution upon the secure basis of observation and experiment, thus bringing about the greatest revolution that has taken place in modern times, not only in our own science, but in every department of Natural History.

Descended from the branch of an ancient Devonshire family which had migrated to East Anglia, our late Fellow was born at Halesworth in Suffolk on June 30th, 1817. His father was William Jackson Hooker, who had already established his reputation as a botanist; his mother was the eldest daughter of Dawson Turner, among whose many acquirements a knowledge of botany was also one. When Joseph Hooker was only three years of age his father was appointed Professor of Botany in the University of Glasgow, and to that city the family removed, Joseph Hooker's education being carried on at the High School and University.

Charles Lyell the elder, also a botanist of some repute, who resided at Kinnordy in Forfarshire, was on terms of closest intimacy and friendship with Joseph Hooker's father and maternal grandfather; and thus originated, from their earliest days, that close connexion between the younger members of the two families which led to such important results in the history of science and was destined to be broken only by death. It was through his friends the Lyells, that Joseph Hooker, soon after he attained to manhood, was introduced to Charles Darwin; and henceforward the lives and life-work of the three friends were bound together by innumerable links.

Fired like Charles Darwin with a passion for foreign travel and research, young Joseph Hooker in 1839 joined the Antarctic expedition of H.M. ships *Erebus* and *Terror* under James Clark Ross. It is not necessary here to refer to the important discoveries, both in geographical and physical science, which we owe to that expedition; but during the four years' voyage in which Hooker, like Darwin, circumnavigated the globe, though in different latitudes, he was able to make very notable contributions to Natural History. Not only did he accumulate that mass of botanical materials from Kerguelen Island, New Zealand, Tasmania, Australia, Tierra del Fuego, and the Falkland Islands, which, after twenty years of labour, enabled him to publish his epoch-making essays on the origin of the southern floras, but, incidentally, he lighted upon a discovery which has had a very important influence on the progress of our own science.

While dissecting marine animals brought up from great depths—for, while acting as assistant surgeon and botanist to the *Erebus*, he never allowed his scientific interests to be circumscribed by these duties—, Hooker had his attention drawn to the existence of the wide-spread diatomaceous ooze of the Antarctic regions, and thus was led to initiate those studies of the deep-sea organic deposits, the important developments and results of which in recent times the young naturalist fortunately lived to see. Had Hooker never accomplished more than this, he would have established a strong claim on the gratitude of the cultivators of geological science for all time.

Returning to England in 1843, Hooker for some years assisted his father in the formation of his famous herbarium; but on April 1st, 1846, he was appointed 'Botanist to the Geological Survey' in succession to Henfrey. A week later, we find that a nomination certificate for this Society was signed by his chief, Sir Henry De la Beche, his colleague Edward Forbes, and, in addition, by John Carrick Moore and Charles Darwin; and, although his connexion with the Geological Survey lasted only eighteen months, Hooker was able in that time to accomplish some very important work. Three memoirs from his pen on the plants of the Coal Measures, illustrated by ten beautiful plates and other illustrations, appeared in the Memoirs of the Survey in 1848; by his great knowledge of living forms and assisted by material and information supplied by Mr. Binney and others of our Fellows, Hooker was able to demonstrate the value of sections of 'coal-balls,' when studied under the microscope, in revealing the actual structure of these ancient representatives of plant-life on the globe. These memoirs differ from all others on the subject published at the time—or, indeed, long afterwards—in receiving unstinted praise alike from geologists and from botanists.

But, despite the attractions of fossil botany, Hooker's main interest lay in the study of recent plants, and especially in the causes—past and present—by which the geographical distribution of the various floras of the globe has originated. He, in consequence, longed to supplement his knowledge of the plants of the frigid and temperate zones by detailed study of tropical and mountain vegetation—and, as the best locality for such studies, he selected India and the Himalayas. In November 1847, therefore, he relinquished his work upon the Geological Survey and set out upon a private expedition to the East, in which he received some help and encouragement from the Government. After three years of intense labour and great hardship—much of the time being spent in the passes of Eastern Nepal and Sikkim that lead round the skirts of Kinchinjunga (then believed to be the highest mountain on the globe) into Tibet—he returned to England in 1851, bringing great stores of information concerning that hitherto unexplored region, as well as on other parts of India. He had spent many weeks together at elevations 2000 feet above the highest Alpine summits, had been opposed, and in the end even imprisoned by jealous officials, but, fortunately, his health seems to have suffered no permanent injury.

In 1854, Hooker published his well-known 'Himalayan Journals,' a work inspired by the reading of Darwin's famous 'Journal of Researches'; and the book fully justified its second title of 'Notes of a Naturalist,' for it deals with almost every branch of Natural History. While botany naturally occupies the foremost place in the work, the observations on geology are scarcely less numerous and important, and ornithology, entomology, ethnology, etc., all receive ample attention. In addition to all this, Hooker made accurate measurements and records in topography and meteorology, while numerous sketches—combining scrupulous fidelity to nature with artistic skill—add greatly to the value of the book. Geologists are especially indebted to the 'Himalayan Journals' for numerous observations on the glaciers of the great mountain-chain, and for valuable details concerning the stupendous effects of subaërial denudation at great elevations.

In 1855, Hooker joined his father in the important work that was being carried on in the great botanical establishment at Kew—work which occupied him during the next thirty years of his busy life. During the earlier portion of that period he published a number of papers on fossil plants in our own and other journals, his observations on the enigmatical *Pachytheca* and the more satisfactory *Trigonocarpon* being of especial value and interest. But, not less helpful to our science than his various memoirs on the subject, were the wise cautions and warnings which he from time to time issued against the growing habit among geologists of trusting to impressions of leaves as a means of identification, and the no less dangerous one of making hasty generalisations concerning habitat and climate from the supposed analogies of fossil and living plants. Hooker's wide knowledge of the existing floras and their distribution, which was so well known, gave the greatest weight to these cautions and criticisms.

From 1852 to 1856 Hooker served on the Council of this Society and again from 1860 to 1862, but, unlike his two friends, he never became one of its Officers, a fact for which the pressure of his other duties will sufficiently account.

In 1873 he visited Auvergne with Prof. Huxley, and made observations on glacial phenomena, which were published in 'Nature' in 1874. Referring to this visit about a year before his death, Hooker wrote

'I am very glad to see prominence given to Scrope's labours and early views. I travelled over the scenes of his labours with Huxley and a copy of his book.'

In 1868 Hooker characterized Fossil Botany as 'the most unreliable of sciences'; yet he nevertheless retained his early interest in it. It is true that the numerous and valuable observations of William Crawford Williamson—given to the world, as they were, in a form that did not appeal to Hooker's critical and cautious mind—for some time failed to obtain full recognition from him. But when, in recent years, the study of Carboniferous, Jurassic, and Cretaceous plants yielded such new and startling results to investigators in this country, France, Germany, and the

United States, all his old enthusiasm was aroused. Dr. D. H. Scott has kindly shown me letters of this period which exhibit not only the great interest that Hooker felt in these discoveries, but a desire to give the fullest credit to Williamson's pioneer labours.

But for geologists, not less than for other naturalists, Hooker's greatest claim to honour will always be the support and assistance which, for more than thirty years, he gave to his friend Charles Darwin in his great and arduous tasks. Hooker's vast knowledge of plants, and especially of their distribution, gathered in his wide travels in the Southern Hemisphere and in India, with those of later years in Asia Minor, Northern Africa, and the Western Territories of the United States, enabled him to give Darwin especial help in marshalling this important branch of the evidence in favour of Evolution. No labours in tabulating materials or in carrying out observations or experiments suggested by his friend were ever too great for Hooker. The records of the candour, critical acumen, and extreme caution with which he, no less than Lyell, discussed with their author the suggestions of Darwin's ever-fertile brain, are fortunately preserved in a great mass of letters, which will be of incalculable value to future historians of science. It was to one or other of these two friends that Darwin, in 1844, proposed to entrust the draft of his great work for publication, in case of his early death, which then seemed only too probable; it was they who were ready at all times to cheer and encourage him in moments of doubt or despondency in his heavy task; and it was to them, also, that were due the measures (which were so generously seconded by Alfred Russel Wallace) that prevented the results of the labours of a quarter of a century from being forestalled. To Huxley, Darwin wrote in 1859:—

'When I put pen to paper for this volume, I . . . . fixed in my mind three judges, on whose decision I determined mentally to abide. The judges were Lyell, Hooker, and yourself.'

And when the 'Origin of Species' on its appearance was met with storms of opposition, it was in the judicious advocacy of Hooker, no less than in the zealous defence of Huxley, that Darwin found his chief support.

In his old age, Hooker seems to have felt with Darwin the risk of indulging in theoretical and speculative questions. He had nearly reached his threescore years and ten when he resigned the Directorship of Kew and retired to a quiet home and pretty garden at Sunningdale, where for nearly twenty-five years he pursued his studies of systematic botany, and, in completing his floras of India and Ceylon, accomplished an amount of work, in this period of well-earned rest, that would be an ample output for the lifetime of most men.

Hooker became President of the British Association in 1868, was President of the Royal Society from 1873–1878, received the Grand Cross of the Star of India in 1897; and, on his ninetieth birthday, the King conferred upon him the crowning distinction of the Order of Merit.

Ever modest concerning his own work, yet generous beyond measure in his estimation of the labours of others, Hooker was the most devoted and helpful of friends. Nevertheless, he knew when it was 'well to be angry.' The same stern determination with which he met the opposition of Sikkim officials and Tibetan guards, made him in later years a doughty champion of science, when its interests were threatened by officialism at home; and no less active in protest and action did he prove, when abuses were suspected by him in the Societies with which he was connected.

Sir Joseph Hooker was twice married: first to the daughter of the botanist and geologist Henslow, and secondly to the daughter of another esteemed Fellow of this Society, the Rev. W. S. Symonds of Pendock. Happy in his peaceful home and much-loved garden, working steadily to the last on a favourite group of plants, equally acknowledged as the foremost naturalist in his own land and the doyen of botanists all over the world, in ripeness of years and in fulness of honour, he passed away on December 10th, 1911.

To many of us it had seemed only fitting that his remains should lie beside those of his two life-long friends and fellow-workers—Lyell and Darwin—in the Abbey of Westminster; but his own modest wishes were rightly respected, and he was buried in the loved Surrey village, now become a city-suburb, where so many of his years were passed, the spot which the labours of his father and himself had made 'the Mecca of Botanists.' [J. W. J.]

Prof. Thomas Rupert Jones was born in London on October 1st, 1819, and was educated in private schools at Taunton and Ilminster. He was destined for the medical profession, and served his apprenticeship, first with Mr. Hugh Norris at Taunton, and finally with Dr. Joseph Bunny at Newbury (Berkshire). While a boy at Ilminster, he became interested in the ammonites and other fossils which were common in the quarries in the Upper Lias of that neighbourhood, and during his subsequent residence at Taunton he had the opportunity of reading Parkinson's 'Organic Remains,' which definitely turned his attention to geological studies. At the end of his apprenticeship in 1842, he began medical practice in London, but his interest in purely scientific work soon led him to seek a more congenial sphere. Among others, he made the acquaintance of a well-known conchologist, Mr. John Pickering, who employed him at times in sorting small shells from beach-material; and during this work he noticed the associated Foraminifera and carapaces of Entomostraca, about which he could obtain very little information. His curiosity was so much excited by these minute remains that he began to make detailed studies of them, and they continued to form the principal subject of his original researches during the remainder of his life. Very soon he formed a friendship with a neighbouring medical practitioner, the late William Kitchen Parker, who was similarly examining Foraminifera, and five years after his settling in London he joined the small party of geologists and naturalists who held frequent meetings at the house of John Morris.

By the year 1849, Rupert Jones was established in the scientific world of London, and he now contributed to the Palæontographical Society's publications a 'Monograph of the Entomostraca of the Cretaceous Formation of England.' In the following year he was appointed Assistant Secretary of the Geological Society, and he held this office until 1862, when he became Professor of Geology at the Royal Military College, Sandhurst. He was subsequently Professor at the Staff College, and finally retired from Sandhurst in 1880.

Prof. Rupert Jones was elected a Fellow of the Geological Society in 1852, and made his first contribution to the 'Quarterly Journal' in the following year, on some Carboniferous Entomostraca collected by Daniel Sharpe near Bussaco in Portugal. In 1856 he wrote on *Estheria minuta* and determined the wide distribution of species of *Estheria* in geological formations; and during the rest of his active life he read before the Society frequent notes and papers on both Entomostraca and Foraminifera. He also prepared for the Palæontographical Society Monographs of the Tertiary Entomostraca of England (1856) and the Fossil Estheriæ (1862), and he cooperated with others in contributing to the same Society Monographs on Crag Foraminifera (1866–97), on Carboniferous Entomostraca (1874–84), and on British Palæozoic

Phyllopoda (1888–99). At the same time he determined and wrote descriptions of numerous collections of fossil Entomostraca for various Colonial and Foreign Geological Surveys; and in 1882 he prepared a Catalogue of the Fossil Foraminifera in the British Museum. He assisted Dr. W. B. Carpenter in his 'Introduction to the Study of the Foraminifera,' published by the Ray Society in 1862, and was one of the editors of the 'Micrographic Dictionary.'

Prof. Rupert Jones was also deeply interested in the wider questions of geology and natural history, and devoted much labour to the revision and editing of important general works. After Mantell's death, he published new editions of that author's well-known 'Wonders of Geology' and 'Medals of Creation,' and between 1865 and 1875 he edited (indeed largely wrote) the 'Reliquiæ Aquitanicæ,' an exhaustive account of Lartet and Christy's discoveries of Palæolithic Man in the caves of Central France. In 1875 he edited for the Admiralty a 'Manual' of the natural history of Greenland and the neighbouring regions, for the use of the Arctic Expedition of that year. In 1878 he revised and edited Dixon's 'Geology of Sussex,' to which he himself made several original contributions. Finally, it must be added that he was one of the founders of the 'Geological Magazine,' and was joint-editor with Dr. Henry Woodward during its first year. From 1871 onwards, Prof. Rupert Jones took an active part in promoting the investigation of the geology of South Africa. He never visited the country; but he was a careful student of the observations of others, and prepared several notes on their collections which he had examined. He began by annotating the writings of G. W. Stow, and subsequently cooperated with Dr. W. Guybon Atherstone and later observers in analysing their results and attempting to form a broad conception of the structure of the region. The Professor's wide learning and remarkable powers of generalization were, in fact, continually in demand, not only in connexion with South African questions, but also in the study of numerous other geological problems. His ever-cheerful manner and his readiness to give information or advice made him a very real friend at need, and his influence on the progress of geological science is not to be reckoned merely by his own published works.

Prof. Rupert Jones was elected a Fellow of the Royal Society in 1872, and was awarded the Lyell Medal of the Geological Society in 1890. He was President of the Geologists' Association from 1879 to 1881, and of Section C (Geology) of the British Association at Cardiff in 1891. He attended the Montreal meeting of the British Association in 1884 as a Vice-President of Section C, and on that occasion made a short tour through the United States. During the last few years he had lived in retirement at Chesham Bois (Buckinghamshire), where he died on April 13th, 1911, in his ninety-second year. [A. S. W.]

Mervin Herbert Nevil Story-Maskelyne was born on September 3rd, 1823, at Basset Down House, near Swindon, and he died at the same place on May 20th, 1911, in his eighty-eighth year. Both his father and grandfather were, like himself, distinguished Fellows of the Royal Society. He graduated at Oxford in Mathematics, and, after working for some time at chemistry, was appointed Deputy-Reader in Mineralogy at that University in 1850, Reader in 1856, and Professor in 1861, a post which he continued to hold until 1895, when he was succeeded by his former pupil H. A. (now Sir Henry) Miers. He also held the appointment of Keeper of Minerals in the British Museum from 1857 until 1880, the condition of tenure of his Professorship permitting, at that time, this duplication of office. At Oxford he exercised his influence in favour of the establishment of science teaching in the University, and in promoting the building of a science museum there. During his term of office at the British Museum he rendered great service, not only by his original work on mineralogy and allied subjects, but in the extension and improvement of the mineral collections, which he increased up to nearly 50,000 specimens. He had, however, many other interests, largely connected with his position as a landowner in Wiltshire; and, in addition to serving on the County Council and acting as Chairman of its Agricultural Committee, he entered Parliament in 1880 and remained a member till 1892. He published a large number of papers on mineralogical subjects, dealing especially with the diamond, with meteorites (in which he discovered enstatite), and with the symmetry of crystals, a property on which he laid great stress. He discovered several new species of minerals, and in 1895 published an important treatise on crystallography. His chief contributions to geology comprise a paper on the petrology of the Stones of Stonehenge, another on the petrology of the Transit of Venus Expedition 1874–75, one on an artificial dioptase-rock, and, finally, one on an enstatite-rock from South Africa. He was an Honorary D.Sc. of Oxford and an Honorary Fellow of Wadham College. His services to mineralogy and geology were recognized by this Society by the award of the Wollaston Medal in 1893. He twice served on the Council, and was a Vice-President in 1882–83.

It falls to me to chronicle, with sincere regret, the death at the age of 79 of George Maw, within a few weeks of that of his friend and colleague Sir Joseph Hooker, whom he joined in the memorable journey to Morocco and the Great Atlas in 1871. Mr. Maw, who joined the Society in 1864, and served on the Council from 1870 to 1871, was a man of deep scientific knowledge, of many interests, and no few accomplishments. He was an excellent chemist, a geologist of keen observation educated by wide travel, a botanist of original mind and patient industry, and an artist not only in matters of taste and appreciation, but possessed of executive skill of no mean order. It was this combination of artist and scientific man which enabled him to establish a new and flourishing industry on the banks of the Severn, that of the manufacture of encaustic tiles. Living in a beautiful house close to the northern end of the Wenlock Edge escarpment, he used his opportunities to form an exceptionally fine collection of Silurian fossils, much enriched in the early eighties by his Wenlock Shale washings, which he carried out and described in company with Thomas Davidson. These resulted, not only in the discovery of many new species and in the minute investigation of the internal structures of new and old genera of brachiopods, but in a subdivision of these monotonous shales into successive zones. Mr. Maw covered so much ground that it is a matter of embarrassment to select any particular subjects for mention. He gave an account of the structure of the Great Atlas, and demonstrated the former existence of glaciers there down to within 5800 feet of the sea-level. He published notes on a journey from Algiers to the Sahara, and discovered and described the shell-bearing drifts of the Severn Valley near Buildwas. He advocated the occurrence of glaciation in Devon, gave theories as to the origin of the Bovey and Poole clays and the occurrence of sand-pockets in the Carboniferous Limestone, dealt with cleavage, denudation, and the history of the American Lakes, recorded the occurrence of Rhætic beds in North Shropshire and Cheshire, and indeed, almost wherever he went, succeeded in observing and adding some new fact or inference of value to the common stock of knowledge. But the paper which will long remain a memorial of him is that dealing with the disposition of iron in variegated strata, a subject which he made his own and dealt with so thoroughly, that since its publication in 1868 but little new work has been done in England on the subject. The paper was founded on his great knowledge of chemistry and of technical processes, and was elaborately illustrated from his own paintings, which the Council permitted him to reproduce at his own expense, a privilege not often accorded to authors in those days. In the course of his studies he formed a large collection of clays, and other ceramic and encaustic substances, illustrating the raw materials and various stages in the products manufactured from them; the collection has now, I am glad to say, been presented to the Museum of Practical Geology. I should like to draw especial attention to his brief letter on the relation of the Trias to the older rocks of Charnwood Forest published in the 'Geological Magazine' in 1868, which appears to have been unaccountably overlooked by geologists. Certainly, had I seen it before the completion of my own study of the buried landscape of that district, much of my work there would have been unnecessary: for, in his comprehensive and rapid observation of that phenomenon and the few trenchant words that he wrote on it, he 'tore the heart' out of the subject. But, though he accomplished so much geological work, he was at heart a botanist and naturalist of the older type, and much of the leisure of his very active life was devoted to the introduction of exotic plants, discovered by himself and others, into English gardens, and to the elaboration of his beautiful monograph on the genus *Crocus*, which he published in 1886, illustrating it with 67 coloured plates made from his own paintings. For the purpose of this book he cultivated practically every species of this large genus in his beautiful garden at Benthall Hall, and at the same time he watched and grew there, as a test of their suitability for introduction into this climate, a large number of other plants. To him we owe the charming flower *Chionodoxa lucillæ*, which gives an added beauty to our spring gardens. He also introduced *Draba mawii* from Spain, and reintroduced *Crocus minimus* from Corsica. In 1886, Mr. Maw removed to his residence at Kenley in Surrey, where he lived in retirement until his death on February 7th this year.

George Parkes Wall was born at Newcastle-on-Tyne in 1832, and died on February 8th, 1912, in his eightieth year. He was one of the earliest students of the Royal School of Mines, where he was practically a contemporary of Bauerman, the Blanfords, Drew, and Robert Hunt, and he obtained the Associateship of the College in Mining in 1855, being, with one possible exception, the Senior surviving Associate of the School. He proceeded to the mines at Freiberg for a year, so as to gain practical experience. His interest in pure geology was, however, greater than that in its applications; and, meeting with Sir Roderick Murchison, he accepted from him an appointment to direct the Geological Survey of Trinidad. In this work he was associated with Mr. J. G. Sawkins, and they jointly published a memoir on the geology of this island in 1860 under the auspices of the Geological Survey of Britain. He returned to Europe and, after spending a year in Italy and Sicily, he went out to Jamaica and started the Survey of that Island, which, however, he was unable to complete, although he made notable contributions to Mr. Sawkins's memoir published also by the Geological Survey of Britain in 1869.

At this stage he was compelled to return to England and give up his profession of a mining engineer, in order to embark upon the manufacture of steel and steel wire. In spite of the pre-occupation thus caused, he retained his interest in geological science, kept himself up-to-date in its literature, and acquired a considerable library on the subject. He attended and spoke on the occasion of the reading of Mr. Guppy's recent paper before the Society, and also at several of the meetings of Section C of the Sheffield Meeting of the British Association in 1910; and his beautiful house was thrown open to Members of the Section, with whom he delighted to talk on his favourite subject. He had a wonderful memory for his age, and was able to tell of many phenomena observed by himself during the experiences of his earlier years. He had an intimate knowledge of art matters, and made a large collection of paintings, especially water-colours, which he delighted to show to his visitors. This included several fine examples of Turner's work, which, with others, he for some time placed on view at the Mappin Art Gallery. He had made his arrangements for attending this Anniversary Meeting, but, to the regret of those who knew him, passed away a few days ago.

Frederick Braby, F.C.I., of Bushey Lodge, Teddington, was head of the great iron firm of Frederick Braby & Co., which was founded by him in 1839, and has now a head office in the Euston Road, as also branch works at Deptford, Glasgow, Liverpool, and Bristol. Born on November 19th, 1829, Mr. Braby passed peacefully away at his Teddington home on October 9th, 1911, and was thus in his eighty-second year. Known chiefly because of the firm which bears his name, he was also a writer of considerable merit. He joined the Society in 1864, and was wont at one time to attend the meetings and excursions of the Geologists' Association.

In George Attwood, who died with startling suddenness on February 9th, 1912, at his home, Steyning Manor, Stogursey (Somerset), the Society lost a Fellow of exceptional and varied experience in metallurgical work and practical engineering. Born at Carlisle in 1845, and educated at Lichfield Grammar School, he was a son of the late Melville Attwood, also a mining engineer and Fellow of this Society, and was descended from an ancient Worcestershire family, whose original name Du Bois had been translated into Attwood. He was also a nephew of the late Prof. Edward Forbes, and of David Forbes one of the pioneers in microscopic petrology. At the age of sixteen George began work under his father in Nevada and California, and was appointed two years later to the Ophir Company on the Comstock Lode in the former State. Other appointments followed, some of which entailed much hardship and danger, especially when engaged on 'prospecting' work. More than once his party was attacked by hostile Indians, and on one occasion lost some of their number during a prolonged fight while retreating down a gorge. As the redskins abandoned the pursuit, and Attwood, like others of his companions, was an excellent shot, the assailants probably paid dearly for all scalps taken.

Few men, probably, have had a wider and more practical experience than Attwood as a prospector and mining engineer, for he could take a metalliferous lode from the first, equip it with machinery, and bring it into complete working order; and his business had taken him not only into various parts of the United States and Canada, but also into Mexico, South America, India, and South Africa. Of late years, when not at his London office, he was especially engaged in the western part of the Dominion, first on mines in the Sudbury district, and afterwards in railway and other developments near Prince Albert on the Saskatchewan. His accurate knowledge and sterling integrity won general respect, one proof of which was that when a certain silver-mine was losing favour with the public, Attwood was sent out by the shareholders in London to report on its value. He told them on his return that the mine 'only presented a geological chance'—for which they had paid a million sterling!

Attwood occasionally contributed short papers to mining and other periodicals, but the pressure of business left him little leisure for writing. He published, however, three papers in our Journal: one, entitled 'Contributions to South American Geology' (vol. xxxv, 1879, pp. 582–88), dealing with the Caratal Goldfield and giving a section of about 150 miles in length between it and the right bank of the Orinoco. The second was on the Geology of part of Costa Rica (vol. xxxviii, 1882, pp. 328–36), describing a gold-bearing district between Punta Arenas and the volcano Turrialba; and the third on Auriferous Tracts of Mysore Province (vol. xliv, 1888, pp. 636–57). Petrological appendices were contributed to the first and third by Prof. Bonney, to the second by the late W. H. Hudleston. Attwood also published in 1880 a most useful volume on 'Practical Blowpipe Assaying,' a subject in which he was unusually expert.

Besides our own, the Chemical, and the Zoological Societies, he was a member of the Institution of Civil Engineers, of the Institution of Mining & Metallurgy, and of sundry other Societies and Institutes in this country and America. His wide experience made him an interesting companion; he was a lover of the country, where he had a residence, first in the New Forest and then in Somerset, a keen sportsman, a most kindly host, and a firm friend. He was in active work to the last, and at the time of his death was contemplating another visit to Canada. He was twice married: first to Maria Louise Tansley, who died at Montreal in 1892, and secondly to Charlotte Caroline Burchell, but no children have survived. [T. G. B.]

Samuel Franklin Emmons was born in Boston on March 29th, 1841, and died in Washington on March 28th, 1911, on the eve of the completion of his seventieth year. He was educated at first at Harvard, graduating in 1861, but proceeded afterwards to the École des Mines at Paris and the School of Mines at Freiberg. In 1867, he was appointed to take part in the Fortieth Parallel Survey, and he both acted as joint author of the volume on Descriptive Geology and assisted J. D. Hague with the volume dealing with the mining industry. During this Survey he gave much attention to problems connected with ore-deposits, and he continued to do so when appointed to take charge of the Rocky Mountain division of the United States Geological Survey. In 1886, he published his famous work on the Geology and Mining Industry of Leadville, which was of great utility in directing attention to the importance of scientific enquiry as a preliminary to the exploitation of a mineral region. Other important works dealt with the secondary enrichment of ore-deposits, with theories of ore-deposition, and with the geology of the Green River and the Uinta Mountains. His influence on the development of the more scientific side of economic geology has been much felt among the younger men of America.

Robert Davies Roberts was born at Aberystwyth in 1851, and educated at University College, London, and at Clare College, Cambridge, where he took a first class in the Natural Sciences Tripos in 1874. He proceeded to the M.A. degree at Cambridge and the D.Sc. in London in 1878; was elected to a Fellowship at Clare in 1884, and became University Lecturer in Geology in the same year. He had much to do with the organisation and success of the Cambridge University Extension Lectures, and also of those of London University, and eventually he became Registrar to the Board to Promote the Extension of University Teaching in London in 1902, a post which he held till his sudden death on November 14th, 1911. He was closely associated with the University of Wales, and was Chairman of the Executive Committee in 1910–11. He was also High Sheriff of Cardiganshire in 1902–3. His chief interests were bound up with educational questions, and for many years he was Lecturer and Secretary to the Gilchrist Trust, for which, as well as for the University Extension movement, he frequently delivered lectures to large audiences. He was a lucid and capable lecturer, and a most painstaking teacher. His duties did not allow him time to attend many meetings at this Society, or to complete any extensive research; but he published papers, chiefly concerned with the pre-Cambrian rocks of North Wales, in the 'Geological Magazine.' His chief interests, however, especially in his later life, lay on the physiographic side, the borderland between Geology and Geography, and he was especially fond of problems connected with river development and the growth of landscape. He devoted many of his holidays to field work in association with investigators on these lines, and was a whole-hearted advocate of the application of Prof. W. M. Davis's methods of work to this country. He published 'An Introduction to Modern Geology,' and his teaching had considerable influence in directing the young men at Cambridge and in many of the more remote parts of the country towards physiographic questions. His health was never very strong, but his friends had not suspected that his life would be cut short at the age of 60 years. He left a bequest to University College, Aberystwyth, to enable its Professors, after a certain period of service, to take a holiday of six months or a year on full salary. The object is

'to enable the Professor to refresh his mind by travel or research or visits to other Universities, and so gain fresh stimulus and equipment for his work.'

The personality of the Rev. Edward Maule Cole was not very well known at the Geological Society, although he was frequently to be met with at the meetings of the British Association. It was, however, on the Yorkshire Wolds, near his vicarage at Wetwang, that he was best known and appreciated, whether conducting excursions to study the geology or archæology of the district, lecturing or reading papers to the local Societies, or engaged in opening barrows or excavating for antiquarian relics. Born in 1833, he passed from Rossall to Oxford, and returned to his old school as a master in 1857. Removing to Wetwang in 1865, he had the opportunity of following up his interest in Geology. He published a number of papers on geological and archæological subjects in the 'Naturalist,' the 'Antiquary,' 'Old Yorkshire,' and the 'Proceedings of the Yorkshire Geological and Polytechnic Society.' He died in March 1911, at the age of 78, not long surviving his friend, J. R. Mortimer, with parts of whose archæological work in the Wolds he was closely associated.

George Elmsley Coke, who died on May 14th, 1911, was a well-known member of the Institution of Mining Engineers, and, both as a member of its Council and as a contributor to its Transactions, he took an active part in the work of the Institution. He was President of the Midland Counties Institution of Engineers in 1901–02, and up to the time of his death was a member of its Finance and Publication Committee. His papers relate chiefly to Coal-mining, and into these, wherever it is necessary, there is introduced more than the usual amount of sound geological inference. He was a member of the Geologists' Association, and a leader of some of the excursions. In Geology, Mr. Coke's name will be chiefly associated with the explorations made in proving the eastern extension of the Yorkshire and Nottinghamshire Coalfield. On this subject his opinion was always highly valued, and in 1895–96 he contributed an important paper on 'The Southern Limit of the Nottinghamshire Coalfield' to the Institution of Mining Engineers. A firm believer in the value of Applied Geology, he strongly urged that the information obtained in underground explorations should become common property, and geologists could always rely on his ready help and influence. He was elected a Fellow of this Society in 1901. [W. G.]

Arthur Longbottom was educated at Bradford Grammar School and Trinity College, Cambridge, from which he graduated in 1905. In 1906 he joined the staff of the Imperial Institute, and between that year and 1909 accompanied Dr. Falconer on three expeditions to Northern Nigeria, in connexion with the Mineral Survey of that Protectorate. He proved himself an enthusiastic worker, a keen observer, an able organiser, a pleasant companion, and a trusty friend. He traversed alone the greater part of the provinces of Borgu and Yola, and the results of his observations are incorporated under his initials in Dr. Falconer's 'Geology and Geography of Northern Nigeria.' During the winter of 1909–10, Mr. Longbottom attended the Royal School of Mines, with the intention of qualifying as a mining engineer. In 1910 he returned to Northern Nigeria on behalf of a private syndicate, to carry out a detailed survey of a tin-concession on the Bauchi plateau. The arduous journey up country in the rainy season resulted in an attack of dysentery, from which he continued to suffer after his arrival at the Bauchi River. He died at Naraguta in November 1910, to the great regret of all who knew him, and especially of all his fellow-workers in that land which has claimed the lives of so many pioneers. [J. D. F.]

During the past year the Geological Society has carried into effect the resolution passed at a Special General Meeting on January 25th, 1911, namely, 'That the space now occupied by the Museum be made available for the extension of the Library.'

After prolonged consideration the Society decided to retain only a few specimens, to present its British specimens to the Museum of Practical Geology at Jermyn Street, and to give all the others to the British Museum (Natural History), South Kensington. In accordance with the resolutions passed at the Special General Meeting held on June 14th, 1911, the Council communicated with the two bodies in question, and received from them their formal acceptance of the presentation and their acquiescence in the not very onerous conditions imposed.

During the Long Vacation the contents of the Museum were removed without any expense to the Society. The Office of Works promptly began operations in the space thus vacated, and, before the opening of the present Session, they had converted the cabinets in the Museum and Galleries into bookcases suitable for relieving the congestion of the Library on the ground floor.

The Treasurer, Dr. Strahan, who carried out the negotiations with the Office of Works, succeeded in ridding the Society of reponsibility for the custody of such of the specimen-drawers as were the property of the Crown; and he has subsequently disposed of the remainder, which were the Society's own property. Dr. Strahan's services in this matter have already received the formal thanks of the Council, and the Society collectively will doubtless ratify this expression of gratitude.

It has not been thought advisable for the present to undertake any radical re-arrangement of the contents of the Library, but rather to take immediate steps to relieve the congestion of books in the ground-floor room, by transferring a large number to the additional bookcases now rendered available on the upper floor, where they will be re-arranged according to a geographical scheme which can be gradually extended, as opportunity occurs, to the lower floor. In this way the books in most frequent request will become more easily accessible, the present catalogue will only need slight modification, and at the same time the space available for readers and investigators will be considerably extended.

The dispersal of the collections will not bring any direct monetary advantage nor will it set free any new source of income to meet the Society's other needs; for, since the preparation of the very comprehensive catalogue by Mr. C. Davies Sherborn and the publication of the late J. F. Blake's 'List of Figured & Type Specimens,' only very small sums have been directly or indirectly consumed in the maintenance of the Museum.

The two lists just referred to are proving of great service to the two Institutions which have entered into possession of the specimens. Doubtless, as the material is worked over at Jermyn Street and South Kensington, specimens of special scientific value additional to those catalogued in the lists will come to light, and we look forward with interest to the reports which will be issued when the collections have been completely overhauled.

The Society may rest assured that it has acted with wisdom in allowing the contents of its Museum to become in this way more readily accessible than before to its own Fellows, and to other investigators and enquirers; and it may feel that it has in this way done more to carry out the wishes of the donors of specimens, than would have been the case if it had continued to store the collections in its own premises. At the same time, the Fellows may congratulate themselves upon the fact that the Society has thus secured in the most advantageous way facilities for bringing one of its greatest assets, the Library, into a state of higher perfection and efficiency than has ever hitherto been possible.

Now more than ever must the Library be a special care of the Society. Already we receive by gift, exchange, or purchase, the chief British and Foreign Geological Periodicals, the publications of Academies and Learned Societies, and a large proportion of separately published works; but there are still many gaps in all these classes which ought to be filled, if the Library is to retain and improve the position that it has acquired.

The present ordinary income of the Society will not allow of the expenditure of a much larger sum than is at present devoted to books and periodicals. There seem to be few opportunities of retrenchment on current expenditure. The sum annually devoted to the printing of the Quarterly Journal would appear to be just sufficient for its needs: it is large enough to enable us to print a considerable number of important papers (many of them of great length) each year, a number which seems to correspond approximately with the annual output of such papers as should naturally be read at our meetings: on the other hand, the sum is sufficiently restricted to compel a careful scrutiny of each paper submitted and the relegation of some of them to Local Societies, or other Bodies, to whose publications they are more appropriate than to the pages of our own Journal. Improvements in the illustrations, and an increase in their number, would in some cases appear to be desirable, but perhaps this is rather a question of securing a more effective class of black and white work than of a larger outlay.

It would certainly appear inadvisable either to curtail or to increase our expenditure on such publications as our 'Proceedings' or the 'Geological Literature.' Some saving will be effected when the elaborate card-catalogue of the older works in the Library has been completed, for it will then be possible to carry on the cataloguing of current literature immediately upon receipt, with economy and promptness by the method that has been adopted.

But, while it does not appear to be possible for the Society to contemplate any immediate change or increase in the expenditure of its ordinary funds, its resources have been increased of late years by the generous bequests of £1000 each from our former Presidents Dr. Sorby and Mr. Hudleston, and of £100 from the late Mr. Hannah. These gifts have been left unfettered, both as to capital and as to income, so that they may be freely applied to whatever purposes and in whatever way the Society thinks best. To devote the income of these funds to special branches of the library work will not only make for the advantage of the Library, but also for the perpetuation of the memory of the generous donors; and it is possible that such devotion may attract similar bequests or donations in the future. It has also been decided on the present occasion not to award the Prestwich Medal, but to devote the accumulated income for the last three years, as the terms of the bequest allow, to the expenses connected with the change in the Library.

In the publication of our list of 'Geological Literature added to the Geological Society's Library' we discharge a most important duty to our Fellows and to geologists at large, and, at the same time, bring to the notice of other publishing bodies the extent and value of our own library, and the need that it should be made as complete as possible. By a careful and judicious distribution of this publication to those responsible for the comparatively few works or serials which we do not yet receive, we may possibly bring home to them the advisability of contributing their journals and other publications to our library, if not for the benefit of science in general, at all events as an excellent means of advertisement.

Indeed, our library must not only retain its present reputation as one of the most representative in the world, but our 'Geological Literature' should constitute the most important current bibliography of geological science. Every possible effort should be put forth to attain these most desirable ends, and the Council, now that the path has been made smooth, and accommodation for many years' expansion provided, should not rest satisfied till they have made clear to all that, after carrying out so advantageously the first resolution of the Society in dispersing the collections, they are now doing their best to carry out the further resolution in which this policy was decided upon and 'extend the Library' to the utmost.

It is to be hoped that both the generosity of the donors to whom I have referred, and their wisdom in leaving their gifts unfettered by conditions, will be followed by other pious benefactors. These may rest assured that they will thus earn a greater meed of gratitude and remembrance from future geologists, than if any restrictive conditions are attached to their gifts. The Funds and Medals which the Society has already at its disposal amply meet all its requirements for this special class of award, and it is to be hoped that no further burden of selection will be laid on the Council.

There is, however, one special fund at the disposal of the Society which has produced results far exceeding the expectations of those who framed the rules under which it is annually awarded. I refer to the Daniel-Pidgeon Fund, which has now been granted nine times, and each time has stimulated and supported research of a high order. The example thus set might well be followed, and I feel sure the Council would willingly add to its labours that of awarding any fund which would aid the research of the younger men, at a time of life when the appetite for investigation is so keen that means for satisfying it are not always at hand. Year by year, in making this award, the Council feels the difficulty of selecting one only out of the list of promising candidates; and, though the selected candidate has always more than justified the confidence of the Council, the event has proved that many of those who have almost succeeded in heading the list have accomplished important research along the lines promised in their application for the fund.

The Coal Supply of Britain.

For the last two centuries the welfare of Britain has been bound up with the extraction and exploitation of its mineral wealth, and the rapid growth of the science of Geology in the country, the increase in number of its students and publications, have been to a large extent the outcome of the same economic development. While all of our mineral products are or have been of importance in the development of industries within the country, those which have been and are of paramount consequence, and have led to the extraordinary industrial advance that placed Britain at the head of the commerce of the world, are its wonderful supplies of coal and iron. Indeed, it is not too much to say that coal and iron have been the mainspring of the unexampled growth in all branches of science which marked the nineteenth century.

(1) Exhaustion of the Coalfields.

(*a*) Royal Commission of 1866.

When the conditions under which coal and iron occur in the earth's crust had become comparatively well known to geologists at the beginning of the second half of the last century, Stanley Jevons, interpreting the economic laws as then understood, predicted the speedy exhaustion of our coalfields, and created so great an apprehension on the subject that the Royal Commission of 1866 was appointed to consider and report upon (1) the amount of coal left available in the coalfields then being worked or likely to exist, (2) the rate of consumption of coal and the possible increase in that rate, and (3) the amount of preventible waste in the processes of extraction and consumption.

This Commission reported in 1871. It confined its attention to seams not less than 1 foot thick, and considered that 4000 feet was likely to be, in most cases, the limit of depth for profitable working. Individual Commissioners dealt with each group of coalfields whether 'exposed' or 'concealed,' and made due allowance for the waste which was found to occur in working the coal. The figures arrived at by the Commissioners were, in round numbers, the following:—

	Millions of tons.
Coal available in exposed fields	90,000
Do. do. in concealed fields	56,000
Total...............	146,000

In addition to this they estimated that 7000 millions of tons existed at depths greater than 4000 feet.

In dealing with the duration of the supply, the Commission indicated several alternative ways of regarding the problem. Among them we note the following, which, however, are placed in a different order from that adopted by the Commission, so as to bring out the wide variation in possible estimates according to the basis taken for calculation.

(1) Taking Prof. Jevons's calculated rate of probable increase at $3\frac{1}{2}$ per cent. per annum, the supply would only last 110 years, that is till A.D. 1981 (and it was noted that the increase in consumption from 1865 to 1869, namely up to 107 millions, had been in agreement with this anticipation).

(2) If the average arithmetical increase of 3 million tons each year deduced from the known output of the years immediately previous to 1866 were to continue, the period of exhaustion would extend over about 276 years, till A.D. 2147.

(3) Making allowance, again, for the fact that the population of the country, though increasing rapidly, is increasing at a diminishing rate, the Commission, on the authority of Mr. Price Williams, gave figures which indicated that, if the diminishing rate continued, the supply would last 350 years, to the year 2231.

(4) Finally, if the rate of extraction and consumption did not exceed that reached by 1870, namely 115 million tons annually, the supply would last over 1200 years, that is, till A.D. 3071.

(*b*) Royal Commission of 1901.

Thirty years after the publication of this first Report, a second Commission was appointed in 1901, with similar terms of reference, to revise the estimate of its predecessor in the light of new knowledge and new developments. This body issued its final report in 1905.

Accepting 1 foot as the limiting thickness for workable seams, and 4000 feet as the workable depth, as had been done by their predecessors, the Commission in their Report divided the coalfields into three groups under the heads of 'exposed coalfields,' 'proved concealed coalfields,' and 'unproved coalfields.' The 'exposed' fields and their already ascertained underground extensions (the 'proved' fields) under post-Carboniferous Formations were treated as collective units in each area, and elaborate methods were devised for ascertaining exactly the amount of coal still available in the exposed portions of the fields, and in such concealed areas as had been actually worked or explored and thus were the subject of definite knowledge. Ready help was given by the majority of colliery owners, managers, and mining engineers, and thus it was possible for the Commissioner in charge of each district to draw up elaborate tables for his area. Due allowance was, of course, made for waste in working. Unfortunately, the figures obtained for the 'exposed coalfields' were not separated in the Report from those given for the 'proved concealed coalfields.' The Commissioners adopted the sensible practice of breaking up the full Report into sections, which can be obtained

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separately, each one dealing with a single group of coal-areas or a single branch of their enquiry.

All the matters relating to the 'unproved' fields were put into the hands of a committee of Geologists specially qualified to deal with them, who issued carefully reasoned and, on the whole, extremely cautious reports on the areas entrusted to them.

The figures issued by the Comissioners may be summarized in round numbers, as follows:—

	Millions of tons.
Coal available in 'proved' fields (exposed and concealed) ...	100,000
Do. do. in 'unproved' fields (concealed)	40,000
Total	140,000

In addition to this, about 5000 million tons were estimated as occurring below 4000 feet in the proved coalfields.

With regard to the probable duration of our coal resources, the second Commission, like the first, although it stated the facts very fully, did not commit itself to any definite opinion. The output in 1903, namely 230 millions of tons, was just double that taken by the first Commission for 1870. This gives an annual increment of 3·6 million tons, or, as the Commission puts it, an increase of $2\frac{1}{2}$ per cent. per annum in the output, and $4\frac{1}{2}$ per cent. per annum in the exports. The Report adds:—

'It is the general opinion of the District Commissioners that, owing to physical considerations, it is highly improbable that the present rate of increase of the output of coal can long continue—indeed, they think that, some districts have already attained their maximum output; but that, on the other hand, the developments in the newer coalfields will possibly increase the total output for some years.

'In view of this opinion and of the exhaustion of the shallower collieries, we look forward to a time, not far distant, when the rate of increase of output will be slower, to be followed by a period of stationary output, and then a gradual decline.'

The Commissioners, however, published, and in their final Report called the attention of readers to, an elaborate series of tables and curves contributed by Mr. Price Williams, which state the probable duration of the coal supply based upon different methods of calculating the consumption. These tables give the output of coal which will on certain assumptions be required to cope with the increasing export and home consumption for each year from 1901 to 2200, and for each decade up to 2300. The estimated export of coal was reckoned upon 'its average decremental rate of increase during the last forty years (1861–1901).' The calculation of the amount of 'home consumption coal' was in the first instance 'based on the consumption per head of the population,' and took account of 'the average decremental rate of increase of the population of Great Britain.' In the second series of figures, the population basis was excluded, and the calculation of future coal production was based, as in the case of export, upon its 'average decremental rate of increase during the last 30 years (1871–1901).'

In the first series the estimated amounts were given in millions of tons as follows:—

	Home Consumption.	*Export.*	*Total Coal raised.*
Years 1901–2000	29,000	16,000	45,000
2001–2100	53,000	23,000	76,000
2101–2200	75,000	24,000	99,000

Thus, according to the population basis for home consumption, the supply in the proved fields would be more than exhausted before A.D. 2100, by which time 121,000 millions of tons would have been consumed.

In the second series, the figures (again in millions of tons) are as given below:—

	Home Consumption.	*Export.*	*Total Coal raised.*
Years 1901–2000	25,000	16,000	41,000
2001–2100	30,000	23,000	53,000
2101–2200	30,000	24,000	54,000
2201–2300	30,000	24,000	54,000

The calculation thus based results in the more comforting inference that we have sufficient coal in the proved fields to last over two centuries, while with what would be left over at the end of that period, together with the contents of the unproved coal-fields, we should have enough to last for another century.

It is not for me to discuss the merits of the two methods of calculation. It is sufficient to remark that the second method seems to accord more closely than the first with the views of the Commission as set forth in the passage quoted above. But it is worthy of remark that the time of any considerable steadying down of the theoretical output is far ahead, and only comes seriously into operation two centuries hence, when the amount of proved coal 'in sight' of the Commission will be approaching exhaustion. Besides this, a host of unseen factors are likely to arise in the meantime which may altogether vitiate the premises on which the calculations are based.

It should again be stated that the Commission relegated these figures to an appendix, and did not commit themselves to any more definite opinion on the probable duration of supply than is contained in the general statement already quoted.

(*c*) Sir William Ramsay's Estimate.

The President of the British Association, Sir William Ramsay, devoted a part of his address at the meeting at Portsmouth last year to the question of the exhaustion of the coal supply of Britain. Coming from one holding so exalted a position, and himself so eminent an authority in science, the opinion thus expressed calls for the most careful consideration and the utmost respect. Founding upon the figures given in the Report of the Second Commission for the amount of coal left in the proved coalfields (100,000 million tons), and computing that the amount mined will increase in the future as it has done in the past thirty years by 3·3 million tons annually, Sir William Ramsay estimates that exhaustion of the British supply will be completed in 175 years. On this conclusion he proceeds to issue a very grave warning against the present waste of coal which is taking place in the process of coke-making, in house-fires, and in consequence of the incomplete efficiency of machinery, and suggests directions in which better economy may be attained.

Sir William Ramsay's estimate is practically in agreement with that based by Mr. Price Williams on his first series of tables, and the startling figure, 175 years from the present time, is useful in laying marked emphasis on the precariousness of our coal supply and in calling the serious attention of the Nation to the adoption of economies in which miners, chemists, metallurgists, manufacturers, engineers, and the general public in their use of house-fires are chiefly concerned.

It is, however, only right that we, as Geologists, should point out that Sir William Ramsay has left out of his calculations the coal estimated by the Commission to occur in the 'unproved' coalfields. The importance of this unproved coal becomes clear when it is remembered that nearly one-third (40,000 million tons) out of the total available coal (140,000 millions of tons) estimated by the Commission is in these 'unproved' fields. And the trustworthiness of such estimates appears from the following:—Assuming the two Commissions to have been in full accord as to the amount of coal in the exposed fields, the 100,000 million tons of the second Commission's proved coal must be made up of the first

Commission's 90,000 millions of *exposed* coal (less 5000 millions consumed up to 1901), plus 15,000 millions transferred from the first Commission's *concealed* to the second Commission's *proved* fields. Thus 15,000 millions of formerly *unproved* coal has 'become *proved*' in thirty years. And the cautiousness of the second Commission's Report appears when it is realised that their 40,000 million tons of *unproved* coal represents the rest of the first Commission's 56,000 millions (less 1000 millions) of *concealed* coal.

As it is possible that the term '*unproved* coalfield' may have been open to misconstruction, it is well to state that the term was employed by the Commission in its literal sense. While the term '*proved* concealed coalfield' implies the continuation of exposed fields beneath an unconformable cover of newer rocks, or under the sea, where working or exploration has already demonstrated the quantity, quality, and position of the seams, the term '*unproved*' does not imply areas in which it is just barely possible that coal may exist. As used by the Commission, the expression connotes the farther extension of the exposed fields or their proved fringes into regions which have not yet been explored sufficiently to make their nature and contents an absolute certainty, but into which, so far as the structure is known, there is the practical certainty of geological inference that Coal-measures, bearing workable coal-seams, will be found at depths not too great for profitable working. As a matter of fact, these estimates were (excluding Scotland) limited to the extension of the fields on both sides of the Pennine Chain, of the North Wales Field, and of the central group of coalfields ranging from Cheshire to Leicestershire, and from Staffordshire to Worcestershire.

Certain areas in which borings have actually proved the existence of coal, but have not yet gone far enough to give us a satisfactory knowledge of the geotectonic structure of the areas, or to furnish a trustworthy estimate of the quantity, quality, or workability of the coal in them, were deliberately excluded, because the evidence so far collected was insufficient to support an estimate which it was necessary to express in figures. Nor was any estimate given in the Report for detached buried coalfields, or for any areas where there was not a very considerable amount of positive fact to rely upon.

All Geologists, on looking into the evidence, will admit that the estimate of these areas by the Commission is of a most conservative character, and that due allowance was made for known causes of variation in thickness and character of the seams themselves and of the measures in which they are contained, and also for losses due to earth movement and inter-formational denudation. Due deduction was also made, and on a liberal scale, for waste in working, which in concealed fields is always likely to be high. Thus the Commissioners' estimate for unproved fields is entitled to great respect.

Hence, whether we estimate future consumption according to Mr. Price Williams's second set of figures, or according to his first set (which is in close agreement with those of Sir William Ramsay), it is safe to place the same reliance on the Commission's 40,000 million tons of 'unproved' coal as on their estimate of 100,000 millions in 'proved' coalfields. If we do this, we add approximately 45 years to Sir William Ramsay's 175, and postpone the theoretical date of exhaustion of the coalfields till about 2130 A.D. Taking Mr. Price Williams's second set of figures, the date of exhaustion would be a little before 2200 A.D.

(2) The Necessity for Systematic Exploration of the Unproved Coalfields.

Surely it is not wise that a nation which owes so much in the past to her coal, and looks to it in the future as the chief of her remaining sources of wealth, should still have no term but 'unproved' to apply to so large a proportion of her unworked coalfields. Neither can it possibly be right to allow a national asset of this great value only to be revealed by casual exploration or accidental discovery. Is it not our duty as a nation to include it in our proved resources, to take deliberate stock of it, and to prepare for its systematic exploitation?

It was the good fortune of Britain to possess large areas of exposed fields from which the coal was easily and cheaply extracted, and working was naturally at first concentrated on those areas. It cannot, however, be said that the development of those fields has been by any means ideal, despite the comparative simplicity of their structure and the shallow depths from which the bulk of the coal was lifted. Some other countries have not been so fortunate. In the Franco-Belgian Coalfield, where the proportion of concealed to exposed coal is far higher than it appears to be with us, it has been found necessary to explore the underground structure in order to ascertain accurately the underground extension of the exposed fields, and to search for other concealed basins that may be entirely hidden beneath a cover of newer rock. So thoroughly has this search been carried out that the tectonics of the entire buried field, though of an exceedingly complicated character, are very completely understood. Had the proportions in Britain been similar we too should have been driven to take the same course. Indeed, the work done in Somerset and Gloucestershire, our chief partly concealed field, is an example of what has been accomplished under the stress of such circumstances. Unfortunately, the chief results in the coalfield just mentioned do not appear to have been available for the service of the Commission.

If we wait long enough, knowledge on the concealed Palæozoic area will undoubtedly grow, but it will be slowly obtained, at excessive cost, with the chance of serious losses, and at the risk of repeating the mistakes and waste which have afflicted the development of the exposed coalfields in the past. It would be more creditable to us as a nation, as well as greatly to our ultimate advantage, if we could by some means gain such an intimate knowledge of our concealed coalfields as to remove them from the category of unproved fields, and acquire such information on their constitution and structure as to enable us to judge, when, where, and how, it would be most profitable to undertake their exploitation.

(*a*) Statement of the Problems.

We stand in this position. We are threatened with the exhaustion of our most valuable resources within a period which may be two centuries or three, according to the rate at which the demand for coal happens to increase in the future. There is a possibility that our stock may be larger than we anticipate. If this should be the case, and if the coal should be capable of profitable working, the aspect of the coal question might undergo a very material change. Would it not be well, therefore, to set this question at rest, to convert our state of uncertainty into definite knowledge, in order that we may know the worst—or best?

The chief problems which await solution are the following:—

(1) Can we ascertain with more exactness the size and form of the buried extensions of our exposed coalfields?

(2) Are there any detached fields, and, if so, where are they situated and what is their approximate size?

(3) What is the thickness of cover under which the coalfields lie?

(4) What will be the most efficient and economical conditions of working them?

It will be most convenient to treat these questions in pairs, taking the first pair together, and following that up with a consideration of the second pair.

(*b*) Buried and Detached Coalfields.

We may approach the first two questions on *à priori* grounds. There can be no doubt that the existing coal-basins are but the relics of a once widely extended area of practically continuous coal formation. This covered the greater part of England and considerable areas in Wales, Scotland, Ireland, and the neighbouring Continental countries. Some parts of the other countries were certainly so situated that, whatever other deposits were or were not forming there, the conditions were not suitable for the growth of coal. But in England, when we except Devon and the extreme south of the country, with some parts of the Midlands and possibly the Lake District, there is no direct evidence that any large tract lay outside the area of deposition of workable coal. The occurrence of coal in the Pas de Calais and in the Franco-Belgian Fields seems to indicate that the area favourable for coal formation was very extensive. There is, then, the probability that under the cloak of Neozoic rocks a number of Coal-measure synclines may be preserved, corresponding to those known and worked where the Palæozoic outcrop has not been hidden beneath newer rocks, and, if so, that they may bear supplies of workable coal. The extension of the worked coal-basins under the cover was part of the result which was confidently anticipated from the application of this course of reasoning. A further consequence is the likelihood of a similar occurrence of other basins, not necessarily connected with those at present known to us, but isolated from the known coal-basins and perhaps from each other. Godwin-Austen's prediction of the occurrence of Coal-measures in South-Eastern England was founded on his grasp of the consequences flowing from a particular type of underground structure, and the verification of his prediction by the discovery of coal at Dover and elsewhere is a triumphant vindication of this class of reasoning. At the same time, it gives some support to the expectation of other concealed and isolated coalfields, and this expectation appears to be justified by the results of borings in other parts of the country.

Now, the collective extent of England and Wales (roughly 58,000 square miles) is divided geologically into two portions. The line dividing the two parts is approximately that which may be drawn from the mouth of the Tees to that of the Exe. More accurately, it corresponds with the outcrop of the base of the Trias. To the north and west Palæozoic rocks outcrop at the present surface of the country; to the east and south the same rocks outcrop at some depth below the surface, against the base of formations not older than the Trias. The first portion has an area of roughly 25,000 and the second of 33,000 square miles, the relative proportions being 43 to 57 per cent.

In the western and northern area, thanks to the labours of the Geological Survey, we possess maps which not only indicate the proportion of the whole area occupied by the outcrop of rocks of the various Palæozoic systems, but also afford a fair general knowledge of the folding and faulting to which the rocks have been subjected.

In the Sub-Triassic eastern and southern area, however, excellent as are the Survey Maps of the surface outcrops of the Neozoic rocks, our knowledge of the concealed outcrop (or incrop as it may be called) of the Palæozoic rocks, owing to the blanketing of that incrop by the overlying formations, is exceedingly limited—indeed, over a considerable part of the region it amounts to practically nothing. And yet it is in this area alone that we have any chance of finding new coalfields.

The total area of the exposed coalfields of England and Wales, including only those in which measures bearing workable coal are known to occur, is approximately 3000 squares miles, as deduced from the figures given by Professor Hull in his work on 'The Coalfields of Great Britain.' This amounts to about a twentieth part of the whole area of the two countries. But the comparative richness of our land in mineral fuel is made clear when it is remembered that the fields referred to are those only which occur outside the Triassic outcrop, and that the proportion of uncovered Coal-measure outcrop to the area of the Palæozoic rocks, as a whole, is just under an eighth, or 12 per cent.

If, now, we make the assumption, not altogether an unreasonable one, that the structure of the hidden Palæozoic floor within the boundary of the Trias outcrop is roughly comparable with that of the visible Palæozoic floor outside of it, there is at least a chance that the incrop of Coal-measures existent below the area occupied at the surface by Neozoic Formations may amount to an eighth of that area—that is to say, approximately 4000 square miles.

It may be urged that the effect of the repetition due to the Pennine fold has been to give to the uncovered Palæozoic region an unduly large area of Coal-measures within a depth easily worked, and that there is no sign, or even likelihood, of the existence of a similar buried fold under the Neozoic rocks. To meet this objection, it may be wise to subtract a third from the provisional estimate just made; and, if that is done, the area of possible buried Coal-measures would be reduced to about 2700 square miles.

There exists, of course, the Wealden anticline with whatever folding may underlie it; but as there is always the possibility that the southern limb of such folds will bear rocks of the Devon type, it must be left outside our consideration on the same principle that the exposed Carboniferous area of Devon has itself been ignored.

It is necessary to point out that the figures last given are merely the expression of arithmetical and not of geological probability. It would be much more satisfactory if we could substitute the latter for the former; but, in view of the present insufficiency of information as to structure of the concealed area, no geological estimate in the form of figures can be made.

(*c*) Conditions of Cover and Structure.

In dealing with this buried area of Palæozoic rocks, its possible content of coal-basins, and the probability that they may be worked with profit, there are three factors to be taken into account:—(1) The thickness of the unconformable cover; (2) the general structures of the concealed Palæozoic rocks on a large scale, the greater folds or faults by which they may be traversed, and the resulting geographical distribution of the outcrops of different members of the Palæozoic group; and (3) the detailed structure of the Carboniferous areas, and the presence of conditions which may or may not render it possible to work them profitably. It is hardly possible to treat these branches of enquiry quite separately, as they overlap one another, as also does the evidence on which our knowledge of them depends.

We possess a certain amount of information as to the directions in which variations in thickness of cover tend to occur. This is partly derived from general principles worked out from surface outcrops, but it is mainly dependent upon the direct evidence yielded by actual borings. Thus, other things being equal, the thickness may be expected to increase on the whole towards the centre of the synclines by which the newer rocks are affected. In spite of this knowledge, remarkable and unexpected variations are now and then brought to light, like the great thickness of certain

Mesozoic strata found by the borings at Battle and Burford, and the exceptional thinness of the same strata more recently demonstrated at Calvert.

An exhaustive study of problems relating to cover has been recently published by Mr. Lamplugh and Dr. Kitchin in a Memoir of the Geological Survey dealing with the Mesozoic rocks as revealed by certain of the coal explorations in Kent. This work is a very valuable example, as showing how much evidence on tectonic questions can be obtained from the thorough examination of the lithology and palæontology of specimens obtained from a comparatively small series of borings.

With regard to the large-scale structure of the buried part of Palæozoic England, it might perhaps be reasonably expected that some accepted general scheme of the tectonic arrangement of the exposed Palæozoic area would by this time have been evolved, which would give us the means of predicting to some extent what is likely to occur under the covered area. A great deal has been done in this direction; but it must be frankly conceded that the tectonic plan of the exposed Palæozoic rocks of Britain is so complicated, that the laws hitherto formulated do not empower us to forecast the structure in disconnected areas buried under the Neozoic rocks and situated far from the margin of the Triassic outcrop. The movements within the solid framework of the earth appear to be as subtle and complex as are the movements of the hydrosphere or the atmosphere upon its surface, and they are even more elusive when an attempt is made to formulate them into general laws.

It is true that geologists are daily increasing our knowledge of tectonic principles, and these principles are certain to add to our power of suggesting possibilities and probabilities with regard to the deeper strata.

The structure of the Pennine anticline and its accompanying troughs, broken by cross-folds into basins, is comparatively simple in the exposed area; but, when partly hidden under the Trias of the Midlands, it at once takes on complications. Again, the Wealden Anticline and the Palæozoic structures hidden beneath it are at present too insufficiently known to admit of any simple expression. And in the case of the minor folds of which these grand arches are composed the difficulties are correspondingly increased.

With regard to the intimate structure of those portions of the Palæozoic floor which are made of Carboniferous rock, the structure of the exposed coalfields makes it quite evident that the structure of the 'unproved' fields will by no means be plain and simple. The folds and faults by which the Coal-measures are affected, the variations in the conditions of sedimentation during deposition, the irregular surface on which the strata were deposited, the denudation to which they have been subjected both during deposition and later, each introduce complications; and there is no likelihood that the concealed coal-basins will be in any way more simple than the exposed ones. Yet it is these details of structure which will make all the difference between success and failure, profit and loss, in the development of the fields.

A typical coal-basin includes five more or less distinct regions, and it is interesting to compare the relative importance of each of these. In the first place, there is the region of profitable working within which productive Coal-measures exist at a depth not too great to be easily reached and worked. In the second place, there is the region where synclinal conditions are in excess and the measures have been carried down too deep for profitable working. In the third place, there is the region where anticlinal conditions are in excess, the underlying rocks have been brought to the surface by folds or faults, and the Coal-measures which once covered them denuded away. In the fourth place, there is the region where no deposition took place in Coal-measure time, owing to the irregularly upstanding land-masses of pre-existing rock to which the Coal-measures are unconformably related. And in the fifth place, there is the region in which the Coal-measures, having been deposited near to the old land areas in later Carboniferous time, are barren and not worth working. Each of the regions may be made up of several more or less distinct areas, the term 'region' being employed as a collective designation for the sum of those areas in which similar conditions obtain.

An estimate founded on these lines could easily be drawn up for each and all of the visible British coalfields, and it might be useful in giving some rough idea as to the average conditions which might reasonably be expected to recur in the concealed areas under the Neozoic cover. But it would not be well to place much reliance on figures so obtained.

Nor, on the other hand, would much be gained if an attempt were made to calculate the possible amount of coal, which might be expected to exist in the problematical 2700 square miles of coal-area that may lie concealed under the Neozoic rocks, on the basis of the amounts which have been taken from, *plus* those that are still left in, the visible Palæozoic area. One consideration alone, not to mention others, serves to eliminate confidence in such figures as a working basis. We may state it as follows :—

If we draw a geological section across Ireland and England, it will be found that the average denudation-line cuts deeper into the folds of the Palæozoic rocks in Ireland on the west than in Great Britain on the east. If this relationship may be exterpolated under the Neozoic cover of England, the depth of the troughs is likely on the whole to increase towards the east and south. Thus, in addition to the thick Neozoic cover, the miner may have to deal with deeper synclines in the coal basins.

(*d*) Sources of Information.

In the Triassic and Super-Triassic eastern and southern area of England, our knowledge of the concealed outcrop of the Palæozoic rocks is limited to four sources of information, each of which provides us with a certain but not very large amount of knowledge.

First, we have the visible plunging of the structures of the Palæozoic rocks under the newer cover. Sometimes this occurs without disturbance, but more usually it is complicated by faulting, and especially by boundary faulting. Moreover, as the axes of folding, and even the lines of the faults of the older rocks, do not run straight but along curves of types which have not yet been reduced to simple general laws, the prolongation of visible structures under an unconformable cover must ever be a complicated phenomenon, and any attempt to forecast it is a matter into which speculation will enter largely. The question is further complicated by variation in thickness and content, and by the occurrence of unconformities and overlaps amongst the Palæozoic rocks themselves. It is largely owing to these circumstances that working on the concealed fringes of exposed fields has always been an uncertain process, carried out timidly and with great caution.

The Report of the Commission on the unproved coalfields should be carefully read by every geologist interested in the British coalfields. It contains a treatment by Professor Charles Lapworth of the buried extensions of the groups of coalfields of Central England, giving a most lucid and convincing picture of the condition of matters which there exists under the Triassic cover.

Secondly, we have the evidence yielded by borings put down through the newer strata, and penetrating far enough to reach the Palæozoic rock-floor under the cover. A glance at the map published by the Coal Commission, which gives all the principal borings in this Triassic and Super-Triassic area, will show how exceedingly few they are in relation to the large area over which they are scattered. Even so, the amount of information yielded by them is remarkable, when we consider that they have rarely been located according to any definite plan, and when further we realise the difficulty that has often been experienced in obtaining and interpreting the evidence which they are capable of affording.

Of the list of borings considered by the 1901 Commission, 53 did not reach the Palæozoic rocks at all, but ceased in Mesozoic rocks; 29 reached Palæozoic rocks other than Coal-measures; and 38 reached Coal-measures. This list includes several borings put down near the margins of the exposed coalfields, so it cannot be taken as expressing the average constitution of the outcrop of the Palæozoic floor.

The light thrown by these borings on the thickness of Neozoic cover is interesting. The greatest depths at which Palæozoic rocks have hitherto been struck is 2000 feet at Scarle, but the cover was 1921 feet thick at Brabourne, 1750 feet thick at Scunthorpe, and 1728 feet at South Carr. The greatest thicknesses reached by the borings in known synclines of Mesozoic rock are 2610 feet at Marston and 2400 feet at Chartley, both borings ending in Trias. The sub-Wealden boring at Battle ceased at 1900 feet in Oxford Clay, and the Penshurst boring at 1867 feet in Kimmeridge Clay.

In the third place, there are the inferences which may be drawn from the application of Godwin-Austen's principle that folding and faulting in newer rocks are often due to the posthumous movement of larger folds or faults in the older and unconformably underlying rocks. In other words, that the buried folds 'show through' the newer cover imperfectly, like a picture 'seen through a glass darkly.' Godwin-Austen applied this principle only to the major folds; but Marcel Bertrand was able to show that it is in certain cases a fairly trustworthy guide, even in the case of minor folds and faults. This principle has already frequently proved a most useful guide to buried structures, and as our knowledge grows it will become of ever increasing value, and may, perhaps, enable Geologists to put out to compound interest each fragment of new knowledge gained as to underground structure. It is known, however, that movement along a given line may be in opposite directions during successive periods, and Mr. Lamplugh's recent study of the structure of the Weald has shown that such is the case in that region. During part of Mesozoic times the fold was synclinal in character, but it afterwards became a tectonic anticline;

therefore caution is necessary in the application of this principle, at least in examples of gentle folding.

In the fourth place, we may obtain a certain amount of evidence if we consider the probable effects of the bearing of Godwin-Austen's principle upon the lithology and distribution of sediments at the time of their deposition. If movement occurs and recurs at the same place and along the same direction in successive periods, it will influence the physical geography during each of these periods of movement. It may thus give rise to ridges, shore-lines, or shallows, some of which will be registered in the absence, thickness, or composition, of deposits forming, it may be, in one or in more than one of the movement-periods. In this way, we may be led to localize not only lines of movement but areas in which strata may be expected to be of exceptional thickness or thinness. Professor P. F. Kendall has successfully applied this line of argument in discussing the probable limits of the South-Eastern Pennine coalfield. The results of his study are embodied in the Report on the unproved coalfields issued by the 1901 Commission.

The careful study and correlation of all these sources of information have already given us a certain amount of information as to Palæozoic rocks under the Triassic cover. This information is most trustworthy near the margin of that cover, but it becomes more vague and less reliable as we recede from the edge. In the Coal Commission Reports some of the maps summarize and build upon this information, as, for instance, that giving the possible extension of the East Pennine Coalfields. But the Commission was too cautious to accept in full several of the conclusions which might be based upon these maps.

(*e*) Importance of Borings.

But in spite of information gathered on more or less theoretical grounds, there is no getting away from the fact that ultimately we shall be driven to seek most of our data in the covered area from borings, and that in this exploration large sums of money will have to be spent.

Further, there seems little doubt that in any circumstances, and especially under the unsatisfactory conditions which at present prevail, much of the money so spent, when not actually wasted (as has frequently been the case in the past by the selection of spots where geological research had already demonstrated that no coal exists), may, nevertheless, appear to have been uselessly thrown away.

But, in so far as every boring sunk in a neighbourhood where there is a geological possibility that coal or some other profitable mineral may exist, will throw light on two important factors of the larger problem, the bulk of the loss, though serious enough to individuals, may be turned into actual gain for the welfare of the community at large. We shall by such means gradually get to know the thickness and composition of the covering Neozoic rocks. And, more slowly, there will grow, stage by stage, a full knowledge of the distribution and arrangement of the buried Palæozoic rocks. The knowledge thus acquired, in so far as it enables us to construct maps of the hypogean outcrops with gradually increasing accuracy, will furnish so reliable a guide to future exploration that fruitless borings will in time decrease in number and perhaps eventually cease.

(*f*) Waste; its Causes and Prevention.

The advantage of a detailed knowledge of the intimate structure of each individual coal basin, before the working of it is actually undertaken, will be brought home to us if we devote some attention to another line of the Commissioners' enquiries, the matter of loss and waste, preventable or otherwise.

In pursuance of their instructions, both first and second Commissions devoted much attention to the fact that only a very small percentage of the energy locked up in the coal as it lies *in situ* is ultimately recovered from it in the form of work. They therefore gave careful consideration to (1) the waste associated with the consumption of coal, and (2) the loss that takes place in connexion with the actual coal-getting. We, as geologists, are mainly concerned with the latter form of loss, and it will be necessary to note the exact lines on which the Commissioners proceed in their estimation of it.

In the first place, there are certain additions to be made to the cost of getting the coal for which the members of the Commission do not appear to have made allowance. They form an estimate of the amount of 'coal remaining unworked in Seams of Coal,' and having made certain deductions from that amount, they, as it were, leave it underground unlifted and undistributed. Thus the cost of unwatering the workings, of underground haulage, and of lifting the coal to the pit mouth are none of them considered in their final Report, although all these charges are paid out of the coal before it is ready for sale. In the past, it has frequently been the practice to neglect the poorer seams in order to get the better ones more expeditiously, although by this practice the poorer seams are in many cases irretrievably lost. Again, there is a constant tendency towards the abandonment of older and less profitable collieries, or even areas, in favour of newer and richer ones. It appears to have been considered by the Commissioners that these practices will be given up and that, at the same time, the actual getting of all seams, including thin ones, will be more economically conducted in the future, so that much coal which is now lost as slack will be brought to bank. With the exception of the deductions to be presently mentioned, the estimates as to coal remaining unworked are apparently based on the expectation that every seam will be got and got out completely. Finally the coal was not charged with the expense of the discovery of coal-areas or with that of the exploration of the areas when located.

The haste with which coal in this country was taken out in the early days of coal-mining, the rush to get that which was easiest and cheapest, the imperfection of the early machinery and methods of coal-getting, all have combined to render many of the older areas practically inaccessible, although in many cases, for the reasons just stated, very considerable amounts of coal, recoverable by modern methods, have been left in them. Some, at least, of this coal might even yet be obtainable if accurate plans and records had only been kept. In the early days, however, this was but rarely done, and the Government mining records were only started in 1848—after a great proportion of the harm was irreparable.

The rotting away of the timbering left in the mines, and the leaving of insufficient pillaring or the 'robbing' of such coal pillars as were left, have caused the eventual collapse of many of the older workings; and it has thus not only become practically impossible to work any coal-seams remaining in such areas, but the ground has in many cases become waterlogged and has proved and still proves, in more ways than one, a source of danger and loss to adjoining areas. Not only must broad underground barriers be maintained as a defence against water, but the irregular subsidence and consequent destruction of the relief of the ground surface has rendered it in some cases impossible to devise any comprehensive system of drainage, and in any case has made drainage schemes inordinately expensive or inefficient. The Commissions have been compelled to 'write off' the majority of these areas, and to proceed on the assumption, which is probably legitimate, that in future no such wreckage will be permitted.

Passing to the deductions actually made by the Commissioners in drafting their estimates, the most important is the allowance for 'faults and other natural causes.' The average deduction made on this account is 17 to 18 per cent. of the coal as it lies *in situ*, and the amounts vary from 30 per cent. in North Wales and Cumberland, and 27 per cent. in South Wales, South Staffordshire, and Scotland, to as little as 18 per cent. in Cheshire and 15 per cent. in Shropshire. The losses under this head comprise 'wants' or destruction caused by folds and faults, the existence of masses of older rocks protruding through the Coal-measures, the effects due to crushing and to alteration by igneous rocks, the variations in thickness and quality of the seams, and the 'wash-outs' and other results of contemporaneous or subsequent denudation. Probably also some allowance is made for the average effects of accidents, fire, water, and creep.

The second principal deduction is for the amount of coal which it is necessary to leave underground in order to support the shafts, plant, and buildings, and to hold up the surface where it and the structures upon it are of more value than the underlying coal-seams. The average deduction under this head amounts to a little over 5 per cent. It varies from 12 per cent. in Durham and Scotland to 2 per cent. in Cheshire, and 1 per cent. in Cumberland. A certain amount of allowance is also made for the present practice of leaving boundary barriers between adjoining properties; but it is assumed that this practice will be reduced to a minimum, or even abandoned under improved conditions of working.

Thus the Commission assumes that coal-working will be carried on in a much more efficient manner in the future than in the past; that the old mistakes will not be made again; but that the most advanced knowledge and the most economic methods and machinery will be made use of. Can we hope that their trust in these respects will be justified? The answer to this question involves a consideration of the special conditions which will prevail in future working.

(*g*) Prospects of Improvement in the Future.

We may perhaps presume that the work which still remains to be done in the exposed fields will justify the expectation of the Commissioners. In the concealed but proved areas too there has been acquired a certain amount of knowledge from workings and borings, though this falls short of that pertaining to the exposed fields.

But when we come to the unproved areas, there will have to be faced not only the increased expenses of working which result from the greater depths and the consequent higher cost of lifting coal and pumping water, but also the grave danger of serious losses and mistakes. Even though the Commissioners limited their consideration under this heading to the subterranean extension of *proved* areas, they are justified in their extremely cautious treatment by the variations in structure and character which are practically certain to occur.

Far greater will be the difficulties which must be associated with those areas, on which the Commission declined to report, areas that may lie concealed beneath the Neozoic cover wholly severed from the exposed fields, and perhaps from each other. In such areas the first charge will be the expense of search and discovery, and, if coal be discovered, there will follow working difficulties at all events not less than those met with in the Commission's *unproved* fields.

In the case of all concealed coalfields the existence of an unconformable cover not only increases directly the costs of exploration and working, but it very effectively conceals the structure of the rocks beneath. And yet, to mine an area of which the structure is not thoroughly comprehended, is to court loss and perhaps disaster. If even in the exposed fields it has been necessary to 'cut the losses' which arose from imperfect tectonic knowledge, losses which are only too well known to those familiar with coalfields that have been long at work, how much greater will be the risk of loss involved in meeting and overcoming structural difficulties while working blindfolded, as it were, by the baffling cover of newer rock? The only way to minimize this more or less inevitable loss is to find means for investigating the concealed areas as thoroughly as possible before the risk of actual mining operations is embarked upon. And as this can be done at the same time as the search for new coal basins is being prosecuted, there is little excuse for not combining the two operations.

Such knowledge as we at present possess on the hypogean geology of the area under Neozoic rocks, other than that due to general tectonic principles as to the prolongation of structural features from exposed into concealed areas, and from borings carried forward a little in advance of working but not far outside the area of proved fields, has in the majority of cases come from corporate or individual expenditure on borings made for various public purposes. Sometimes these bores have been made for exploration, but more usually the commodity sought has been water, salt, or some substance other than coal. Some of the information thus acquired has been published, and a great deal more has found its way to the Offices of the Geological Survey. This body, realizing the great economic importance of such data, has taken infinite trouble to record, store, index, and interpret the evidence yielded by boring, and has thus provided a storehouse of extremely valuable information. Whenever it is possible or advisable, such portion of this as is open for the purpose has been published in Memoirs dealing with coalfields or water-supply areas, or in the ordinary map-sheet Memoirs.

This plan is, in itself, admirable as making the best of a difficult and complicated array of circumstances; but the best codification and publication of results obtained, as it were by accident, from a series of scattered borings executed without a comprehensive plan, is a poor substitute for a systematic boring survey rationally planned with the view of obtaining a definite result. The matter is ripe for deliberate research instead of haphazard discovery.

(*h*) Epigean Surveys in the Past and Present.

Let us consider what would have happened if, when coal-mining first began, geological science had advanced sufficiently to allow of the making of accurate maps of the coalfields on a large scale, and if the geological structure of the coalfields had been completely worked out. It is evident that much of the money thrown away in fruitless exploration would have been saved, that very many of the sources of waste would have been avoided, that difficulties of drainage and those associated with mine-planning would have been materially lessened, and that it might have been possible to deal with tectonic units instead of miscellaneous areas depending upon surface conditions which have little or no relation to underground structure. Even now that the exposed coalfields have been so extensively worked, coalowners, colliery proprietors, and others interested in coal are again and again demanding exact new surveys to provide them with large-scale maps and sections embodying the whole of present-day information. It is certainly true that a great deal of our present knowledge of structure is the outcome of the development of mining itself, and that in many cases it has been gained by those actually engaged in mining operations. For this Geologists are, and should be, ever grateful. But it must be remembered that Geologists were, at the outset of coal-mining operations, and are still, up to the present day, limited in their observations to the surface, and to those exposures made by natural and artificial sections cut into the earth's crust. In very few cases has there been any means or opportunity of carrying out experimental exploration of the earth's crust for the purpose of pure discovery, whether in its scientific or in its economic application.

Now that the area of coal-mining has advanced beyond the visible outcrops of Palæozoic rocks into areas where those outcrops are hidden from sight under Neozoic formations, history is about to repeat itself, and it seems to me that this is the time to take to heart the lessons of the past. We follow this plan in other matters of everyday life, in history and politics, in economics, in war, in trade, even in agriculture and education; surely the same course must be followed in relation to the mineral structure of the earth and to the development of our mineral wealth.

The most valuable of our resources are contained in the Palæozoic rocks. These are, however, only exposed over less than half the area of our country. More than the other half of the Palæozoic outcrop is buried under a variable thickness of newer rocks. The borings already carried out have in no case at present proved a cover of thickness greater than the depth of profitable coal-mining, although probably some of them, if continued, would have passed through more than 4000 feet before reaching Palæozoic rocks. On the other hand, the cover in many places has proved to be surprisingly thin. Explorations to ascertain the possible concealed coal-resources under the buried area are certain to be undertaken. They are sure to cost large sums of money; and yet, if carried on without a very definite plan, much of the money will be employed to less than maximum advantage, even if it is not actually thrown away.

(3) A Hypogean Survey.

Cannot some means be devised by which this expenditure shall be systematically laid out in the most profitable fashion? Cannot some way be found, some plan drawn up, by which spasmodic, uncertain, often ill-advised exploration, may be replaced by a well-considered scheme which shall ensure that the concealed area shall be regularly and deliberately explored? There is a clean sheet upon which to work, and a fair possibility of avoiding the worst errors of the past. Is it not possible to plan out the exploration of these fields under the conditions which we admit would have been ideal in the case of the exposed fields had the opportunity been afforded? Cannot we have a systematic geological survey of the area now concealed beneath the newer rocks?

Sir Roderick Murchison, before the first Commission, advocated the exploration of concealed Palæozoic rocks by means of borings. The subject was again taken up by Mr. F. W. Harmer in a paper read at the British Association Meeting in 1895, and a scheme was drafted by him for a systematic survey by means of borings.

The vital importance of coal to Britain, and the chance that coalfields other than those at present known or suspected may exist, make out at the least a case for serious consideration, and suggest that if it is not regarded as inconsistent with the ordinary canons of economy and business, some attempt ought to be made to determine the existence and extent of these possible concealed coal-basins.

(*a*) A Profitable Investment.

If such a survey were possible, and if it should prove that there is any considerable area of buried coalfield, the money spent upon it would be a most profitable investment. If carried out by a group of individuals, it would be a good business proposition, because it would save loss of capital, and would point the way to the avoidance of waste. If carried out by the Nation, it would imply the probable discovery and establishment of a national asset by which the disaster of early exhaustion of our coalfields might be postponed.

The object of a planned series of borings carried out on a definite system would be very different from those as a rule put down under present conditions. Their deliberate purpose would be to elucidate the geological structure of the concealed area. The majority of them would, of course, be put down mainly with a view to direct and immediate economic results, the search for coal where there might be some likelihood of its discovery. But many would have to be made without necessarily any direct prospect of gain, for the purpose of ascertaining the general or detailed structure of the concealed area, and for the acquisition of that tectonic knowledge which is a vital necessity for the profitable development of any coalfield. By such borings, maps might be made which would serve to guide the miner to spots where coal actually exists as distinct from areas where it is absent, as do the published maps in the unconcealed areas. But, although these maps would be at first merely rough indications, increasing exploration would gradually give such a clue to the tectonic arrangement of the Palæozoic rocks under the Neozoic cover, that they would eventually furnish the same class of structural information with reference to hypogean outcrops as is given by the ordinary outcrop maps.

(*b*) Value of Increased Tectonic Knowledge.

The great advantage of the study of geological structure is that each set of observations makes the next step easier and more definite. Abundant proof of this is afforded by the study of the borings that have already been carried out. Each boring has given some leading to help in locating the next, or in saving useless expenditure. The knowledge of the exact succession of the visible Carboniferous and other rocks, and of their zonal palæontology, which has been pushed forward so rapidly of recent years, both by individual investigators and by the Officers of the Geological Survey, has already rendered valuable aid, and will give still more assistance in the interpretation of results obtained by boring.

It is the gradual growth of tectonic knowledge, as it has been ascertained stage by stage in the process of mining as well as by the growth of the study of outcrops of all kinds of strata at the surface of the ground, that has been one of the most important factors in improving the efficiency of working in the exposed fields. But in the concealed coalfields such knowledge is certain to be of far higher service. It should result in minimizing many sources of loss. It will aid in the selection of the best places for shafts and in indicating the most economical planning of the field for hauling, pumping, and lifting; it should lessen the underground loss due to natural causes, and permit of such arrangements being made that the minimum damage is done to the surface and to its amenities.

It would seem that the state of knowledge, as well as the appropriateness of the time, justifies the taking of this new step in the study of the mineral resources of Britain.

At the same time, it is not intended to imply that the work of surveying the surface outcrops of either Palæozoic or Neozoic rocks is completed. There can be little doubt that as we pass eastward and southward from the margin of the Neozoic cover, the tectonic structure of the older rocks becomes increasingly complex, and will require for its interpretation the highest knowledge of geological principles which it will be possible to bring to bear upon it. Nor can there be any doubt that many of the more important lessons on the behaviour and arrangement of rock-masses have been learnt without any economic incentive, by study made among those older rocks which have suffered most from the effects of earth-movement, and are at the same time, fortunately, so well exposed that their structures can be easily seen in the field and their relations in many cases satisfactorily worked out. Such study of outcrops, whether Palæozoic or Neozoic, must by no means be relaxed, it ought to be carried on more vigorously than ever. For this reason, while it is well that geological surveys should devote special attention to areas giving prospect of immediate economic return, it is not right or wise to confine their energies to such areas, or to rocks containing or overlying products of economic value. It is a general principle that what is merely of academic interest to-day, always becomes of economic importance to-morrow; and it is at least as certain that tectonic laws worked out in the study of the Highlands or the Pennine will prove applicable to the coalfields that may be found in the future, as it is that the zonal study of the ammonites or the graptolites in the past has brought about the discovery of principles and methods which are now being successfully applied to the Carboniferous rocks. A thorough understanding, not only of the Coal-measures and the rocks overlying them, but also of those underlying them, is required before a thorough grasp of the tectonic features of the coalfields, as a whole, can be obtained. And, further, as the tectonic structure of the entire kingdom hangs together as a unit, we must not rest satisfied till the whole of that structure, economic or apparently non-economic, simple or complicated, outcropping or covered, has been unravelled as thoroughly as all possible observations within the area itself, and all reasonable comparisons with other areas, will allow.

(*c*) Difficulties.

It is unquestionable that it will be by no means an easy matter to devise any scheme by which such a survey of underground geology as I have outlined could be carried out. One thing obvious is that some modification of the existing law would be required: for, as the law stands, there does not seem to be any possibility of bringing about exploration by a system of encouragement and compensation. Both would be required. A landowner could not be expected to go to the expense of proving any portion of his property without some hope of direct benefit to himself. He would not be willing to take the risk of loss resulting from doubtful experiments, or the damage of a negative result, without some help or compensation. Nor, if successful in locating coal, would he be satisfied unless he could command access to a mining area large enough to pay a good return on the capital risked in exploration.

On the other hand, the appointment of a Government Survey Department to carry out explorations needing so considerable an expenditure would be a new departure for this country, and one which could not be taken in hand without the assurance that not individuals alone, but the country as a whole, would benefit by the scheme.

(*d*) A Royal Commission suggested.

The question is so difficult and complicated, and yet of such far-reaching importance, that perhaps the best course would be the appointment of a Royal Commission to consider it in all its bearings, to study the plans adopted by the Colonies and Foreign Countries, and to suggest such alterations in the law as may bring about a solution of the problems by which we are confronted, while avoiding the innumerable pitfalls that surround the subject.

If such a Commission were appointed, it seems almost inevitable that it should suggest the grouping together of the numerous Departments and fractions of Departments which deal with various branches of our mineral industries under a single expert Department and Minister, as is done in many of our Colonies and in Foreign Countries. After many centuries under other Departments, Agriculture has at last achieved a Department of its own. It is to be hoped that it will not be necessary to wait until our mining industries are in as parlous a state as that which Agriculture had reached, before they too receive similarly favourable treatment.

(4) Summary.

The enquiries of the Coal Commissions have shown that of the coal left unworked in Britain 100,000 millions of tons remain in the proved and 40,000 millions in the unproved coal-fields. It is pointed out that it is as safe to reckon confidently on the latter quantity as on the former.

Careful estimates by competent authorities show that this quantity of coal is likely to become exhausted between 2130 and 2200 A.D., according to the precise basis upon which the calculation is made.

The fact, that of the potential energy resident in the coal *in situ* not more than 8 per cent. is extracted as work, indicates that there is room for immense improvement in getting and employing the coal, and for effecting important savings in our known resources. This economy touches mainly Miners, Chemists, and Engineers.

The Geologists' share of the problem is to ascertain whether or no we possess other supplies of workable coal not included in the estimate of the Commissioners, and it is pointed out that in Eastern and Southern England there exists an area of Palæozoic rocks unconformably covered by Neozoic rocks larger in extent than the uncovered Palæozoic outcrop of England and Wales.

This area has only been explored in regions which are in direct prolongation of the exposed coalfields, and by a very small number of borings put down elsewhere. Some of these have demonstrated the existence of Coal-measures or other Carboniferous rocks, and none have yet proved a Neozoic cover so thick as to preclude the possibility of successfully working any coal which may be found beneath it.

It is argued that the time has now come for the organization of a systematic survey of this area by means of a considered series of borings, so planned as to investigate the structure of the concealed Palæozoic floor, to ascertain the thickness of cover, to locate any coal basins which may form part of the floor, and to elucidate their exact tectonic conditions in order to determine their suitability for profitable working.

It is admitted that such an exploration would involve many practical difficulties, and would introduce a new practice into British Institutions, but it is pointed out that similar methods have been employed in Foreign Countries and even in British Colonies.

It is urged that the close dependence of the future of the Nation on its coal supplies justifies a new departure, and that it would be a wise act of statecraft to take deliberate measures to devise a comprehensive and well-considered scheme of exploration, the results of which might be at hand for application before the growing scarcity of coal shall have begun to produce its inevitable economic consequences upon the manufactures and upon the very conditions of existence in this country.

(5) Conclusion.

In concluding this address I desire to express my very sincere thanks to my friends Prof. Charles Lapworth and Mr. W. G. Fearnsides, both of whom have patiently and most good-naturedly worked through the manuscript of this as well as of my former address to the Society, and have made a number of corrections, suggestions, and additions to them. For any views expressed, I, of course, take sole responsibility.

I have now reached the end of my second year of office as your President, and it is my duty to lay down that office and to ask you to give to him whom you have elected to succeed me the same loyal support and kindly consideration that you have accorded to me. Dr. Strahan has served on the Council for ten years, and has acted first as Vice-President and later as Treasurer. It is in the latter capacity that his services to you will be freshest in your memory. It will suffice to say that he has brought the Society through a year of exceptional expenditure with a surplus, and that he has carried out, with the maximum of economy and the minimum of inconvenience, the details of the greatest change in the Society's Apartments that they have hitherto seen. It is not for me to dwell on the scientific work or attainments of your future President; they are too well known to you to need any words of mine. But I feel that I leave the affairs of the Society, its scientific influence, the capable conduct of its business, and the guidance of its policy, in the hands of one of the most competent of British Geologists.

In conclusion, I should like to thank the Officers of the Society, both temporary and permanent, for the loyal support and cordial co-operation that they have given me during my period of office. Their consideration, and the kindly toleration of the whole Fellowship of the Society, have made my term as your President one of the pleasantest periods of my life, and one that it will always be a delight to look back upon.

February 28th, 1912.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Crellyer Colgrave Bissett, B.Sc., 10 Clarendon Place, Sheffield; Charles Edward Blaker, Irrigation Secretariat, Lahore (Punjâb), India; Jack Lane Jeffery, Assoc.R.S.M., 32 Primrose Mansions, Battersea Park, S.W.; Reginald Charles Wilson, B.Sc., Imperial Institute, South Kensington, S.W.; and Disney Alexander Wray, B.Sc., Demonstrator in Geology at the Imperial College of Science & Technology, Addingford, Horbury (Yorkshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Late Glacial and Post-Glacial Changes in the Lower Dee Valley.' By Leonard Johnston Wills, M.A., F.G.S., Fellow of King's College, Cambridge.

2. 'The Glen Orchy Anticline (Argyllshire).' By Edward Battersby Bailey, B.A., F.G.S., and Murray Macgregor, M.A., B.Sc.

The following lantern-slides, specimens, etc. were exhibited:—

Lantern-slides, exhibited by L. J. Wills, M.A., F.G.S., in illustration of his paper.

Rock-specimens, photographs, and lantern-slides, exhibited by E. B. Bailey, B.A., F.G.S., and Murray Macgregor, M.A., B.Sc., in illustration of their paper.

March 13th, 1912.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Tom Eastwood, Geologist, H.M. Geological Survey, 4 Rosenau Road, Battersea, S.W.; and Robert Douglass Vernon, B.A., B.Sc., Emmanuel College, Cambridge, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Glacial Origin of the Clay-with-Flints of Buckinghamshire, and on a Former Course of the Thames.' By Robert Lionel Sherlock, D.Sc., A.R.C.S., F.G.S., and Arthur Henry Noble, B.A., F.G.S.

2. 'Some New Lower Carboniferous Gasteropoda.' By Mrs. Jane Longstaff (*née* Donald), F.L.S. (Communicated by Dr. G. B. Longstaff, M.A., F.G.S.)

The following specimens and lantern-slides were exhibited:—

Specimens and lantern-slides, exhibited by Dr. R. L. Sherlock, F.G.S., and A. H. Noble, B.A., F.G.S., in illustration of their paper.

Specimens, casts, and models of gasteropoda, exhibited in illustration of Mrs. Jane Longstaff's paper.

A series of Palæolithic implements from the Test Valley gravels at Romsey, Kimbridge, and Dunbridge (Hampshire), also lantern-slides, exhibited by William Dale, F.S.A., F.G.S.

Geological Survey of England & Wales: 1-inch Map, new series, Sheet 337, Tavistock, 1912; presented by the Director of H.M. Geological Survey.

March 27th, 1912.

Dr. Aubrey Strahan, F.R.S., President, in the Chair.

C. H. Cunnington, H.M. Geological Survey, 28 Jermyn Street, S.W.; Harold John Frederick Gourley, 13 Japan Crescent, Crouch Hill, N.; George Hickling, D.Sc., Lecturer in Palæontology & Demonstrator in Geology in the Victoria University of Manchester, Glenside, Marple Bridge, near Stockport; William Ranger, B.Sc., Meadow Villa, Dalton-in-Furness; Frederick Sadler, 98 Creffield Road, Acton, W.; Thomas William Saunders, 195 Coronation Villas, Thorpe Road, Melton Mowbray (Leicestershire); and S. James Shand, D.Sc., Professor of Geology in the Victoria College, Stellenbosch (South Africa), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Glaciation of the Black Combe District (Cumberland).' By Bernard Smith, M.A., F.G.S.

2. 'The Older Palæozoic Succession of the Duddon Estuary.'[1] By John Frederick Norman Green, B.A., F.G.S.

The following specimens, lantern-slides, etc. were exhibited:—

Rock-specimens and lantern-slides, exhibited by Bernard Smith, M.A., F.G.S., in illustration of his paper.

[1] Withdrawn by permission of the Council.

Rock-specimens and lantern-slides, exhibited by J. F. N. Green, B.A., F.G.S., in illustration of his paper.

Geological Survey of England & Wales: 1-inch Map, new series, Sheet 113, Ollerton, 1911; presented by the Director of H.M. Geological Survey.

April 17th, 1912.

Dr. AUBREY STRAHAN, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The PRESIDENT announced that the Council had awarded the Proceeds of the Daniel-Pidgeon Fund for the present year to OTWAY H. LITTLE, M.A., Royal College of Science for Ireland, who proposes to investigate the chemical and mineral changes which have taken place in the metamorphic limestone of Connemara.

The following communications were read:—

1. 'The Pre-Cambrian and Cambrian Rocks of Brawdy, Hayscastle, and Brimaston (Pembrokeshire).' By Herbert Henry Thomas, M.A., B.Sc., Sec.G.S., and Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S.

2. 'The Geological Structure of Central Wales and the Adjoining Region.' By Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S.

The following specimens and lantern-slides were exhibited:—

Rock-specimens, microscope-sections, and lantern-slides, exhibited by H. H. Thomas, M.A., B.Sc., Sec.G.S., and Prof. O. T. Jones, M.A., D.Sc., F.G.S., in illustration of their paper.

Lantern-slides exhibited by Prof. O. T. Jones, M.A., D.Sc., F.G.S., in illustration of his paper.

May 1st, 1912.

Dr. AUBREY STRAHAN, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The PRESIDENT referred to the loss which the Society had just sustained, in the decease of Mr. JOSEPH DICKINSON, at the age of 93. Mr. Dickinson had been a Fellow of the Society for no less than seventy years, having been elected in 1842, and he had retained undiminished to the last his keen and vigorous interest in geological and mining matters.

The following communications were read:—

1. 'On the Geology of Mynydd Gader, Dolgelly; with an Account of the Petrology of the Area between Dolgelly and Cader Idris.' By Philip Lake, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S.

2. 'Insect-Remains from the Midland and South-Eastern Coal-fields.' By Herbert Bolton, F.R.S.E., F.G.S., Director of the Bristol Museum.

The following specimens and lantern-slides were exhibited:—

Specimens and lantern-slides exhibited by P. Lake, M.A., F.G.S., and Prof. S. H. Reynolds, M.A., F.G.S., in illustration of their paper.

Specimens and lantern-slides exhibited by H. Bolton, F.R.S.E., F.G.S., in illustration of his paper.

May 15th, 1912.

Dr. Aubrey Strahan, F.R.S., President, in the Chair.

Percival Gordon Broad, M.A., St. Andrew's Lodge, Eastbourne; Jervis William Jervis, Superintendent of the Mineral Department of Bikanir State, Palana, Bikanir (India); Reginald Raoul Lempriere, M.A., Rozel Manor (Jersey); J. Reid Moir, 12 St. Edmund's Road, Ipswich; Edward Donald Nicholson, Whitehaven, Llynelys, near Oswestry; and John Switzer Owens, Hurst Cottage, Hemingford Road, Worcester Park (Surrey), were elected Fellows of the Society; Prof. Marcellin Boule, Museum of Natural History, Paris, was elected a Foreign Member of the Society; and Dr. Frank Wigglesworth Clarke, United States Geological Survey, Washington (D.C.); Dr. Whitman Cross, F.G.S., United States Geological Survey, Washington (D.C.); and Ferencz Baron Nopcsa, Schloss Ujarad, Temesmegye (Hungary), were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The specimens (boring cores) exhibited included Silurian from Ware and Cliffe; Silurian or older rock from Harwich and Culford; Devonian from Tottenham Court Road, Turnford, and Brabourne; Old Red Sandstone from Willesden, Chiswick, Southall, Richmond, Streatham, Beckton, and Crossness; Coal Measures and Carboniferous Limestone from Ebbsfleet, near Ramsgate.

The President stated that, no papers having been ready for presentation at the meeting, he had obtained the consent of the

Director of the Geological Survey to exhibit the specimens. He drew attention to many points of interest which came up for consideration. The red rocks reached by the Richmond, Streatham, and Crossness boreholes had been originally classed, with some doubt, as Poikilitic or New Red Sandstone. He had himself, however, always held to the opinion that they were of Old Red Sandstone age and had so entered them in the Table of Borings published in the Report of the Royal Commission on Coal-Supplies; the recent borings at Willesden, Chiswick, and Southall confirmed this view.

Another point of interest to which he specially directed attention was the existence of rocks of Old Red Sandstone aspect, in the same region as rocks with Devonian fossils and of Devonian appearance. It would be of the greatest interest to ascertain the relations of the two types one to the other.

The exhibits included three of particular interest: namely, the rock from the Harwich boring showing a structure which was mistaken for a '*Posidonia*,' but which Prof. Watts had shown to be an accidental fracture; the Upper Old Red Sandstone fishes which had been obtained by Mr. Procter from the Southall cores; and the Carboniferous Limestone from Ebbsfleet, the first recorded occurrence of that formation in the South-East of England.

Prof. E. Hull, in opening the discussion, expressed pleasure in having an opportunity of examining the specimens of cores brought up from the borings under and around London. The specimen of reddish grit from Richmond he considered to be of Devonian age; the depth of the boring was 1445 feet—but it was waterless and disappointing. Of similar age was the formation at Meux's brewery, where Upper Devonian red shales and sandstones were passed through at 1144 feet, and contained numerous characteristic fossils such as *Spirifer disjunctus*, etc., described in the Society's Journal by Prestwich (vol. xxxiv, 1878). Similar Devonian rocks were reached under Jurassic beds at Streatham, but the most important were those at Ware in Hertfordshire, where shales at a depth of 800 feet yielded characteristic Wenlock fossils described by Etheridge. This gave a definite starting-point for the series of Palæozoic rocks which form the pre-Triassic ridge, and consist of Silurian, Devonian, and Carboniferous strata in succession from Hertfordshire to Kent.

The speaker wished to call attention to the remarkable fact that in none of the borings in the London area had the Carboniferous Limestone been proved. He believed that this limestone would most probably be found by boring under Croydon, and to form the base of the Carboniferous series of Kent and Surrey; but the borings at Croydon had not gone sufficiently deep to determine the point.

Mr. E. Procter stated that the red rocks exhibited by him came from a borehole at Southall on the Great Western Railway, midway between Paddington and Windsor. They were struck at a depth of 1130 feet, and were still present at 1261 feet, the lowest level yet reached by the borehole. They consist of red and mottled clays and sandstones, with occasional bands of grit; mica is very abundant, and the rocks show false bedding. Microscopic crystals of dolomite, and particles of galena are also present. On close investigation these rocks yielded fish-remains, which Dr. Smith Woodward kindly determined. They consist of scales and teeth of *Holoptychius* and plates of *Bothriolepis*, both characteristic Upper Devonian or Old Red Sandstone fishes. There is close lithological similarity between the red rocks of Southall and Richmond; and he therefore suggested that the Richmond rocks were of the same age. This applies also to the rocks from Kentish Town and Crossness, which in the absence of fossils were attributed by Prof. Judd to the Poikilitic Series, and by Prestwich to the Devonian. It is interesting to note that these Southall rocks bear little resemblance to the undoubted Devonian rocks from Meux's brewery, and from Turnford. They represent a shallower-water facies, and indicate that under the London Basin rocks of Old Red Sandstone type as well as rocks of true Devonian type occur, an association similar to that found in Russia.

Mr. F. W. Harmer hoped that the officers of the Geological Survey would not lose sight of an important boring at some ice-works at Lowestoft, which, after they had been carried on intermittently for some years, were abandoned on account of the unsatisfactory character of the water that was met with. He had just learned that operations had been recommenced. As a depth had already been reached much greater than that of any boring hitherto attempted in the district, it was to be hoped that information of much value and importance might be gained during the further prosecution of the work.

Dr. J. W. Evans regarded the specimens on the table as an excellent illustration of the importance of the proposals put forward by Prof. Watts in his Presidential Address, in favour of the systematic examination by borings of the rocks below the Mesozoic strata of the South-East of England. The speaker regarded the discovery of typical Upper Old Red Sandstone fishes at Southall as an event of the greatest interest and importance. There was nothing surprising in the occurrence of the Upper Old Red and Upper Devonian lithological types in borings in the same area. The latter were shown by the fossils to be of the same littoral character as that with which we are familiar in North Devon in the Baggy and Marwood and Pilton Beds; while the former closely resemble the Pickwell Down Beds which immediately underlie the Baggy and Marwood Group, and are of a pronounced Old Red Sandstone type, with indeterminable plant- and fish-remains.

Mr. W. Whitaker stated that the Lowestoft boring had gone through Tertiary beds, Chalk, and Gault to the Lower Greensand at about 1600 feet from the surface, but the water was salt and useless. He still considered that New Red rocks might exist under the London district, for the Dolomitic Conglomerate had been proved to occur at Brabourne; he also threw out the warning that some of the red rocks might possibly be red-stained Carboniferous. He wished to emphasize the importance of placing the Geological Survey in possession of the details of all deep borings, in order that the facts obtained might be used to the best advantage.

Prof. W. W. Watts, replying to the point raised by the previous speaker, pointed out that it was the resemblance of the rock of the Southall boring to the other 'red rocks' obtained in the London area which made him suggest to Mr. Procter that he should make a thorough search for fossils in as much of the core as he could obtain for breaking up. Whatever difficulties might be raised by the occurrence of marine Devonian rocks (spoken of as 'Eifelian' by Prof. Judd) in some of the borings, the Southall case admitted of no doubt, the fish-remains, on Dr. Smith Woodward's authority, being certainly of Upper Old Red Sandstone age.

He called attention to the remarkable rock which had been found in so many borings in the Eastern Counties, the Midlands, and the South-East of England. This rock, which yielded at Harwich what was erroneously supposed to be *Posidonomya*, had at Stutton proved to contain an *Orthoceras* of indeterminate species. Similar rock at the Spinney Hills, Leicester, underlay fossiliferous Cambrian rocks; and it was strange that such a rock occurred at so many underground localities, but was not anywhere recognizable above ground.

Prof. Sollas remarked that the presence of Silurian rocks in the South-East of England, and their distribution so far as it was known, suggested many interesting problems. The Caledonian chain, so constant to a north-easterly and south-westerly trend for a great part of its course, seemed to curve into conformity with the Armorican chain as it approached those mountains, thus forming an arc convex towards the south, such as would arise under thrusts coming from the north. Observations in North Wales and Scandinavia are in harmony with this view, and the Caledonian chain would thus seem to obey the Asiatic régîme. Sutherland remains as a strange exception. The Caledonian chain is confined to a restricted region in Europe, but movements of corresponding age may be looked for elsewhere. Thus the Charnian axis may represent part of a chain which curved away to the south and east, and found its continuation in the axis of Condroz. If so, we should have a Condrozian chain which would have joined the Caledonian by linking, and, like it, have arisen under thrusts from the north. Evidence of this might easily be obscured by subsequent movements of Hercynian age. This view is suggested by the interesting work of Mr. Mackintosh, of Dover, who has brought together many important facts in its support, and is led by them to believe that the Condrozian chain may play an important part in the tectonics of Southern England.

It is clear, in any case, that speculations based on the views of Godwin-Austen and Marcel Bertrand are not sufficiently trustworthy guides in underground exploration. Nothing less than a systematic survey by boring, such as is now in progress and has long been carried on in Holland, will meet the case. This should be undertaken by the Government, who in return might claim to exercise authority over the coalfields which such a survey could scarcely fail to bring to light.

Dr. A. M. Davies called attention to some further evidence for Prof. Kendall's view, in support of the tectonic importance of the Charnian system in the buried Palæozoic floor north of the London Basin. If the direction of the Lickey anticline be followed to the south-east for 22 miles, Batsford is reached, where a boring has proved Coal Measures resting upon Silurian; 6 miles farther is Daylesford, where, many years ago, Prof. Hull discovered conglomeratic marlstone full of Palæozoic pebbles; while 6 miles farther still is a point 3 miles east of the Burford boring, where the Palæozoic floor proved to be over 800 feet below sea-level. The pre-Cretaceous folding of the Jurassic rocks also follows the Charnian trend, and there are doubtful suggestions of the same trend in the Palæozoic rocks under London, but beyond this it could not be traced.

Mr. G. Barrow remarked that, having examined most of the specimens obtained by boring from the Palæozoic floor under London, he had little doubt that the red rocks were all of Old Red Sandstone age. Where cores were obtained, many of the specimens were quite unlike any known Trias in England; they were far too hard, and often had too high a dip to be of Triassic age. Starting from Cliffe, near Gravesend, and going westwards, the sequence of Palæozoic rocks, on the whole, seemed to be ascending. The speaker was especially interested in the saltness of the water usually met with in the old rocks, where the upper water had been shut out by a tube lining. He inclined to the opinion that, in many cases, this represented part of the original sea-water in which the beds had been deposited. The beds in such cases had never been brought sufficiently near the surface for this water to have been removed.

Dr. A. Vaughan thought that a careful revision of the horizons indicated by the exhibited fossils was needed. For example, the specimens labelled '*Spirifer disjunctus* Sow.' from the Turnford boring might be safely labelled Upper Devonian or basal Carboniferous. Turning to tectonics, he thought that, although no precise information respecting the buried Palæozoic floor could be deduced from a scrutiny of the South-Western Province, yet the broad features were probably similar in the two cases, namely :—

(1) In the south, a folded and overthrust belt; followed on the north by

(2) a wide ripple of east-and-west ridges and troughs, widening out northwards into

(3) the broad coal-basins of South Wales and of Bristol and the Forest of Dean.

Accumulating evidence pointed to the deposition of these two coalfields in distinct basins, separated by contemporaneous ridges, the origin of which might be ascribed to the effect of meridional stress upon deposits filling deep, delta-like indentations in an east-and-west coast. He finally suggested a series of borings, south of the Old Red Sandstone patch round London, to be continued across the Weald along a meridian. This scheme would probably determine the structure of the floor, although coal might not actually be detected.

Mr. G. W. Lamplugh said that Mr. Whitaker's suggestion as to the possibility of subsequent red staining in the Palæozoic rocks was justified, as secondary staining of this kind was found in the dark Palæozoic rocks of the Brabourne boring for 20 feet below the Trias. But other evidence showed it to be improbable that the Trias extended into North Kent, as a progressive cutting out and overlapping of the older Mesozoic formations by the newer in a northerly direction had been proved by all the borings. The Mesozoic structure of the country appeared to bear little or no relation to its Palæozoic structure, and the planing down of the Palæozoic floor had been repeated at several different stages of Mesozoic time. Subangular gravel and sand derived from quartz-veins had been found in several borings at the base of the Wealden Series, and indicated the proximity of quartz-veined rocks as yet unknown.

In addition to the exhibits already mentioned, the following specimens and maps were exhibited :—

A series of cores from a boring at Southall showing fossil fish-scales, exhibited on behalf of Ernest Procter, Assoc.R.C.S., by Prof. W. W. Watts, Sc.D., LL.D., F.R.S., V.P.G.S.

A sheet showing the methods of scaling the Geological Survey colours for the various divisions of Formations for the colour-printing of maps ; also several sheets so printed, exhibited by the Director of H.M. Geological Survey.

Seismograph Records, 1912, from the Guildford Observatory, exhibited by F. E. Norris, B.A., F.G.S., and explained by C. E. N. Bromehead, B.A., F.G.S.

Geological Survey of Scotland, 6-inch Map : Lanarkshire, Sheets VIII N.E. and XI N.W. (Solid and Drift), 1911, presented by the Director of H.M. Geological Survey.

June 7th, 1912.

Prof. W. W. Watts, Sc.D., LL.D., F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Section VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communications were read :—

1. 'The Further Evidence of Borings as to the Range of the South-Eastern Coalfield and of the Palæozoic Floor, and as to the Thickness of the Overlying Strata.'[1] By Hon. Prof. W. Boyd Dawkins, M.A., D.Sc., F.R.S., F.S.A., F.G.S.

2. 'Shelly Clay dredged from the Dogger Bank.' By John Walker Stather, F.G.S.

The following specimens and map were exhibited :—

Specimens from borings in the South-Eastern Coalfield and the Palæozoic floor of Southern England, exhibited by Hon. Prof. W. Boyd Dawkins, M.A., D.Sc., F.R.S., F.S.A., F.G.S., in illustration of his paper.

Specimens of 'moorlog' and shelly clay dredged from the Dogger Bank, exhibited by J. W. Stather, F.G.S., in illustration of his paper.

Union of South Africa, Mines Department, Geological Map of the Transvaal, Sheet 9: Marico, 1 inch = 2·347 miles, 1912—H. Kynaston, Director; presented by the Department.

June 19th, 1912.

Dr. Aubrey Strahan, F.R.S., President, in the Chair.

David Joseph Davies, Birch Rock, Pontardulais (Glamorgan); Frederick Richard Lanfear Miller, 1 Berkeley Gardens, Campden Hill, Kensington, W.; and William Gambell Weeks, Assoc.R.S.M., Inspector of Mines to the Siamese Government, 81 Widmore Road, Bromley (Kent), were elected Fellows of the Society.

The List of Donations to the Library was read.

The names of certain 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 the Arrears of their Contributions.

The following communications were read :—

1. 'On the Geology and Palæontology of the Warwickshire Coalfield.' By Robert Douglass Vernon, B.A., B.Sc., F.G.S.

2. 'On the Discovery of a Fossil-bearing Horizon in the Permian Rocks of Hamstead, near Birmingham.' By Walter Henry Hardaker, M.Sc. (Communicated by Prof. Charles Lapworth, LL.D., F.R.S., F.G.S.)

[1] Withdrawn by permission of the Council.

The following lantern-slides and specimens were exhibited :—

Lantern-slides exhibited by R. D. Vernon, B.A., B.Sc., F.G.S., in illustration of his paper.

Specimens from the fossil-bearing horizon in the Permian of Hamstead, near Birmingham, and lantern-slides, exhibited in illustration of the paper by W. H. Hardaker, M.Sc.

Carboniferous plants from Claverley Boring, exhibited by the Director of H.M. Geological Survey.

On Wednesday, June 26th, 1912, a Conversazione, at which about four hundred ladies and gentlemen were present, was held in the Society's Apartments, from 9 to 11.30 P.M. In the course of the evening, lectures, illustrated by lantern-slides, on 'Tin-Mining in the Federated Malay States' by J. B. Scrivenor, M.A., F.G.S., and on 'Palæolithic Paintings in the Caverns of Northern Spain' by Dr. A. S. Woodward, F.R.S., Sec.G.S. Many interesting exhibits were shown by Mr. G. E. Dibley, Dr. J. W. Evans, Mr. J. Francis, Mr. W. F. Gwinnell, Prof. E. Hull, the Rev. H. N. Hutchinson, Mr. A. E. Kitson, Mr. A. L. Leach, Dr. J. M. Maclaren, Mr. A. T. Metcalfe, Mr. H. S. Poole, Mr. S. Priest, Dr. H. H. Swinnerton, Mr. B. J. Tully, Dr. A. Wade, Mr. W. Whitaker, Mr. T. H. Withers, and the Director of the Geological Survey.

ADMISSION AND PRIVILEGES

OF

FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

Every Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

Fellows on election pay an Admission Fee of Six Guineas. The Annual Contribution paid by Fellows is Two Guineas, due on the 1st of January in every year, and payable in advance; but Fellows elected in November or December pay no Contribution for the current year. The Annual Contribution may, at any time, be compounded for by a payment of Thirty-Five Pounds.

The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

CONTENTS.

PAPERS READ.

[No. 273 of the Quarterly Journal will be published next March.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library at the Apartments of the Society is open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.