THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE PERMANENT 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 SEVENTY-SECOND,

FOR 1916.

LONDON:
LONGMANS, GREEN, AND CO.
PARIS: CHARLES KLINCKSIECK, 11 RUE DE LILLE.
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MCMXVII.

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Elected February 18th, 1916.

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TABLE OF CONTENTS.

PROCEEDINGS.

LIST OF THE FOSSILS FIGURED AND DESCRIBED IN THIS VOLUME.

Name of Species.	Formation.	Locality.	Page
	Madreporaria rugosa.		
Aulina rotiformis, gen. et sp. nov., pl. xxii, figs. 6–11 & text-figs. 3–4	Millstone Grit (Fell Top Limestone & Botany Beds).	Various	290
Lithostrotion basaltiforme, pl. xxiv, fig. 6	Carboniferous Limestone	Clifton, Bristol.	302
—— *martini*, text-fig. 2		Various	283
Orionastræa ensifer, pl. xxiv, figs. 3–5		Various	301
—— (gen. nov.) *phillipsi*, pl. xxiii, figs. 1–5, pl. xxiv, figs. 1–2 & text-fig. 1		Various	298
—— *placenta*, pl. xxiii, figs. 6–8		Various	300
Phillipsastræa hennahi, pl. xxii, figs. 1–4	Upper Devonian.	Barton, St. Marychurch	288
—— sp. pl. xxii, fig. 5		S.W. England	286
	Insecta.		
Ædæophasma anglica, pl. iii, fig. 1 & text-fig. 1	Middle Coal Measures	South Lancashire	43
Dictyoneuron higginsii, pl. iii, fig. 2		Ravenhead, St. Helens	46
Hypermegethes northumbriæ, gen. emend. & sp. nov., pl. iv, figs. 2–3 & text-fig. 5	Shale above Crow Coal	Crawcrook (Durham)	55
Palæomantis macroptera, gen. et sp. nov., pl. iii, figs. 3–4 & text-figs. 2–3	Middle Coal Measures	Ravenhead, St. Helens	48
Pseudofouquea cambrensis, pl. iv, figs. 4–5 & text-fig. 6	Lower Coal Measures	Llanbradach Colliery	59
Spilaptera sutcliffei, sp. nov., pl. iv, fig. 1 & fig. 4	Middle Coal Measures	Sparth Bottoms	53

Name of Species.	Formation.	Locality.	Page
	LAMELLIBRANCHIATA.		
Isocardia humana, pl. ii, fig. 13	North Sea Limestone ...		18
Nucula lævigata, pl. ii, fig. 11.			16
Sinodia tertiaria, sp. nov., pl. ii, figs. 14–16			18
Tellina benedeni, pl. ii, fig. 17.			19
Yoldia oblongoides, pl. ii, fig. 12			16
	GASTROPODA.		
Ficus simplex, pl. ii, figs. 4 & 5.	North Sea Limestone ...		14
Naticina alderi, pl. ii, figs. 7 & 8			15
Ranella gigantea, pl. ii, fig. 1.			11
Ringiculella ventricosa, pl. ii, figs. 9 & 10			15
Streptochetus sexcostatus, pl. ii, figs. 2 & 3			14
Xenophora sp., pl. ii, fig. 6 ...			14
	ELASMOBRANCHII.		
Campodus sp., pl. i, figs. 8–10	Millstone Grit .	Brockholes	3–5
—— *variabilis*, text-fig.	Not stated	Not stated	4
Edestus minor, text-fig.			
—— *newtoni*, sp. nov. pl. i, figs. 1–7 & text-fig.	Millstone Grit .	Brockholes	1–5

EXPLANATION OF THE PLATES.

PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES

BESIDES THOSE IN THE PLATES.

Dates of Issue of the Quarterly Journal for 1916.

No. 285—May 8th, 1917.
No. 286—September 10th, 1917.
No. 287—November 23rd 1917.
No. 288—December 31st, 1917.

Vol. LXXII. **No. 285.**
Part 1.

THE QUARTERLY JOURNAL OF THE GEOLOGICAL SOCIETY.

EDITED BY

THE PERMANENT SECRETARY.

[With Seven Plates, illustrating Papers by Dr. A. Smith Woodward & Mr. J. Pringle, Mr. R. B. Newton, Prof. S. H. Reynolds, Mr. H. Bolton, and Mr. H. Dewey.]

May 8th, 1917.

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ORDINARY MEETINGS OF THE GEOLOGICAL SOCIETY
TO BE HELD AT BURLINGTON HOUSE.
Session 1916–1917.

1917.	
Wednesday, May	16*
„ June	6—20*

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1915–16.

November 3rd, 1915.

Dr. A. Smith Woodward, F.R.S., 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 second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

Dr. C. W. Andrews, F.R.S., gave an account of the discovery and excavation of a very large specimen of *Elephas antiquus* near Chatham. The specimen was originally discovered about three years ago, by a party of sappers who were digging a trench. The attention of the authorities of the British Museum was drawn to this find by Mr. S. Turner, of Luton, Chatham. The extraction of the bones was delayed until the past summer. A great part of the skeleton had now been collected, owing largely to the skill of Mr. L. E. Parsons, Junr. The skull, unfortunately, was in a very bad condition, but two complete upper, and one lower, second molars were obtained. One tusk, about 7 or 8 feet long, was also found. The lower ends of both femora were destroyed in the original trench; but, of the other limb-bones, nearly complete specimens from one or both sides had been obtained, as well as a sufficiently large series of bones of the feet to allow of their reconstruction. Many vertebræ had also been collected.

The animal, which was adult, must have been of very great size, having stood about 15 feet at the highest part of the back, or more than $3\frac{1}{2}$ feet higher than the large African Elephant mounted in the Entrance Hall of the Natural History Museum.

The molar teeth show conclusively that the species represented is *Elephas antiquus*; and, from the thickness of the enamel and some other characters, it may be inferred that the animal was probably of a type as early as, or earlier than, that found at Grays. It is the first British example of this species in which the skeleton has been found directly associated with the teeth.

Lantern-slides and remains of *Elephas* were exhibited.

A short discussion followed, and the cordial thanks of the Fellows present were expressed to Dr. Andrews for his lecture.

Mr. G. C. CRICK exhibited two Nautili from the Upper Cretaceous rocks of Zululand. Each showed approximation of the last three septa, indicative of the comparatively-sudden arrest of growth of the animal and of the accompanying forward movement of the animal in its shell, a character usually attributed to senility. One specimen showed also irregularities of depth in the other chambers of the camerated part of the shell.

November 17th, 1915.

Dr. A. SMITH WOODWARD, F.R.S., President,
in the Chair.

Charles Albert Edward Fenner, B.Sc., Principal of the School of Mines, Ballarat (Victoria); Montagu Austin Phillips, F.L.S., Devonshire House, Reigate Hill, Reigate (Surrey); and John Edward Maddock Pritchard, B.A., 1 Sloane Court, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. JOHN PARKINSON gave an account (illustrated by specimens and lantern-slides) of some observations on the Structure of the Northern Frontier District and Jubaland Provinces of the East African Protectorate, made by him while conducting a water-supply survey for the Government of the Protectorate. A floor of gneisses and schists, among which the Turoka Series of metamorphosed sediments was found at several places, is overlain on the western side by lavas, including those arising from the volcanoes Kulal, Assi ('Esie' of the maps), Hurri, Marsabit, etc., and by probably older lava-fields, which together extend as far as longitude 39° E. On the south, it was found that the lavas north of Kenya reached the Guaso Nyiro, leaving 'inselberge' of the crystalline rocks in their midst, but that a high gneiss country extended north-westwards from latitude 1° N.

and longitude 38° E. to within a short distance of Lake Rudolf. Eastwards the coastal belt of sediments proved to be of Upper Oxfordian age and to extend to longitude $40\frac{1}{2}°$ E. (west of Eil Wak); these were lost southwards under the great alluvial plain of Jubaland.

At intervals throughout the alluvial plain and lying in hollows in the Jurassic rocks, disconnected exposures were found of soft calcareous sandstones or limestones (Wajhir, Eil Wak), the age of which cannot now be definitely fixed.

Evidence of the desiccation of the country was adduced from (1) the Laks or water-channels characteristic of Jubaland, which contained surface-water only during the rainy season and then very rarely, if ever, throughout their length; (2) the presence of freshwater molluscs in the scarcely-consolidated beds of such Laks, and at other places where now no surface-water is present (Buna and near the Abyssinian frontier); and (3) the presence of wells along fault-lines and in other places where, but for the previous presence of springs, it appears improbable that the natives would have begun sinking.

The region between Lake Rudolf and Marsabit was pointed out as one of exceptional interest, which the lecturer had so far not been able to investigate.

The depression between the Mathews and associated ranges and the Abyssinian frontier on which the Marsabit and Hurri volcanoes were situated, and the origin of the Kuroli Desert (Elgess), were the outstanding features of the district that required further elucidation.

Mr. G. C. Crick stated that the cephalopoda submitted to him by Mr. Parkinson consisted chiefly of crushed ammonites from dark-grey shales at Kukatta on the Juba (latitude 2° 8′ N.), there being also a belemnite preserved in a yellowish-brown rock-fragment from Serenli on the same river and somewhat north of Kukatta. He regarded all the ammonites as referable to *Perisphinctes* and its section *Virgatosphinctes*, and to species which had previously been described from the neighbourhood of Mombasa. From this assemblage of forms he concluded that the shales at Kukatta were of Upper Oxfordian (Sequanian) age. He stated that the belemnite from Serenli indicated the presence there of a slender sulcate form, similar to those previously recorded from British Somaliland on the north and from the neighbourhood of Mombasa on the south; but, although of Jurassic age, it was too imperfectly shown in the rock-fragment for accurate determination.

Mr. R. Bullen Newton said that he had examined a small series of non-marine Kainozoic molluscan remains belonging to recent species, and associated with hard and soft limestones, calcareous sandstones, and conglomerates, which had been collected by Mr. Parkinson, and had determined them as follows:—

AMPULLARIA OVATA (?) Olivier. Locality.—Lak Buna.

Distribution.—Recent: Victoria Nyanza, Tanganyika, Nile; post-Pliocene: Egypt; Miocene: Victoria Nyanza.

MELANIA TUBERCULATA (Müller) (=*curvicosta* Deshayes). Localities.—Archer's Post; Lak Buna; Chikali Khofu.

Distribution.—Recent: Nile, Rudolf, Nyasa, Tanganyika, India, etc.; post-Pliocene: Egypt and Sahara; Pliocene: Lake Assal, French Somaliland (formerly regarded as Abyssinia); Miocene: Rudolf (Omo River), Greece, North Italy, etc.

CLEOPATRA BULIMOIDES (Olivier). Localities.—Lak Buna; Chikali Khofu.

Distribution.—Recent: Nile, Rudolf, French Somaliland, Zanzibar; post-Pliocene: Egypt; Pliocene: French Somaliland; Miocene: Victoria Nyanza.

BYTHINIA and PLANORBIS spp. Locality.—Waihir.

LIMICOLARIA RECTISTRIGATA E. A. Smith. Locality.—Archer's Post.

Distribution.—Recent: Rudolf and Tanganyika regions.

RHACHIS RHODOTÆNIA Martens. Locality.—Chikali Khofu.

Distribution.—Recent: Victoria Nyanza and Mount Kenya plateau.

LEPTOSPATHA SPATHULIFORMIS (Bourguignat). Localities.—Turbi and Lak Buna.

Distribution.—Recent: Rudolf and Zanzibar.

CORBICULA FLUMINALIS (Müller) (=*saharica* Fischer). Localities.—Turbi, Lak Buna, Chikali Khofu.

Distribution.—Recent: Nile, Rudolf, Marguerite, and Abyssinia; post-Pliocene: Egypt and Sahara; Pliocene: French Somaliland; Miocene: Rudolf (Omo River).

CORBICULA RADIATA (=*pusilla*?) Philippi. Locality.—Chikali Khofu.

Distribution.—Recent: Nile, Rudolf, Victoria Nyanza, Albert Edward, Nyasa, Tanganyika; post-Pliocene: Egypt; Pliocene: French Somaliland; Miocene: Rudolf (Omo-River beds).

No vertebrates occurred with these shells, hence their age would probably be younger than the Omo-River deposits north of Lake Rudolf, that have yielded a somewhat similar molluscan fauna, but with the addition of *Dinotherium* and other vertebrate remains. The presence of that genus, as pointed out by Dr. Haug,[1] was indicative of the Pontian or Upper Miocene Period. There are, however, some lacustrine beds near Lake Assal, in French Somaliland (formerly regarded as Abyssinia), which contain shells also bearing a resemblance to those collected by Mr. Parkinson in British East Africa, especially *Melania tuberculata*, *Cleopatra bulimoides*, *Corbicula fluminalis*, and *C. radiata*, which are common to both sets of deposits. These Lake-Assal beds, which are also without vertebrate remains, have been identified by Aubry,[2]

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[1] 'Traité de Géologie' vol. ii (1908–11) p. 1727.

[2] Bull. Soc. Géol. France, ser. 3, vol. xiv (1885) pp. 206–209.

and Pantanelli[1] as of Pliocene age. If, from these facts, such widely-distant beds can be recognized as contemporaneous, then the suggestion may be made that the northern half of British East Africa was probably an extensive freshwater region during Pliocene times, limited on the north by Lake Assal, on the east by Suddidima, on the south by Archer's Post and the Mount Kenya plateau, and on the west by Lakes Rudolf, Stefanie, and Marguerite.

Assistance in the determination of these shells had been kindly rendered by Mr. E. A. Smith, I.S.O.

December 1st, 1915.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

Albert Charles Chibnall, B.A., Cedar House, Chiswick Mall, W.; John Henri Davies, Lecturer in Mining, Glamorgan County Council, Gors Street, Cwmgors, Gwauncaegurwen (Glamorgan); Walter Eite, B.Sc., 7 Dora Road, Small Heath, Birmingham; Edward Lloyd Jones, Plasisa, Rhosymedre, Ruabon; George Pickering, Glencoe, Harrogate Hill, Darlington; Frederick George Rappoport, 25 The Vale, Golders Green, N.W.; Percy Lucock Robinson, B.Sc., Demonstrator in Geology in the Armstrong College (Newcastle-on-Tyne), 60 Earl's Dene, Low Fell, Gateshead; William Alfred Richardson, B.Sc., Lecturer in Civil Engineering, University College, Nottingham; and Henry Marshall Taylor, Principal of Fouriesburg School, Fouriesburg (Orange Free State), were elected Fellows of the Society.

The List of Donations to the Library was read.

The President exhibited lantern-slides lent by Prof. Gordon Elliot Smith to illustrate the fossil human skull found at Talgai, Darling Downs (Queensland), in 1914. The specimen was brought to the notice of the British Association in Sydney by Prof. T. W. Edgeworth David, and would shortly be described by him and Prof. Arthur Smith. It was obtained from a river-deposit in which remains of *Diprotodon* and other extinct marsupials had already been discovered, and there could be no doubt that it belonged to the Pleistocene fauna. It therefore explained the occurrence of the Dingo with the extinct marsupials. The skull is typically human and of the primitive Australian type, but differs from all such skulls hitherto found in possessing relatively-large canine teeth, which interlock like those of an ape. The upper canine shows a large facet worn to its base by the lower premolar. The discovery of the Talgai skull was, therefore,

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[1] Atti Soc. Tosc. Sci. Nat. Proc.-verb. vol. v (1887) pp. 204–206, & vol. vi (1888) p. 169.

an interesting sequel to that of Mr. Charles Dawson's Piltdown skull, in which the canine teeth are even more ape-like.

The cordial thanks of the Fellows present were conveyed to Prof. G. Elliot Smith.

Dr. J. W. EVANS discussed the different methods of obtaining the directions-image ('interference-figures') of a small mineral in a rock-slice, unaffected by the light from neighbouring minerals. He preferred the use of a diaphragm in the focus of the eye-piece, in conjunction with a Becke lens.

He also described the inferences that might be drawn from the form, position, and movement on the rotation of the stage of the isogyres (dark bars or bushes) in the directions-images, both of chance sections and of those cut parallel to planes of optical symmetry or at right-angles to optical axes. He showed how the character or sign of the crystal and its approximate optic axial angle might be determined.

Lantern-slides, petrological microscopes, and accessories were exhibited; and the cordial thanks of the Fellows present were expressed to Dr. Evans for his lecture.

December 15th, 1915.

Dr. A. SMITH WOODWARD, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

Dr. AUBREY STRAHAN, F.R.S., gave an account of a deep boring which was made in 1913 in search of coal, in the parish of Little Missenden, at an elevation of 459 feet above sea-level. The collection of specimens and the identification of fossils were carried out by Mr. J. Pringle. For the first 1200 feet the hole was punched, and nothing is known of the strata traversed down to that depth—beyond the fact that the boring started in the top of the Middle Chalk, passed through some Oxford Clay, and, below that, some oolitic limestones which presumably belong to the Great Oolite Series. From 1200 feet the hole was drilled for 64 feet, and cores were preserved. The cores consisted of alternations of limestone and mudstone, with a rich and characteristic Upper Ludlow fauna. Among the fossils was *Orthoceras damesi* Rœmer, [? Krause], which had not previously been obtained in this country.

The boring served to fix part of the northern boundary of the tract of Old Red Sandstones which underlie London. It was intended to publish a full account in the next issue of the Summary of Progress of the Geological Survey.

Fossils of Ludlovian and Oxfordian age, from the boring at Little Missenden, were exhibited by Dr. A. Strahan, F.R.S.

A new geological map of Belgium (scale 1 : 160,000, in five sheets), prepared by the officers of H.M. Geological Survey, was also exhibited by Dr. Strahan.

January 5th, 1916.

Dr. A. Smith Woodward, 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: Henry A. Allen and S. Hazzledine Warren.

The President announced the decease, on December 17th last, of William Rupert Jones, formerly Assistant Librarian, and stated that he had represented the Society at the funeral.

The Secretary read the following communication:—

'The Islay Anticline (Inner Hebrides).' By Edward Battersby Bailey, B.A., F.G.S., 2nd Lieut. R.G.A.

January 19th, 1916.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

Ernest Howard Adye, Director of the Geological Survey of Porbandar State, Porbandar, Kathiawar (India); George James Brooke Le Mesurier, Ballarpur, Chanda District, Central Provinces (India); Sidney Melmore, North How, Maryport (Cumberland); Charles Butterworth Newton, M.Inst.C.E., 204 Park Avenue, Hull; Herbert Pilkington, M.Inst.C.E., Brierly House, Sheepbridge, Chesterfield; and Alfred Norris James Sair, A.M.Inst.C.E., Cottage Homes, Bryncoch, Neath (Glamorgan), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Physical Geography of Bournemouth.' By Henry Bury, M,A., F.L.S., F.G.S.

Lantern-slides and an enlarged sketch-map were exhibited by the Author in illustration of the above paper.

February 2nd, 1916.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

Arthur W. Dean, B.Sc., 114 Winston Road, Stoke Newington, N., was elected a Fellow of the Society.

The List of Donations to the Library was read.

A Lecture was delivered by Richard Dixon Oldham, F.R.S., on the Support of the Himalaya.

He said that it was known that the major prominences of the Earth's surface are in some way compensated by a defect of density underlying them, with the result that they do not exert the attractive force, either in a vertical or in a horizontal direction, which should result from their mass. A study of the distribution of this compensation shows that there is a general balance between it and the topography, such that the weight of any vertical column through the crust of the earth is, on the average, constant, whatever may be the elevation of the surface. To this condition the term isostasy has been applied, which does not merely denote a static condition, but implies a power of adjustment of the compensation to the variation in load produced by surface-denudation and transport.

The explanations that have been proposed of the existence of compensation fall into two classes. One supposes the relief of the surface to be due to an alteration in the volume of the underlying rock, and may be regarded as hypotheses of tumefaction. They involve no addition of matter to the crust under a mountain-range, and do not provide, either for any departure from a balance between topography and compensation, or for a restoration of the balance when disturbed by denudation. The other group of hypotheses attributes the origin of the range to a compression of the crust, the injection of molten matter, or the 'undertow' of the lower part of the crust. To provide for compensation, any hypothesis of this class will require a downward protuberance of the nether surface of the crust, causing a displacement of denser by lighter material, as also an effect of buoyancy owing to this difference of density: this group of hypotheses, therefore, may be regarded as one of support by flotation. They involve a migration of matter from outside to beneath the range, they allow of a considerable local departure from exact balance between load and support (or topography and compensation), so long as the defect in one tract is balanced by an excess in an adjoining one, and they provide for an adjustment of any disturbance of this balance.

The geodetic observations in the Himalayas show that there is a defect of compensation in the outer hills, which increases in amount until, at some 50 miles from the edge of the hills, it reaches an equivalent to an overload of about 2000 feet of rock. In the interior of the Himalayas the only observation yet published shows that, at about 140 miles from the edge of the hills, this overload has disappeared, and compensation is in excess. The variation in the balance between topography and compensation points to one of the second group of hypotheses, to a support of the range by flotation, and to the conclusion that the growth of the support has been more rapid than that of the range. The primary problem then becomes, not as to how the Himalayas are supported at their actual height, but why they are not even loftier: in other words, the problem is carried one stage farther back, from the origin of the range to the origin of its 'root.'

This result of the examination of the geodetic data simplifies the explanation of some difficult geological questions. It affords an easy explanation of the indications which are found in the interior of the Himalayas, and of other similar ranges, of simple vertical uplift without disturbance, and also of the manner in which the contorted and faulted strata, the disturbance of which must have taken place under the pressure of some thousands of feet of rock, have been brought up to a level where they are exposed to denudation and their structure revealed; but it brings us very little nearer to an explanation of the ultimate origin of the range. It is a distinct step forward in illustration of the mechanism of the production of mountain-ranges of the type of the Himalayas and the Alps, but we are as far as ever from an understanding of the power by which this mechanism is driven.

A short discussion took place, and the cordial thanks of the Fellows present were expressed to Mr. Oldham for his lecture.

ANNUAL GENERAL MEETING,

February 18th, 1916.

Dr. Arthur Smith Woodward, F.R.S., President.
in the Chair.

Report of the Council for 1915.

During the year under review, 31 new Fellows were elected into the Society (6 less than in 1914). Of the Fellows elected in 1915, 23 paid their Admission Fees before the end of that year, and of the Fellows who had been elected in the previous year, 8 paid their Admission Fees in 1915, making the total accession of new Fellows during the past year amount to 31 (14 less than in 1914).

Allowing for the loss of 87 Fellows (22 resigned, 42 deceased, and 23 removed from the List, under Bye-Law, Sect. VI, Art. 5), it will be seen that there is a decrease of 56 in the number of Fellows (as compared with a decrease of 11 in 1914, and an increase of 21 in 1913).

The total Number of Fellows is, therefore, at present 1257.

Turning now to the Lists of Foreign Members and Foreign Correspondents, the Council has to regret the loss during the past year of Prof. C. R. Zeiller, and of M. E. Rigaux. It will be remembered that, in the list of Foreign Members at the end of 1914, there was one vacancy, and four in that of Foreign Correspondents; and, as no elections were held to make up the numbers during the past year, there are, at present, two vacancies in the List of Foreign Members and five vacancies in that of Foreign Correspondents.

With regard to the Income and Expenditure of the Society during 1915, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £105 18*s.* 5*d.* brought forward from the previous year) amounted to £2836 2*s.* 10*d.*, being £291 16*s.* 10*d.* more than the estimated Income.

On the other hand, the Expenditure during the same year amounted to £2306 7*s.* 11*d.*, being £237 18*s.* 1*d.* less than the estimated Expenditure, and the year closed with a Balance in hand of £635 13*s.* 4*d.* This money is mainly required for printing the Journal now in progress.

Of the four permanent members of the Society's staff, three are still serving in various capacities under the War Office. Meanwhile, temporary help has been obtained in the shape of the appointment of Mr. Walter Davis as Assistant in the Office, and of Miss M. Seymour (recently on the staff of the Royal Society's Catalogue of Scientific Papers) as Assistant in the Library.

The former Assistant Librarian, Mr. William Rupert Jones, who entered the Society's service as long ago as 1873, and retired on a pension in May 1913, died suddenly on December 17th last from heart-failure.

The fourth part of Vol. LXX of the Quarterly Journal and the first part of Vol. LXXI were issued in 1915. The absence of the Assistant Secretary on War Office work has necessitated considerable delay in passing the Journal through the press. Also, on account of the manifold duties devolving upon the Assistant Librarian, it has not been found possible to make any progress with No. 20 of the Geological Literature (for 1913).

A Special General Meeting of the Society was held on March 10th, 1915, at 7.45 P.M. (before the Ordinary Meeting), when the following Motions were considered:—

> (*a*) That Bye-Law Section VI, Art. 4, shall be modified to the effect that 'The Contributions from any Fellow serving with His Majesty's Forces may, on the motion of the Treasurer, be remitted in whole or in part by the Council.' This modification of the Bye-Law to remain in force during the continuance of the war and no longer.
>
> (*b*) That Bye-Law Section XII, Art. 1, be altered to read 'Afternoons or Evenings' instead of 'Evenings.'
>
> (*c*) That Bye-Law Section XII, Art. 2, be repealed, and the following substituted:—
>
> 'Due notice of the days and hours of meeting shall be given to every Fellow whose address is known.'
>
> Motion (*a*) was carried *nemine contradicente.*
>
> Motion (*b*) was, after discussion, carried by 18 votes to 15.
>
> Motion (*c*) was carried *nemine contradicente.*

Also, at the same Special General Meeting, the Fellows present confirmed the appointment of Mr. Charles Panzetta Chatwin as Assistant Librarian.

In accordance with the provision of (*a*) the Council has, on the motion of the Treasurer, remitted the contributions of 19 Fellows now serving with His Majesty's Forces.

In accordance with the provision of (*b*) the Council decided, on October 22nd, 1915, that, for the present, the Ordinary Meetings be held at 5.30 P.M.

During the past year the Apartments of the Society have been used for General or for Council Meetings by the Mineralogical Society, the Palæontographical Society, the Ray Society, the British Association, the Institution of Mining & Metallurgy, the Institution of Mining Engineers, and the Institution of Water Engineers.

The thirteenth Award from the Daniel-Pidgeon Trust Fund was made on March 24th, 1915, to Edward Talbot Paris, B.Sc., who proposed to continue his researches on the Lamellibranchia of the Rhætic, Lias, and Lower Oolites of England.

The following Awards of Medals and Funds have also been made:—

The Wollaston Medal is awarded to Dr. Alexander Petrovich

Karpinsky, in recognition of his researches concerning the Mineral Structure of the Earth, especially in connexion with the Geology and Palæontology of Russia.

The Murchison Medal, together with a Sum of Ten Guineas from the Murchison Geological Fund, is awarded to Dr. Robert Kidston, in recognition of his valuable contributions to Geological Science, especially in connexion with the Flora and Stratigraphy of the Carboniferous Rocks.

The Lyell Medal, together with a Sum of Twenty-Five Pounds, is awarded to Dr. Charles William Andrews, as an acknowledgment of the value of his researches in Vertebrate Palæontology.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. William Bourke Wright, in recognition of his contributions to Quaternary Geology.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. George Walter Tyrrell, in acknowledgment of his contributions to petrography, especially in connexion with Igneous Rocks in Scotland.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Martin A. C. Hinton, in recognition of his researches on the British Pleistocene Mammalia.

A second moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Alfred Santer Kennard, in recognition of his work on the Pleistocene Deposits of the South of England, and on their Molluscan Fauna.

REPORT OF THE LIBRARY COMMITTEE FOR 1915.

The general state of the Library continues to be satisfactory, and numerous and important additions have been made during the past year. Unfortunately, European Literature is but poorly represented among these additions. The binding of serials has progressed satisfactorily, but no opportunity has been found to make any progress in instituting a systematic arrangement of the books. The demands made upon the Library for reference, research, and the borrowing of books are by no means less than in normal times; and it is satisfactory to note that use has been made of the completeness of the Library by those whose lines of enquiry are connected with some of the special needs of the country at the present juncture.

There were received by Donation 19 Volumes of separately-published Works, 194 Pamphlets, and 9 detached Parts of Works; also 87 Volumes and 334 detached Parts of Serial Publications, 76 Volumes and 280 detached Parts of the publications of Geological Surveys and other public bodies, and 25 Volumes of Weekly Periodicals.

The total number of accessions by Donation amounts, therefore, to 207 Volumes, 194 Pamphlets, and 623 detached Parts.

There has been a notable decrease in the number of new Maps received.

Among the Books and Pamphlets mentioned in the foregoing paragraphs, especial attention may be drawn to the following works:—The Scientific Results of the Norwegian North Polar Expedition, 1893–96, edited by Fridtjof Nansen, vols. i–vi, 1900–05 (presented by Sir Archibald Geikie); Mr. E. Howard Adye's 'Memoir on the Economic Geology of Navanagar State in the Province of Kathiawar, India,' 1914; Dr. A. Wade's 'Report on Petroleum in Papua' (with map), published by the Government of the Commonwealth of Australia, 1914; the 'Handbook of Kaolin, China Clay, & China Stone in the Museum of Practical Geology,' by J. Allen Howe (published by H.M. Geological Survey, 1914); 'Catalogue of the Library of the British Museum (Natural History),' by B. B. Woodward, vol. v, So–Z, 1915; the 'Catalogue of Mesozoic Plants in the Department of Geology, British Museum (Natural History), Part 2—Lower Greensand (Aptian) Plants of Britain,' by M. C. Stopes, 1915; the 'Papers from the Geological Department of Glasgow University,' vol. i, 1915; reprint of several papers on Victorian Palæontology, by F. Chapman; and extensive series of publications from the United States Geological Survey and the Canadian Department of Mines.

The Library has also received, through the kindness of Mr. J. F. N. Green, a most useful addition of numerous Colonial Office Reports, which were hitherto not represented in the Society's collection.

The Donors during the preceding year included 99 Government Departments and other Public Bodies, 103 Societies and Editors of Periodicals, and 108 Personal Donors.

The Purchases included 23 Volumes and 12 detached Parts of separately-published Works, and 17 Volumes and 14 detached Parts of Works published serially.

The Expenditure incurred in connexion with the Library during the year under review was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased	41	1	7
Binding	102	12	7
Total..............	£143	14	2

The Assistant Librarian's time, owing to the absence of other members of the staff on military service and on War Office work, is occupied largely in the performance of general duties connected with the conduct of the Society's business; and, in consequence, no progress has been made with No. 20 of the 'Record of Geological Literature.'

On September 1st, 1915, the Council appointed Miss M. Seymour (recently a member of the staff of the Royal Society's Catalogue of Scientific Papers) as a temporary Assistant in the Library.

Mr. C. Davies Sherborn reports as follows:—

'The Card Catalogue is now edited up to GOT, and completed (from 1800–1912) up to FIT. Since the beginning of the year the whole of the entries (vol. xiv) of the Royal Society's Catalogue of Scientific Papers have been carded, indexed, and incorporated, 20,000 cards being used in the process. The editing of the whole is now proceeding regularly, and much reduction in bulk is thus effected.'

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.

American Museum of Natural History. New York.
Australia (S.), etc. *See* South Australia, *etc.*
Bergens Museum. Bergen.
Birmingham, University of.
British Columbia.—Department of Mines. Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
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.—Department of Mines. Ottawa.
——, High Commissioner for. London.
Cape of Good Hope.—South African Museum. Cape Town.
Chicago.—'Field' Columbian Museum.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Denmark.—Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Great Britain.—British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
Holland.—Rijksopsporing van Delfstoffen. The Hague.
Hull.—Municipal Museum.
Illinois State Geological Survey. Urbana (Ill.).
India.—Geological Survey. 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. Tokyo.
——. Geological Survey. Tokyo.
Kingston (Canada).—Queen's College.
Leeds, University of.
London.—City of London College.
——. Imperial College of Science & Technology.
——. Imperial Institute.
——. Metropolitan Water Board.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academía de Ciencias Exactas, Físicas & Naturales.
Melbourne (Victoria).—National Museum.
Mexico.—Instituto Geológico. Mexico City.
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
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 of.
Paris.—Académie des Sciences.
Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Pisa, Royal University of.
Portugal.—Commissão dos Trabalhos Geologicos. Lisbon.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth.—School of Mines.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Russia.—Comité Géologique. Petrograd.
——. Musée Géologique Pierre le Grand. Petrograd.
——. Section Géologique du Cabinet de S.M. l'Empereur. Petrograd.
São Paulo (Brazil).—Commissão Geographica & Geologica. São Paulo City.
——. Secretaria da Agricultura, Commercio & Obras Publicas. São Paulo City.
Sendai (Japan).—Tohoku Imperial University.
South Africa, Union of.—Department of Mines. Pretoria.
South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tokyo.—College of Science (Imperial University).
Turin.—Reale Accademia delle Scienze.
Union of South Africa. *See* South Africa.
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.
Washington (D.C.).—Smithsonian Institution.
Washington, State of (U.S.A.).—Geological Survey. Olympic (Wash.).
Western Australia, Agent-General for. London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.

II. SOCIETIES AND EDITORS.

Adelaide.—Royal Society of South Australia.
Basel.—Naturforschende Gesellschaft.
Bergen.—'Naturen.'
Berne.—Schweizerische Naturforschende Gesellschaft.
Boston (Mass.).—American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Buenos Aires.—Sociedad Científica Argentina.
Calcutta.—Asiatic Society of Bengal.
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
Cardiff.—South Wales Institute of Engineers.
Chicago.—'Journal of Geology.'

Christiania.—'Nyt Magazin for Naturvidenskaberne.'
Croydon Natural History & Scientific Society.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat (Jurjew).—Naturforschende Gesellschaft.
Edinburgh.—Geological Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles
Falmouth.—Royal Cornwall Polytechnic Society.
Geneva.—Société de Physique & d'Histoire Naturelle.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Hereford.—Woolhope Naturalists' Field-Club.
Hertford.—Hertfordshire Natural History Society.
Hull Geological Society.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lancaster (Pa.).—'Economic Geology.'
Leeds.—Yorkshire Geological Society.
Leicester Literary & Philosophical Society.
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.
——. 'Nature.'
——. Palæontographical Society.
——. Prehistoric Society of East Anglia.
——. 'The Quarry.'
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies).
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological & Mining Society.
——. Literary & Philosophical Society.
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 & Sciences.
——. 'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'

Northampton.—Northamptonshire Natural History Society.
Oporto.—Academia Polytecnica. [Coimbra.]
Ottawa.—Royal Society of Canada.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Plymouth.—Devonshire Association for the Advancement of Science.
Rochester (N.Y.).—Academy of Science.
——. Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Truro.—Royal Institution of Cornwall.
Washington (D.C.).—Academy of Sciences.
——. Philosophical Society.
Wellington (N.Z.).—New Zealand Institute.
Worcester.—Worcestershire Naturalists' Club.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Allen, E. T.
Allen, H. A.
Andersen, O.
Arber, E. A. N.
Arctowski, H.

Beale, Sir William P.
Beljankin, D.
Bell, A.
Bolton, H.
Bonney, T. G.
Boswell, P. G. H.
Bowen, N. L.
Buckman, S. S.

Cantrill, T. C.
Cayeux, L.
Chapman, F.
Choffat, P.
Cole, G. A. J.
Coomaraswamy, A. K.
Cotton, C. A.
Crenshaw, J. L.
Crick, G. C.
Cross, W.

Daly, R. A.
Dawson, C.
Day, A. L.
Dewey, H.

Falconer, J. D.
Fenner, C. N.
Ferguson, J. B.
Fox, C.

Galloway, W.
Garrard, J. J.
Ginsberg, A. S.
Gregory, J. W.

Hall, T. C. F.
Hallissy, T.
Haselhurst, S. R.
Haward, F. N.
Heim, A.
Hill, H.
Hills, R. C.
Holmes, A.
Holst, N. O.

Kato, T.
Kellerman, K. F.
Knight, C. W.

Lawson, R. W.
Lees, P. B.
Lugeon, M.
Lull, R. S.

McLearn, F. H.
McLintock, W. F. P.
Martin, E. A.
Maufe, H. B.
Mellor, E. T.
Merrill, G. P.
Merwin, H. E.
Miller, W. G.
Moberg, J. C.

Nathorst, A. G.
Newton, R. B.

Odling, M.
Oswald, F.

Parry, T. W.
Petrie, F.
Popoff, C.
Preller, C. S. Du Riche.
Pringle, J.

Reade, A. L.

Sacco, F.
Salter, A. E.
Sauvage, H. E.
Schwarz, E. H. L.
Seward, A. C.
Shaw, F. G.
Shepherd, E. S.
Sheppard, T.
Sherlock, R. L.
Smith, B.
Smith, R. N.
Spath, L. F.
Speight, R.
Stevenson, J. J.
Strahan, A.

Thiele, E. O.
Thompson, B.
Troxell, E. L.
Tyrrell, J. B.

Urquhart, J.
Ussher, W. A. E.

Vaughan, T. W.

Wade, A.
Walford, E. A.
Washington, H. S.
Wherry, E. T.
Whitaker, W.
White, W. P.
Wieland, G. R.
Wilson, R. C.
Winwood, H. H.
Withers, T. H.
Wood, H. O.
Woodward, H.
Worth, R. H.
Wray, A.

Zealley, A. E. V.
Zeiller, R.

COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE CLOSE OF THE YEARS 1914 AND 1915.

	Dec. 31st, 1914.	Dec. 31st, 1915.
Compounders	241	233
Contributing Fellows	1056	1009
Non-Contributing Fellows	16	15
	1313	1257
Foreign Members	39	37
Foreign Correspondents	40	39
	1392	1333

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1914 and 1915.

Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1914 ...		1313
Add Fellows elected during the former year and paid in 1915		8
Add Fellows elected and paid in 1915		23
		1344
Deduct Compounders deceased	10	
Non-Contributing Fellow deceased	1	
Contributing Fellows deceased	31	
Contributing Fellows resigned	22	
Contributing Fellows removed	23	
	—	87
		1257
Number of Foreign Members and Foreign Correspondents, December 31st, 1914	79	
Deduct 2 Foreign Members deceased	2	
Deduct Foreign Correspondent deceased	1	
	76	
	—	76
		1333

Deceased Fellows.

Compounders (10).

Adams, W. G.
Cash, W.
Fitch, O.
Gray, M. H.
Hunt, A. R.
Ives, J. T. B.
Marsham-Townshend, Hon. R.
Spicer, H.
Vincent, M. C.
Williams, W. H.

Non-contributing Fellow (1).

Howell, H. H.

Resident and other Contributing Fellows (31).

Anderson, W.
Assheton, R.
Balfour, D.
Barker, R. A.
Bewsher, S.
Bion, H. S.
Brown, N.
Burns, D.
Day, J. T.
Drummond, W.
Eccles, J.
Fleming, Sir Sandford.
Geikie, J.
Green, L. C.
Hamilton, A.
Holgate, B.
Hollingworth, G. H.
Hotblack, J. T.
Hughes, J. S.
Isaacson, E. D. E.
Kerr, R.
Kynaston, H.
Louis, D. A.
Loury-Corry, F. H.
Melvill, E. H. V.
Millett, F. W.
Rands, W. H.
Rofe, H.
Rudler, F. W.
Simpson, H.
Vaughan, A.

Fellows Resigned (22).

Austin, J. E.
Borrer, W.
Bowden-Smith, H. N.
Brierley, B. T.
Brook-Fox, F. G.
Davies, W. T.
Everard, J. B.
Gard, W. G. S.
Gray, C. J.
Hart, T. S.
Hughes, W. G. C.
Hull, E.
Lloyd, E. R.
Mathers, F. P.
Mitchinson, Rt. Rev. John.
Newton, C. E.
Oriel, Rev. B.
Thomas, G. R.
Tweddill, S. M.
Twelvetrees, W. H.
Winstanley, G. H.
Wood, F.

FELLOWS REMOVED (23).

Audas, J. T.
Bose, A.
Burrell, E. J.
Cooke, R. C. H.
Cotsworth, M. B.
Dunstan, B.
Edwards, G. M.
Everitt, C.
Grützmacher, F. L.
Home, H.
Kidd, T.
Kinsey, W. B.
Leighton, H. T.
Macdonald, W.
Marsters, V. F.
Neil, J. S.
Price, S. W.
Rosewarne, D. D.
Saise, A. J.
Smith, R. N.
Sommerfeld, E.
Wolff, M. A.
Wright, G. H. C.

FOREIGN MEMBERS DECEASED (2).

Count Hermann zu Solms-Laubach.
Prof. C. R. Zeiller.

FOREIGN CORRESPONDENT DECEASED.

M. E. Rigaux.

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 Dr. A. Smith Woodward, retiring from the office of President, to Dr. H. H. Bemrose, Mr. Clement Reid, and Dr. Aubrey Strahan, retiring from the office of Vice-President and also from the Council, and to the other retiring members of the Council, Dr. J. W. Evans and Prof. O. T. Jones.

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.—1916.

PRESIDENT.

Alfred Harker, M.A., LL.D., F.R.S.

VICE-PRESIDENTS.

Sir Thomas H. Holland, K.C.I.E., D.Sc., F.R.S.
Edwin Tulley Newton, F.R.S.
The Rev. Henry Hoyte Winwood, M.A.
Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

SECRETARIES.

Herbert Henry Thomas, M.A., Sc.D.
Herbert Lapworth, D.Sc., M.Inst.C.E.

FOREIGN SECRETARY.

Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.

TREASURER.

Bedford McNeill, Assoc.R.S.M.

COUNCIL.

Henry Bury, M.A., F.L.S.
Prof. John Cadman, G.M.G., D.Sc.
Prof. Charles Gilbert Cullis, D.Sc.
R. Mountford Deeley, M.Inst.C.E.
Prof. William George Fearnsides, M.A.
Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
Walcot Gibson, D.Sc.
Alfred Harker, M.A., LL.D., F.R.S.
Sir Thomas Henry Holland, K.C.I.E., D.Sc., F.R.S.
Finlay Lorimer Kitchin, M.A., Ph.D.
Herbert Lapworth, D.Sc., M.Inst. C.E.
Bedford McNeill, Assoc.R.S.M.
John Edward Marr, Sc.D., F.R.S.
Edwin Tulley Newton, F.R.S.
Richard Dixon Oldham, F.R.S.
Robert Heron Rastall, M.A.
Prof. Thomas Franklin Sibly, D.Sc.
Prof. William Johnson Sollas, Sc.D., LL.D., F.R.S.
J. J. Harris Teall, M.A., D.Sc., LL.D., F.R.S.
Herbert Henry Thomas, M.A., Sc.D.
William Whitaker, B.A., F.R.S.
The 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 1915.

Date of Election.	
1884.	Commendatore Prof. Giovanni Capellini, *Bologna.*
1885.	Prof. Jules Gosselet, *Lille.* (*Deceased.*)
1886.	Prof. Gustav Tschermak, *Vienna.*
1891.	Prof. Charles Barrois, *Lille.*
1893.	Prof. Waldemar Christofer Brögger, *Christiania.*
1893.	Prof. Alfred Gabriel Nathorst, *Stockholm.*
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. Hans Reusch, *Christiania.*
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, *Petrograd.*
1901.	Prof. Antoine François 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.* (*Deceased.*)
1907.	Hofrath Dr. Emil Ernst August Tietze, *Vienna.*
1907.	Commendatore Prof. Arturo Issel, *Genoa.*
1908.	Prof. Bundjirô Kôtô, *Tokyo.*
1909.	Prof. Johan H. L. Vogt, *Christiania.*
1909.	Prof. Charles René Zeiller, *Paris.* (*Deceased.*)
1911.	Prof. Baron Gerard Jakob de Geer, *Stockholm.*
1911.	M. Emmanuel de Margerie, *Paris.*
1912.	Prof. Marcellin Boule, *Paris.*
1912.	Prof. Johannes Walther, *Halle an der Saale.*
1914.	Prof. Friedrich Johann Becke, *Vienna.*
1914.	Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1914.	Prof. Franz Julius Lœwinson-Lessing, *Petrograd.*
1914.	Prof. Aléxis Petrovich Pavlow, *Moscow.*
1914.	Prof. William Berryman Scott, *Princeton* (*New Jersey*).

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1915.

Date of Election.	
1879.	Dr. H. Émile Sauvage, *Boulogne-sur-Mer*. (*Deceased.*)
1889.	Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890.	Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892.	Prof. Johann Lehmann, *Weimar.*
1894.	Dr. Francisco P. Moreno, *La Plata.*
1898.	Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899.	Dr. Gerhard Holm, *Stockholm.*
1899.	Prof. Theodor Liebisch, *Berlin.*
1899.	M. Michel Félix Mourlon, *Brussels.* (*Deceased.*)
1900.	Prof. Federico Sacco, *Turin.*
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 Stephens Washington, *Washington, D.C.* (*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, *Zürich.*
1909.	Dr. Daniel de Cortázar, *Madrid.*
1909.	Prof. Maurice Lugeon, *Lausanne.*
1911.	Prof. Arvid Gustaf Högbom, *Upsala.*
1911.	Prof. Charles Depéret, *Lyons.*
1912.	Dr. Frank Wigglesworth Clarke, *Washington, D.C.* (*U.S.A.*).
1912.	Dr. Whitman Cross, *Washington, D.C.* (*U.S.A.*).
1912.	Baron Ferencz Nopcsa, *Temesmegye* (*Hungary*).
1912.	Prof. Karl Diener, *Vienna.*
1912.	Prof. Fusakichi Omori, *Tokyo.*
1912.	Prof. Ernst Weinschenk, *Munich.*
1913.	Dr. Émile Haug, *Paris.*
1913.	Dr. Per Johan Holmquist, *Stockholm.*
1914.	Dr. Paul Choffat, *Lisbon.*
1914.	Dr. Charles Richard Van Hise, *Madison, Wisconsin* (*U.S.A.*).

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 T. 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. Sir Jethro J. H. Teall.
1906. Dr. Henry Woodward.
1907. Prof. William J. Sollas.
1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William B. Scott.
1911. Prof. Waldemar C. Brögger.
1912. Sir Lazarus Fletcher.
1913. The Rev. Osmond Fisher.
1914. Dr. John Edward Marr.
1915. Prof. T. W. Edgeworth David.
1916. Dr. A. P. Karpinsky.

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. Dr. 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. Henry Howe Bemrose.
1906. Dr. Finlay Lorimer Kitchin.
1907. Dr. Arthur Vaughan.
1908. Dr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.
1914. Mr. R. Bullen Newton.
1915. Mr. Charles Bertie Wedd.
1916. Mr. William Bourke Wright.

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. Dr. Charles T. Clough.
1907. Dr. 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.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.
1915. Prof. William Whitehead Watts.
1916. Dr. Robert Kidston.

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.
1913. Mr. Ernest Edward Leslie Dixon.
1914. Mr. Frederick Nairn Haward.
1915. Mr. David Cledlyn Evans.
1916. Mr. George Walter Tyrrell.

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. A. Smith 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.
1913. Mr. Sydney S. Buckman.
1914. Mr. C. S. Middlemiss.
1915. Prof. Edmund J. Garwood.
1916. Dr. Charles W. Andrews.

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. Edmond 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. C. Davies 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. Prof. W. G. Fearnsides.
1906. Mr. Richard H. Solly.
1907. Mr. T. Crosbee Cantrill.
1907. Mr. Thomas Sheppard.
1908. Prof. T. Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Dr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Prof. Charles Gilbert Cullis.
1912. Dr. Arthur R. Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.
1914. The Rev. Walter Howchin.
1914. Mr. John Postlethwaite.
1915. Mr. John Parkinson.
1915. Dr. Lewis Moysey.
1916. Mr. Martin A. C. Hinton.
1916. Mr. Alfred S. Kennard.

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. Sir Jethro J. H. 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.
1913. Sir Thomas H. Holland.
1915. Dr. Henry Hubert Hayden.

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 (John) Evans.
1912. Library extension.
1915. Prof. Émile Cartailhac.

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. H. J. Ll. Beadnell.
1906. Mr. Henry C. Beasley.
1908. Contribution to the Fund for the Preservation of the 'Grey Wether' sarsen-stones on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. {Mr. Bernard Smith.
{Mr. John Brooke Scrivenor.
1915. Mr. Joseph G. Hamling.

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. E. W. Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.
1906. Miss Helen Drew.
1907. Miss Ida L. Slater.
1908. Dr. James A. Douglas.
1909. Dr. Alexander M. Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian C. Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.
1914. Dr. Percy G. H. Boswell.
1915. Mr. E. Talbot Paris.
1916. Dr. John K. Charlesworth.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				35	0	0
Arrears of Admission-Fees	50	8	0			
Admission-Fees, 1916	138	12	0			
				189	0	0
Arrears of Annual Contributions	192	18	0			
Annual Contributions, 1916	1600	0	0			
Annual Contributions in advance	60	0	0			
				1852	18	0
Sale of the Quarterly Journal, including Longmans' Account				100	0	0
Sale of other Publications				5	0	0
Miscellaneous Receipts				10	0	0
Interest on Deposit-Account				15	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 2½ 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
				£2558	14	0

the Year 1916.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House-Expenditure:						
Taxes	0	15	0			
Fire- and other Insurance	31	6	0			
Electric Lighting and Maintenance	40	0	0			
Gas	15	0	0			
Fuel	35	0	0			
Furniture and Repairs	15	0	0			
House-Repairs and Maintenance	15	0	0			
Annual Cleaning	15	0	0			
Washing and Sundry Expenses	35	0	0			
Tea at Meetings	17	0	0			
				219	1	0
Salaries and Wages, etc.:						
Assistant-Secretary	360	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	165	0	0			
Assistant-Clerk	100	0	0			
Deputy Assistant-Clerk	91	0	0			
Junior Assistant	55	12	0			
Library Assistant	72	16	0			
House-Porter and Wife	94	0	0			
Housemaid	50	0	0			
Charwoman and Occasional Assistance	20	0	0			
Accountants' Fee	10	10	0			
				1029	13	0
Office-Expenditure:						
Stationery	15	0	0			
Miscellaneous Printing	50	0	0			
Postages and Sundry Expenses	65	0	0			
				130	0	0
Library (Books and Binding)				120	0	0
Library Catalogue:						
Cards and Cabinets	40	0	0			
Compilation	50	0	0			
				90	0	0
Publications:						
Quarterly Journal, including Commission on Sale	750	0	0			
Postage on Journal, Addressing, etc.	80	0	0			
Abstracts of Proceedings, including Postage	100	0	0			
List of Fellows	40	0	0			
				970	0	0
				£2558	14	0

BEDFORD McNEILL, *Treasurer.*

January 29th, 1916.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1915	98	0	8			
,, Balance in the hands of the Clerk at January 1st, 1915	7	17	9			
				105	18	5
,, Compositions				105	0	0
,, Admission-Fees:						
Arrears	50	8	0			
Current	151	4	0			
				201	12	0
,, Arrears of Annual Contributions	193	1	0			
,, Annual Contributions for 1914:—						
Resident Fellows	1791	2	0			
,, Annual Contributions in advance	65	12	0			
				2049	15	0
,, Publications:						
Sale of Quarterly Journal:*						
,, Vols. i to lxx (less Commission £6 18*s.* 3*d.*)	73	13	6			
,, Vol. lxxi (less Commission £2 10*s.* 10*d.*)	41	15	11			
				115	9	5
,, Other Publications (less Commission)				3	4	1
,, Miscellaneous Receipts				10	5	0
,, Interest on Deposit				14	18	10
,, Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock	66	8	4			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	13	10	4			
£2250 London & North-Western Railway 4 per cent. Preference Stock	81	1	10			
£2800 London & South-Western Railway 4 per cent. Preference Stock	100	18	4			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	46	8	1			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	7	2	0			
				315	8	11
,, Income Tax recovered				20	9	7
				£2942	1	3

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales, etc. ... £36 4 3

Year ended December 31st, 1915.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire- and other Insurance	31	6	10			
Electric Lighting, Installation and Maintenance	43	2	1			
Gas	14	16	2			
Fuel	22	1	5			
Furniture and Repairs	2	14	0			
House-Repairs and Maintenance	69	17	1			
Annual Cleaning	8	8	0			
Washing and Sundry Expenses	44	2	11			
Tea at Meetings	17	17	5			
Redecoration of the Society's Rooms	16	16	0			
				271	16	11
,, Salaries and Wages:						
Assistant-Secretary	363	6	8			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	160	0	0			
do. Honorarium	15	15	0			
Extra Assistance in Library	26	10	8			
W. R. Jones's Pension	100	0	0			
Assistant-Clerk	90	5	0			
Deputy Assistant-Clerk	85	10	0			
Junior Assistant	55	12	0			
House-Porter and Wife	91	14	0			
Housemaid	49	18	0			
Charwoman and Occasional Assistance	17	10	0			
Accountants' Fee	10	10	0			
Extra Assistance during Redecoration	5	11	6			
				1082	17	10
,, Office-Expenditure:						
Stationery	13	16	4			
Miscellaneous Printing	41	17	1			
Postages and Sundry Expenses	62	4	11			
				117	18	4
,, Library (Books and Binding, etc.)				147	5	5
,, Library-Catalogue:						
Cards	7	4	6			
Compilation	50	0	0			
Royal Society Catalogues	13	3	4			
				70	7	10
,, Publications:						
Quarterly Journal, Vol. lxxi, Paper, Printing, and Illustrations	469	14	6			
Postage on Journal, Addressing, etc.	36	15	9			
Abstracts, including Postage	109	11	4			
				616	1	7
,, Balance in the hands of the Bankers at December 31st, 1915:						
Current Account	127	13	7			
Deposit Account	500	0	0			
,, Balance in the hands of the Clerk at December 31st, 1915	7	19	9			
				635	13	4
				£2942	1	3

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

HENRY A. ALLEN,
S. H. WARREN, } *Auditors.*

BEDFORD McNEILL, *Treasurer.*

January 29th, 1916.

Statements of Trust-Funds: December 31st, 1915.

‘WOLLASTON DONATION FUND.’ TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1915	32	2	5	By Cost of Medal	10	10	0
„ Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	28	10	0	„ Award from the Balance of the Fund	21	12	5
„ Income Tax recovered	1	17	7	„ Balance at the Bankers’ at December 31st, 1915	30	7	7
	£62	10	0		£62	10	0

‘MURCHISON GEOLOGICAL FUND.’ TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1915	21	2	8	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	36	1	2	„ Award from the Balance of the Fund	28	15	4
„ Income Tax recovered	2	6	8	„ Balance at the Bankers’ at December 31st, 1915	20	5	2
	£59	10	6		£59	10	6

‘LYELL GEOLOGICAL FUND.’ TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1915	53	11	7	By Award to the Medallist	25	0	0
„ Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan 3½ per cent. Stock	62	6	0	„ Award from the Balance of the Fund	44	6	9
„ Income Tax recovered	4	2	2	„ Balance at the Bankers’ at December 31st, 1915	50	13	0
	£119	19	9		£119	19	9

‘BARLOW-JAMESON FUND.’ TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1915	20	12	9	By Award	27	0	0
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	12	13	1	,, Balance at the Bankers’ at December 31st, 1915	7	2	2
,, Income Tax recovered	0	16	4				
	£34	2	2		£34	2	2

‘BIGSBY FUND.’ TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1915	9	4	10	By Cost of Medal	12	1	6
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	11	9	,, Balance at the Bankers’ at December 31st, 1915	3	2	5
,, Income Tax recovered	0	7	4				
	£15	3	11		£15	3	11

‘GEOLOGICAL RELIEF FUND.’ TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1915	47	12	3	By Grants	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	3	13	7	,, Balance at the Bankers’ at December 31st, 1915	41	0	10
,, Income Tax recovered	0	5	0				
	£51	10	10		£51	10	10

‘PRESTWICH TRUST FUND.’ TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1915	56	15	0	By Cost of Medal	20	0	0
,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock	18	11	11	,, Balance at the Bankers’ at December 31st, 1915	56	11	7
,, Income Tax recovered	1	4	8				
	£76	11	7		£76	11	7

‘Daniel Pidgeon Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1915 ……	16	2	3	By Award ……	29	16	1
,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	27	1	4	,, Balance at the Bankers' at December 31st, 1915 ….	15	3	2
,, Income Tax recovered ……	1	15	8				
	£44	19	3		£44	19	3

SPECIAL FUNDS.

Hudleston Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Dividends (less Income-Tax) on the Fund invested in £1000 Canada 3½ per cent. Stock ……	30	19	10	By Balance at the Bankers' at December 31st, 1915 ….	33	0	8
,, Income Tax recovered ……	2	0	10				
	£33	0	8		£33	0	8

Sorby Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Dividends (less Income-Tax) on the Fund invested in £1000 Canada 3½ per cent. Stock ……	30	19	9	By Balance at the Bankers' at December 31st, 1915 ….	33	0	7
,, Income Tax recovered ……	2	0	10				
	£33	0	7		£33	0	7

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

BEDFORD McNEILL, *Treasurer.*
January 29th, 1916.

HENRY A. ALLEN, } *Auditors.*
S. H. WARREN, }

Statement relating to the Society's Property:
December 31st, 1915.

	£	*s.*	*d.*	£	*s.*	*d.*
Balance in the Bankers' hands, December 31st, 1915:						
On Current Account	127	13	7			
,, Deposit ,,	500	0	0			
Balance in the Clerk's hands, December 31st, 1915	7	19	9			
				635	13	4
Due from Messrs. Longmans & Co., on account of the Quarterly Journal, Vol. LXXI, etc.	36	4	3			
Arrears of Admission-Fees (estimated)	50	8	0			
Arrears of Annual Contributions (Estimated to produce £192 18*s.* 0*d.*)	382	0	6			
				468	12	9
				£1104	6	1
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			
				£13716	2	9

[Note.—*The above amount does not include the value of the 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, 1915, amounted to £*9,837 3*s.* 2*d.*]

BEDFORD McNEILL, *Treasurer.*

January 29th, 1916.

AWARD OF THE WOLLASTON MEDAL.

In handing the Wollaston Medal, awarded to Dr. ALEXANDER PETROVICH KARPINSKY, to M. CONSTANTIN NABOKOFF, Councillor of the Imperial Russian Embassy, the PRESIDENT addressed him as follows:—

Councillor NABOKOFF,—

The Council of the Geological Society has this year awarded the Wollaston Medal, its highest distinction, to Dr. Alexander P. Karpinsky, Honorary Director of the Geological Committee of Petrograd, which is responsible for the geological survey of the Russian Empire. Dr. Karpinsky's activities have extended over a period of more than forty years, and so long ago as 1874 he made one of his most important discoveries, that of a marine formation in the Ural Mountains intermediate between the Carboniferous and the Permian Systems. This Artinskian Stage, as Dr. Karpinsky termed it, has now been traced in Russia almost from the Arctic Ocean to the Caspian Sea, besides being recognized in more remote regions, as in the Salt Range of India. Its interesting fauna has also been the subject of several important monographs, of which one of the most valuable is that on the Ammonoids, contributed by Dr. Karpinsky himself to the Imperial Academy of Sciences of Petrograd in 1889. Dr. Karpinsky has continued to take the deepest interest in the geological problems presented by the Urals, and has treated them with remarkable versatility from every point of view, whether tectonic, petrographical, or palæontological; but as official director of the surveys from 1885 to 1903 he also extended his researches to many other districts, and took a prominent part in the preparation of the beautiful geological maps which were issued during his period of active service. The useful Geological Map of Russia in Europe, which he edited in 1893, is especially well known. All Dr. Karpinsky's work is characterized by the most painstaking thoroughness, of which I need only cite his two exhaustive memoirs on the Carboniferous ichthyolite, *Helicoprion*, as conspicuous examples. Those who have the privilege of his personal acquaintance recognize in him an unassuming and enthusiastic student, still absorbed in following and aiding the progress of our science, and pre-eminently one whom the Geological Society delights to honour.

The Council will be glad if you will convey this medal to Dr. Karpinsky as a token of its esteem and admiration, with an expression of its best wishes.

Councillor NABOKOFF replied in the following words :—

Mr. PRESIDENT,—

Please accept my sincere thanks for the honour that you have done me in asking me to come here to-day and to convey to Dr. Karpinsky, with the expression of your good wishes, the Wollaston Medal which the Council of the Geological Society has awarded to him. I feel certain that this great distinction will be deeply appreciated by the recipient of the medal, as well as by the Russian Geological Committee as a high tribute to their Director. My distinguished friend, Dr. H. H. Hayden, Director of the Geological Survey of India, who crossed the Pamirs from India into Russian Turkestan a few months before the war, has often expressed to me the wish and hope that the highly interesting and valuable scientific researches, which have been carried out on both sides of the Pamirs by the British and Russian geologists, may be linked up and conducted on a basis of firmer and more complete unity and coordination. I venture to avail myself of this opportunity of expressing, on behalf of my countrymen, the same wish, and the confident hope that the ties of friendship which now unite Britain and Russia may extend from the fields of battle to the lofty peaks of science and enlightenment.

AWARD OF THE MURCHISON MEDAL.

The PRESIDENT then handed the Murchison Medal, awarded to Dr. ROBERT KIDSTON, F.R.S., to Dr. F. L. KITCHIN, for transmission to the recipient, and addressed him as follows :—

Dr. KITCHIN,—

The Council has awarded to Dr. Robert Kidston the Murchison Medal as a mark of its appreciation of his numerous and valuable contributions to our knowledge of fossil plants, especially those of the Carboniferous Period. For nearly forty years he has devoted himself to an exhaustive and successful study of the external characters of the plant-remains associated with the various coal-seams; and in this manner he has acquired an unrivalled knowledge of the distribution of the Carboniferous flora, which has proved of fundamental importance both to the geologist and to the practical miner. I may mention, as examples of this work, his classic memoirs on the fossil plants of the Yorkshire and Staffordshire Coalfields and of Belgian Hainaut. During more recent years he has also extended his researches to various facts of structure and morphology which have a direct bearing on evolutionary problems. His memoir on the fructification of *Neuropteris heterophylla* was the first description of the seed of a Pteridosperm in direct continuity with the frond; while his account of the microsporangia of the Pteridosperms first demonstrated the nature of the male organs in plants of this transitional group. His description of the internal structure of *Sigillaria*, and his remarkable series of memoirs, with the late Prof. Gwynne-Vaughan, on the evolution of the Osmundaceæ, must also be specially mentioned.

While pursuing his researches he has continually recognized the importance of careful field-work, and has thus made a large and valuable collection of specimens, which has always been placed freely at the disposal of his fellow-palæobotanists. In transmitting this medal, please express our hope that he will treasure it not only as a token of our admiration, but also of our gratitude.

Dr. KITCHIN replied in the following words:—

MR. PRESIDENT,—

It gives me great pleasure and satisfaction to be here to-day as Dr. Kidston's representative, to accept on his behalf this valued award and to convey to you his thanks for the honour conferred on him by the Council of this Society. And I desire to thank you, Sir, in his name, for the kind words with which you have accompanied this presentation.

It is gratifying to be the transmitter of the Murchison Medal to one who, a Scotsman himself, has laboured so long and so assiduously in elucidating the stratigraphical bearings of the Carboniferous Flora. Dr. Kidston, I feel sure, would have received this medal with enhanced pleasure, could he have listened to your graceful and appreciative references to his work. He asks me to express to you his great regret that he is unable to be here in person; and

I may add that he is detained by responsible public duties, which have the first claim upon his time.

I have received a letter from Dr. Kidston which, with your permission, I will read:—

> 'Will you please express to the President my sorrow at not being able to be present to thank the Society personally for the honour that they have done me in presenting me with the Murchison Medal, an honour which, it is needless for me to say, I very much value and appreciate.
>
> 'The award of this Medal brings vividly to my memory that a number of years ago the Society awarded to me the Balance of the Proceeds of the Murchison Geological Fund, and I would like them to know that these proceeds were spent in the purchase of books dealing with Palæozoic Botany. It is only workers situated where not a single book on their special subject of study is obtainable for reference, who can fully appreciate the value of the help that I received from that award, and I hope that the books will eventually be placed where they will be of help to others.
>
> 'I have now only to thank the Council of the Geological Society once more for its kind and encouraging recognition of my work.'

Award of the Lyell Medal.

In presenting the Lyell Medal to Dr. Charles William Andrews, F.R.S., the President addressed him as follows:—

Dr. Andrews,—

The Council has awarded to you the Lyell Medal as an acknowledgment of the value of your numerous researches in Vertebrate Palæontology. Since your appointment to the Geological Department of the British Museum in 1892, you have made excellent use of the opportunities for research afforded by your official duties, and have made important contributions to our knowledge of fossil reptiles, birds, and mammals. You were soon attracted by the unique Leeds Collection of Oxfordian marine reptiles, and your studies of this collection eventually culminated in the two handsome volumes of the Descriptive Catalogue, published by the Trustees of the British Museum (1910–13), which must always remain a standard work of reference on Ichthyopterygia, Sauropterygia, and Crocodilia. Your papers on the South American Stereornithes, on Rails from islands in the Southern Seas, and on *Prophaëthon* from the London Clay, are equally valuable contributions to our knowledge of extinct birds. Your researches on the fossil mammals of Egypt, many of them discovered by yourself, are still more noteworthy; and your Descriptive Catalogue of the Tertiary

Vertebrata of the Fayûm (Egypt), published by the Trustees of the British Museum in 1906, began a new era in the history of mammalian life. Your demonstration of the stages in the evolution of the Proboscidea, and of the relationship between the Proboscidea and the Sirenia; your description and interpretation of the strange Eocene genus *Arsinoitherium*; and your recognition of the early differentiation of the Hyracoids in Africa are especially fundamental contributions to biological and geological science. I would further add that all your writings are characterized by remarkable thoroughness and insight into the meaning of the facts described.

As your colleague in the British Museum during the whole period of your service, it gives me great pleasure to hand to you this medal, which the Council of the Geological Society could not have more worthily bestowed.

Dr. ANDREWS replied in the following words:—

Mr. PRESIDENT,—

I wish to express my most sincere thanks to the Council of the Geological Society for the honour that it has done me in awarding to me the Lyell Medal, and to you, Sir, for the too flattering terms in which you have made the presentation. I am particularly pleased to have received this medal from the hands of one with whom I have been associated for so many years. You will remember that, exactly twenty years ago, you yourself received this award from Dr. Henry Woodward, and that at the same time I received a moiety of the Balance of the Proceeds of the Lyell Geological Fund.

If I have been able to accomplish something in Vertebrate Palæontology, it is mainly due to the fortunate environment in which I have found myself. An assistant in the British Museum possesses quite exceptional advantages, having free access to the great libraries and to the ever-increasing collections, and lastly, but by no means least, having many opportunities of making the personal acquaintance of workers interested in his subject. Having enjoyed these privileges, I feel that I have somewhat fallen short of what I ought to have accomplished; but, although it is just now uncertain what the future may have in store for us, I hope that I may still have opportunities of doing further work such as will justify this award.

AWARD FROM THE WOLLASTON DONATION FUND.

The PRESIDENT then handed the Balance of the Proceeds of the Wollaston Donation Fund, awarded to WILLIAM BOURKE WRIGHT, B.A., to Mr. G. W. LAMPLUGH, F.R.S., for transmission to the recipient, addressing him as follows:—

Mr. LAMPLUGH,—

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. William Bourke Wright, in recognition of his contributions to Quaternary Geology. After completing his geological studies under Prof. J. Joly at Dublin University, Mr. Wright joined the Irish branch of the Geological Survey, and came under the influence of yourself when you were engaged in working out the glacial problems of the Dublin district. He took part in the revision of the memoirs and drift-maps of the Dublin, Belfast, and Cork districts, and shared with Mr. H. B. Maufe the discovery of a continuous raised-beach feature older than the Glacial Period. He also observed this pre-Glacial rock-shelf or beach in the West of Scotland, showing that a general subsidence allowed the sea to enter the valleys along the coasts of the British Isles, almost at the present sea-level, before they were occupied by the ice. After some experience both in Scotland and in England, Mr. Wright returned to Ireland, where, as Senior Geologist of the Irish Survey, he has since been successfully engaged on the glacial geology of the Kenmare and Killarney district. Much of his leisure has been devoted to the preparation of an important work on 'The Quaternary Ice Age,' in which he has made good use of his observations not only in the British Isles, but also in Scandinavia. Impressed by the value of Mr. Wright's researches, the Council will be glad if you will transmit this award to him, with its best wishes for the progress of the work which he has so well begun.

AWARD FROM THE MURCHISON GEOLOGICAL FUND.

In handing the Balance of the Proceeds of the Murchison Geological Fund, awarded to Mr. GEORGE WALTER TYRRELL, F.G.S., to Dr. H. LAPWORTH, Sec.G.S., for transmission to the recipient, the PRESIDENT addressed him in the following words:—

Dr. Lapworth,—

The Balance of the Proceeds of the Murchison Fund has been awarded to Mr. G. W. Tyrrell in recognition of his contributions to the petrology of South-Western Scotland. His keen petrographic insight was first shown in his description of the quartz-dolerite sills of Kilsyth. His results of most general interest to geologists are those connected with the Palæozoic alkaline rocks; for his investigation of lugarite has added to petrology a peculiar rock-species and important evidence in favour of the differentiation of igneous rocks by the sinking of their heavier constituents. In several papers on the Auchineden Hills he has described their igneous rocks and their glacial and physical features; and, in his recent account of the ravine known as the Whangie, he has advanced conclusive evidence of its formation by earth-movements. As the Senior Assistant in the Geological Department of Glasgow University, and later also as Lecturer on Petrology there, he has done much towards the development of that school of geology.

The Council hopes that this award may encourage and assist him in further research.

Awards from the Lyell Geological Fund.

The President then presented a moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Martin A. C. Hinton, addressing him as follows:—

Mr. Hinton,—

The Council has awarded to you a moiety of the Proceeds of the Lyell Fund in recognition of your researches on the British Pleistocene Mammalia, and as an incentive to further work of the same kind. Under circumstances frequently discouraging, you have for many years devoted yourself especially to the study of the Rodentia and the Insectivora, and have obtained a remarkable knowledge of the skeleton and teeth of certain groups which are most commonly met with among fossils. In this manner you have made discoveries with an important bearing on many problems of Pleistocene geology, which you have never failed to recognize. As one who has followed your work with great interest for several years, I have much pleasure in handing to you this award.

The President presented the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Alfred Santer Kennard, F.G.S., addressing him in the following words:—

Mr. Kennard,—

It is particularly appropriate that the second moiety of the Proceeds of the Lyell Fund should be awarded to you, who have worked so long and so successfully with Mr. Hinton at problems of Pleistocene geology in the South of England. In the leisure of a busy life, you also have made yourself thoroughly acquainted with a group of fossils, the non-Marine Mollusca, which are of fundamental importance in classifying and interpreting the various deposits in which they occur. Both alone, and with Mr. B. B. Woodward, you have published many interesting notes and lists of such mollusca from Pleistocene and Holocene deposits in different parts of Britain. The Council desires to acknowledge the value of this work, and I have much pleasure in handing to you a tangible expression of its good wishes.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

ARTHUR SMITH WOODWARD, LL.D., F.R.S.

AMONG those whom we have lost by death during the past year are two distinguished Foreign Members, Count Solms-Laubach and Dr. C. R. Zeiller, who devoted themselves to Palæobotany. For obituary notices of them I am indebted to Prof. A. C. Seward. There are also two Foreign Correspondents, and several Fellows who have done great service to Geology.

HERMANN Graf zu SOLMS-LAUBACH died on November 24th, 1915, in his seventy-third year. He was elected a Foreign Member of the Linnean Society in 1887, of the Royal Society in 1902, and of the Geological Society in 1906; in 1911 the Gold Medal of the Linnean Society was awarded to him, and with other foreign visitors he received an Honorary Degree at Cambridge on the occasion of the Darwin Celebration in 1909. Solms-Laubach belonged to 'one of the most ancient German families, who were sovereigns in their own right down to the year 1806' ('Nature,' January 13th, 1916). He occupied the Chair of Botany at Göttingen, and succeeded the eminent botanist de Bary as Professor in the University of Strassburg. Though well known as the author of many important papers on recent plants, it is the distinguished part that he took in the reformation and revival of palæobotanical research which more particularly appeals to geologists. When he began to write his 'Einleitung in die Paläontologie,' he found it necessary to study the unrivalled collection of sections in the possession of Prof. W. Crawford Williamson, and for this purpose paid several visits to Manchester, which, as he says in a sympathetic biographical sketch of his friend published in 'Nature,' September 5th, 1895, knitted closer the bonds of reverence and friendship between himself and his English colleague. The publication of Solms-Laubach's book in 1887 led to a greater appreciation of the value of Williamson's work, and his critical treatment of the widely-scattered literature enabled botanists to obtain a general view in truer perspective than had previously been possible of the significance of palæobotanical records. In the preface he wrote:—'Botany, which in former times generally treated Palæophytology in a very stepmotherly manner, now finds it to be a subject of the highest interest to herself on account of the prominence at present assumed by the point of view of the theory of descent.' The publication of an English translation in 1891 by the Clarendon Press conferred a boon upon many students to whom Count Solms's involved and difficult style was a serious obstacle. The book contains a mass of valuable information, based in great measure on an actual examination of the specimens described; it is characterized by vigorous and discriminating criticism of the conclusions of previous writers, and the whole bears striking testimony to the author's grasp of his subject, his exceptional power of handling details without losing sight of guiding principles, and his wonderful energy. For many years Solms-Laubach contributed to the 'Botanische Zeitung,' and later to the 'Zeitschrift für Botanik,' critical summaries of recent work, which have played a conspicuous part in keeping botanical readers informed of the more important results of palæobotanical enquiry. The great majority of Solms-Laubach's published papers deal with petrified plants, and it was but rarely that he concerned himself with impressions. He made notable additions to our knowledge of the Palæozoic genera *Medullosa*, *Protopitys*, *Sphenophyllum*, and other types, and supplied fresh data of special interest from an evolutionary point of view. His researches into the structure of Lower Carboniferous and Upper Devonian plants yielded results of the greatest interest; he not only corrected the mistakes of earlier investigators, but presented for the first time an accurate picture, so far as the fragmentary nature of the material permitted, of the morphological characters of some of the oldest known plants. The discovery of several new generalized types gave emphasis to the view that the extinct Devonian genera represent highly-complex terms in a series extending back into ages far beyond those that have left any decipherable records. The account of his investigations on *Stigmariopsis* and other plants in the quarries of St. Étienne threw new light on a subject that is still far from exhausted, and in a more recent paper he cleared up certain difficulties connected with the method of growth of the root-encircled stems of *Psaronius*. In collaboration with Capellini, Solms gave a systematic account of the splendid Cycadean stems from Northern Italy in the Bologna Museum, and, by his discovery of pollen-grains associated with a female flower, foreshadowed the later discoveries of Wieland, who had at his disposal the much more complete

American material. His work on the reproductive shoots of the English Cycadean stem *Bennettites gibsonianus*, originally described by Carruthers, is especially noteworthy as an example of intensive study combined with rare morphological insight. Papers on the structure of some Conifers from the copper-bearing Permian beds of Ilmenau and Frankenberg, and on Jurassic Gymnosperms collected in Franz-Josef Land by members of the Jackson-Harmsworth Expedition in 1894–96, are of special value as elucidating the structural features of genera previously known only as casts or impressions. Count Solms added greatly to our knowledge of recent and fossil calcareous Algæ, not only in his text-book, but also in his monograph of the Acetabularieæ published by the Linnean Society in 1895, and in other papers.

His name will long be remembered with gratitude and respect by students of ancient plants; he raised the subject of Palæobotany to a higher plane, and by his writings, as also in no small degree by his enthusiasm and infectious energy, he was the means of attracting many botanists to a branch of the science which had suffered neglect and had been discredited through its treatment at the hands of authors insufficiently equipped with a knowledge of recent plants. Solms-Laubach paid several visits to this country, where he was always a welcome guest. He was a man of considerable force of character, cultivated, and endowed with a sense of humour; a warm-hearted friend; and an investigator of marked originality, whose work, more especially in the domain of Palæobotany, has had a wider influence than that of many men whose output was larger. [A. C. S.]

Charles René Zeiller died in Paris on November 27th, 1915, after a long and painful illness, at the age of 68. He was born at Nancy, his father being Ingénieur-en-Chef des Ponts et Chaussées, and his mother a great-granddaughter of the Lorraine artist Guibel, sculptor to King Stanislaus of Poland, Duke of Lorraine. He married in 1877 the sister of Léon Ollé-Laprune, the Catholic philosopher and a Member of the Institute, whose religious and philosophical views he shared.

Prof. Zeiller was a Member of the Institute, Commander of the Legion of Honour, Inspector-General of Mines, and Professor at the École Nationale Supérieure des Mines; in 1905 he was elected a Foreign Member of the Linnean Society, and of the Geological Society in 1909. Zeiller rarely travelled in other countries than his own: he paid his first visit to England in 1909, when he attended the Darwin Celebration at Cambridge; and it is a satisfaction to learn from his daughter that, during his illness, he derived no little pleasure from the recollection of the days spent in this country. His dignified bearing and handsome face made him conspicuous among the distinguished foreigners upon whom the Chancellor conferred Honorary Degrees. Despite exacting official duties, Prof. Zeiller found time to make numerous substantial contributions to Palæobotany and, incidentally, to Geology. One of his earliest works, published in 1878 (the year in which he instituted the course of lectures on Palæobotany at the School of Mines), is an account of the plants of the French Coal Measures, the first of a series of admirable volumes on Upper Carboniferous and Permian floras. The two volumes on the botany of the Valenciennes Coalfield which appeared in 1888 afford a good example of the author's thoroughness of treatment and lucidity of style; they are not merely important from the point of view of the systematist and stratigraphical geologist, but the enlightened and philosophical treatment of the extinct types in their relation to recent plants gives them a high botanical value. Zeiller's attitude was thoroughly scientific; he was always ready to consider criticisms and suggestions, and punctilious in his reference to the labours of colleagues: in him Solm-Laubach's aphorism, 'Bescheidenheit ist eine Zier,' was conspicuously demonstrated. The description of the flora of Commentry and of the plants of Autun was shared with Renault. In the volumes on the Brive, Creusot, and Blanzy fossils, Zeiller made many additions of the first importance to our knowledge of several Palæozoic types, notably, in the Brive flora, as regards the main anatomical features of *Psaronius*. His work on the Coal Measures of Heraklia, in Asia Minor, and his description of Permian plants from Lodève, contain much of great botanical interest. Without attempting to give a list of the types which he was the first to describe, or to enumerate the genera on which his investigations threw new light, one may refer to his memoir on the fructification of *Sphenophyllum*, published in 1893, as a remarkable example of the valuable results that can be obtained by a patient and skilful examination of unpromising material. Reference must also be made to the discovery of Palæozoic species closely allied to *Selaginella*, to his more recent researches into the anatomical characters of *Lepidostrobus*, and to his discovery of new forms of Fern-like fructifications. Zeiller was the first to recognize the generic identity of the Indian genus *Trizygia* and the European *Sphenophyllum*; and his ingenious explanation of the peculiar features of the widespread Indian and Southern-Hemisphere genus *Vertebraria* is the best that has so far been suggested. One of the outstanding features of Zeiller's work is the high standard of excellence of his descriptions of plants preserved as impressions: the comparatively few papers on petrified plants show that he was also thoroughly competent as an anatomist, but it is the high standard of his descriptive work, the determination to exhaust every method of attack, and his sanity of judgment and breadth of view that give a permanent value to his achievements. Zeiller's accurate stratigraphical knowledge of the French coalfields enabled him to contribute in no small degree to the better appreciation of the value of plants as indices of geological age. He considerably extended our knowledge of the *Glossopteris* flora in Brazil and South Africa, and described some new forms from the Lower Gondwana rocks of India; his paper on 'Les Provinces Botaniques à la Fin des Temps Primaires,' in the 'Revue Générale des Sciences' (1897), is a model of clear exposition and a highly-suggestive presentation of one of the most fascinating problems of geographical distribution and plant-migration. Another contribution of especial interest from the same point of view is his critical examination of the Siberian plants referred by Schmalhausen to a Jurassic age, which led to their recognition as members of a Permian flora closely allied to those of Gondwanaland. Among many publications dealing with Mesozoic floras, the monograph of the Tongking Rhætic plants deserves special mention; it is one of the best works of the kind that we possess, not merely because of its excellent illustrations, but for the wealth of information which it contains and the masterly treatment of the rich material. Zeiller described collections of fossil plants from many parts of the world, from New Caledonia, Madagascar, China, Peru, North Africa, the Balkans, and elsewhere; his 'Éléments de Paléobotanique,' published in 1900, though of necessity greatly condensed, is a useful book for beginners as well as for experienced students. For several years Zeiller supplied comprehensive and critical summaries of recent palæobotanical literature to the 'Revue Générale de Botanique,' and the thoroughness with which the laborious task was performed is characteristic of the man; he was ever ready to help others, and unsparing of himself in the interests of the subject which he loved. It was a privilege to count Zeiller a friend; he was a man of strong affections, and deeply religious. While we admire his intellectual power and his whole-hearted devotion to the advancement of knowledge, it is his singularly-attractive personality and his lovable character that bulk largest in our recollection of the colleague whom we have lost. To quote the words used by Zeiller in a biographical sketch of the Marquis of Saporta: he has left for all 'le souvenir d'un maître aussi aimé que respecté, en même temps que d'un des esprits les plus éminents dont ait à s'enorgueillir la paléontologie.'

[A. C. S.]

Michel Félix Mourlon, who was elected a Foreign Correspondent in 1899, was born on May 11th, 1845, and graduated at Brussels in 1867. He was appointed Conservator of the Royal Museum of Natural History at Brussels in 1872, and became Director of the Geological Survey of Belgium in 1897. Between 1875 and 1883 he contributed important papers on the Devonian formations of Belgium to the 'Bulletin' of the Royal Academy of Brussels. He also edited the Memoirs on the Cretaceous and Tertiary formations of Belgium prepared for the Survey by A. Dumont. In 1880–81 he published his useful 'Géologie de la Belgique' in two volumes, and during more recent years he wrote several papers on the Tertiary and Quaternary geology of that country.

Edmond Rigaux, who received an award from the Lyell Fund in 1883, and became a Foreign Correspondent in 1893, was an able amateur geologist residing at Boulogne. He made many important contributions to our knowledge of the geology of the Lower Boulonnais, which were eventually summarized in a memoir published by the Société Académique de Boulogne-sur-Mer in 1892. His acquaintance with the Jurassic rocks and fossils was especially profound, and his amiable services were always at the disposal of those who visited the district for geological work. He died in April 1915.

Glacial Geology has lost a pioneer by the death of Prof. James Geikie, which occurred at Edinburgh on March 1st, 1915. The younger brother of Sir Archibald Geikie, he was born in

Edinburgh on August 23rd, 1839, and was educated at the High School and University of that city. Having been naturally inclined to geological studies from early youth, he joined the Geological Survey of Scotland in 1861, and became a District Surveyor in 1869. He was employed chiefly in the Lowlands and Southern Uplands of Scotland, often in districts of which the solid geology had already been examined, and his most important duty was to study, map, and describe the superficial deposits or 'drift.' Such formations proved to have a special fascination for him, and he spent several vacations in investigating them in the Highlands, Outer Hebrides, and other areas which were beyond his official sphere. The peat-bogs especially soon attracted his notice, and seemed to him to indicate a succession of climatic changes during the period of their formation, which he described in his first important contribution to Pleistocene geology, 'On the Buried Forests & Peat-mosses of Scotland, & the Changes of Climate which they indicate' Trans. Roy. Soc. Edinb. vol. xxiv, 1867. He thus gradually arrived at the conclusion that the Pleistocene glacial period had not been continuous, but had been interrupted by several mild episodes or interglacial periods, and his results were eventually summarized in 1874 in his well-known volume on 'The Great Ice Age & its Relation to the Antiquity of Man,' of which new editions appeared in 1877 and 1894. This work was supplemented by another on 'Prehistoric Europe' in 1881.

In 1882 Dr. Geikie succeeded his brother as Murchison Professor of Geology in the University of Edinburgh. In that year he contributed an important memoir on the geology of the Færöe Islands to the Transactions of the Royal Society of Edinburgh, and expressed his views on 'The Aims & Method of Geological Inquiry' in his inaugural lecture at the University. He began educational work in earnest, devoting especial attention to the improvement of geographical teaching; and in 1884 he became one of the founders of the Royal Scottish Geographical Society, which fostered this work. From 1904 until 1910 he was President of that Society, and for many years he was honorary editor of its Magazine. His University students were provided for by his 'Outlines of Geology,' which passed through four editions (1886–1903), and his 'Structural & Field Geology for Students' (three editions, 1905–12); while the relations of geology and geography were treated in a more general way in 'Fragments of Earth-Lore' (1893), 'Earth Sculpture, or the Origin of Land-forms'

(1898), and 'Mountains, their Origin, Growth, & Decay' (1913). In the midst of all these new interests he continued to the end to pursue his enquiries into glacial geology, and an admirable brief summary of his latest conclusions was given in his Munro Lectures in 1913, published in book-form as 'The Antiquity of Man in Europe' in the following year. He retired from his Professorship in June, 1914.

Prof. Geikie was an ideal teacher, both in the class-room and in the field, and gained from his numerous students the same deep esteem as that in which he was held by all who had the privilege of his friendship. He was elected a Fellow of the Geological Society in 1873, but had already contributed his first geological paper on the metamorphic Lower Silurian rocks of Carrick (Ayrshire) to the Quarterly Journal in 1866. Our Murchison Medal was awarded to him in 1889, and he received the Brisbane Medal of the Royal Society of Edinburgh in the same year. He was elected a Fellow of the Royal Society of London in 1875, and was President of the Royal Society of Edinburgh at the time of his death. A list of his writings and a portrait appear in the 'Geological Magazine,' dec. 5, vol. x (1913) pp. 241–48 & pl. ix.

Richard Lydekker, who was born in 1849 and died on April 16th, 1915, was a Fellow of the Geological Society from 1883 to 1914, served on the Council, and became a Vice-President in 1894–97. Educated at Trinity College, Cambridge, he graduated in 1871, taking the second place in the first class of the Natural Science Tripos. In 1874 he was appointed to the Geological Survey of India, and proceeded to the exploration of the mountains of Kashmir, on which he wrote an important geological memoir. While there, his opportunities for sport gradually led him to take a special interest in the mammals and birds of India, and on returning to Calcutta he began to study the Indian Tertiary vertebrate fossils in the Survey collection. Planning a series of memoirs on these fossils for the 'Palæontologia Indica,' he soon felt the necessity of ample materials for comparison. He accordingly retired from the Indian service, returned to England in 1882, and had the Calcutta collection sent in instalments to the British Museum, where he completed his work. Between 1885 and 1887 he prepared a Catalogue of the Fossil Mammals in the British Museum, in five parts. This was followed in 1888–90 by a similar Catalogue of the Fossil Reptilia & Amphibia, in four parts; and in 1891 by a Catalogue of the Fossil Birds, in one part. The whole series of ten small volumes did useful service to Vertebrate Palæontology at the time, and included the first systematic attempt to correlate European with American vertebrate fossils. In 1893 and again in 1894, Lydekker visited the Argentine Republic at the invitation of Dr. Francisco P. Moreno, Director of the La Plata Museum. Here he studied the remarkable collection of mammalian remains from the Tertiary and post-Tertiary formations of the Republic, besides a few dinosaurian bones from a Cretaceous deposit in Chubut. Some beautifully-illustrated memoirs in the 'Anales' of the La Plata Museum were the result. By this time Lydekker had begun to realize the important bearing of recent discoveries of fossil mammals on the problems of geographical distribution; and in 1896 he published the most original and most philosophical of his works, 'The Geographical History of Mammals.' During all these researches he contributed numerous preliminary notes to various serials, including the Quarterly Journal of the Geological Society.

In 1889 Lydekker wrote the volume on vertebrates for the third edition of Prof. H. A. Nicholson's 'Manual of Palæontology,' and in 1891 he joined Prof. (afterwards Sir) William H. Flower in the authorship of a valuable 'Introduction to the Study of Mammals.' From 1893 to 1896 he edited the 'Royal Natural History,' to which he himself contributed the sections on vertebrates. From 1896 until his death, much of his time was spent in arranging the public exhibition of Recent Mammals in the British Museum (Natural History), for which he was specially employed by the Trustees. His later studies therefore became more purely zoological, and he published several more or less popular volumes adapted to the needs of sportsmen. He also wrote a 'Catalogue of the Ungulate Mammals' and some Guide-books for the British Museum. His industry was phenomenal, but he sometimes bewailed his facility for literary composition which betrayed him into errors that on further reflection became at once apparent to him. In his ancestral home at Harpenden, though oppressed by sad domestic trouble, he continued absorbed in his favourite pursuits until the end, and his last volume for the British Museum was published posthumously. He had a large circle of devoted friends, whose admiration for his character increased the more closely they became associated with him. An excellent portrait of him appears as frontispiece to the fourth volume of the 'Catalogue of the Ungulate Mammals in the British Museum.'

Mr. Lydekker was elected a Fellow of the Royal Society in 1894, and the Geological Society awarded to him the Lyell Medal in 1902.

Charles Callaway, who was a Fellow of the Geological Society from 1875 to 1906, and to whom the Murchison Medal was awarded in 1903, was a pioneer in the study of the British pre-Cambrian rocks, and also made valuable contributions to our knowledge of the Cambrian and Ordovician Systems. He was born at Bristol in 1838, and died at Cheltenham on September 29th, 1915. From 1876 until 1898 he resided at Wellington in Shropshire, and began his original researches in the area of the Wrekin. So long ago as 1874 he discovered an Upper Cambrian fauna in the Shineton Shales. A few years later he identified the underlying greenish sandstone with the Hollybush Sandstone of Malvern. He was thus able to prove that the ancient masses of the Wrekin and the Longmynd represented a pre-Cambrian formation, which he termed Uriconian. Callaway next studied Anglesey, and came to the conclusion that the unfossiliferous metamorphic rocks of that island were also probably of pre-Cambrian age. He then visited the still more difficult region of the North-West Highlands of Scotland, and took an important share in the discussion of the great thrust-planes now recognized there. After so much experience of metamorphic rocks, Callaway began to consider the theory of dynamo-metamorphism, and applied it to the explanation both of the crystalline schists of the Malvern Hills and of certain old rocks in Galway, Donegal, and Wexford. He finally returned to the geology of Anglesey, and re-interpreted it in the light of new knowledge, attempting to show that large masses of crystalline schists had been produced by intense changes in igneous rocks. This revised interpretation has been largely confirmed by the researches of Mr. Edward Greenly during more recent years, and will be fully dealt with in the forthcoming Geological Survey Memoir on the island.

A portrait of Dr. Callaway and a list of his writings are published in the 'Geological Magazine,' dec. 6, vol. ii (1915) pp. 525–28 & pl. xviii.

Arthur Vaughan was a brilliant exponent of the modern methods of stratigraphical geology, which he applied with success to the Lower Carboniferous formations. Born in London in 1868, he graduated both at Cambridge and at London with high mathematical honours, and removed in 1891 to Clifton, where he resided until 1910. In the latter year he was appointed Lecturer in Geology in the University of Oxford, where he died on December 3rd, 1915. Beginning with the study of the Earth's crust from the point of view of mathematical physics, he gradually became interested in all geological questions; and an intimate association with our late Fellow, Edward Wilson, definitely turned his attention to the stratigraphical distribution of fossils. After various preliminary researches, Vaughan proceeded to examine in detail the sections of Carboniferous Limestone in the Avon Gorge, and the results of his work, published in our Quarterly Journal for 1905. and in the Proceedings of the Bristol Naturalists' Society for 1906, were not only a fundamental advance in our knowledge of the Carboniferous Limestone itself, but also a stimulating new departure in stratigraphical studies. Further researches in other areas in England, Wales, Ireland, and Belgium, enabled him to show how widely his results could be applied; and he gradually acquired so precise a knowledge of the mutations and variations of the Lower Carboniferous fossils, especially corals and brachiopods, that he was able to attempt correlations which otherwise would have been impossible. His last great work, a comparison of the Belgian with the British Carboniferous, was published in our Quarterly Journal so recently as September last.

Vaughan had been in failing health for some years, and much of his investigation was carried on under difficulties, but he ever retained his cheerful and buoyant spirit and unflagging zeal. He was an inspiring teacher and genial friend, and his untimely loss is mourned by all who knew him. He was elected a Fellow of the Geological Society in 1900, served on the Council from 1912 onwards, received the Wollaston Fund in 1907, and the Lyell Medal in 1910. A list of his writings and a portrait appear in the 'Geological Magazine,' dec. 6, vol. iii (1916) pp. 92–96 & pl. v.

ORVILLE ADALBERT DERBY, who died suddenly at Rio de Janeiro on November 27th, 1915, had devoted his life to the study of the geology of Brazil, and had done great service to our science. He was born at Kelloggsville (New York) on July 23rd, 1851, and proceeded in 1868 to Cornell University, where he came under the influence of Prof. Charles F. Hartt, who had accompanied the Agassiz Expedition to Brazil in 1865, and had published his pioneer volume on the Geology of Brazil in 1870. After graduating in 1873, Dr. Derby became Assistant to Prof. Hartt, who had just been appointed Director of an Imperial Geological Commission of Brazil; and in the following year he went to Rio de Janeiro to act as Assistant in the contemplated survey. On the death of Hartt in 1878 the work of the Commission ceased, and in 1879 Derby was made chief of the geological section of the National Museum of Rio de Janeiro. The most important of his early memoirs on the Region of the Lower Amazons, the Cretaceous Basin of Bahia, and the Diamantiferous Region of the Paraná, were published in the 'Archivos' of the Rio Museum in 1877 and 1878. In 1886 Derby left Rio and became Director of the Geographical and Geological Commission of the State of São Paulo, where he remained until 1905. He then undertook an examination of the diamond-bearing rocks of the State of Bahia, and shortly afterwards returned to Rio as Director of a new Geological and Mineralogical Survey of Brazil, which he carried on energetically until his lamented death. In 1887 and 1891 Derby contributed two papers on the nepheline-rocks of Brazil to the Quarterly Journal of the Geological Society. He was especially interested in petrology and in the occurrence of accessory minerals in rocks, and published many papers in the 'American Journal of Science' and in the 'Journal of Geology,' which are not only of scientific importance but of economic value. At the same time, he did not neglect any aspect of the science; and one of his latest papers was devoted to an exhaustive study of the stem of the Permo-Carboniferous plant, *Psaronius brasiliensis.*

Derby was an attractive personality, full of enthusiasm for his science, and always eager to welcome geologists who visited the land of his adoption. He gave special help and encouragement to Prof. J. C. Branner during his numerous researches in Brazil, and he similarly aided Dr. I. C. White in the preparation of his monumental volume on the coal-bearing rocks of Rio Grande do Sul. He was also associated with our Fellow, Mr. Joseph Mawson, when he was resident in Brazil and devoting attention to the geology of the country. In 1896, and again in 1907, I had the pleasure of experiencing his welcome both in Rio de Janeiro and in São Paulo, and learned to appreciate the difficulties under which he pursued his work with a strangely unsympathetic Government. He was elected a Fellow of the Geological Society in 1884, and received an award from the Wollaston Fund in 1892. An excellent portrait of him appropriately appears as the frontispiece of the first edition of Prof. J. C. Branner's 'Geologia Elementar,' published at Rio de Janeiro in 1907.

HENRY HYATT HOWELL was born on July 13th, 1834, and began his lifelong career on the Geological Survey of Great Britain in the autumn of 1850. As Assistant-Geologist, his first task was to accompany Beete Jukes in mapping the South Staffordshire coalfield; and for a few subsequent years he was occupied in the survey of the Midland counties. His most important memoir referred to the Warwickshire coalfield (1859). In 1855 Howell was transferred to Scotland, and devoted himself chiefly to the mapping of the Mid- and East-Lothian and Fifeshire coalfields. In 1857 he was promoted to the rank of Geologist, and he co-operated with (Sir) Archibald Geikie in producing their well-known volume on 'The Geology of the Neighbourhood of Edinburgh,' published in 1861. His work in association with Geikie and John Young laid the foundation of our present knowledge of the Carboniferous succession in Southern Scotland. In 1861 Howell returned to England, where he surveyed Jurassic areas in Northamptonshire, Bedfordshire, and Huntingdonshire. He then supervised the staff engaged in the survey of the North-Eastern counties, and was promoted to the rank of District Geologist in 1872. Ten years later he succeeded (Sir) Archibald Geikie as Director for Scotland, and eventually in 1888 became Director for Great Britain. He retired in 1899, after nearly half a century of disinterested public service, highly esteemed by all his colleagues. He had been elected a Fellow of the Geological Society in 1853.

An account of the official work of Mr. Howell, with a portrait, appears in the 'Geological Magazine,' dec. 4, vol. iv (1899) pp. 433–37 & pl. xxi. He died in June 1915.

WILLIAM ANDERSON, who was born at Edinburgh in February 1860, and died at Sydney (New South Wales) on May 30th, 1915, was elected a Fellow of the Geological Society in 1899. After studying in the University of Edinburgh, he joined the Geological Survey of New South Wales in 1886, and wrote many valuable reports on the geology and mineral resources of that State, besides undertaking a series of researches on water-supply. In 1893 he retired from the New South Wales Survey, and, after a few years' service as Mining Specialist to the Geological Survey of India, he proceeded to South Africa. From 1899 to 1905 Anderson was Government Geologist of Natal, and he published three important reports on his work, with descriptions of the fossils by various specialists. After leaving South Africa, he returned to Scotland, but the climate proved too severe for his failing health, and he finally retired to Sydney. He was an excellent observer, full of enthusiasm for our science, and gained the esteem of all who knew him.

South African geology loses one of its most active workers by the premature death of HERBERT KYNASTON on June 28th, 1915. He was born on July 19th, 1868, at Durham, and educated at Eton and at King's College, Cambridge. The Worts Travelling Fund was awarded to him in 1892, and he began his geological career by studying the Cretaceous Gosau Beds of Austria, of which he contributed an account to the Quarterly Journal of the Geological Society in 1895. From 1895 to 1902 he was engaged on the Geological Survey of Scotland, and in February 1903 he became Director of the Geological Survey of the Transvaal. Later, on the formation of the Union of South Africa, he assumed the direction of the newly-constituted Geological Survey under the Department of Mines. He carried on his Survey work with enthusiasm and success, and his annual reports were looked forward to no less by the student of pure geology than by the practical miner, whose needs in such a country are naturally paramount. Mr. Kynaston was of a retiring disposition and little known outside his department, in which he was universally esteemed; but he took part in the proceedings of the Geological Society of South Africa, and was its President in 1908. He was elected a Fellow of the Geological Society in 1894.

The Hon. ROBERT MARSHAM (since 1893 MARSHAM-TOWNSHEND), who was born on November 15th, 1834, and died in April 1915, took a deep interest for many years in the study of stratigraphical geology, and in 1877 presented his valuable collection of British fossils to the British Museum. When in Brazil as Attaché at Rio de Janeiro, 1855–59, he obtained some Cretaceous fishes from Ceará, which he also gave to the British Museum. He was elected a Fellow of the Geological Society in 1859.

Sir **SANDFORD FLEMING**, who was born at Kirkcaldy (Fife) in 1827, and died at Halifax (Nova Scotia) on July 22nd, 1915, became a Fellow of the Society in 1877. During the preliminary surveys and the early years of its construction, he was Engineer-in-Chief of the Canadian Pacific Railway. He was also associated with other railway enterprises in Canada; and his important public work was recognized by the conferment on him of the Knight Commandership of the Order of St. Michael & St. George in 1897. His interests were many and varied, and geological science, both theoretical and practical, was among them.

WILLIAM GRYLLS ADAMS, born on February 16th, 1836, was elected a Fellow of the Geological Society in 1865. He was a distinguished mathematician and physicist, and Professor of Natural Philosophy & Astronomy at King's College, London, from 1865 to 1906. He became a Fellow of the Royal Society in 1872, and an account of his work is published in the Proc. Roy. Soc. ser. A, vol. xci (1915) pp. lxiii, lxiv. He died in April 1915.

RICHARD ASSHETON was a distinguished vertebrate embryologist, interested in all branches of biological and geological science. Born at Downham Hall (Lancashire) on December 23rd, 1863, he died at Grantchester, Cambridge, on October 24th, 1915. He had been elected a Fellow of the Geological Society in 1886, and of the Royal Society in 1914.

HERBERT STANLEY BION, who was elected a Fellow of this Society in 1911, died on June 6th, 1915, at the early age of 27. He was born in India, and educated at University College, London, graduating as B.Sc. at London University. He joined the Geological Survey of India as Assistant-Superintendent in 1911, and was engaged chiefly in Burma and Kashmir.

FORTESCUE WILLIAM MILLETT, who was born in 1833, and died on February 8th, 1915, became a Fellow of the Geological Society in 1900. He was a well-known authority on the Foraminifera, and contributed an account of those found in the St. Erth Clay to the Palæontographical Society's Monograph of the Foraminifera of the Crag.

ANDREW DUNLOP, who graduated as M.D. at Edinburgh University in 1863, resided for 47 years in Jersey, and devoted much of his leisure to the study of the geology of that island. He contributed papers to the Quarterly Journal of the Geological Society on the Jersey Brick-clay and on Jersey Raised Beaches in 1889 and 1893 respectively; and so recently as November 1914 he communicated to the Society another paper on a raised beach on the southern coast of Jersey. He became a Fellow of the Society in 1874, and died at the age of 73 on December 30th, 1915.

GEORGE HENRY HOLLINGWORTH was an active member of the Manchester Geological Society, of which he was Treasurer for many years and President in 1903–1904. He was especially interested in the geology of coal-mining, but he also studied other geological questions in Lancashire, and in 1881 he contributed to the Quarterly Journal of the Geological Society a description of a peat-bed interstratified with Boulder-drift at Oldham. He was elected a Fellow in 1879, and died in April 1915.

BENJAMIN HOLGATE, who was born at Leeds in 1838, became a Fellow of the Geological Society in 1877. He devoted the leisure of his long life to a study of the geology and natural history of the district round Leeds, and made several contributions to the Transactions of the Leeds Geological Association. A portrait and a list of his writings are published in 'The Naturalist' for April 1915 (pp. 145, 146).

WILLIAM SIMPSON was an active member of the Yorkshire Geological Society and the Yorkshire Naturalists' Union. He was especially interested in glacial geology, but also published notes on borings in the Millstone Grit at Halifax, where he resided until 1903. He was elected a Fellow of the Geological Society in 1893, and died at Catteral Hall, near Settle, in March 1915, aged 56.

JOHN TURNER HOTBLACK resided at Norwich, and for a long period took an active part in the public life of the city. He was a Member of the Museum Committee, and a valued supporter of the local scientific societies. In 1899–1900 he was President of the Norfolk & Norwich Naturalists' Society, and communicated to it in 1906 a paper on excavations in the Castle Mound. He was elected a Fellow of the Geological Society in 1900, and died on November 1st, 1915, aged 67.

Henry Rofe, who was born on February 15th, 1839, and died on March 2nd, 1915, became a Fellow of the Society in 1890. He was a distinguished waterworks engineer, and constructed important works for the water-supply of many English towns. In 1905 he visited and reported on the water-supply of British East Africa.

Richard Kerr, who was elected a Fellow of the Society in 1882, was engaged for many years in educational work at Folkestone, and subsequently became well known as a popular exponent of science. He died at Mitcham (Surrey) on May 21st, 1915.

William Hutton Williams, who was born at Clifton, Bristol, in 1875, and became a Fellow of the Society in 1905, was a mining engineer who had done much work in Korea, Southern Manchuria, and India. He held a commission as Captain in the East Surrey Regiment, and was killed in action in France in May 1915.

I have also to record the death on December 17th, 1915, of William Rupert Jones, who was Assistant in the Geological Society's Library from 1872 until 1913. He was born in 1855, the eldest son of Prof. T. Rupert Jones, F.R.S., and inherited his father's retentive memory, which enabled him to give most valuable help to the Fellows using the Library. From its beginning until 1912 he prepared the slips for the Society's annual Record of Geological Literature.

THE USE OF THE HIGHER VERTEBRATES IN STRATIGRAPHICAL GEOLOGY.

A.S. Woodward

THE study of fossil fishes, to which I referred last year, seems to show that each of the successive dominant groups is sharply distinguished from its immediate predecessor by some fundamental character, marking an advance towards the extreme adaptation for locomotion in water, which was ultimately attained in the Cretaceous Period. It is also evident that various members of each of these successive groups soon became specialized for every possible mode of life in the circumstances of the time. Fishes of the same general outward appearance and habit have thus originated repeatedly from progressively higher groups; similar adaptations have recurred with only minor differences; and nearly the same changes, though perhaps with increasing intensity, have always marked the approach to racial old age. These phenomena are, indeed, so remarkable, that the question arises as to whether animals of apparently the same family, genus, or species may not originate more than once from separate series of ancestors. We may even hesitate further in deciding whether or no the really fundamental advances in life at successive periods have occurred more than once in the faunas of which they are respectively characteristic.

The study of fishes, however, is scarcely sufficient to solve these problems, because the large majority of the fossils are marine, the animals would spread rapidly and widely, and the limits of the seas in which they lived are never clearly recognizable. The higher vertebrates, which inhabited the land, seem to be a much more hopeful source of necessary facts; for the land has always been subdivided into well-defined areas, isolated by seas, mountains, and deserts. Animals in these several areas must often have developed independently for long periods; alterations in the barriers can be detected by the geologist when he studies the migrations and mingling of faunas; while, as researches progress, the varying geography of successive periods may be more or less successfully restored. Like the fishes, the terrestrial vertebrates have advanced by successive fundamental steps towards perfection in powers of locomotion, and during this progress have at each stage diverged into various analogous specializations. They have, indeed, advanced one step farther by the final increase in the relative size and efficiency of the brain, which culminated in Man. If, in these circumstances, the same type of animal has originated more than once, it should be possible, in some cases at least, to discover the phenomenon and determine its limitations.

Although the enquiries involved are almost entirely biological, it is especially important for the geologist to take note of them, because students of shells from the modern standpoint are unanimous in recognizing what they term homœomorphy. They continually find ammonites, gastropods, and brachiopods, for example, which are essentially identical when full-grown but differ completely in their early stages. When the fossils happen to be perfect, these early stages are, of course, preserved and distinguishable; and if they reproduce, even only approximately, the ancestral condition in each case, they certainly suggest that the same type of shell may have arisen from more than one source. If this be so, shells from different horizons and widely-separated localities need very careful scrutiny before they can be used for correlating geological formations; for, even if nearly similar, they may represent animals that have no really close affinity, and any diagnostic features that they show may be inconspicuous points which have generally been overlooked as insignificant. For a clearer view of general principles, we therefore turn with expectancy to vertebrate skeletons, which have much more numerous and tangible characters, and approach senility in more varied ways.

Even among vertebrates it is by no means easy in every case to interpret the evidence that most concerns the geologist, and I need only refer to the supposed thylacines (Sparassodonts) and the horned tortoises (*Miolania*) of the Argentine Tertiary, which have often been quoted as specially strong proofs of the former existence of an Antarctic continent uniting the Australian and South American regions. So far as can be determined from their fossil remains, the Sparassodonts of the Santa Cruz Beds of Patagonia differ only in the slightest particulars from the Pleistocene and existing thylacines of Australia, and they have been placed in the same family by American palæontologists. It is, however, to be noted that the thylacines and Sparassodonts are essentially identical with the primitive Creodonta, which are known to have ranged over all the continental land of the Northern Hemisphere at the beginning of the Tertiary Era. They only differ from these early mammals in certain senile specializations which might be expected in any long-lived group;

and, as these specializations are not altogether the same in the two cases, it is probable that they have arisen independently. Again, *Miolania* is a senile heavily-armoured form of the Pleurodiran Tortoises, which had a universal distribution in the late Secondary and early Tertiary Eras. The arrangement of the bony bosses on the skull is not absolutely the same in the species from Australia and Patagonia, and these indubitable marks of racial old-age may therefore have been acquired by separate groups in different regions. In other words, the essential identity of these land-animals does not prove a former direct connexion between Australia and South America; they may be merely survivors of cosmopolitan races at the two extremes of their former range, with certain inevitable marks of senility. In making comparisons, indeed, it is not enough to distinguish the fundamental and merely adaptive characters of animals; it is also essential to note separately those characters which depend on the early, mature, or senile position of the particular animals in the evolving series to which they belong.

In the present state of our knowledge there seems to be only one case in which we begin to have materials for forming a judgment as to whether fundamental advances—the 'expression points' of Cope—occur more than once. I refer to the acquisition of warm blood and its correlatives or consequences which started the career of the mammals. The only reptiles that ever made a close approach to mammals in their skeleton existed during the Permian and Triassic Periods, and they were precisely intermediate between the Palæozoic Amphibia and the Mesozoic Mammalia. It is, therefore, presumably in Permo-Triassic times that mammals arose. These intermediate or Theromorph reptiles, however, were spread widely over many lands. Their remains were first found in the Karoo formation of South Africa, were afterwards recognized in India, Scotland, Northern Russia, and Central Europe, and also proved to occur in great numbers in the Permian of North America. Traces of them have also been met with in Southern Brazil. The African, Asiatic, and European remains belong to animals so closely similar, that it is probable that they lived on a continuous land-area; but the American forms, although in the beginning not unlike, soon began to evolve into several groups which are almost or completely unknown in the Old World. The American Theromorphs, therefore, probably flourished in isolation. Large collections from both regions have been studied during recent years by

Dr. R. Broom, Dr. E. C. Case, and others, and a critical summary of the results was published by Dr. Case last summer.[1] It now appears that all the specializations in the American groups were in the direction of higher reptiles; while all those in the South African groups made a progressively closer approach to mammals, and as nearly as possible culminated in typically mammalian skeletons. Hence, although we have evidence of two possible sources of mammals, only one appears to have produced them.

Secondly, consider a case of less fundamental character, the origin of the Monkeys or lower Anthropoidea. It is generally admitted that they arose from the next lower grade, that of the Lemurs or Lemuroidea, which were almost universal in their distribution over the great continents at the beginning of the Tertiary Era. It is also suspected (though the palæontological evidence is still very scanty) that the two markedly distinct groups of Monkeys, the Platyrhines in America and the Catarhines in the Old World, were derived independently from the Lemurs in these two separate continental areas. If this be so, a zoologist's 'sub-order' has arisen by two parallel, though readily distinguishable, developments from an earlier and lower 'sub-order.' Now, the surviving Lemurs of the Asiatic and African regions and Madagascar have lived on from early Tertiary times practically unchanged; but there is one isolated area, the island of Madagascar, where some families during the later Tertiary periods attained remarkable specialization. Unfortunately, we only know the Pleistocene and Holocene members of these families that are discovered in the caverns and swamps of Madagascar; but they represent the culminating genera, and suffice to indicate what happened. In this isolated region the highly-specialized late Tertiary Lemurs curiously resembled in some characters both the Platyrhine and the Catarhine Monkeys. The first portion of skull of *Nesopithecus*, in fact, appeared to so experienced an observer as Dr. Forsyth Major so monkey-like that he originally placed it among the Monkeys, in a new family intermediate between the South American Cebidæ and the Old-World Cercopithecidæ. It is now clear, however, from the researches of Dr. G. Grandidier and Dr. H. F. Standing, that none of these animals really passed beyond the typical Lemur-grade. They eventually grew large,

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[1] E. C. Case, 'The Permo-Carboniferous Red Beds of North America & their Vertebrate Fauna' Publication 207 (1915) of the Carnegie Institution of Washington, p. 121.

some of them (*Megaladapis*) almost rivalling donkeys in size; they also diverged for various modes of life, a few of them even entering the proper sphere of hoofed animals. Removed from the stress of competition with other mammals such as swarmed on the continents, they flourished in luxurious ease; and we are tempted to speculate whether it was not the strenuous competition in the crowded continental forests of America and Africa (or Asia) that made the difference, and led to the increase of brain-power which is the specially distinctive characteristic of Monkeys. If this be so, the lower race passed into the higher race only where the struggle for existence was keenest. Why the higher race never advanced further in America, while it began at once to give rise to the man-like Apes in the Old World, is still an unsolved problem.

The case of the Anthropoidea suggests that a widely-distributed group of early Tertiary mammals experienced in three separate regions an essentially-similar initial impulse to become a higher group, evolved on parallel though not identical lines, and ended at three different stages in its onward progress. It is, therefore, interesting to consider the geological history of some of the families of Ungulata which are already sufficiently well known by a succession of fossils to reveal the main episodes in their career. This history is especially instructive, because all the surviving groups originated in the Northern Hemisphere on two or three large continental areas which were sometimes united, at other times separate; and the fossils are beginning to show how and when the various connexions and isolations occurred. Northern Africa, probably with part of Southern Asia, is one of the areas on which Ungulates made an independent start; Europe, with North-Central Asia, is another; while North America is the third.

The Rhinoceroses are a well-marked family, of which numerous fragmentary fossil remains can easily be recognized and compared. They seem to have arisen at the beginning of the Eocene Period from some small generalized Perissodactyl which had a slender snout and a regular close series of 22 low-crowned teeth in each jaw; and, as ages passed, the nasal bones became enlarged and thickened to support a dermal horn, the front teeth tended to disappear as the lips became more prehensile, while the molars and premolars increased in effectiveness for grinding hard and dry herbage. As in other Perissodactyls, the premolars were at first comparatively simple, but afterwards gradually approached the molars in complexity; while the successive representatives of the family showed a progressive increase in bodily bulk. These changes took place almost simultaneously both in the Old World and in North America, though in the latter region the whole family died out in early Pliocene times as soon as a rudimentary nasal horn was beginning to appear. After the earliest stage, however, the European series at least can readily be distinguished from the American series by the premolar teeth, and there must have been independent evolution in the two regions. According to Prof. O. Abel, the oldest known recognizable member of the family is the small *Prohyracodon* from the Middle Eocene of Transylvania; and both this and the later *Epiaceratherium*, from the Lower Oligocene of Northern Italy, agree with the earliest North American Rhinoceroses in having the foremost premolar more nearly like a molar than is the hindmost premolar. They thus show the first step in the complication of the premolars from front to back, which, according to Prof. H. F. Osborn, is the direction of this complication during geological time in all the American Rhinoceroses. On the same account, they differ from all the known Rhinoceroses which followed them in Europe: for in these the complication of the premolars always began with the hindmost, and proceeded forwards. Not only can two distinct progressive groups be thus recognized in two distant regions, but more than one line of development can also be traced within each. The fossils, indeed, seem to justify the conclusion that the Rhinoceroses arose from a common stock, but evolved in several different ways and at varying rates towards the same goal of specialization.

It is curious that extreme specialization in the family was reached only in the Old World, and still more curious that the large-horned woolly rhinoceros (*Rh. antiquitatis*), which lived in the Arctic Regions with the mammoth, never accompanied that animal to North America. Equally interesting is the exceptional case of high specialization in the Old-World Pleistocene *Elasmotherium*, in which the extreme deepening, enlargement, and complication of the molar and premolar teeth seem to have been correlated with the reduced development of the epidermal horn. The large bony boss on the frontals of this animal was probably covered only by a very thin capping of horn. At least, it is difficult to suggest any other interpretation for such a horn, which was found isolated a few years ago by the Prussian Geological

Survey, in a superficial deposit in the Luckau district south of Berlin.

A detailed study of the tooth-pattern in the successive groups of extinct Horses, seems to reveal the same phenomenon that is observable in the Rhinoceroses—the approach to nearly-identical extreme specialization by several separate lineages in approximately the same time. The earliest Eocene forerunners of the Horses are essentially similar in Europe and in North America, and some of the later forms also exhibit many resemblances which may be due to migrations from one region to the other; but the most exhaustive modern researches leave no doubt that the gradual reduction of the foot to a single toe and the deepening of the teeth for effective grinding of hard food, with various correlated specializations, occurred in several distinct groups of Horses in different localities. The climax was reached during the Pliocene Period, both in Europe and Asia and in North America; while the greatest diversity of form appeared in the latter region and among the immigrants to South America, where all Horses died out before historic times.

Even in families of more restricted geographical range, the same unswerving tendency towards a fixed goal is very clearly recognizable. Among the Camels, for instance, which seem to have accomplished the whole of their evolution in part of North America, the characteristic cushioned foot appears to have been produced more than once. All the small early ancestors of the Camels had feet like those of deer or gazelles, with pointed toes; and Prof. W. B. Scott has observed that even the Lower Miocene genera, which were already differentiated into two groups, still exhibited the same primitive feature. All the later Miocene Camels of both these groups, however, possess the irregularly-nodular ungual phalanges which indicate the presence of the cushions or pads. It is thus evident that two progressive series independently acquired one and the same structure.

A study of the extinct representatives of several other familiar Ungulata has led to the discovery of many facts which tend to confirm the results just mentioned. In every case, either the feet become perfectly adapted for rapid locomotion over hard ground, or the teeth acquire more grinding power by deepening, folding, and the frequent infilling of the hollows with cement; or both these progressive adaptations take place at the same time. When, however, this evolution first started in the Eocene Period, the common ancestors of the groups that were thus destined to flourish were accompanied by other generalized Ungulates which began to acquire running feet without any of the requisite changes in the arrangement of the wrist- and ankle-bones, and often showed a deepening or other complication of the grinding teeth without any infilling of the resultant hollows by cement. These animals with 'inadaptive modifications' (as Kovalevsky termed them) were soon handicapped in the race with their better-endowed contemporaries, and all became extinct before they had advanced far. In South America, on the other hand, which was an isolated centre of mammalian development during the greater part of the Tertiary Era, all the early Ungulates began to advance in the 'inadaptive' manner, without any more efficient contemporaries and competitors. Here we are, therefore, able to follow to the end a course of evolution which was abruptly stopped in the Northern Hemisphere. It resulted in less variety than is observable among ordinary Ungulates, but some of the later genera are strange mimics of the Rhinoceroses and Horses in outward shape. At least one of the bulky three-toed forms acquired a rhinoceros-like horn: and some of the small one-toed forms exhibited a greater reduction of the lateral toes even than in the horse. The molar teeth were also sometimes invested with a little cement, but they never became such effective grinders as those of the Horses and Elephants. The latest of these South American animals, indeed, soon disappeared when a land-connexion in the Pliocene Period allowed the animals of North America to invade the Southern Continent and compete with them.

None of the South American Ungulates developed the symmetrical pair of toes such as characterizes so large a proportion of the northern forms, but their single enlarged toe, which became the centre of symmetry, was always the third, as in the ordinary tapirs, rhinoceroses, and horses. It is, therefore, interesting to note that among the Australian Marsupials, which have independently developed a hind foot for rapid locomotion or leaping on hard ground, the largest toe is not the third, but the fourth. So far, unfortunately, we lack nearly all the ancestors of these animals; but available evidence seems to show that they are descended from tree-dwellers in which the first digit had become opposable. When they began to live habitually on the ground and the foot became modified accordingly, this digit dwindled to a projecting rudiment (as preserved in *Diprotodon*), and the axis of the foot was displaced outwards from the third to the fourth toe. In other words, an essentially ungulate foot was produced as usual, only disturbed by an initial twist.

From these and many similar facts in mammalian evolution, we may therefore conclude that parallel development or 'homœomorphy' undoubtedly occurs. Some of the changes are adaptations to the same altering modes of life, perhaps also to the same progressive modifications in the environment; among which may be enumerated the increasing efficiency of the teeth for grinding and of the feet for running. Other changes are the inevitable marks of racial maturity or old age, such as increase of size, the development of excrescences, and the reduction in number of the teeth. While, however, both these series of changes always take place in approximately the same order and may be used to mark the successive periods of Tertiary time by a palæontologist who is accustomed to deal with such evidence, there is still no reason to suppose that identical animals have arisen from more than one source. Distinct families or genera which may be difficult to separate on superficial examination, are readily recognized in most cases when studied in detail with our present knowledge of general principles. It is, indeed, usually possible to distinguish between traits of heredity that are fundamental, and those that are merely adaptive or depend on racial antiquity. The new palæontology is thus as useful in relation to world-problems, as was the old palæontology in determining the relative ages of the rocks in the restricted European area to which it was first applied.

The adaptive characters just mentioned change with much rapidity, and allow a tolerably detailed subdivision of the series of strata which contain the fossils exhibiting them. It is therefore interesting to notice that some other characters which can scarcely be correlated with utility or efficiency, persist without change for comparatively long periods and are of little value for stratigraphical geology. Huxley long ago directed attention to the problem of 'persistent types,' as he termed them, and most of them are still as inexplicable as they were when first considered. Only in the case of certain fishes have I suggested that advance was stopped by the appearance of various modifications or specializations in the wrong order. It may be that single peculiar characters persist when they cannot be affected by Natural Selection. One of the most striking examples was described by Egerton in the Society's Journal for 1871 in a Chimæroid fish from the Lower Lias of

Lyme Regis, which he named *Ischyodus orthorhinus* (now known to be *Prognathodus*). The prolongation of the snout in this early Jurassic fish is of precisely the same remarkable shape as that in the existing Chimæroid *Callorhynchus*. Notwithstanding the many changes which have occurred in Chimæroid fishes since that remote period, including a total replacement of the genera, the pattern of snout in one group at least has persisted. Again, the existing Lamnid sharks are characterized by a curious dwarfing of the third or fourth tooth, or both, on each side of the upper jaw. A study of associated sets of teeth of some of the earliest-known members of the family from the Chalk, proves that this feature was already established even in Cretaceous times: not only in the genera which have survived, but also in the extinct *Corax*. Finally, in the Society's Quarterly Journal for 1910, I pointed out that in the Lower Jurassic carnivorous dinosaurian, *Megalosaurus*, three or four pairs of the teeth in front of the lower jaw are diminutive, perhaps functionless. Last year, through Mr. W. E. Cutler, the British Museum received from the Upper Cretaceous of Alberta (Canada) the jaws of a gigantic Megalosaurian, evidently of another genus, in which exactly the same reduction of the teeth at the mandibular symphysis occurs. Through a wide range of time and space, therefore, this small and apparently insignificant feature persisted, and even passed from one genus to another.

The strength of heredity is, in fact, one of the most remarkable phenomena with which a palæontologist is repeatedly impressed. Even when one great group gives rise to another, the later type often seems to be handicapped at first by the inheritance of some characters which are no longer congruous. The large majority of the Permian and Triassic Reptiles, for example, although true land-animals, still retained the large head and short neck which were well adapted to the aquatic habits of their amphibian and piscine ancestors. This was first strikingly shown by Seeley's restoration of the South African *Keirognathus*, afterwards by Boulenger's sketch of the Scottish *Telerpeton*, and has been emphasized more recently by the numerous restorations of Permian reptiles from North America by Williston, Case, and others. Similarly, when Reptiles passed into Mammals, the relatively-large tail of the gliding or swimming animal was no longer needed; but it persisted in nearly all Mammals at least through the first half of the Eocene Period, and even at the present day the abdominal region gradually tapers into the thick root of the large tail in such lowly types as the Marsupial *Thylacinus* and the Edentate *Orycteropus*. *Archæopteryx* suggests that the persistence of the reptilian tail was also a handicap to the earliest birds.

It may be that the same conservative tendency is the origin of various other apparently incompatible structures, for which adaptive explanations have been sought in vain. For instance, it has been surmised that the great bony brow-ridges of apes like the gorilla are needed to resist the strain produced by the working of the powerful jaws; but the same explanation will not apply to the nearly similar forehead of Neanderthal Man, in which the jaws are no heavier than those of many modern men. This must be a case either of direct inheritance or (as at present seems more probable) of curious reversion in a higher group to a tendency characterizing an ancestral lower group. Many similar instances might be cited.

The palæontologist is, indeed, now continually tempted to trespass on the domain of the speculative philosopher. He has had to abandon the old vague methods of comparative anatomy by which the solid foundations of his science were first laid. He now sorts out characters into several categories before beginning to compare them, and arrives at his interpretations in accordance with certain general principles which I have tried to illustrate. If, as Sir Jethro Teall has said, 'the state of advancement of a science must be measured, not by the number of facts collected but by the number of facts co-ordinated,' Palæontology is well in the forefront of progress. Its devotees may be wrong in some of their broader speculations, but during recent years they have rarely met with new facts which could not be reconciled with the general scheme of things developing in their minds. The value of its results for the purposes of geology must thus be constantly increasing.

Leaving high philosophy, it now only remains for me, in conclusion, to thank the Fellows of the Geological Society for the great honour which they conferred upon me two years ago when they elected me to be their President. I also wish to express my appreciation of the kind help and forbearance of the Officers, Council, Fellows, and Permanent Staff, which have made my term of service to the Society one of the most pleasant and memorable episodes of my life. My own special studies are so completely on the borderland of our science, that I fear I must sometimes have wearied you with matters that seem almost extraneous; but it is one of the greatest charms of geology that it needs co-operation with the whole circle of the sciences to further its aims. You have now turned from palæontology to petrology, and I have much pleasure in resigning the Presidential Chair to an old friend, an accomplished Fellow who has indeed delved deeply into the mineral structure of the Earth.

February 23rd, 1916.

Dr. Alfred Harker, F.R.S., President,
in the Chair.

William David Purdy, 7 Christchurch Terrace, Chelsea, S.W., and George James Roberts, Noyna, Avenue Rise, Bushey (Hertfordshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read :—

'On the Origin of some River-Gorges in Cornwall and Devon.' By Henry Dewey, F.G.S. (Communicated by permission of the Director of H.M. Geological Survey.)

Lantern-slides were exhibited in illustration of the above paper.

A nodule surrounded by a layer of cone-in-cone structure, without any trace of calcite, from Lower Palæozoic rocks near Machynlleth (Montgomeryshire), was exhibited by Dr. A. Smith Woodward, F.R.S., V.P.G.S.

March 8th, 1916.

Dr. Alfred Harker, F.R.S., President,
in the Chair.

Wilfrid Baker, Royal Grammar School, Worcester; and Arthur G. Pomeroy, M.A., B.Eng., 21 Orange Street, Haymarket, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The President referred with regret to the death, on March 3rd, of Prof. John Wesley Judd, C.B., LL.D., F.R.S., Past President of the Society. He spoke of the value of Prof. Judd's contributions to geological science, and of his eminence as a teacher of the science, and stated that the Society was well represented at the funeral.

Dr. Aubrey Strahan, F.R.S., Director of H.M. Geological Survey, exhibited and described briefly a set of specimens from the Western Front, illustrating the character of the rocks in which trenches, tunnels, etc. are being dug. They included specimens from the Cretaceous and Tertiary formations showing remarkable similarity in characters to the contemporaneous formations in Britain.

The following communication was read:—

'On some Insects from the British Coal Measures.' By Herbert Bolton, M.Sc., F.R.S.E., F.G.S., Reader in Palæontology in the University of Bristol.

Lantern-slides and specimens were exhibited in illustration of the above paper.

March 22nd, 1916.

Dr. Alfred Harker, F.R.S., President,
in the Chair.

Lieut. Kenneth Neville Moss, B.Sc., Royal Engineers, Fieldgate, Walsall, was elected a Fellow of the Society.

The List of Donations to the Library was read.

Dr. A. Smith Woodward, F.R.S., V.P.G.S., exhibited specimens of the problematical ichthyolite, *Cœlorhynchus*, from an Eocene deposit in the Ombialla district (Southern Nigeria), and discussed the nature of this fossil. Microscope-sections of the well-preserved Nigerian specimens confirmed W. C. Williamson's determination that *Cœlorhynchus* is an essentially dermal structure. A similar section of part of the rostrum of the teleostean fish *Blochius*, from the Upper Eocene of Monte Bolca, near Verona, showed an almost identical structure. The precise nature of this rostrum remained to be determined, but there could be no doubt that the so-called '*Cœlorhynchus*' is the corresponding part, either of *Blochius* or of an allied genus.

The following communication was read:—

'The Pseudo-Tachylyte of Parijs (Orange Free State) and its Relation to "Trap-Shotten Gneiss" and "Flinty Crush-Rock."' By S. James Shand, D.Sc., F.G.S., Professor of Geology in the Victoria College, Stellenbosch (S.A.).

April 5th, 1916.

Dr. Alfred Harker, 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 JOHN KAYE CHARLESWORTH, M.Sc., Ph.D., F.G.S., who proposes to conduct researches in connexion with the Glaciation of Donegal.

The following communication was read:—

'The Picrite-Teschenite Sill of Lugar (Ayrshire) and its Differentiation.' By George Walter Tyrrell, A.R.C.Sc., F.G.S.

Lantern-slides were exhibited in illustration of the above paper.

A Bronze Bust of Sir Charles Lyell, presented to the Society by Mrs. J. W. Judd, through Prof. W. W. Watts, was also exhibited.

May 10th, 1916.

Dr. ALFRED HARKER, F.R.S., President,
in the Chair.

Keir Arthur Campbell, B.A., Trinity College, Cambridge; Ednyfed Wynne Hughes, M.Sc., The Grange, Lesness Park, Belvedere; and Christopher Luke Waite, Newlands, Pontefract Road, Castleford, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Carboniferous Fossils from Siam.' By F. R. Cowper Reed, M.A., Sc.D., F.G.S.

2. 'The Lurgecombe Mill Lamprophyre and its Inclusions.' By Herbert Gladstone Smith, B.Sc., F.G.S.

Carboniferous fossils from Siam were exhibited by F. R. Cowper Reed, M.A., Sc.D., F.G.S., in illustration of his paper.

Lantern-slides, rock-specimens, and microscope-sections were exhibited by H. G. Smith, B.Sc., F.G.S., in illustration of his paper.

Sapphire-bearing xenoliths, from a Tertiary sill in the Island of Mull, were exhibited on behalf of H.M. Geological Survey.

May 24th, 1916.

Dr. ALFRED HARKER, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

Dr. A. SMITH WOODWARD, F.R.S., V.P.G.S., exhibited Devonian fish-remains from Australia and the Antarctic

Regions, and discussed our present knowledge of the Devonian fish-fauna of the Southern Hemisphere. So far as is known, there are no strange elements in this fauna, and the remains discovered closely resemble those met with in the Northern Hemisphere. Even the rocks are very similar to those containing the corresponding fossils in the Northern Hemisphere. There is, as yet, no satisfactory evidence of the basal Devonian fish-fauna such as occurs in the Downtonian of England and Scotland; but both Lower and Upper Devonian forms occur in Victoria and New South Wales (Australia). A Coccostean related to *Phlyctænaspis* from Gippsland (Victoria), and another related to *Macropetalichthys* from Goodra Vale (New South Wales), may be regarded as Lower or Middle Devonian; typical plates of *Bothriolepis* from the Harvey Range (New South Wales) indicate an Upper Devonian fauna. The fish-remains obtained by the 'Discovery' Expedition in Granite Harbour (Antarctica) comprise *Bothriolepis*, another Ostracoderm related to *Byssacanthus*, Acanthodian scales, Selachian dermal tubercles, a Coccostean, scales of Osteolepidæ, and scales of a very small Palæoniscid. They must be regarded as Upper Devonian.

Dr. Smith Woodward expressed his indebtedness to the Government Geologist of New South Wales for the loan of the Australian specimens exhibited.

Mr. R. Bullen Newton exhibited some so-called Orbitoidal Limestones from Dutch New Guinea, the microscopical structures of which were shown by lantern-illustrations. The specimens were collected by Dr. A. F. R. Wollaston during his expedition to that country in 1912–13, on the snow-line of Mount Carstensz at a height of 14,200 feet, this mountain forming the highest elevation of New Guinea, with an altitude of about 16,000 feet. The foraminiferal organisms determined in this material included five species of *Lepidocyclina (sumatrensis, martini, neodispansa, murrayana,* and cf. *insulæ-natalis), Amphistegina, Carpenteria, Cycloclypeus* (cf. *orbitoideus*), etc.; the marine alga or nullipore, *Lithothamnium*, was also largely represented. This assemblage compares favourably with that which characterizes rocks of similar age in other Pacific regions, such as Christmas Island (Indian Ocean), Formosa, the Philippines, Borneo, Celebes, Sumatra, Nias, Timor, and Australia, besides indicating a Miocene origin. It was pointed out that the genus *Orbitoides* of A. d'Orbigny had been restricted by Schlumberger (relying on the researches of Gümbel, Verbeek, and others) to species having rhomboidal equatorial chambers and belonging only to Cretaceous times; species furnished with rectangular chambers, and recognized as *Orthophragmina* of Munier-Chalmas, were limited to the Eocene and Oligocene formations; while Gümbel's genus *Lepidocyclina*, with rounded or hexagonal chambers, included species of Miocene and later age. As the result of a study of species from Borneo and the Philippines, Prof. Douvillé had proposed to divide *Lepidocyclina* into two sections—*Eulepidina* and *Nephrolepidina*: the first including forms of generally large size, recognized as Aquitanian; the second for those of small dimensions, regarded as Burdigalian—these geological divisions representing the oldest stages of the Miocene System. This distinction, however, was not applicable to the New Guinea limestones nor to corresponding rocks from Christmas Island, as both large and small species occurred in association; it was, therefore, suggested that the age of the New Guinea material might be referable to the later part of the Aquitanian. Several writers have already written on rather similar limestones from various parts of New Guinea, although we are indebted to Dr. K. Martin for the first announcement in connexion therewith: he reported the discovery in 1881 of Lepidocycline organisms from rocks found in the northern and south-western districts of the country (Geelvink Bay, islands of Kei, Aru, etc.), which he attributed to the older Miocene. The same author also referred to the occurrence of similar organisms in Mount Wilhelmina, obtained by Dr. Lorentz, beneath which the *Alveolina* Limestone was identified, proving the existence of Eocene rocks.

The *Cycloclypeus* remains, which are of frequent occurrence in the present material, bear a strong resemblance to Prof. Douvillé's new genus and species from the Miocene of Borneo, known as *Spiroclypeus orbitoideus*. This genus was stated to have all the characters of *Cycloclypeus*, but differs from it in the possession of superficial chamberlets in the shelly layers of the central region. Recent investigations, carried out by the speaker, had proved the presence of this character (hitherto unrecognized) in recent forms of *Cycloclypeus* from Funafuti; hence the retention of *Spiroclypeus* now appeared to be unnecessary. A full report on this New Guinea collection by the speaker had been lately published, entitled: 'Notes on some Organic Limestones, &c. collected by the Wollaston Expedition in Dutch New Guinea,'—forming No. 20 of a series of reports, and it was to be included in vol. ii of those reports.

By permission of the Secretary of State for the Colonies, Mr. J. F. N. Green exhibited a manuscript report by Mr. J. E. Eaglesome, C.M.G., on the Udi Colliery in Nigeria, containing a number of photographs and plans, and made some observations on the economic importance of this development in Equatorial Africa. There were placed with it for comparison two photographs of the outcrop of manganese-ore in the Gold Coast, also discovered by Mr. A. E. Kitson, F.G.S.

June 7th, 1916.

Dr. ALFRED HARKER, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

Dr. F. L. KITCHIN, M.A., F.G.S., exhibited a representative set of Mesozoic fossils obtained from deep borings and pit-sinkings in Kent. The specimens were selected from the collections of the Geological Survey, by permission of the Director. The life of the successive zones present in the various sections was illustrated by the arrangement of the specimens in sequence, the series comprising a time-range from the Lower Lias up to the top of the Lower Greensand. The section revealed in the Brabourne Boring is remarkable for the range of formations found there in superposition, and may be regarded as the type-section for the study of the hidden Mesozoic succession in Kent. Specimens were exhibited from that locality and from the shafts at Dover, but these were supplemented by materials obtained more recently from various borings situated east of a line drawn from Folkestone to Canterbury.

The speaker described the principal characters of the faunas as developed in this area, and made incidental references to the nature and distribution of some of the associated rock-types. At some horizons, the molluscan assemblage assumes a particular aspect, by reason of the preponderance of species fitted for life amidst the special conditions of deposition. On the other hand, there are evolutionary phases which recur repeatedly with considerable uniformity, and seem to arise independently of immediate surrounding conditions. Such are illustrated by the degenerative changes shown to occur in many ammonites, and by some of the forms repeatedly assumed by the members of separate series among Mesozoic oysters.

The evidence of ammonites, so important for the purpose of zonal determination, is frequently forthcoming at these localities in Kent, even in borings of narrow diameter; but it is often necessary to rely entirely upon the aid afforded by the more abundant bivalves. Many of these, although belonging to undescribed species, are found to have a limited vertical range, and by their distribution throughout this area, as well as farther afield, prove of much service in these correlation-studies. Specimens of many undescribed species have come to light, as well as others which are known from their occurrence in Continental localities, though not previously recorded in this country.

A small series of Jurassic Cephalopoda from Kachpur (Russia), collected by the late G. F. Harris, F.G.S., at the time when the International Geological Congress met at Petrograd (1897), was exhibited by James Francis, F.G.S.

June 28th, 1916.

Dr. Alfred Harker, F.R.S., President,
in the Chair.

Herbert Theodore Mayo, B.A., care of Port Master, Rawal Pindi (India); and William Guy de Gruchy Warren, Capel Issa, Manordilo (Carmarthenshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On a New Species of *Edestus* from the Upper Carboniferous of Yorkshire.' By A. Smith Woodward, LL.D., F.R.S., V.P.G.S. With a Geological Appendix by John Pringle, F.G.S.

2. 'The Tertiary Volcanic Rocks of Mozambique.' By Arthur Holmes, D.I.C., B.Sc., A.R.C.Sc., F.G.S.

Dr. A. Strahan, F.R.S., exhibited cores from borings in Kent, showing pebbles of coal embedded in Coal-Measure sandstones. With the coal-pebbles occurred a few partly-rounded fragments of chert, and in one of these radiolaria had been identified by Dr. G. J. Hinde. The chert resembled that which had been described from Lower Carboniferous rocks elsewhere. Its occurrence suggested that the sequence of strata had been similar in South Wales and Kent, and, taken in connexion with the piping of the limestone-surface at Ebbsfleet and the absence of Millstone Grit in Kent, tended to confirm the view that there is unconformity between the Coal Measures and the Carboniferous Limestone in that county.

Mr. F. P. Mennell exhibited a geological sketch-map of the northern margin of Dartmoor.

He said that the central part of Devon was to a great extent a *terra incognita*; but, as regarded the fringe of altered Carboniferous rocks along the northern border of the Dartmoor granite, he had been led, in the course of observations originally concerned with the petrology alone, to the conclusion that it might prove possible to establish a definite order of succession. This was rendered feasible by the occurrence of some well-characterized bands of rock, especially limestones and tuffs, which were exposed in every good river-section. It was true that almost everywhere overfolds, sometimes accompanied by thrusts, were to be detected, and tended to make the observer somewhat doubtful of his ground. Nevertheless, it seemed impossible to escape the conclusion that, as one approached the granite from the north, continuously older rocks were met with, and the extremely continuous character of some of the beds seemed to show that, despite all minor disturbances, the general sequence could be trusted. The comparison of the different lines of section leading up to Dartmoor showed them to be strikingly similar. The granite was, moreover, intruded all along at precisely the same horizon, and its direct offshoots never reached into the lower of the two important bands of limestone, but were confined to the altered shales at the bottom of the series, which afforded, where fresh, good examples of andalusite-hornfels. The series, which extends from south of Sourton to Drewsteignton, and perhaps right round to Doddiscombeleigh, appears clearly older than the shales which have been so carefully searched for fossils in the Exeter region by Mr. F. J. Collins. These last are considered to be of Pendleside age, and nowhere contain any traces of limestone. The probability is thus indicated that the distinctly calcareous series under consideration may represent part of the Carboniferous Limestone.

It may be noted that, although a number of bands of epidiorite representing intrusions of dolerite occur roughly parallel to the strike of the sediments, the contemporaneous rocks are never of such basic character. The main band of tuff stretches from Lake, near Bridestowe, to beyond Sticklepath, and, of the numerous well-preserved rock-fragments that it contains, most are of rhyolitic or trachytic character, with some which represent altered andesites.

Lantern-slides and specimens of *Edestus* were exhibited by A. Smith Woodward, LL.D., F.R.S., V.P.G.S., in illustration of his paper.

Lantern-slides, microscope-slides, and rock-specimens were exhibited by Arthur Holmes, D.I.C., B.Sc., A.R.C.Sc., F.G.S., in illustration of his paper.

THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

VOL. LXXII

FOR 1916.

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1. *On a* NEW SPECIES *of* EDESTUS *from the* UPPER CARBONIFEROUS *of* YORKSHIRE. By ARTHUR SMITH WOODWARD, LL.D., F.R.S., V.P.G.S. *With a* GEOLOGICAL APPENDIX *by* JOHN PRINGLE, F.G.S. (Read June 28th, 1916.)

[PLATE I.]

THE remarkable Upper Palæozoic fossil *Edestus* has already been proved to represent a row of symphysial teeth of an Elasmobranch fish, but it has hitherto been found only once in direct association with portions of jaws.[1] A second specimen, still more instructive, has now been obtained by the Geological Survey from the upper part of the Millstone Grit at Brockholes, near Huddersfield, and I am indebted to Dr. Aubrey Strahan and Dr. F. L. Kitchin for the opportunity of studying it. The circumstances of its discovery are described in the Appendix by Mr. John Pringle.

The new fossil, shown of two-thirds the natural size in Pl. I, fig. 1, displays a single example of *Edestus*, with a detached dental crown and another fragment of the same form, near the tapering ends of a symmetrical pair of cartilages (*c*) which evidently represent a jaw. Whether they are upper or lower is uncertain, on

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[1] O. P. Hay, 'On an Important Specimen of *Edestus*; with Description of a New Species, *Edestus mirus*' Proc. U.S. Nat. Mus. vol. xlii (1912) pp. 31–38 & pls. i–ii.

account of the shortness of the portions preserved; but, as the anterior ends suddenly begin to taper and eventually become very slender, they are probably the pterygo-quadrates of the upper jaw. The cartilage is well calcified in very small tesseræ, and, as shown both by the portions of jaws themselves and by remains in front of the fossil, the calcification penetrates more deeply than is usual in recent Elasmobranchs. The best-preserved outer surface of the cartilage, on the side of the specimen not shown in the figure, is slightly marked with scattered fine pittings, such as have already been described in *Edestus mirus*.[1]

The row of fused symphysial teeth (*s*) of the *Edestus* type is bilaterally symmetrical, and arched almost in the form of a semicircle. The eight teeth of which it is composed do not increase much in size backwards, and the depth of each crown slightly exceeds twice that of its root. The crown is laterally compressed and triangular in shape, much deeper than wide, with the sharp anterior and posterior edges nearly straight, and the postero-inferior angles much produced into slender, pointed extensions, which clasp the next following tooth about as far as the posterior edge of its crown. The superficial gano-dentine is smooth, but the base of the crown is impressed irregularly with a few large vertical plications or flutings, which are deepest in the anterior half and gradually disappear in the posterior extension. There is also a faint longitudinal median ridge on part of this extension. The anterior and posterior edges of the crown are coarsely serrated, the serrations (Pl. I, fig. 7) being about 30 in number on each edge, bluntly rounded (not crenulated), and those in the apical portion inclined upwards. In most of the teeth, however, the serrations are much worn by an apparently single row of opposing teeth. They are especially worn in the foremost tooth, irregularly on its anterior edge, most deeply in the lower half of its posterior edge. The wear is nearly similar in the second, third, and fourth teeth; while in the fifth and sixth teeth a large worn hollow (*w*) is conspicuous in the upper half of the posterior edge. The apical portion of the seventh tooth is unfortunately lost, but the eighth tooth is complete and unworn, displaying all the serrations as previously described. The separate tooth (*t*) behind is crushed at the base, and thus was probably not completely developed; but the crown exhibits well its smooth face and unworn serrated edges. It may be either a ninth tooth of the series displayed or one of the opposing dentition, which is otherwise represented only by a broken fragment of one tooth in the edge of the shaly matrix of the fossil.

The root of the fused symphysial teeth is well seen in front, where it has been extricated from the matrix, but it becomes vague behind where the teeth were in process of formation. In side view (Pl. I, fig. 1) the limits of the successive components are only just distinguishable; but in lower view (Pl. I, fig. 2)

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[1] O. P. Hay, Proc. U.S. Nat. Mus. vol. xlii (1912) p. 32.

the divisions between the roots of the three anterior teeth are well marked by lines of calcite. In each tooth the root is much shorter than is usual in *Edestus*, scarcely extending backwards beyond the hinder production of the base of the crown. As shown by the foremost tooth (figs. 2 & 3), the anterior margin of the root slopes downwards and backwards, and is compressed to an edge nearly as sharp as that of the crown. Its truncated lower face (fig. 2) is excavated into a triangular hollow, so that the lower face of the arch of clasping teeth is impressed by a wide longitudinal groove, of which the shape and depth are well seen in cross-section (fig. 4). Sections prove that both root and crown are solid, consisting of the usual vascular dentine of rather open texture.

Irregularly scattered over the shale below the arch of *Edestus* are the more or less broken remains of comparatively small Orodont teeth (*o*), of the form commonly described as *Campodus* or *Agassizodus.* Some of these teeth are much extended laterally, with a low central cusp (Pl. I, fig. 8); while others appear to have had little lateral extension, but a relatively-large and elevated central cusp (figs. 9 & 10). The longitudinal ridge on the summit of the crown and all the vertical buttresses on its outer and inner face are sharp and simply serrated; the superficial gano-dentine is otherwise smooth. The serrated buttress of the central cusp is especially conspicuous on its outer face; but both this and the lateral buttresses, which are widely spaced in from one to four pairs, are much more prominent on the outer than on the inner face. The compressed root is of very open texture, and seems to be inclined slightly inwards.

The fossil itself affords no definite proof that the Orodont teeth thus described belong to the same jaw as the *Edestus*, and their very small size seems at first to make their connexion improbable. Teeth of the same type, however, have already been found in association with *Edestus mirus* [1]; and one jaw of *Campodus* has been described, in which a single arched series of high-crowned symphysial teeth is relatively enormous.[2] Moreover, it will be noticed that in the new fossil from Yorkshire there is no difficulty in regarding the teeth of the *Edestus* type as an extreme modification of those of the *Campodus* type which occur with them. In the new *Edestus* the central cusp of *Campodus* has become excessively enlarged and laterally compressed, while the lateral extensions of the tooth are reduced and attenuated, and their sharp crest is represented merely by a faint longitudinal ridge. The irregular basal plications or flutings in the *Edestus* are the last remnants of the anterior (outer) lateral buttresses in *Campodus.* The first approach, indeed, towards this extreme modification occurs in the symphysial teeth of the typical jaw of *Campodus (Agassizodus)* itself, as shown in the accompanying text-figure (p. 4). Here the

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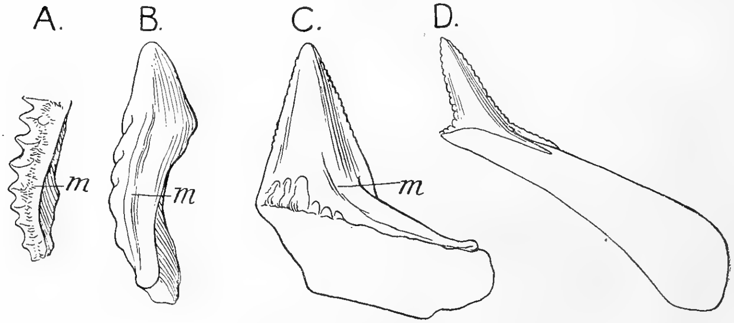
[1] O. P. Hay, Proc. U.S. Nat. Mus. vol. xlii (1912) p. 36.

[2] C. R. Eastman, 'On the Nature of *Edestus* & Related Forms' Bull. Mus. Comp. Zool. Harvard Coll. vol. xxxix (1902) pp. 55–77 & pls. i–iv.

central cusp is much enlarged and elevated, and begins to be somewhat laterally compressed, with sharp anterior and posterior (outer and inner) edges; but the lateral extensions of the tooth, although attenuated, still retain the characteristic anterior (outer) buttresses, the apical ridge throughout their length, and the typical root (B). In the new specimen of *Edestus* the same enlargement of the central cusp with reduction of the lateral extensions has progressed so far that the central feature predominates immensely, while the diminutive lateral parts curve backwards along the modified root to clasp the next successional tooth (C). In typical *Edestus* the tooth is almost entirely a laterally-compressed central cusp, while the clasping root is excessively enlarged (D).

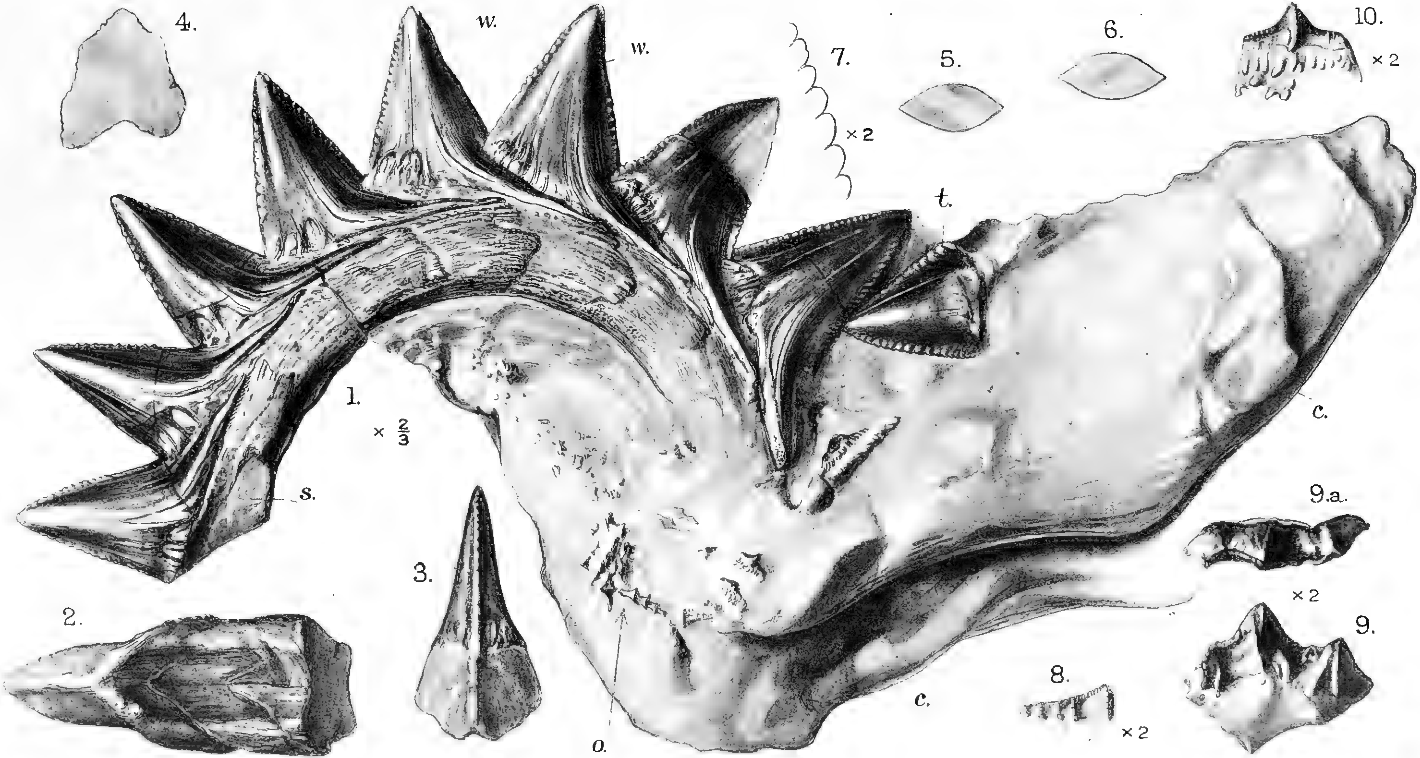
Diagrammatic sketches of half of a lateral tooth of Campodus variabilis, *upper view* (A), *and symphysial teeth of* Campodus variabilis (B), Edestus newtoni (C), *and* Edestus minor (D), *left side view, to show progressive modification.*



[m = longitudinal ridge.]

There seems thus to be no doubt that the small teeth of the *Campodus* type occurring with the new fossil really belong to it, and a question arises as to how the species represented by this jaw shall be named. *Campodus* (1844) is an older generic term than *Edestus* (1856), but it is evident that the teeth to which its definition applies belong to more than one genus: for the symphysial teeth of *Campodus variabilis*, as made known by Eastman,[1] must be regarded as generically distinct from those of the specimen now described, while the former must have been arranged as a single row only in one jaw, and as a paired row in the opposing jaw; whereas in the Yorkshire teeth the surfaces of wear show that there must have been an unpaired median row in each jaw. As the latter arrangement has already been proved by Hay to characterise *Edestus*, and as the symphysial teeth in the new fossil merely differ from those of the typical *Edestus* in the relatively-small size and extension of the root, I propose to regard it as

[1] Bull. Mus. Comp. Zool. Harvard Coll. vol. xxxix (1902) p. 58.



G. M. Woodward, del.

EDESTUS NEWTONI, sp. nov.

Bemrose, Collo., Derby

representing an extremely generalized species of *Edestus*. It differs from all known forms, not only in the shape and proportions of the root, but also in the shape of the crown and the significant flutings and faint lateral ridge at its base. It represents, in fact, a very distinct species, which may be appropriately named *Edestus newtoni*, after Mr. E. T. Newton, F.R.S., who first recorded the occurrence of *Edestus* in British Carboniferous rocks.[1]

EXPLANATION OF PLATE I.

Edestus newtoni, sp. nov.; anterior ends of cartilages of jaw (*c*), median symphysial dentition (*s*), a detached symphysial tooth (*t*), and small scattered Orodont teeth (*o*). — Millstone Grit; Brockholes, near Huddersfield, Yorkshire. (Museum of Practical Geology, London.)

[Figs. 1–6 are two-thirds of the natural size, figs. 7–10 are twice the natural size.]

Fig. 1. The whole fossil. *w*=worn surface on edge of tooth.
2. Anterior end of symphysial dentition, lower view.
3. Front view of the same.
4. Vertical transverse section of root of third tooth of the same.
Figs. 5 & 6. Transverse sections of second and eighth teeth of the same.
Fig. 7. Serrations of the border of the eighth tooth.
8. Left half of an elongated Orodont tooth (*Campodus*), front view.
9. Elevated Orodont tooth (*Campodus*), front view; and (9 *a*) upper view.
10. Elevated Orodont tooth (*Campodus*), back view.

APPENDIX.—NOTE *on the* WELL-SECTION *at* ROCK MILLS *and the* FAUNA *associated with* EDESTUS. By JOHN PRINGLE, F.G.S.

THE well at Rock Mills (Messrs. Joseph Sykes & Co.) is situated in the mill-grounds in the valley of the River Holme at Brockholes, about 4 miles south of Huddersfield. According to the Geological Survey-map (Quarter-Sheet 88 S.E.), the alluvium in the valley at this point rests on shales which underlie the Rough Rock, the uppermost member of the Millstone Grit. The shales appear to vary considerably in thickness in this district. Green[2] states that 100 feet of shales are present between the Rough Rock and Grit A about Holmfirth, which lies 2 miles south of Brockholes; while on Holestone Moor, west of Huddersfield, he estimates that they are 200 feet thick between the same horizons. Spencer[3] has shown that in the district embraced in the next sheet to the north (Quarter-Sheet 88 N.E.) the shales contain a marine fauna; and the discovery of *Edestus* should stimulate the efforts of the local geologists to further work on this horizon.

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[1] E. T. Newton, 'On the Occurrence of *Edestus* in the Coal-Measures of Britain' Q. J. G. S. vol. lx (1904) pp. 1–8 & pl. i.

[2] A. H. Green & others, 'The Geology of the Yorkshire Coalfield' Mem. Geol. Surv. 1878, p. 59.

[3] J. Spencer, 'Additional Notes on the Millstone Grit of the Parish of Halifax' Trans. Manchester Geol. Soc. vol. xiii (1873–74) p. 109.

During the excavation of the well no record of the various strata passed through was made by the sinkers; but it appears, from notes supplied by Mr. J. R. Simpson, of Banks, Honley, that the rocks were mainly shales, with some thin beds of sandstone. At the depth of 120 feet the specimen of *Edestus* was obtained by Mr. H. H. Freer in a bed of rock—rather friable shale,—which also contained numerous fragments of marine shells. Among the specimens the following have been identified:—*Posidoniella lævis* (Brown), *Gastrioceras* sp., *Glyphioceras reticulatum* (Phill.), and *Orthoceras* cf. *aciculare* Brown. At the depth of 142 feet was a dark-grey flaggy micaceous shale, crowded with shells which appear identical with *Modiola transversa* Hind. This shale formed the roof of a 3-inch coal which overlies a hard grey sandstone. The coal-seam probably corresponds to the thin coal which lies on the top of Grit A in the Huddersfield district. Water was reached at the depth of 163 feet, and the sinking was stopped after being carried down a few feet lower.

Our thanks are due to Mr. J. R. Simpson, who brought the discovery of the specimen of *Edestus* to our notice, and for his kindness in placing his specimens of the associated fauna at the disposal of the Geological Survey. The specimen was presented to the Museum of Practical Geology by Mr. E. Crowther, Managing Director of Messrs. Joseph Sykes & Co.

Discussion.

Dr. A. Strahan expressed his appreciation of the skill with which the fossil had been developed at the Natural History Museum. He wished also to take the opportunity of acknowledging the obligation under which geologists had been laid by Mr. E. Crowther in placing this unique specimen in a National Museum, where it will be studied by specialists from all parts of the world.

Mr. J. Pringle remarked that it was seldom that so interesting a specimen came before the Society, and he congratulated the Fellows on having had the opportunity of hearing Dr. Smith Woodward's lucid and illuminating account of this little-known genus. He referred briefly to the geological position of the specimen and to the associated fauna. He had had the opportunity of studying examples of marine shells obtained from the shales which yielded the *Edestus.* These comprised species of *Glyphioceras, Gastrioceras*, *Orthoceras*, and *Posidoniella.*

Mr. E. T. Newton asked Dr. Smith Woodward whether he could explain how it was that, while in *Edestus* the base of the tooth seemed to be extended backwards from the crown, in *Helicoprion* it was directed forwards.

Dr. A. Smith Woodward agreed with the last speaker that it was difficult to explain the difference in the direction of extension of the tooth in *Edestus* as compared with *Helicoprion.* The two forms seemed to have had a distinct origin.

2. *On a* Fossiliferous Limestone *from the* North Sea.[1] By Richard Bullen Newton, F.G.S. (Read June 23rd, 1915.)

[Plate II.]

Through the good services of Mr. R. W. Thomson, of the Fishery Office, Aberdeen, the British Museum has been placed in possession of two blocks of limestone, one of considerable size, crowded with the remains of marine shells, which had been obtained from the bed of the North Sea by the steam-trawler, the 'Procyon,' commanded by Captain Wood, some 80 miles east of Orkney or 100 miles north-east ½ north of Buchan Ness.

In order to acquire further information as to this unique occurrence, I communicated with Dr. A. W. Gibb, the Curator of the Geological Museum of Marischal College, Aberdeen, who kindly sent me some interesting particulars on the subject. He was familiar with the rock, having had a sample forwarded to him by Dr. Bowman, the scientific investigator on the North Sea Fisheries' boat, the 'Goldseeker,' who from considerable experience had gained some knowledge of the physical characters of the floor of the North Sea. Dr. Bowman informed Dr. Gibb

> 'that at the spot where it [the limestone] occurs, there is what seems to be a gorge or submerged channel of some kind, with much deeper water than in the adjoining sea, and he thinks that there is a considerable mass of the rock in all probability [*in situ?*], as trawlers report that they frequently break their gear upon it.'

Although found beneath the sea, this limestone nowhere displays any unusual abrasion, its aspect being entirely that of a rock which might have been obtained from an ordinary quarry or land exposure. There is nothing in its appearance to suggest transportation by glacial agencies, and it can only be surmised that deep down in the North Sea a considerable development of the rock may actually occur *in situ*. So far as can be ascertained at present, no similar limestone is known in either England or Scotland. The so-called 'Crag Strata' of Aberdeenshire, described by Jamieson as occurring beneath the Boulder Clay and consisting of stratified sand and gravel, have yielded marine mollusca of a northern type, mixed with a few Red Crag species, which Searles Wood regarded as of Red Crag age[2]; although, according to Clement Reid,[3] such beds resemble the 'Bridlington Crag' deposits of Yorkshire, and would therefore be of Pleistocene horizon. Mr. Reid further stated that there is no Pliocene in Scotland, the Red Crag shells of the glacial beds of Aberdeenshire having been probably derived from strata of that age lying beneath the North Sea. A very

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[1] Communicated by permission of the Trustees of the British Museum.

[2] Q. J. G. S. vol. xvi (1860) p. 373.

[3] 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, p. 208.

similar molluscan fauna to that occurring in the Scottish deposits has been found in the rocks of Iceland which Gwyn Jeffreys considered as Post-Tertiary and Searles Wood as 'not later than Middle Red Crag.'[1]

Reference may also be made to Jamieson's account of some semi-fossil shells of Arctic character, dredged by Robert Dawson from glacial beds underneath the sea, off the Aberdeenshire coast, from 3 to 8 miles away from land, at a depth varying from 30 to 45 fathoms. Similar shells had even been brought up by fishermen's lines at a distance of 30 miles from the coast, and none of the species were thought to occur alive in that district.[2] Besides this, we have Alfred Tylor's account[3] of fossil marine Arctic shells dredged off the Shetland Islands by Gwyn Jeffreys in about 90 fathoms of water—the species being stated to occur fossil in Sweden and still living in extreme Arctic seas.

These records of fairly late fossiliferous deposits beneath the sea are of great interest, but scarcely assist us in understanding the history of the present rock.

This North Sea limestone is of a dark-greyish colour, and is built up almost entirely of shell-remains belonging chiefly to the Pelecypoda. Microscopical tests have proved it to be highly siliceous, thus accounting for its great hardness and tenacity, which have frequently militated against complete development of some of the organisms, especially when the attempt was made to expose internal characters; otherwise, speaking generally, the fossils are well preserved, and many of their finer external markings are perfectly displayed. It has been possible to determine 23 different forms of mollusca, ten being Gastropoda, while the remainder belong to the Pelecypoda, a new species being included in that group.

If the material had been more dismantled, some additional forms might have been available for study, although in that case the larger block would have diminished in value as a museum specimen.

The shells are essentially of southern character, although it is interesting to mention that one of the commonest forms is the large *Cyprina islandica*, which is so well known as existing in boreal seas and around our British coasts, but has never been recorded from the Mediterranean: its origin, however, is to be found in the Vindobonian stage of the Miocene Period. I have mentioned this species incidentally, because it frequently occurs in the Scottish and Icelandic deposits previously mentioned, which I consider of much later age than the present limestone.

Occasional small brown masses of woody structure[4] occur in

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[1] Q. J. G. S. vol. xli (1885) p. 96.

[2] *Ibid.* vol. xxi (1865) p. 200.

[3] *Ibid.* vol. xxv (1869) p. 8.

[4] The occurrence of drift-wood in the Coralline Crag near Sudbourn Church was mentioned by Clement Reid ('The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, p. 28); but, so far as can be ascertained, no such material has been systematically described.

contact with the limestone, but of very much softer character, which from a preliminary examination appear to be of a coniferous nature, although requiring further study before a more accurate determination can be attempted.

Out of the 23 determined molluscs of this limestone 18 (or nearly 80 per cent.) trace their origin from the Vindobonian stage of the Miocene Period, 10 (or about 40 per cent.) may be regarded as extinct, whereas 12 (or 50 per cent.) are found living in recent seas.

The extinct species include :—

Streptochetus sexcostatus.
Ficus [Pyrula] simplex.
Ringiculella ventricosa.
Arcoperna sericea.
Nucula lævigata.
Yoldia oblongoides.
Lævicardium fragile.
Sinodia tertiaria, sp. nov.
Tellina benedeni.
Panopæa menardi.

The existing species are found chiefly in British and Mediterranean seas, although *Spisula ovalis* and *Cyprina islandica* belong to more boreal waters, and are never found so far south as the Mediterranean. This list embraces :—

Ranella gigantea.
Turritella communis.
Aporrhais pespelicani.
Naticina alderi.
Actæon tornatilis.
Scaphander lignarius.
Nucula nucleus.
Dentilucina borealis.
Thyasira flexuosa.
Cyprina islandica.
Isocardia humana (= cor).
Spisula ovalis.

The majority of the species recognized are fairly evenly represented in both the Coralline and the Red Crag deposits, 15 occurring in the former and about 12 in the latter. Among them the genus *Yoldia*, belonging at the present day entirely to Arctic seas, is well distributed through the limestone, specimens having been identified as Wood's *oblongoides*, which is known from the Red Crag, Norwich Crag, and later deposits of East Anglia, although never yet recorded from the Coralline Crag. Another species, however, of this genus, but not occurring in the present limestone, is *Y. semistriata*, which is restricted to Coralline Crag beds, and therefore forms an illustration of the Arctic genus *Yoldia* having been associated with a more southern fauna than prevailed during Red Crag or later geological times as represented in England.

Further support is given to the southern aspect of the fauna by the occurrence in the limestone of a new Dosiniform shell, *Sinodia tertiaria*, which presents affinities that are only to be found in the Indian Ocean and regions of Southern Asia. The comparatively large number of extinct species is greatly in favour of the North-Sea rock being of older horizon than the Red Crag, as among them are *Arcoperna sericea*, *Tellina benedeni* and *Panopæa menardi* (= *gentilis*), which are not known of later age in this country than the Coralline Crag, although *Tellina benedeni* occurs as well in the Lenham Beds and *Panopæa menardi* in the Boxstones. In connexion with the antiquity of this fauna, mention should also be made of the occurrence of *Streptochetus sexcostatus* and *Ficus simplex*, *Streptochetus sexcostatus*, a Fusiform shell, belongs to the Upper Miocene deposits of Northern Germany and Belgium (Anversian Beds), which are variously regarded as Messinian, Mio-Pliocene, or the Sarmatian-Pontian Series; in Holland the species has been recorded as of Vindobonian age. This is its first acknowledgment as a British fossil, although remains of it are found in the Lenham Beds, a fact, however, published since the reading of this paper.[1]

Ficus [*Pyrula*] *simplex* occurs only in the Messinian Beds of Northern Germany, never having been previously determined from British rocks.

In addition to these species, Gottsche[2] has recorded from the same horizon and country, *Scaphander lignarius*, *Arcoperna sericea*, *Lævicardium fragile*, and *Dentilucina borealis*, all of which form part of the fauna of the North-Sea rock.

On the assumption, therefore, that the limestone belongs to some part of the Crag system, there appears to be ample evidence that it is of older age than the Red Crag, on account both of the total absence of Arctic species, and of the comparatively large number of extinct forms which have been recognized in it. It is more likely, therefore, to be of Coralline Crag age: for, in addition to the fact that the fauna agrees in the main with the molluscan fauna of that period, there are some lithological features which may be worthy of mention.

According to the constitution of the Coralline Crag deposits of East Anglia, as explained by Prestwich,[3] the lower beds of the series contain 'irregular seams of shelly limestone'; in more recent years Mr. F. W. Harmer has also referred to a similar formation in the same deposits as 'tabular layers of limestone, very hard, and difficult to penetrate,' which were discovered in a boring at Gedgrave Hall.[4] I have not seen specimens of these limestones, although it would be desirable to compare them with the present rock. It does seem possible, however, that this North-Sea material may represent the lower portion of the Coralline Crag, and has, therefore, no connexion with Red Crag deposits, which are throughout of a sandy nature and furnish no evidence of intercalated calcareous beds.

Considering the large number of extinct molluscan species furnished by the limestone, namely, 10 out of a total of 23 (or about 40 per cent.), as against Searles Wood's computation of the Coralline Crag mollusca made in 1874, that out of 391 species 142 were not now living[5] (thus representing about 36 per cent. of extinct forms), one may infer that, if the North-Sea rock really belongs to

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[1] R. B. Newton, 'On the Conchological Features of the Lenham Sandstones of Kent & their Stratigraphical Importance' Journal of Conchology, vol. xv (1916) p. 74.

[2] Verhandl. Ver. Naturwissensch. Unter. Hamburg, 1876–78, pp. 182–85.

[3] Q. J. G. S. vol. xxvii (1871) pp. 123, 125.

[4] *Ibid.* vol. liv (1898) p. 336.

[5] See Clement Reid, 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, p. 38.

the Coralline Crag, that formation is probably of earlier age than it is usually supposed to be at the present day; and it is interesting in this connexion to note that, in his earlier researches on the Crag mollusca, Searles Wood was of opinion that the Coralline Crag deposits represented the remains of the Miocene Period in England—a view, however, which he afterwards relinquished[1] in favour of regarding them as early Pliocene. Clement Reid placed them in his 'Older Pliocene' group in association with the St. Erth Beds, the Lenham Beds, and the Boxstones,[2] whereas Mr. F. W. Harmer regards them as the base of the 'Newer Pliocene' Series and younger than the Lenham and Boxstone Beds, which he restricts to the 'Older Pliocene' division as represented in this country.[3]

It should be also stated that long before Reid and Harmer published their views on this subject, Mayer-Eymar had established the group-name 'Messinian' for the later Miocene deposits of Europe, including in it the Lower Crag because a great number of its species were found in the Helvetian stage of the Miocene.[4]

From my own studies of these mollusca, and especially those of the Lenham sandstones, I believe that no great disparity of age separates the so-called 'Older Pliocene' deposits. The faunas may differ somewhat in detail according to the special environments which governed their existence; but they all exhibit a strong southern character, and in other ways appear to resemble more the later Miocene life of Europe than that of the succeeding period.

Judging entirely, therefore, from palæontological evidence, and apart from any physical considerations, I am inclined to regard this limestone as of Coralline Crag age.

List of Molluscan Species.

GASTROPODA.

Family LAMPUSIDÆ.

RANELLA GIGANTEA Lamarck. (Pl. II, fig. 1.)

Ranella gigantea Lamarck, 'Hist. Nat. Anim. sans Vert.' 1822, vol. vii, p. 150.
Ranella reticularis Hœrnes, Abhandl. K.K. Geol. Reichsanst. 1853, vol. iii, p. 211 & pl. xxi, figs. 1–2.

Remarks.—A small example, represented by a cavity in the limestone which, with the aid of a wax squeeze, yields the sculpture characters of this species.

Distribution.—Vindobonian (Austria); Plaisancian (France and Italy); Recent (Mediterranean).

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[1] Monogr. Pal. Soc. 1848, p. v (Introduction); *ibid.* 1857, pp. 301, 302.

[2] 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, p. 2.

[3] 'Geology in the Field' Jubilee Vol. Proc. Geol. Assoc. 1909, p. 90.

[4] 'Catal. Syst. Foss. Tert. Mus. Zurich' pt. 2 (1867) p. 13.

DISTRIBUTION IN TIME AND SPACE OF THE MOLLUSCA FOUND IN THE FOSSILIFEROUS LIMESTONE FROM THE NORTH SEA.

Genera and Species.	Aquitanian.	Burdigalian.	Vindobonian (Helvetian –Tortonian).	Redonian (= Tortonian).	Messinian (Bolderian and Anversian).	Diestian.	Boxstones.	Lenham Beds.	St. Erth Beds.	Coralline Crag.	Red Crag.	Norwich Crag.	Scaldisian.	Plaisancian.	Astian.	Sicilian.	Post-Pliocene.		RECENT SEAS.
GASTROPODA.																			
Ranella gigantea Lamarck	...	...	×	...	...	...	...	...	...	...	...	...	...	×	...	...	...	×	Mediterranean.
Streptochetus sexcostatus (Beyrich).	...	...	×	...	×	...	...	×											
Ficus simplex (Beyrich)	...	...	...	...	×														
Turritella communis Risso	...	...	×	...	...	...	...	...	...	×	?	×	...	...	...	...	×	×	British and Mediterranean.
Xenophora sp.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Genus, Mediterranean and Pacific.
Aporrhais pespelicani (Linnaeus).	...	...	×	...	×	×	...	×	...	×	×	×	×	...	...	...	×	×	British and Mediterranean—Iceland.
Naticina alderi (Forbes)	...	...	×	×	...	...	...	...	...	×	...	×	...	...	...	...	×	×	British and Mediterranean (Gibraltar to Bergen).
Ringiculella ventricosa (J. de C. Sowerby).	...	...	×	...	...	...	...	...	...	×	×	×	×	×	×				

Actæon tornatilis (Linnæus) ...	...	...	...	...	×	...	...	×	...	×	×	×	×	×	×	...	×	×	British and Mediterranean.
Scaphander lignarius (Linnæus).	...	...	×	×	×	×	...	×	...	×	×	...	×	...	...	...	...	×	British and Mediterranean.
PELECYPODA.																			
Arcoperna sericea (Bronn)	...	...	×	...	×	×	...	...	...	×	...	...	×	...	×				
Nucula nucleus (Linnæus)	...	...	×	×	×	×	...	...	×	×	×	...	×	...	...	...	×	×	British, Mediterranean, and Scandinavian, not Greenland.
Nucula lævigata J. Sowerby ...	...	...	×	×	×	×	...	...	...	×	×	...	×						
Yoldia oblongoides (S. V. Wood).	...	...	...	...	...	...	...	...	...	...	×	×	...	...	...	...	×	...	Genus belongs to Arctic Seas at the present day.
Dentilucina borealis (Linnæus) .	...	...	×	...	×	×	...	...	×	×	×	×	×	×	×	...	×	×	British, Mediterranean, and North American.
Thyasira flexuosa (Montagu) ...	...	...	...	×	×	×	...	...	×	×	×	×	×	...	...	...	...	×	British, Mediterranean, and North American.
Lævicardium fragile (Brocchi) .	...	...	×	...	×	...	...	...	...	...	...	...	...	×	×				
Cyprina islandica (Linnæus) ...	...	...	×	...	×	×	×	?	...	×	?	×	×	×	×	...	×	×	British and boreal—not Mediterranean.
Isocardia humana (Linnæus) ... (*= cor*)	...	...	×	...	...	×	×	×	...	×	×	...	×	...	×	...	...	×	British and Mediterranean.
Sinodia tertiaria, sp. nov.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Genus restricted to seas off Southern Asia.
Tellina benedeni Nyst & Westendorp.	...	...	...	...	×	×	...	×	...	×	...	...	×	...	...	...	...	...	[Derivative in Red Crag.]
Panopæa menardi Deshayes......	...	...	×	...	×	...	×	...	...	×	...	...	×	...	...	...	...	...	[Derivative in Red Crag.]
Spisula ovalis (J. Sowerby)	...	...	×	×	...	...	...	...	...	...	×	×	×	...	..	...	×	×	British, not Mediterranean.

Family FUSIDÆ.

STREPTOCHETUS SEXCOSTATUS (Beyrich). (Pl. II, figs. 2 & 3.)

Fusus sexcostatus Beyrich, Zeitschr. Deutsch. Geol. Gesellsch. 1856, vol. viii, p. 73 & pl. xxiv, fig. 2.
Streptochetus sexcostatus Cossmann, 'Essais de Paléoconchologie Comparée' 1901, pt. iv, p. 31.

Remarks.—This species, I believe, is represented in the English Crag deposits by Wood's *Fusus waeli*,[1] a form that I am unable to recognize as the Belgian shell which was originally described by Nyst from the Oligocene (Rupelian) rocks of that country. A perfect comparison, however, is impossible, as Wood's type-specimens do not appear to be in the British Museum. It is worthy of notice that Wood directed attention to an artistic error in his figure 10 *b*, which exhibited denticulations on the inner surface of the labrum, a character which was neither present in the English shell nor in *S. sexcostatus* from the German Miocene.

Distribution.—Vindobonian (Holland); Messinian (North Germany); Anversian (Belgium); Lenham Beds (Britain).

Family FICIDÆ.

FICUS SIMPLEX (Beyrich). (Pl. II, figs. 4 & 5.)

Pyrula simplex Beyrich, Zeitschr. Deutsch. Geol. Gesellsch. 1854, vol. vi, p. 777 & pl. xviii (xv), fig. 3.
Ficula simplex Gottsche, Verhandl. Ver. Naturwissensch. Unter. Hamburg, 1878, vol. iii, p. 182.

Remarks.—Bolten's *Ficus* of 1798 antedates both Lamarck's *Pyrula* and Swainson's *Ficula*, all of which are founded on the same Linnæan type of *Bulla ficus*.

Distribution.—Messinian (North-Western Germany).

Family TURRITELLIDÆ.

TURRITELLA COMMUNIS Risso.

Turritella communis Risso, 'Histoire Naturelle de l'Europe Méridionale' 1826, vol. iv, p. 106 & pl. iv, fig. 37.
Turritella terebra J. de C. Sowerby, 'Mineral Conchology' 1827, vol. vi, p. 126 & pl. dlxv, fig. 3, *non* Linnæus.

Distribution.—Vindobonian (France); Coralline Crag to Post-Pliocene (Britain); Recent (Mediterranean and British Seas).

Family XENOPHORIDÆ.

XENOPHORA sp. (Pl. II, fig. 6.)

Distribution.—This genus is unknown in the East Anglian Crag deposits, although occurring in the Lenham Beds of Kent.

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[1] Mon. Pal. Soc., Crag Mollusca, Suppl. 2 (1879) p. 9. & pl. i, figs. 10 *a*–10 *c*.

It belongs more particularly to the Mio-Pliocene strata of Italy, Belgium, Holland, and Austria, besides surviving in recent seas (Mediterranean and Pacific).

Family APORRHAIDÆ.

APORRHAIS PESPELICANI (Linnæus).

Strombus pespelicani Linnæus, 'Systema Naturæ' 10th ed. 1758, p. 742.

Distribution.—Vindobonian (Austria, Italy); Plaisancian and Astian (Italy, France); Anversian and Scaldisian (Belgium); Lenham Beds (Britain); Coralline Crag to Post-Pliocene (Britain); Recent (Mediterranean and British Seas).

Family NATICIDÆ.

NATICINA ALDERI (E. Forbes). (Pl. II, figs. 7 & 8.)

Natica alderi E. Forbes, 'Malacologia Monensis' 1838, p. 31 & pl. ii, figs. 6–7.
Natica (Naticina) alderi Dollfus, C. R. Assoc. Franç. Av. Sci. (Cherbourg, 1905) 1906, p. 368.

Distribution.—Vindobonian (Holland); Messinian (Germany); Redonian (France); Coralline and Norwich Crags to Post-Pliocene (Britain); Recent (Mediterranean and British Seas).

Family RINGICULIDÆ.

RINGICULELLA VENTRICOSA (J. de C. Sowerby). (Pl. II, figs. 9 & 10.)

Auricula ventricosa J. de C. Sowerby, 'Mineral Conchology' 1824, vol. v, p. 99 & pl. cccclxv, fig. 1.
Ringiculella auriculata var. *ventricosa*, Sacco, 'Moll. Terz. Piemonte' 1892, pt. 12, p. 25; *ibid.* 1904, pt. 30, p. 110 & pl. xxiv, figs. 25–26.

Remarks.—The shorter, broader, and more inflated volutions, as mentioned by S. V. Wood, are sufficient to separate this species from Brocchi's *R. buccinea*, which belongs to the Italian Tertiaries and existing seas. The genus is well known in the Mediterranean.

Distribution.—Vindobonian to Astian (Italy); Scaldisian (Belgium); Coralline Crag to Norwich Crag (Britain).

Family ACTÆONIDÆ.

ACTÆON TORNATILIS (Linnæus).

Bulla tornatilis Linnæus, 'Systema Naturæ' 10th ed. 1758, p. 728.
Actæon striatus J. de C. Sowerby, 'Mineral Conchology' 1824, vol. v, p. 87 & pl. cccclx, fig. 2.
Actæon tornatilis S. V. Wood, Monogr. Pal. Soc. (Crag Mollusca) 1848, p. 170 & pl. xix, fig. 5.

Distribution.—Vindobonian (Holland); Plaisancian and Astian (Italy); Anversian and Scaldisian (Belgium); Lenham Beds (Britain); Coralline Crag to Post-Pliocene (Britain); Recent (Mediterranean and British Seas).

Family SCAPHANDRIDÆ.

SCAPHANDER LIGNARIUS (Linnæus).

Bulla lignaria Linnæus, 'Systema Naturæ,' 10th ed. 1758, p. 727.
Scaphander lignarius Montfort, 'Conchyl. Syst.' 1810, vol. ii, pp. 334–35.

Distribution.—Vindobonian (Austria, Holland, Italy); Redonian (France); Plaisancian and Astian (Italy); Bolderian to Scaldisian (Belgium); Lenham Beds (Britain); Coralline and Red Crags (Britain); Recent (Mediterranean and British Seas).

PELECYPODA.

Family MYTILIDÆ.

ARCOPERNA SERICEA (Bronn).

Modiola sericea Bronn, 'Italiens Tertiär-Gebilde' 1831, p. 112; Philippi, 'Enum. Moll. Siciliæ' 1836, vol. i, p. 71 & pl. v, fig. 14.
Arcoperna sericea Sacco, 'Moll. Terz. Piemonte' 1898, pt. 25, p. 43 & pl. xii, figs. 8–9.

Distribution.—Vindobonian (Austria, Italy); Messinian (North Germany); Anversian to Scaldisian (Belgium); Coralline Crag (Britain); Astian (Italy).

Family NUCULIDÆ.

NUCULA NUCLEUS (Linnæus).

Arca nucleus Linnæus, 'Systema Naturæ' 10th ed. 1758, p. 695; *ibid.* (Gmelin) 1790, 13th ed. vol. i, pt. 6, p. 3314.

Distribution.—Vindobonian (Austria); Redonian (France); Anversian to Scaldisian (Belgium); Coralline Crag to Post-Pliocene (Britain); Recent (Mediterranean and British Seas, etc.).

NUCULA LÆVIGATA J. Sowerby. (Pl. II, fig. 11.)

Nucula lævigata J. Sowerby, 'Mineral Conchology' vol. ii, 1818, p. 207 & pl. cxcii, figs. 1–2.

Remarks.—This large and tumid Nuculoid shell is of frequent occurrence in the limestone, and in general features resembles *Nucula cobboldiæ* of J. Sowerby, but is without the divaricate sculpture of that species.

Distribution.—Vindobonian (Holland); Redonian (North-Western France); Anversian to Scaldisian (Belgium); Coralline and Red Crags (Britain); Astian (Holland).

Family NUCULANIDÆ.

YOLDIA OBLONGOIDES (S. V. Wood). (Pl. II, fig. 12.)

Nucula oblongoides S. V. Wood, Mag. Nat. Hist. (Charlesworth), 1840, n. s. vol. iv, p. 297 & pl. xiv, fig. 4.
Leda myalis S. V. Wood, Monogr. Pal. Soc. (Crag Mollusca) 1851, p. 90 & pl. x, fig. 17, *non* Couthouy.

Remarks.—This species is of fairly abundant occurrence, and shows relationship both to *Y. hyperborea* Torell and to *Y. limatula* Say, of modern seas (boreal), from which it chiefly differs in the possession of thicker and more convex valves.

Distribution.—Red Crag to Post-Pliocene (Britain).

Family LUCINIDÆ.

DENTILUCINA BOREALIS (Linnæus).

Venus borealis Linnæus, 'Systema Naturæ' 12th ed. 1767, vol. i, pt. 2, p. 1134.
Dentilucina borealis Sacco, 'Moll. Terz. Piemonte' 1901, pt. 29, p. 80 & pl. xviii, figs. 23–26.

Distribution.—Vindobonian (Holland, Italy, Austria); Redonian (North-Western France); Messinian (North Germany); Anversian, Diestian, and Scaldisian (Belgium); Plaisancian and Astian (Italy, France); St. Erth Beds to Post-Pliocene (Britain); Recent (Mediterranean and British Seas, etc.).

Family THYASIRIDÆ.

THYASIRA FLEXUOSA (Montagu).

Venus sinuosa Donovan, 'Nat. Hist. British Shells' 1801, pl. xlii, fig. 2, *non* Pennant, 1777.
Tellina flexuosa Montagu, 'Test. Britannica' 1803, pt. 1, p. 72.
Thyasira flexuosa (Leach MS.), Lamarck, 'Histoire Naturelle des Animaux sans Vertèbres' 1818, vol. v, p. 492.

Distribution.—Redonian (North-Western France); Anversian to Scaldisian (Belgium); Coralline Crag, Chillesford Beds, and Post-Pliocene (Britain); Recent (Mediterranean and British Seas, etc.).

Family CARDIIDÆ.

LÆVICARDIUM FRAGILE (Brocchi).

Cardium fragile Brocchi, 'Conchiologia Fossile Subapennina' 1814, vol. ii, p. 505 & pl. xiii, fig. 4.
Lævicardium norvegicum Sacco, 'Moll. Terz. Piemonte' 1899, pt. 27, p. 51 & pl. xi, figs. 41–42.

Distribution.—Vindobonian (Austria); Messinian (North-Western Germany); Plaisancian and Astian (Italy).

Family CYPRINIDÆ.

CYPRINA ISLANDICA (Linnæus *em.* Müller).

Venus islandica Linnæus, 'Systema Naturæ' 1767, 12th ed. vol. i, pt. 2, p. 1131 (without reference to a type form); Müller, 'Zool. Danicæ Prod.' 1776, p. 246 (no. 2977).
Cyprina islandica Nyst, 'Coquilles & Polypiers Foss. Tert. Belg.' Mém. Cour. Acad. Roy. Belg. 1843–45, vol. xvii, p. 146, pl. ix, fig. 1 & pl. xi, fig. 1.

Remarks.—The valves of this species are of abundant occurrence, while some of the adult examples measure from 80 to 85 millimetres in length and height.

Distribution.—Vindobonian (Holland); Anversian to Scaldisian (Belgium); Plaisancian and Astian (Italy); Boxstones, Lenham Beds, and Coralline Crag to Post-Pliocene (Britain); Recent (British and Boreal seas, *non* Mediterranean).

ISOCARDIA HUMANA (Linnæus). (Pl. II, fig. 13.)

Cardium humanum Linnæus, 'Systema Naturæ' 1758, 10th ed. p. 682.
Chama cor Linnæus, 'Systema Naturæ' 1767, 12th ed. vol. i, pt. 2, p. 1137.
Isocardia cor Lamarck, 'Hist. Nat. Anim. sans Vert.' 1819, vol. vi, pt. 1, p. 31.
Isocardia humana Dall, Trans. Wagner Free Inst. Sci. Philadelphia (Tertiary Fauna of Florida), 1900, vol. iii, pt. 5, p. 1064.

Distribution.—Tortonian (Italy, Holland); Plaisancian and Astian (Italy); Diestian and Scaldisian (Belgium); Boxstones, Lenham Beds, Coralline Crag, and derivative in Red Crag (Britain); Recent (Mediterranean and British Seas).

Family DOSINIIDÆ.

SINÓDIA TERTIARIA, sp. nov. (Pl. II, figs. 14–16.)

Description (Right valve).—Shell solid, inæquilateral, suborbicular, height in excess of length, well arched; posterior region deep, sloping, marginal curvature extensive; dorso-anterior margin oblique, straight, long; ventral margin gradually ascending to unite with the expanded and rounded edge of the lower anterior side; lunuloid region superficial, large, ovately-elongate, obscurely circumscribed; hinge area massive, deep, bearing two divergent, thick, robust, cardinal teeth, also a third and smaller cardinal in front, of more or less laminate appearance; ligamental furrow wide, long, and prominent; pallial sinus triangulate, moderately wide at the base, apex obtuse; internal margin smooth; surface covered with well-marked, nearly equidistant, elevated growth-lines and numerous finer concentric striæ occupying the intervening spaces, the whole crossed by obscure radial striations.

Dimensions in millimetres.—Largest example, right valve. Length = 50; height = 53; diameter = 16.

Remarks.—The more striking features of this shell include the anterior obliquity, the long and superficial lunuloid area, the nearly equidistant growth-lines, and the extensive curvature of the posterior margin. It appears to be allied to Chemnitz's *Venus excisa* rather than to the other forms referred to this genus, which are of more distinctly trigonal contour. The shell is fairly common in the North-Sea limestone, although it is difficult to obtain specimens with perfect internal characters; one example, however, does exhibit a partial internal cast of a left valve, showing the presence of a well-marked, obtusely-pointed, and triangulate pallial sinus. It is proposed to name this shell *Sinodia tertiaria*.

It is interesting to find among these fossils a new Dosiniform shell that can be referred to Jukes-Browne's *Sinodia*,[1] which was established on the type of *Dosinia trigona* of Reeve, and also includes the *Venus excisa* of Chemnitz. *Sinodia* is chiefly distinguishable from the true *Dosinia* by reason of its oblique and straight dorso-anterior margin, followed by an expanded anterior side. It is known only in the living state, being restricted to the waters of the Indian Ocean, particularly the coasts of Southern Asia.

Family TELLINIDÆ.

TELLINA BENEDENI Nyst & Westendorp. (Pl. II, fig. 17.)

Tellina zonaria Nyst, 'Recherch. Coq. Foss. Anvers' 1835, p. 4, *non* Basterot.
Tellina benedeni Nyst & Westendorp, Bull. Acad. R. Sci. Bruxelles, 1839, vol. vi, pt. 2, pl. ii, fig. 5 *bis* & pl. iii, fig. 5, p. 399. =*T. fallax* Beyrich, a manuscript name.

Remarks.—This is by far the most abundant mollusc in the limestone, and well agrees with the typical form from the Belgian Upper Tertiaries. Examples are chiefly preserved as natural casts which exhibit well-marked muscular and other impressions, as also the extensive pallial sinus with its elevated and obtuse summit.

Distribution.—Anversian to Scaldisian (Belgium); Middle Pliocene (Holland); Lenham Beds and Red Crag—derivative (Britain).

Family SAXICAVIDÆ.

PANOPÆA MENARDI Deshayes.

Panopæa faujasii Basterot, Mém. Soc. Hist. Nat. Paris, 1825, vol. ii, pt. 1, p. 95, *non* Ménard de la Groye.
Panopæa menardii Deshayes, 'Dict. Class. Hist. Nat.' 1828, vol. xiii, p. 22.
Panopæa gentilis J. de C. Sowerby, 'Mineral Conchology' 1840, vol. vii, p. 1 & pl. dcx, fig. 1.

Distribution.—Vindobonian (France, Poland, Austria, Switzerland, Italy, Holland); Anversian and Scaldisian (Belgium); Boxstones, Coralline Crag, and Red Crag—probably derivative (Britain).

Family MACTRIDÆ.

SPISULA OVALIS (J. Sowerby).

Mactra ovalis & dubia J. Sowerby, 'Mineral Conchology' 1817, vol. ii, p. 136 & pl. clx, figs. 2–5.

Distribution.—Vindobonian (Switzerland); Redonian (North-Western France); Middle Pliocene (Holland); Scaldisian (Belgium); Red Crag to Post-Pliocene (Britain); Recent (British Seas, *non* Mediterranean).

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[1] Proc. Malacol. Soc. London, vol x (1912) pp. 100–104.

Postscript.

[Since the reading of this paper two memoirs have been published on some Miocene limestones from the North-Sea basin (Denmark and Germany) containing molluscan remains, several species of which are identical with those found in the North-Sea Limestone.

In a Middle Miocene boulder from Esbjerg (Denmark), E. M. Nörregaard[1] has reported the occurrence, among other shell-remains, of *Arcoperna sericea, Tellina benedeni, Naticina alderi, Streptochetus sexcostatus,* and *Actæon tornatilis*; while Karl Gripp[2] enumerates the same species as occurring in some older Miocene deposits of Denmark and Germany, with the following additional forms:—*Isocardia humana (=cor), Thyasira flexuosa, Dentilucina borealis, Lævicardium fragile, Cyprina* cf. *islandica, Tellina benedeni (=fallax), Panopæa menardi, Ficus simplex,* and *Ringiculella ventricosa,* all of which are found in the North-Sea Limestone. Again, attention may be directed to a recently published account of the Lenham Sandstone Mollusca,[3] which have been referred to a late Miocene age, the following species contained therein indicating affinities with the fauna of the North-Sea Limestone:—*Aporrhais pespelicani, Streptochetus sexcostatus, Actæon tornatilis, Scaphander lignarius, Yoldia oblongoides, Isocardia humana, Dentilucina borealis, Tellina benedeni,* and *Panopæa menardi.* R. B. N. March 27th, 1917.]

EXPLANATION OF PLATE II.

[All the figures are of the natural size, except where otherwise stated.]

Fig. 1. *Ranella gigantea* Lamarck. (See p. 11.) Prepared from a wax model taken from a limestone cavity.
2. *Streptochetus sexcostatus* (Beyrich). (See p. 14.)
3. The same, showing magnified sculpture.
4. *Ficus simplex* (Beyrich). (See p. 14.)
5. The same, showing details of sculpture, magnified.
6. *Xenophora* sp. (See p. 14.) Fragmentary specimen exhibiting adherent cavities on the whorl.
7. *Naticina alderi* (E. Forbes). (See p. 15.)
8. The same.
9. *Ringiculella ventricosa* (J. de C. Sowerby). (See p. 15.) Front view, × 3.
10. The same, showing sculpture lines, magnified.
11. *Nucula lævigata* J. Sowerby. (See p. 16.)
12. *Yoldia oblongoides* (S. V. Wood). (See p. 16.)
13. *Isocardia humana* (Linnæus). (See p. 18.)

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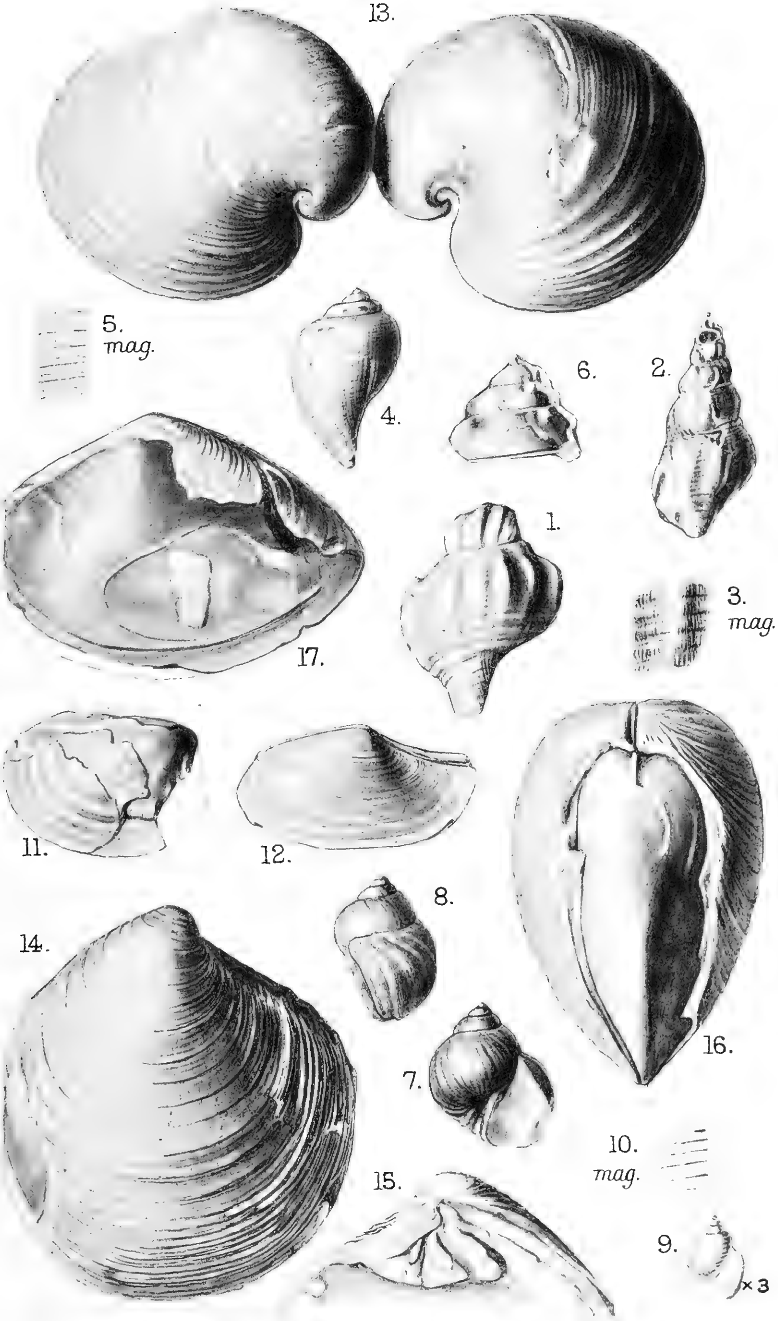
[1] 'Mellem-Miocæne Blokke fra Esbjerg' Danmarks Geol. Undersög. ser. 4, vol. i, No. 5 (1916) pls. i–iii, pp. 58.

[2] 'Ueber das Marine Altmiocän im Nordseebecken' Neues Jahrb. Beilage-Band xli (1916) p. 59, pls. i & ii (maps).

[3] R. B. Newton, 'On the Conchological Features of the Lenham Sandstones of Kent & their Stratigraphical Importance' Journal of Conchology, vol. xv (1916) pp. 111, 112.



G. M. Woodward, del.
Bemrose, Collo., Derby.

TERTIARY MOLLUSCA FROM NORTH SEA LIMESTONE.

[All the figures are of the natural size, except where otherwise marked.]

Fig. 14. *Sinodia tertiaria*, sp. nov. (See p. 18.) Right valve, external view.
15. The same specimen, showing dentition.
16. Wax model of a limestone cavity of another example, with parts of both valves in the closed condition.
17. *Tellina benedeni* Nyst & Westendorp. (See p. 19.) Internal cast, showing features of the pallial line, etc., accompanied by fragments of shell-structure.

DISCUSSION.

The PRESIDENT (DR. A. SMITH WOODWARD) alluded to the interest of the discovery in submarine geology which had been studied with so much care by the Author. So far as could be judged from the accounts of the trawlers, the block of rock was broken from a prominent ridge well known to them. He looked forward to important results from borings in the bed of the sea, which might be obtained by such an apparatus as (he understood) was about to be used by Prof. John Joly.

Mr. G. W. LAMPLUGH congratulated the Author on his very notable addition to our scanty knowledge of the rock-floor of the North Sea. Geologically, this area was as essentially part of Europe as the land above water, and deserved every possible effort to determine its structure. Much of the Glacial Drift on the margin of Eastern England had been dragged in from seaward, and gave some indication of the character of the sea-floor. This material included transported patches of early Glacial marine deposits, along with masses of Jurassic and Cretaceous strata; but in no case had the speaker seen, in the Drifts between the Tees and the Humber, any rock resembling that now exhibited. It seemed unlikely that any bed of rock like that on the table existed beneath the southern part of the North Sea, and the present discovery certainly added a new and important factor to the geology of the whole basin. He would ask whether the Author had considered the possibility that the rock might originate from a detached mass carried by the ice-flow from the Baltic basin, as the site of the discovery lay in the right position for such transport.

Mr. T. CROOK welcomed this further addition to the record of areas beneath the sea and around the British coasts, where boulders and other masses of rock-detritus are to be found lying on or very near the submarine outcrops from which they have been detached. The fact that these latitudes have been affected by glaciation has led many to adopt too readily the view that, wherever large boulders occur on the sea-floor, their presence is to be attributed to transport by ice. There are doubtless many glacial erratics on the sea-floor, and in some areas there is apparently an abundance of detritus of the ordinary Glacial-Drift type—as, for instance, in the almost landlocked Irish Sea, and in parts of the North Sea where one naturally expects to find much ice-carried material.

For some years past, however, strong evidence has been accumulating to show that there are extensive areas beneath the sea around the British coasts, where the amount of Glacial detritus, and even far-transported detritus of any sort, is insignificant compared with the amount of detritus derived from local submarine outcrops. This seems to be the rule throughout extensive areas on the submerged continental shelf west of the British Isles. The immense burden of gabbro-boulders on the Porcupine Bank is one of many good examples. The Porcupine Bank is some 130 miles west of the Galway coast, and presumably it consists in large part of a submarine outcrop of gabbro.[1] Submarine outcrops of Cretaceous and Eocene limestones have been fairly well proved to exist in the English Channel and off the south-western coast of Ireland.

The present record of a submerged outcrop of supposed Coralline Crag off the east coast of Scotland was all the more interesting, because it related to an area where a covering of Glacial detritus might be expected.

Mr. E. A. Martin understood that the submarine channel from which this and similar specimens had been obtained was well known to the Aberdeen trawlers, and he wished to enquire whether there was any information available as to the current-flow through the channel; for the current, if a strong one, would tend to remove any marine detritus that would otherwise have masked the outcrop of the rock. It seemed to him that the channel might have formed a part of the old bed of the Rhine when the North-Sea area was land. He hoped that investigations in submarine geology would, in the near future, be facilitated by the use of submarine vessels suitably equipped for the purpose.

Mr. H. W. Monckton remarked on the great interest of the paper and of the specimens exhibited. He thought that, in the absence of evidence that the specimens were derived from a boulder, it was safest to assume that the rock had been *in situ* in the North Sea. The association of forms in the big block did not look like Red Crag or, for the matter of that, like Coralline Crag. He suggested Diestian as a possible age for the formation in question.

Mr. G. W. Young enquired as to the condition of the exterior of the specimen. If it had been dragged off an exposed mass of rock *in situ*, one would expect to find numerous recent marine organisms attached to it; whereas, if it were a boulder from Glacial Drift, this condition would be less likely.

Mr. W. H. Booth stated that he had himself secured a piece of shell-conglomerate, similar to the piece on the table, from a London borehole. He had always referred it to the Woolwich Beds, but could now state definitely that it had been found below the Thanet Sand.

The Author replied to the various points raised in the discussion, and thanked the Fellows for the reception of his paper.

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[1] See G. A. J. Cole & T. Crook, 'Rock-Specimens Dredged from the Floor of the Atlantic, & their Bearing on Submarine Geology' Mem. Geol. Surv. Ireland, 1910.

3. FURTHER WORK *on the* IGNEOUS ROCKS *associated with the* CARBONIFEROUS LIMESTONE *of the* BRISTOL DISTRICT. By SIDNEY HUGH REYNOLDS, M.A., Sc.D., F.G.S., Professor of Geology in the University of Bristol. (Read April 28th, 1915.)

CONTENTS.

I. INTRODUCTION.

IN 1904 the Geological Society published a paper[1] by Prof. Lloyd Morgan and myself on 'The Igneous Rocks associated with the Carboniferous Limestone of the Bristol District.' Since that date enough additional information has been obtained, largely by digging trial-holes, to justify the present paper. The paper mentioned above summarizes the previous work on these rocks, and the references there given will not be repeated here. The following further communications have, however, been published:—

1. Prof. W. S. Boulton,[2] in 1904, recorded many additional observations on the lava of Spring Cove, Weston-super-Mare, and its relations to the associated tuff and limestone. Prof. Boulton had already, at the meeting of the British Association at Southport[3] in 1903, given a preliminary account of the section.
2. In 1904 a paper was published in the Bristol Naturalists' Society's Proceedings[4] entitled 'The Field Relations of the Carboniferous Volcanic Rocks of Somerset.' In this paper the field-observations by all previous writers were collected together.
3. A short paper, 'The Igneous Rocks of the Bristol District,'[5] which I prepared for the visit of the Geologists' Association to Bristol in 1907, summarizes the character of these rocks, but contains no fresh information.

   The report by the Directors,[6] on the excursions made during this visit, includes a short account of the Spring-Cove section with a plate of reproductions of photographs.
4. There is a brief description of these rocks in the chapter on the Palæozoic rocks of Gloucestershire and Somerset, in 'Geology in the Field,' the Jubilee volume of the Geologists' Association,[7] published in 1910.

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[1] Q. J. G. S. vol. lx, pp. 137–57.

[2] *Ibid.* pp. 158–69.

[3] Rep. Brit. Assoc. (Southport, 1903) p. 660.

[4] N. s. vol. x, pt. 3 (issued for 1903) pp. 188–212.

[5] Proc. Geol. Assoc. vol. xx (1907–1908) pp. 59–65.

[6] *Ibid.* pp. 154–55 & pl. iv, figs. 1–2.

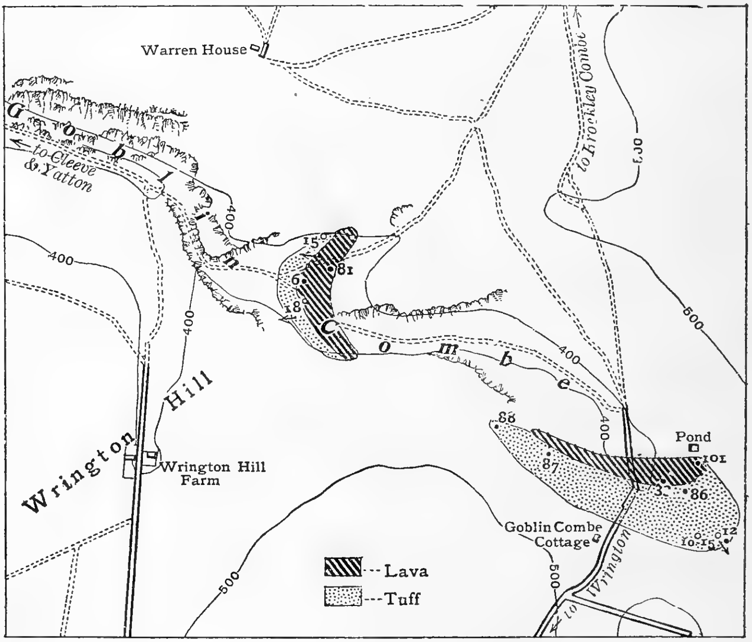
[7] Pp. 322–23, pl. vi, fig. 2, & pl. vii, figs. 1–2.

This is illustrated by vertical sections showing the position of the volcanic series in the Carboniferous sequence of the district, and by three reproductions of photographs.

5. In 1912, in connexion with the preparation of the second edition of the Geological Survey Memoir explanatory of Sheet 263, 'The Country around Cardiff,' Dr. Strahan re-examined the exposures of the Weston-super-Mare district, and recorded certain fresh ones (pp. 26–35).
6. The rocks are described in my Geological Excursion Handbook for the Bristol district (published by Arrowsmith in 1912): Excursions 8, 11, 12, 13.

Note.—In connexion with the investigations recorded in this paper, more than fifty trial-holes were dug. The cost of these, as also of the chemical analyses, was defrayed by grants from the University-of-Bristol Colston Society. Unless otherwise stated, the analyses were all carried out by Mr. E. G. Radley.

Fig. 1.—*Sketch-map of the igneous exposures in Goblin Combe, on the scale of 4 inches to the mile.*



II. Field Relations of the Rocks.

(*a*) Goblin Combe.

The existence of volcanic rocks in Goblin Combe was first proved by William Sanders, whose map, published in 1864, shows four exposures: two small ones near the eastern end of the Combe, and two farther west.

No allusion to these rocks is made in the Geological Survey Memoir on the East Somerset & Bristol Coalfield, published in 1876; but two patches are shown as intrusive masses in the 1-inch Geological Survey map revised to 1873. In the account by Sir Archibald Geikie and Dr. Strahan of the volcanic group in the Carboniferous Rocks of North Somerset[1] it is suggested that the two outcrops may belong to the same band, and it is mentioned that the western one was traced for some distance by means of débris thrown out by moles. In the 1-inch Geological Survey map, with additions to 1899, which is at present on sale, the outcrop of the igneous rock is shown as forming an oval ring.

Western group of exposures.—These lie in the neighbourhood of the footpath which, diverging from the main path due south of Warren House, trends in a north-easterly direction. It is clear, from the material thrown out by rabbits, that lava occupies a considerable area in this neighbourhood, and the digging of a series of trial-holes showed that the exposure is shaped somewhat like a boomerang—one arm extending a considerable distance up the hillside south-south-east of Warren House, while the other crosses the main path and runs up the slope to the south.

I am confident that the ring-shaped outcrop as marked in the latest 1-inch Geological Survey map does not accurately represent the facts, and that for a long distance along the northern line of the supposed outcrop, and for a shorter distance along the southern, the rock really present is limestone. Along the line of a track (not shown in the 6-inch map) which leads off to the left from the north-eastward-trending path alluded to above, occurs a relatively continuous section of calcareous tuff which was further exposed by pick-work. The rocks dip at about 15° in a westerly direction, and clearly overlie the lava. The section is as follows:—

		Thickness in feet.
6. Red sandy limestone passing up into pale calcareous sandstone, and down into moderately coarse calcareous tuff	about	22
5. Fine green calcareous tuff	about	9
Gap of about 5 feet.		
4. Fine greenish calcareous tuff very poorly exposed	about	5
Gap of 30 feet—nothing seen, except a small and poor exposure of dolomitized limestone.		
3. Red and greenish calcareous tuff, sometimes gritty, sometimes rather coarse, exposed by pick-work	say	8
Gap of 8 feet.		
2. Band of Carboniferous Limestone.		
1. Basalt (81) exposed by trenching at the bottom of the lateral valley.		

The limestone (band 2) is probably on the strike of a mass exposed in the angle between the main path through the Combe and that which diverges to the north-north-east.

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[1] 'Summary of Progress of the Geological Survey for 1898' Mem. Geol. Surv. 1899, p. 110.

Eastern group of exposures.—The best of these exposures (at the point marked 12 in the map, fig. 1) was somewhat fully described in 1904. It consists of about 12 feet of red and greenish calcareous tuff dipping at 10° to 15° south-eastwards. Much red calcareous tuff occurs as blocks heaped up in the neighbouring hedge-banks, and the rock is seen *in situ* at the root of a tree a short distance north of spot 12, and was exposed at the spot 86 (in the corner of the next field to the west) by a little excavation. It was in this field that blocks of fresh olivine-basalt were noticed in 1902, although nothing was found in place. The basalt, however, occurs here, and was exposed at the point 33 by a little work with the pick. The basalt also extends into the next field to the east, where it forms a somewhat noticeable ridge, and was quickly reached by trenching at the point 101 to the south-east of the pond. This is the last sign of the igneous series in that direction, nothing but limestone occurring on the north and north-west until the western exposure is approached. A broad band of tuff, identical in character with that seen at the point 12, extends in a west-north-westerly direction through the orchard north-west of Goblin Combe Cottage. It was exposed by digging trial-holes at the points 87 and 88, and numerous blocks are to be seen built into the neighbouring walls. The basalt also accompanies the tuff in its extension to the west-north-west; numerous pieces thrown out by rabbits were to be found in 1914 near the point 87, and the rock was proved by digging at a spot some distance farther north-west.

(*b*) Uphill.

The exposure here is in a little overgrown quarry opening off from the western side of the railway, about 250 yards north of Bleadon & Uphill Station. The rock is very badly exposed, but at the southern margin of the quarry (see figs. 2 & 3) an amygdaloidal rock is seen resting upon a distinctly uneven surface of cherty limestone. Immediately north and south of this exposure débris and vegetation obscure the relations of the rocks; but a short distance away to the south a continuous section of limestone is seen, the beds striking directly at the igneous rock. This is probably explicable by a fault to the south of the igneous exposure; but if, as is possible, the rock is intrusive, no fault need be postulated, and the uneven line of junction between trap[1] and limestone is itself suggestive of an intrusion.

Six excavations were made in the floor of the quarry, and in four of these trap was met with. In the two southernmost (1 and 2), only the base of the trap, which is in a much weathered condition, was exposed, resting on cherty limestone stained red by iron oxide. An excavation (3) at the base of the cliff on the west side of the quarry, showed cherty limestone overlying the trap.

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[1] The old term 'trap' is convenient for use, when one does not wish to prejudge the question, either as to the nature of the rock, or as to its method of occurrence.

In two near the middle of the quarry (4 and 5) massive trap was well exposed, and in one (6) at the northern end of the quarry the underlying limestone was penetrated. These excavations, although they do not prove whether the trap is a sill or a lava-flow, show that it extends as a band, perhaps 4 feet thick, across the floor of the quarry.

Fig. 2.—*Sketch of the little old quarry by the railway, 250 yards north of Bleadon & Uphill Station. (Length = about 30 yards.)*

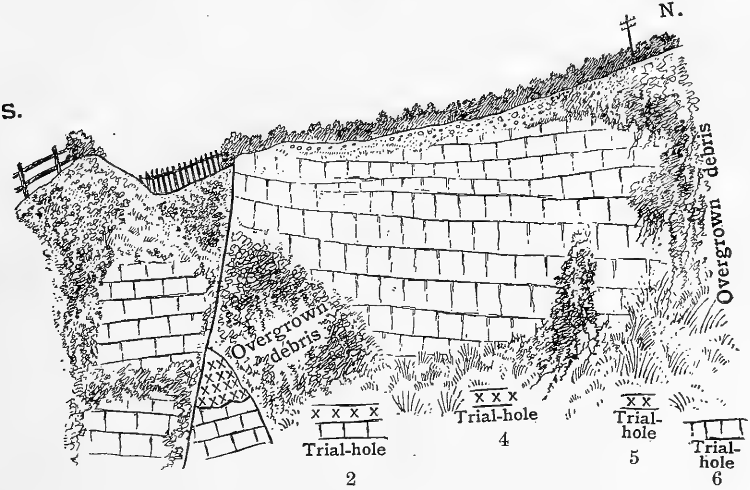
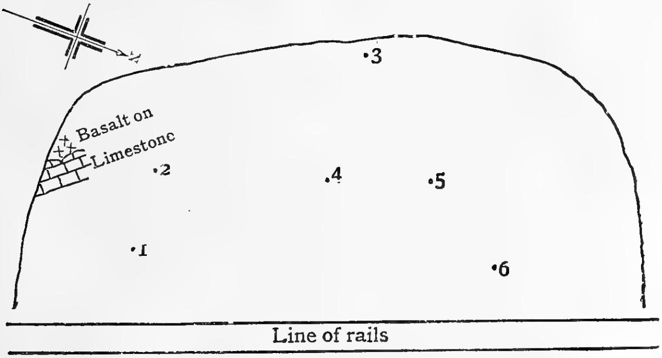


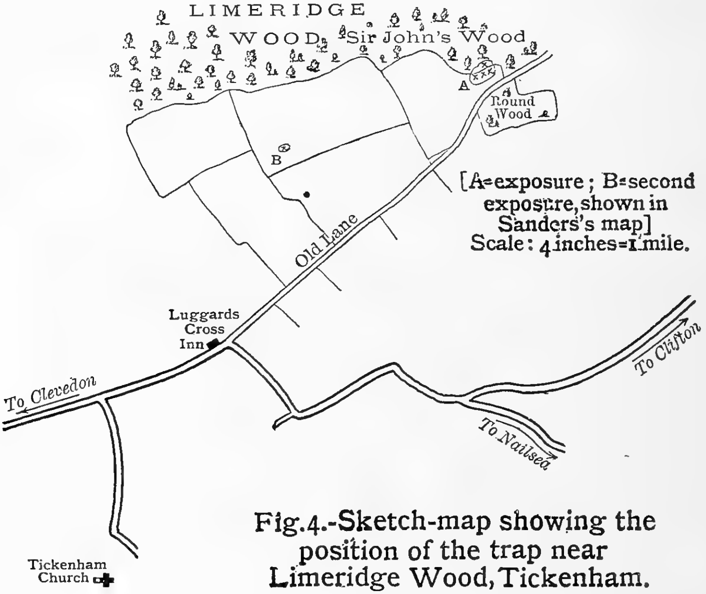
Fig. 3.—*Rough plan showing the excavations in the little old quarry by the railway, 250 yards north of Bleadon & Uphill Station.*



Position of excavations indicated by numbers 1 to 6.
Scale:-1 inch=about 9¾ yards

(*c*) Limeridge Wood, Tickenham.

Probably owing to the visit having been made in the summer when vegetation was luxuriant, no exposures of igneous rocks were detected when Dr. Lloyd Morgan and I were working at the Carboniferous volcanic rocks of the Bristol district in 1903. A visit, however, paid in March 1913, showed that 'trap' is fairly well exposed on the border of Sir John's Wood (the name of the southern portion of Limeridge Wood). The exposure is reached by following Wood Lane (or, as it appears in the 1904 Ordnance map, Old Lane), which diverges north-eastwards from the main road at the corner known as Luggard's Cross. It may also be approached across the field from Hale's Farm, Tickenham Hill. The exposure lies five-sixths of a mile north-east of Tickenham Church.



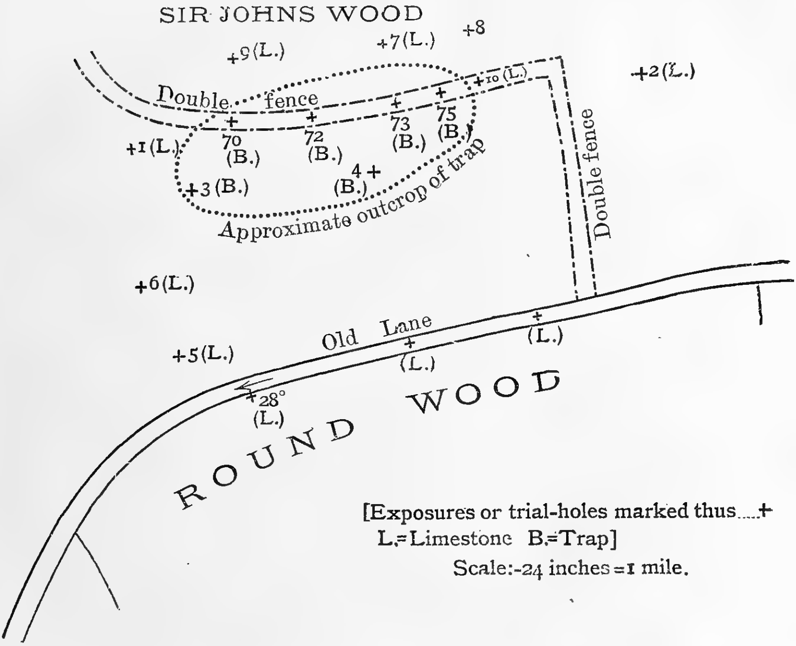
[A=exposure; B=second exposure, shown in Sanders's map]
Scale: 4 inches=1 mile.

Fig. 4.—Sketch-map showing the position of the trap near Limeridge Wood, Tickenham.

In Sanders's map two exposures of 'trap' are shown in this neighbourhood, the more easterly being the one now under consideration. Of Sanders's more westerly exposure I have met with no trace: numerous pieces of limestone, but none of 'trap,' were found in March 1914 scattered over the part of the field where the exposure is marked. In the 1-inch Geological Survey map no igneous rocks are shown in this locality. In Q. J. G. S. vol. lx (1904) p. 147, the exposure is mentioned as occurring 'near Cadbury Camp,' which lies about three-quarters of a mile to the west.

The exposures occur in the hedge-bank along the southern border of Sir John's Wood, where the eastern end of a field suddenly narrows, and is enclosed between Sir John's Wood on the north and Round Wood on the south (see fig. 5). The exposures in the hedge-bank continue for about 20 yards. At the westernmost point (70) compact trap was exposed after a small amount of excavation, and the same rock is fairly well seen at the point 72; farther east the rock becomes strongly amygdaloidal (73, 75). Ten trial-holes were dug in the wood and field adjacent to this exposure. Of these 1, 2, 5, 6, 7, and 10 all exposed limestone after passing through 4 or 5 feet of soil. No. 8 was carried deeper, but nothing was found *in situ.* Nos. 3 and 4 exposed trap, the rock 76, of which the silica and alkali content were estimated (see p. 38), being obtained from trial-hole 3. In no case was the contact between limestone and trap met with, and no sign of alteration was seen in any of the limestone. Limestone dipping at one point 28° west-south-westwards is exposed nearly all along the hedge-bank in the lane on the south; and it seems clear that it completely surrounds the trap, which forms an oval mass measuring not more than 60 by 25 yards. The field evidence indicates that the trap is an intrusive mass.

Fig. 5.—*Sketch-map showing the position of the trial-holes at Limeridge Wood, Tickenham.*



(*d*) Spring Cove and Milton Hill, Weston-super-Mare.

The most recent description of these rocks is by Dr. A. Strahan in the 2nd edition of the Geological Survey Memoir explanatory of Sheet 263 ('The Country around Cardiff'). He writes as follows:—

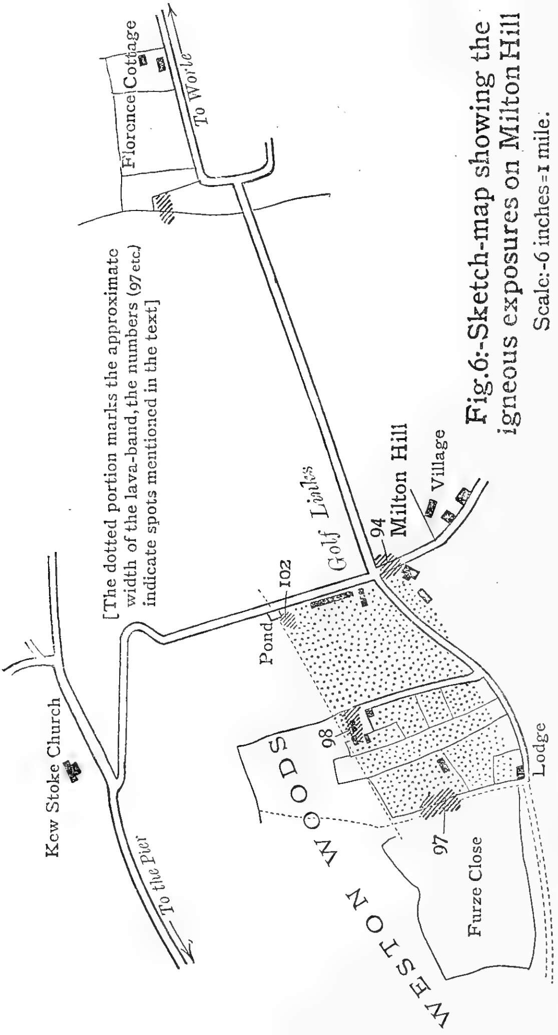


Fig. 6:-Sketch-map showing the igneous exposures on Milton Hill

Scale:-6 inches = 1 mile.

'The volcanic series is fully exposed to view in Spring Cove, 100 yards north-east of the pier to Birnbeck Island (sheet 279). Thence eastwards it is concealed[1] as far as the eastern margin of Weston Woods. On that margin, at a distance of 160 to 190 yards north of the Milton Hill Lodge, its outcrop can be fixed exactly, and in a field west of the four cross-roads at Milton Hill the débris of it is abundant. At this point it appears to be shifted about 200 yards northwards by the Milton Hill fault, for the next point determined upon the outcrop is a small pit, now a pond, observed by Professor Lloyd Morgan some years ago. The easternmost exposures occur in the sides of a pond near Florence Cottage, 700 yards east of the Milton Hill fault. No evidence of its existence farther east has been found.'

Since Dr. Strahan re-examined the ground, two further exposures have been made:—

1. In May 1911 trap was exposed in erecting a cistern at the spot marked 98 on the map (fig. 6, p. 30) about 250 yards north-north-east of Milton-Hill Lodge. The exposure is now, however, completely obscured.
2. In 1912 the southern branch of the cross-roads at Milton Hill was widened. At first the lava was exposed in a small road-cutting, but this is now hidden by a wall. Poor exposures are still visible at the side of the road. Several slightly-varying types of lava are seen, but no signs of tuff—in fact, the only evidence for the existence of tuff on Milton Hill is an observation made by Prof. Lloyd Morgan in 1894 at a spot near the Kew Stoke road, now the site of a small pond. Excavations were undertaken during the year 1915 at this locality. At the point 102 immediately south-west of the pond, highly-vesicular lava closely resembling that of Florence Cottage, and unlike any other rock hitherto exposed on Milton Hill, was reached at a depth of about 5 feet. In a second hole immediately west of the pond nothing *in situ* was reached; and the tenant informed me that, when the pond was made in 1904, surface-soil to a depth of 12 or 14 feet was penetrated. A careful search in the neighbouring fields, though yielding much lava, did not provide any tuff. These observations, though unfortunately not confirming Prof. Lloyd Morgan's record of tuff, in no way invalidate it. The spot where he observed the tuff is exactly on the line where one would expect it to occur: namely, between the limestone and the basalt. Its non-occurrence as surface-débris, and the great thickness of soil overlying it, are clearly due to its softness. The net result of the observations made by various geologists on Milton Hill shows that the lava has an outcrop about 200 yards wide, which, with a dip of 23° or thereabouts, would imply a thickness of about 150 feet, and that it forms the whole of the strip of well-cultivated ground between Furze Close and the road leading from Milton Hill to Kew Stoke.

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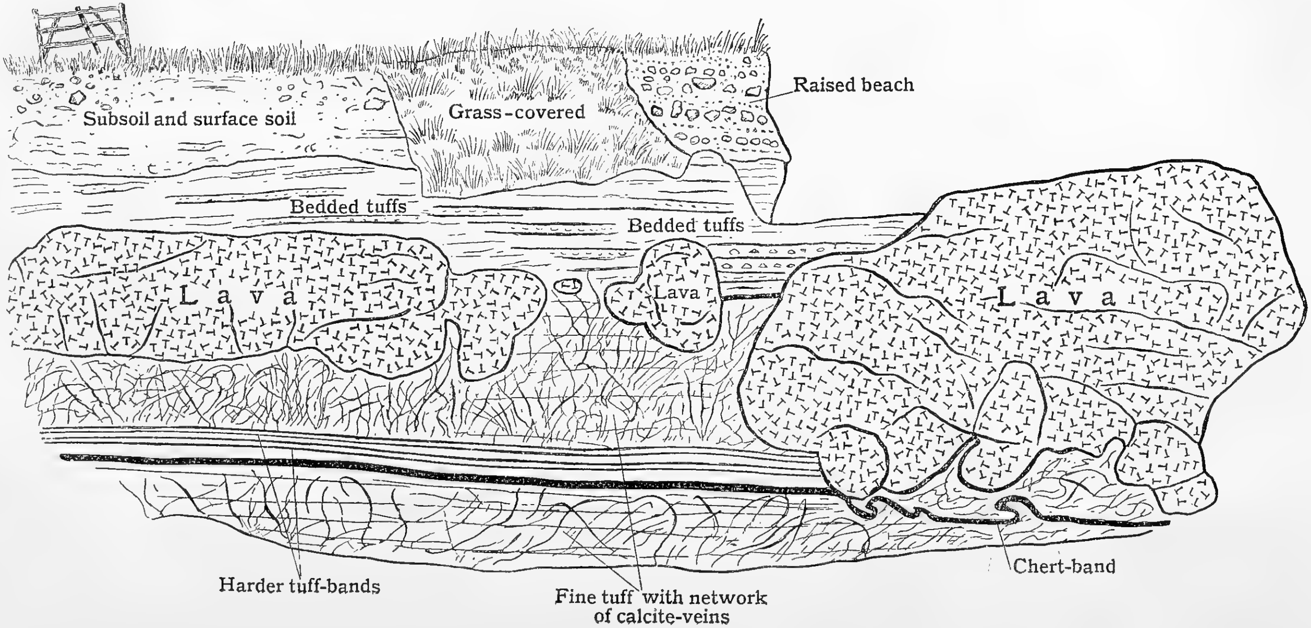
[1] Not only is the lava unexposed, but (despite careful search) I have been unable to find any débris.

Fig. 7.—*Sketch of the lava and associated rocks of the western igneous exposure, at Middle Hope or Woodspring. (Length of section=50 feet.)*



All attempts, either to trace the lava eastwards from Spring Cove through the woods of Worlebury Hill, or, with the exception of that at Florence Cottage, to find any exposures east of the cross-roads at Milton Hill, have been unsuccessful.

(*e*) Middle Hope or Woodspring.

There are four exposures of the igneous series in this section.

First or western exposure.—Previous descriptions of the lava have alluded to it as a band 12 or 14 feet thick, and this is the case at the seaward end of the section. If, however, the whole length of the section, some 50 feet along the strike of the rocks, is examined, it will be seen that the lava forms a most irregular and discontinuous band, as shown in the sketch (fig. 7, p. 32). The calcite-amygdules, 4 inches long, mentioned by Sir Archibald Geikie and Dr. Strahan, are near the top of the exposure at its western end. Bands of tuff in places strike up against, and are truncated by, the pillowy lava-masses. Chert-bands, strongly contorted in places, are associated with the tuff.[1]

The only other additional fact worthy of record is that a well-marked band of vesicular lapilli, which reach a length of 2 inches, occurs at the base of the limestone overlying the igneous series.

Second exposure.—The opportunity may be taken of correcting a misprint in the section described on p. 141, Q. J. G. S. vol. lx (1904): in Band 19 'grit' is a misprint for 'gap.' In the tuff-band 9 of this section a few gastropods occur, as also lamellibranchs.

Third exposure.—These rocks are considerably disturbed: the main series of tuffs and thin limestone-bands is bent into an irregular basin-shaped fold, and some of the thinner bands in the upper part of the section are much contorted. Crinoids abound in the more calcareous portions: these are sometimes definite, more or less lenticular bands of limestone, sometimes they merely are highly calcareous patches of tuff. Bands full of lamellibranchs occur at intervals throughout the series of tuffs, and gastropods are met with occasionally. A large mass of *Michelinia favosa* Goldfuss was obtained in one of the calcareous tuff-bands, and two rolled masses with portions of tuff still adhering to them were found on the foreshore. The British Museum also contains a specimen in tuff, collected by Mr. Spencer Perceval at this locality in 1890.

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[1] [In the greenish tuff immediately overlying the lava a single specimen of each of the following brachiopods was found during a visit to this section with Prof. E. J. Garwood, in September 1916:—*Camarophoria isorhyncha* McCoy, *Spiriferina laminosa* (not McCoy), and a Terebratulid. Prof. T. F. Sibly kindly examined the Spiriferid and Terebratulid.—*S. H. R., March 20th, 1917.*]

III. Petrographical Details.

(*a*) Goblin Combe.

In hand-specimens the lavas are dark-greenish or black rocks, with abundant amygdules of calcite and chlorite.

The lavas from the eastern exposure were described in this Journal, vol. lx (1904) p. 152, as amygdaloidal olivine-basalts, and further examination, supplemented by chemical analyses, confirms this view as to their character. The extinction-angles of the felspar-laths appear to indicate a somewhat acid labradorite.

In the western area of Goblin Combe fresher rocks were found by digging trial-holes than had been previously obtained: for instance, that at spot 81, which has not only the augite, but also part of the olivine unweathered. In all essential characters the rock from 81 is identical with that from 33. A good deal of dark isotropic glass is present between the crystals. In the rock from 81, while the augite and felspars are fresh, the olivine is to a great extent serpentinized. In the rock from 6, the olivine is replaced by a carbonate, the felspars are much weathered, and most of the augite in the interstices between the felspars is serpentinized.

A comparison of the two freshest lavas, from the eastern and western exposures respectively, yields the following results:—

	O. 33: Goblin Combe. Eastern exposure.	*O. 81: Goblin Combe. Western exposure.*
Specific gravity	2·84 to 2·86	2·80 to 2·81
SiO_2	49·12 per cent.	48·49 per cent.
K_2O	0·41	0·46
Na_2O	2·37	2·39
Li_2O	not found	not found

The chemical results recorded above fully confirm the opinion reached from a microscopical examination that these rocks are typical olivine-basalts. In the low percentage of alkalies, and particularly of potash, they contrast with the other rocks of this area.

The tuffs were fully described (*op. supra cit.* p. 154), and there are only two additional facts to record. One of these is the presence of well-preserved foraminifera in some of the tuffs of the western exposure. The other fact is the occasional occurrence of well-rounded pebbles of considerable size in the tuff at the eastern end of the Combe. These include a pebble of crinoidal limestone measuring $2\frac{1}{4} \times 1\frac{3}{4}$ inches, and one of chert about an inch and a half long.

(*b*) Uphill.

The Uphill 'trap' is a much-weathered, highly-amygdaloidal rock with a reddish colour owing to the abundant iron-oxide. The amygdules may consist of calcite, or of calcite and chlorite. The specific gravity of the freshest and least vesicular example obtainable (50) is 2·60, and its silica percentage 43·17. In thin sections, four of which were examined, the bulk of the rock is seen to be composed of felspar-laths, which tend to be larger than in the Goblin-Combe rocks and in those of Milton Hill and Spring Cove. The felspars, though much weathered, are seen to extinguish practically straight, and their refractive index is higher than that of Canada balsam. Hence it is probable that they are oligoclase. Needles of peroxidized magnetite, similar to those occurring in some of the Goblin-Combe rocks, are sometimes present. Pseudomorphs after olivine in an iron-stained carbonate are plentiful. Partly owing to the extensive weathering, and partly to the ferruginous staining, no unaltered augite was seen; but, in one section, small serpentinized augite-grains filling the interstices between the felspars are easily recognizable.

(*c*) Limeridge Wood, Tickenham.

Hand-specimens from this locality are fairly fresh-looking dark-brown rocks, generally crowded with calcite- or chlorite-filled amygdules, though sometimes non-vesicular. Eight slices were examined. In all, the main part of the rock consists of felspar-laths generally about 0·5 mm. long, and, as a rule, too much weathered for the extinction-angle to be ascertainable. When, however, the rock is a little less weathered, the extinction-angle is found to be practically straight. Associated with the felspar is interstitial augite much weathered and obscured by iron-oxide. In nearly every section regularly-idiomorphic pseudomorphs after olivine are abundant: in some cases they are in a carbonate, in others in serpentine.

The specific gravity of three specimens ranged from 2·63 to 2·68. The silica-percentage of one rock (76) is 43·92, the soda is 0·44, and the potash 4·03. The high percentage of potash and the straight extinction suggest that the bulk of the felspar is orthoclase. Amygdules formed of calcite, or partly of chlorite, partly of finely-spherulitic chalcedony, are common.

The rock is closely related to that of Uphill.

(*d*) Spring Cove and Milton Hill.

Spring Cove.—The Spring-Cove lava is a very fine-grained red rock in which practically nothing of the nature of the constituent minerals can be ascertained without microscopical examination. The amygdules and red variolitic patches, which (as already mentioned)[1] are a characteristic feature, are very irregular in their distribution. Each variolitic patch is a group of imperfect varioles. The macroscopic characters of the rock, and, in particular, the occurrence of imperfect pillows[2] and of varioles, suggest that this rock may be related to the spilites. The specific gravity is also low for basalts. Specimens taken from about the

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[1] Q. J. G. S. vol. lx (1904) p. 152.

[2] See 'Summary of Progress for 1893' Mem. Geol. Surv. 1899, p. 105.

middle of the mass had specific gravities of 2·72 and 2·74, while that of a specimen from the eastern end was 2·67. The chemical analyses quoted on p. 38 (though the percentage of magnesia and soda is somewhat low for a basalt, while that of the potash is high) do not bear out the idea of a spilitic relationship, the soda especially being far too scanty. The occurrence of well-terminated pseudomorphs in carbonate after olivine in certain parts of the Spring-Cove lava is also inconsistent with a spilitic relationship. The felspars are, in every case, too much weathered for the extinction-angle to be ascertained with accuracy, but they appear to extinguish straight. In none of the nine slices examined could any recognizable pyroxene be detected. Much brown glassy material is present in the ground-mass.

Milton Hill.—The westernmost exposure is that mentioned by Dr. Strahan[1] as occurring 160 to 190 yards north of Milton-Hill Lodge at the eastern margin of Weston Woods. Here a compact, black, only slightly vesicular rock (97) occurs in the path along the edge of Furze Close; but the exposure is so bad that it may easily be overlooked. The specific gravity (2·78) is higher than that of any other rock of Milton Hill. The percentage of silica and alkalies (see Table I, p. 38) is that of a normal basalt; and the agreement between this rock and those in Goblin Combe is close, both chemically and mineralogically. It has a rather fine-grained ground-mass, composed of felspar-laths with an extinction-angle of 10° to 15°, magnetite and granulitic augite, with phenocrysts of fresh augite and of idiomorphic olivine replaced by green serpentine. The chemical characters and extinction-angle suggest that the felspar is probably andesine. The rock differs considerably from any other seen on Milton Hill.

The next exposure lies north-north-east of Milton-Hill Lodge at the point 98 in the sketch-map (fig. 6, p. 30), and has already been mentioned as having been made in 1911 in the course of erection of a cistern. No trace of this exposure is now to be seen. The rock here is brown, considerably weathered, and rather strongly amygdaloidal. In a hand-specimen it bears a general resemblance to that from Limeridge Wood, Tickenham, which it also resembles as regards specific gravity (2·66 to 2·68) and silica-percentage (42·21). Of alkalies Mr. Radley found 2·89 per cent. of potash and 0·68 of soda. The resemblance to the Limeridge-Wood rock is further brought out in a thin section, particularly as regards the relatively-large size of the felspar-laths in comparison with those in the Spring-Cove rock and that of the cross-roads, Milton Hill. The felspars are too much weathered for anything to be made out with regard to the extinction-angle. Olivine in idiomorphic crystals, mainly replaced by a very pale serpentine, is abundant.

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[1] 'Geology of the South Wales Coalfield: Part III—The Country around Cardiff' 2nd ed. Mem. Geol. Surv. 1912, p. 29.

The next point where the lava is exposed is at the cross-roads at the top of Milton Hill. The highest bed seen here, when the exposure was in a better condition for observation than it is now, was a rock which in a hand-specimen was not obviously amygdaloidal, although it shows many ill-defined patches of a green alteration-product. Numerous pseudomorphs in carbonate after olivine occur with iron-oxide aggregated along their margins and cracks. Underlying this is a coarsely amygdaloidal rock with calcite-filled vesicles sometimes an inch and a half long. There are other vesicles filled wholly or in part with a chloritic mineral, while other amygdules consist of calcite enclosing a nucleus of quartz. It is difficult to ascertain whether certain spots are amygdules or imperfect varioles. The bulk of the rock consists of felspar-laths of somewhat variable size, which extinguish straight or nearly so, and have a lower refractive index than the Canada balsam in which they are mounted. These characters indicate orthoclase, the presence of which is further suggested by the high percentage of potash—namely, 5·83, found by Mr. Radley (Mr. Sturgess found 5·34). Much iron-oxide is present. The phenocrysts include large (often idiomorphic) olivines, represented by pseudomorphs in carbonate associated with much iron-oxide, and a few felspars which have very low extinction-angles. Some of the large felspars have isotropic patches which Dr. H. H. Thomas suggests may be due to analcitization.[1] There are also isotropic patches in the ground-mass which are probably analcite. The specific gravity of the rock (94) is 2·57 to 2·58. A close resemblance exists to the Spring-Cove rock, particularly in the high percentage of potash. A trace of lithia was also observed.

The easternmost exposure on Milton Hill is that found by Dr. A. Strahan near Florence Cottage, 700 yards east-north-east of the cross-roads. This exposure occurs in the bed of a small pond about 150 yards west of the Cottage, and in wet weather nothing can be seen. The rock is very highly vesicular, and so much weathered that no sections were cut and the specific gravity was not ascertained. As has been already pointed out, it closely resembles the rock (102) from the little pond on Milton Hill, the rock in each case probably coming from quite the bottom of the flow.

(*e*) Woodspring.

The Woodspring trap in a hand-specimen is a much-weathered dark-greenish rock with numerous amygdules, which in the bulk of the rock are small, rounded, and filled with green material. In places very large calcite-amygdules occur. In thin sections the main part of the rock is seen to consist of small felspar-laths in a greatly weathered state; sometimes, however, it is possible to satisfy one's self that the extinction is practically straight. Much

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[1] Analcitization in albitized basic felspars is described by E. B. Bailey & W. Grabham from Arthur's Seat, Edinburgh, Geol. Mag. dec. 5, vol. vi (1909) p. 254.

finely-divided magnetite is distributed through the sections. Very numerous olivine-crystals, sometimes represented by pseudomorphs in carbonate, sometimes by pseudomorphs in serpentine, occur, and in many cases show crystal outlines. No pyroxene, however, can be identified.

IV. Tables of Chemical Analyses.

1.

	I.	II.	III.	IV.	V.
SiO_2 …………………	49·69	48·80	50·75	55·44	51·76
TiO_2 …………………	2·80	—	1·46	0·16	0·47
Al_2O_3 …………………	11·54	17·65	12·15	18·60	12·36
Fe_2O_3 …………………	5·83	4·71	9·26	2·09	4·88
FeO …………………	3·29	2·72	0·15	4·48	4·60
MnO …………………	0·36	—	0·43	—	0·11
CaO …………………	6·36	7·65	6·31	6·76	7·14
MgO …………………	4·29	3·30	6·22	4·75	9·57
K_2O …………………	5·01	4·93	7·03	6·63	3·83
Na_2O …………………	0·72	1·10	0·55	1·79	1·99
H_2O at 105° C. ………	1·65	0·69	—	0·25	3·05
H_2O above 105° C. ..	3·61	2·77	—		
P_2O_5 …………………	0·35		—	—	0·56
CO_2 …………………	4·77	5·93	3·76	—	
Li_2O …………………	trace	—	—	—	
Totals…………	100·27	100·25	98·07	100·95	100·32
Specifie Gravities……	2·59		2·617	2·7	

I. Variolitic olivine-basalt, Spring Cove, Weston-super-Mare (E. G. Radley).
II. Do. do. do. do. (J. H. Sturgess).
III. Rock from Knowle Quarry near Spencecombe, Devon (957). (J. Grant Wilson.)
IV. Ciminite, Fontana di Fiesole, Monte Cimini, near Viterbo, Italy. (H. S. Washington.)
V. Absarokite, Raven Creek, Yellowstone Park, U.S.A. (L. G. Eakins.)

2.

	Specific Gravities.	SiO_2.	K_2O.	Na_2O.
33. Olivine-basalt, Goblin Combe, east exposure.	2·84–2·86	49·12	0·41	2·37
81. Olivine-basalt, Goblin Combe, west exposure.	2·80–2·81	48·49	0·46	2·39
97. Olivine-basalt, Furze Close, Milton Hill, Weston-super-Mare …………………	2·78	49·58	0·73 0·75*	1·96 1·81*
98. Olivine-basalt, north-east of Milton-Hill Lodge, Weston-super-Mare …………	2·66–2·68	42·21*	2·89	0·68
76. Olivine - orthoclase - basalt, Limeridge Wood, Tickenham …………………	2·63–2·68	43·92*	4·03	0·44
50. Olivine-basalt, Uphill cutting, Weston-super-Mare …………………………	2·60	43·17	—	—
23. Olivine-basalt, Middle Hope, Weston-super-Mare …………………………	2·54	45·69	—	—
17. Variolitic basalt, Spring Cove, Weston-super-Mare …………………………	2·59	49·69 48·80*	5·01 4·93*	0·72 1·10*
94. Olivine - orthoclase - basalt, cross - roads, Milton Hill, Weston-super-Mare………	2·57–2·58	46·16	5·83 5·34*	1·07 0·94*

The estimates marked with an asterisk in the foregoing table (2) were determined in the Chemical Laboratory of the University of Bristol by Mr. J. H. Sturgess, the remainder by Mr. E. G. Radley. I am much indebted to my colleague, Lieut. D. E. Innes, B.A., and to my pupil, 2nd Lieut. F. S. Wallis, for determining the specific gravities.

V. Comparison with Rocks of other Areas.

Chemical and mineralogical examination show the presence in certain of these rocks of acid felspar: orthoclase (Limeridge Wood Tickenham, and Milton Hill) and probably oligoclase (Uphill); while, in regard to their general aspect and composition, and particularly in respect of the low silica-percentage and abundance of olivine, the rocks are basalts.

Rocks showing a similar association of olivine and orthoclase have been described from several other localities. The following are the most important:—

1. Some of the Permian lavas of the Exeter district[1] are well known to contain orthoclase in association with olivine; and, though in the field, owing to their generally pale and reddish tints, the difference between these rocks and those of the Bristol area is considerable, the resemblance both in microscopical structure and in chemical composition is quite close. This is particularly the case with the lavas described by Sir Jethro Teall as the Knowle-Hill (Crediton) type. These rocks are, he remarks,[2] 'basic so far as silica percentage is concerned, but (which) differ from ordinary basic rocks in containing a large amount of potash.' An analysis of the rock from Knowle Quarry, Spencecombe, is quoted above (p. 38), and it is evident how close is the correspondence between this rock and that from Spring Cove in the percentages of silica, alumina, lime, and alkalies. A section of the rock from Spencecombe Farmhouse Quarry (E 3219 in the Geological Survey collection) resembles very closely some of the Milton-Hill rocks. Sir Jethro Teall clearly regarded the orthoclase in these rocks as original, but remarks[3] on the reduction of the lime through the leaching-out of the carbonate.

2. Dr. Flett suggested comparison with certain of the rocks of Pelvoux described by Prof. Termier,[4] particularly with certain 'diabases' which, while originally rich in lime, now contain much potash. The changes in these rocks that are entirely attributed to the metasomatic action of surface-water, are twofold: (*a*) the elimination of the bulk of the lime, and to a less extent of the alumina and magnesia; (*b*) the addition of potash, which is believed to be derived from the neighbouring mass of the Pelvoux

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[1] See 'Geology of the Country around Exeter' (sheet 325), Mem. Geol. Surv. 1902, pp. 55–85.

[2] *Ibid.* p. 83.

[3] *Ibid.* p. 79.

[4] Bull. Soc. Géol. France, ser. 3, vol. xxvi (1898) pp. 165–92.

granite and gneiss. A series of analyses is quoted of the actual rocks, and these are paralleled in each case with a statement giving the supposed composition of the rock when unaltered.

The contrast between the environment of the rocks in the two localities is so great as to show that the richness in potash cannot be due to similar causes. Thus the Bristol rocks are everywhere associated with thick masses of Carboniferous Limestone, and, if there had been any transference of material, might have been expected to have had the percentage of lime increased. No granite or other rock rich in potash is known to occur nearer than Malvern on the one hand, and Dartmoor and Lundy on the other. Hence, any elimination of lime and addition of potash, such as Prof. Termier describes, can scarcely be contemplated.

3. The Milton-Hill rocks seem to bear a considerable resemblance to the ciminites of Dr. H. S. Washington,[1] both rocks containing orthoclase, pyroxene, and olivine, and being devoid of hornblende and biotite. The resemblance is brought out by the analyses quoted on p. 38, particularly as regards the excess of potash over soda, but the percentage of silica in a ciminite is distinctly higher than in the Milton-Hill rocks, and Dr. Washington estimates that as much as 22·8 per cent. of anorthite is present.

4. The Bristol rocks resemble in some respects members of the somewhat variable series from the Yellowstone Park, described by Prof. J. P. Iddings as absarokites.[2] The two groups of rocks agree in the occurrence of abundant olivine and augite, in association with orthoclase and a variable amount of more basic felspar. The silica-percentage in each case is low, that of the alkalies moderately high with potash higher than soda. Some of the absarokites contain leucite, others quartz. The rock from Raven Creek, of which the analysis is quoted (p. 38), seems to come nearest the Bristol rocks; it is fine-grained, and consists of augite, serpentinized olivine, magnetite, and orthoclase, with no leucite and only a very little lime-soda felspar.

Despite the unusual association of minerals in some of the rocks which are the subject of this paper, it does not seem possible to avoid the conclusion that the acid felspars are original, and hence that these rocks are comparable to certain of the Exeter traps, to the ciminites of Dr. Washington, and to certain of the rocks described by Prof. Iddings.

It will probably be best to term them orthoclase-basalts.

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[1] Journ. of Geology, vol. v (1897) p. 349.

[2] *Ibid.* vol. iii (1895) p. 938.

VI. Summary and Conclusions.

The igneous rocks associated with the Carboniferous Limestone of the Bristol district may be arranged in three groups:—

(*a*) Normal olivine-basalts (Goblin Combe, eastern and western exposures, and 97 from Furze Close, Milton Hill). All these have a very low percentage of potash.

(*b*) Olivine-bearing rocks, with a rather high percentage of potash and a low percentage of soda (Limeridge Wood, Tickenham, and 98 from north-east of Milton-Hill Lodge; probably the rocks from Uphill and from Middle Hope or Woodspring belong here).

(*c*) Olivine-orthoclase basalts, with sometimes an imperfectly variolitic structure, a very high percentage of potash, and a low percentage of soda (Spring Cove and cross-roads, Milton Hill).

I am greatly indebted to Dr. J. S. Flett and Dr. H. H. Thomas for help and advice; also to the latter for the loan of sections of rocks from the Exeter district. Sincere thanks are also tendered to the following, for permission accorded to dig trial-holes:—Mr. J. Gibson, J.P. (Goblin Combe); Mr. H. B. Napier, of the Ashton-Court Estate (Limeridge Wood, Tickenham); and the Great Western Railway Company (Uphill).

Discussion.

Dr. A. Strahan commented on the difficulty which had been experienced in tracing these igneous rocks, owing to lack of exposures. Much of the outcrop in Goblin Combe, as shown on the geological map, was founded on the occurrence of igneous débris in the soil, and in part only on actual exposures. He was not satisfied that its continuity had been disproved. That the lavas in the various occurrences in Somerset were discontinuous was obvious, but that other evidences of igneous action were confined to such limited areas as the Author claimed, seemed improbable. Geologists were greatly indebted to the Author for the additions that he had made to their knowledge of Somerset geology by opening trial-holes in doubtful ground.

Prof. T. Franklin Sibly enquired whether the Author's further investigations on Milton Hill had enabled him to utilize the volcanic horizon of Spring Cove for mapping the dip-faults, later in date than the great longitudinal overthrust fault which traversed the Weston-Worle ridge of Carboniferous Limestone. The faulted structure of this ridge was a typical illustration of the displacements which had affected the Carboniferous rocks of neighbouring areas.

Dr. A. P. Young said that the Author's discovery of pillow-lavas and associated rocks would furnish a key to many phenomena observed in this area. The speaker had collected from the shore about Woodspring Cove some rock-specimens for which he was in fact indebted to the Author, as they had been obtained during the visit of the Geologists' Association to Bristol in 1907. The slides from these specimens showed forms the organic origin of which could scarcely be doubted, recalling radiolaria and other organisms, but too imperfect for determination. These bodies were embedded in the ground-mass of the lava, in such a way as to suggest that they had been taken up by a subaqueous lava-flow from sediments still in the state of mud.

It was believed that the exceptional microscopic occurrences, and the general relations of lava to sediments, could be best explained on the hypothesis of a subaqueous eruption over a floor of imperfectly-consolidated sediment.

The Author, in reply to Dr. Strahan, said that the information leading him to map the igneous rocks at Goblin Combe as two separate crescentic masses could have been obtained only by digging many trial-holes. To Prof. Sibly he said that at Worle Hill his attention had been confined to the igneous rocks, and that he had not attempted to study the general structure of the hill; he had, however, little doubt that the failure to find any trace of igneous material east of Florence Cottage and between Spring Cove and Furze Close indicated that the volcanic rocks of the Milton-Hill neighbourhood were cut off at both ends of their outcrop by cross-faults.

4. *On some* INSECTS *from the* BRITISH COAL MEASURES. By HERBERT BOLTON, M.Sc., F.R.S.E., F.G.S., Reader in Palæontology in the University of Bristol, and Director of the Bristol Museum. (Read March 8th, 1916.)

[PLATES III & IV.]

THE present paper consists of a critical study of some hitherto undescribed wings of fossil insects from the British Coal Measures, and of insect-wings previously noted by other authors. I am indebted to Mr. William Eltringham, of Newcastle-on-Tyne, and to the authorities of the Geological Survey Museum, the National Museum of Wales, and the Liverpool, Manchester, and Newcastle Museums for their courtesy in placing the specimens at my service for study.

ÆDŒOPHASMA ANGLICA Scudder. (Pl. III, fig. 1.)

1885. *Ædœophasma anglica* Scudder, Geol. Mag. dec. 3, vol. ii, p. 265.
1885. *Ædœophasma anglica* Scudder; Scudder, in Zittel's 'Handbuch der Paläontologie' vol. ii, p. 758, fig. 941.
1906. *Ædœophasma anglica* Scudder; Handlirsch, 'Die Fossilen Insekten' p. 125 & pl. xiii, fig. 4.

This specimen was obtained by Major Chambers, and presented to the Derby & Mayer Museums, Liverpool, in 1858. It is contained in an ironstone nodule, much similar to those of Ravenhead (Lancashire). Its horizon is not known, but it is undoubtedly from the Middle Coal Measures. It was partly described and named, but not figured, by S. H. Scudder in 1885; and a figure of the wing appeared in the same year in Zittel's 'Handbuch der Paläontologie.' This figure was probably due to Scudder, who wrote the entomological section of the work for that edition of Zittel's manual.

The wing lies in a fine-grained ironstone nodule, one half showing a left wing, and the other half of the nodule containing the impression. Since the specimen came into my hands for examination, I have been able to uncover the apex of the wing and a small portion of the base. A little of the base of the wing is missing, and also the middle portion of the inner margin. The total length of the wing as now seen is 87 mm., and the greatest breadth (across the middle of the wing) 40 mm. When complete, the wing was probably 100 mm. long.

The costal margin is gently convex.

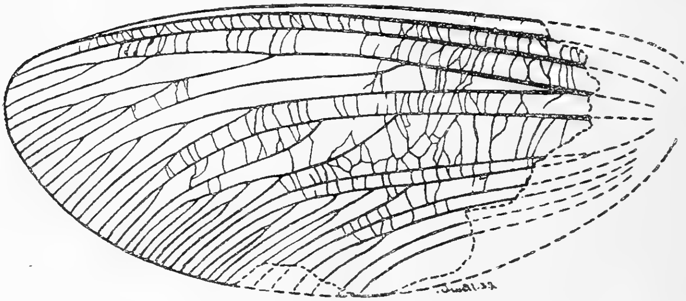
The sub-costa is a broad flat vein which gradually diminishes in width as it passes outwards to the wing-apex, which it just fails to reach.

The radius is an even broader vein than the sub-costa, also flat, and passes outwards, parallel to the sub-costa, to the outer angle of the tip of the wing. It remains undivided throughout its whole length.

The median divides low down near the base into two equal branches, the outer of which gives off four successive twigs. The first of these twigs (regarded by Handlirsch as the radial sector) arises before the branch reaches the middle of the wing, and remains undivided throughout the whole of its course to the inner angle of the tip of the wing. The second twig divides twice, the outer and inner twigs of the second bifurcation dividing again, so that the ultimate twigs reaching the margin are six in number; the remaining branches, which are three in number, remain simple and undivided. The anterior branch of the median occupies the greater part of the wing-tip, and ends upon it in seven twigs.

The inner branch of the median is simpler in character than the outer, and does not divide until well past the middle of the wing. It then gives off four twigs, which pass outwards to the junction of the inner wing-margin with the apex. The first of the twigs forks before reaching the margin, and consequently the inner branch of the median has six ultimate twigs.

Fig. 1.—*Restoration of wing of* Ædœophasma anglica *Scudder, showing the general character of the intercalary venation. (Natural size.)*



The cubitus passes out from the base of the wing parallel to the main stem of the median and to its inner branch for the greater part of its length. It sends off at a wide angle, at the middle of the wing, a strongly-curved branch, which bends first inwards and then outwards towards the apex, breaking up into five twigs before reaching the inner margin. The second of these twigs forks. A second branch comes off a little farther out, and also at a wide angle. This remains undivided along its whole length. The main stem of the median runs out to the margin, forming a small fork immediately in front of it. The cubitus ends in the inner wing-margin in six twigs.

The next two veins were probably united a little way out from the base, and their direction is such that the single stem from which they arose may have been given off at the base of the cubitus. If this were the case, the two veins would form an inner division of the cubitus. I am of opinion that this supposition is the correct one.

The outer of the two veins is undivided, and reaches the inner margin beyond the middle of the wing. The second or innermost vein runs fairly parallel to the first along its whole length, giving off, as it does so, four inwardly-directed twigs. The first and fourth veins fork before reaching the margin. The whole vein ends on the margin in six twigs.

The venation of the radial and median areas consists of straight or slightly curved cross-veins placed at fairly regular distances.

The very wide cubital and cubito-anal areas are crossed by irregular wavy veins, which branch, and at times join into a loose network. The anal area is occupied by simple cross-veins.

Affinities.—At the time when Scudder described the wing, he was of opinion that it had relationships with *Meganeura (Dictyoneura) monyi*, and that it was a member of the group Protophasmidæ. Handlirsch has, however,[1] removed it to the group of Palæodictyoptera incertæ sedis.

Scudder was undoubtedly mistaken in referring the wing to the Protophasmidæ, as a glance at the figure of *Protophasma dumasii* Brongniart[2] will at once show. Handlirsch apparently deduced the Palæodictyopteroid affinities only from a study of Scudder's drawing of the wing.

I have not been able to adopt Handlirsch's view of the structure of the wing, but have arrived at slightly different conclusions.

Handlirsch regards what I have described as an anterior branch of the median vein, as the radial sector. If this view be correct, the radial sector and the median vein are completely fused for a distance of 10 to 15 mm. from their point of origin.

The basal portion of the radius is widely divergent from the base of the median—more so, in fact, than at any other part of the whole course of the radius and supposed radial sector. They could, therefore, have come into union only at the actual point of origin of the wing. This may have been the case; but, in my opinion, the radius is wholly simple and undivided, and no radial sector is present. The median vein is free and strongly developed, a remark which applies also to the cubitus. The cubitus may, and probably did, send off the long simple vein lying inwards to the main stem; and the simple vein may also have given origin to the next vein, which divides into three before reaching the wing-margin. The interpretation that I make of the wing is, then, that the sub-costa and radius are simple and undivided. The median and cubitus are large, much divided, and take up the greater part of the wing-area; while the anal veins are few, and but one shows evidence of forking.

If my view be correct, the wing is undoubtedly a very primitive type of the Proto-orthoptera, still retaining evidence, in the costa, sub-costa, and radius, of its Palæodictyopteroid origin.

[1] 'Die Fossilen Insekten' 1906, p. 125.

[2] *Ibid.* pl. xvi, figs. 1 & 2.

Type-specimen in the Derby & Mayer Museums, Liverpool.
Locality.—Unknown. Donor: Major Chambers, 1858.
Horizon.—Unknown. Middle Coal Measures, South Lancashire.

(*Dictyoneuron*) HIGGINSII (Handlirsch). (Pl. III, fig. 2.)

1871. 'Neuropterous Insect-Wing' Higgins, Presidential Address, Proc. Liverpool Naturalists' Field Club, 1870–71, p. 18, fig. 15.
1906. *(Palæodictyopteron) higginsii* Handlirsch, 'Die Fossilen Insekten' p. 125 & pl. xiii, fig. 6.

This wing was described as follows by the late Rev. H. H. Higgins:—

> 'A second and smaller specimen [of insect-wing] was obtained by myself and referred to the genus *Corydalis*. Mr. J. P. G. Smith compared it with *Fulgora*. A slight sketch of it was seen by F. Smith, of the British Museum, whom it reminded of *Gryllotalpa*. Mr. Benjamin Cooke, of Manchester, after a careful examination, says: "I believe the fossil represents the basal portion, about one-third only, of the fore wing of a *Chrysopa*, Golden-eye, or Lace-wing fly, or rather *Nothochrysa*, separated from *Chrysopa* by Mr. McLachlan on account of the manner in which the third cubital cell is divided." This cell is remarkably well shown in the fossil, and though I could only judge from memory, I believe it is sufficient to settle its relationship.'

The specimen was afterwards named, but not described, by Handlirsch as '*(Palæodictyopteron) higginsii*.' Handlirsch's figure is a copy of that given by Higgins. He did not see the specimen.

The impression is that of the basal portion of a left wing, the portion preserved having a length of 32 millimetres. The greatest width is 22 millimetres, across the distal portion of the anal area.

The 'cubital cell' mentioned by Mr. Benjamin Cooke is an elongated, somewhat oval area lying in the middle of the base of the wing. It has been formed by a twig of a cubital vein coming off forwards and outwards to join on to the main vein lying in front of it. This is a feature of rare occurrence, and will be considered more fully later.

The costal border, which is preserved for a length of 29 mm., is strongly curved proximally, and is gently arcuate as it passes outwards towards the middle of the wing. The sub-costa is a feeble vein, which rises towards the anterior margin of the wing and passes outwards almost in a straight line. The area enclosed between the costal margin and the sub-costa is very wide proximally, and rapidly narrows down to an acuminate point where the sub-costa reaches the frontal margin of the wing.

The complete wing must have been at least three times as long as the portion preserved, and the sub-costa would therefore join the costal margin about the middle, or a little beyond the middle, of the wing.

The radius runs almost parallel to the sub-costa along its whole length, giving off the radial sector a little beyond the middle of the portion of wing preserved. The radial sector comes off from the radius at an acute angle, and passes outwards parallel to it in the direction of the wing-tip, the upper portion of which it doubtless reached.

The median and cubital veins present certain unusual problems. In all Palæodictyopteroids, the median and cubital veins each arise and continue outwards for some distance as a single stem. The median shows least tendency to branch near its point of origin, while frequently it continues as a single unbranched vein for the greater part of its length. The cubitus in many Carboniferous insects often sends off a long anterior branch only a little way out from the base, or early divides by forking. In the present instance, three veins occupy the position of the normal median and cubitus. Of these, two either arise from a common root or so close together as to be indistinguishable, while the third has an independent origin from the other two. Further, the third of these three veins sends off, soon after its origin, a stout outwardly- and forwardly-directed twig, which joins the second of the two anterior veins and merges with it.

If we assume that the two veins, arising from a common point, represent the median vein, which forks at the base of the wing, the third of the three veins will be necessarily the cubitus, sending a twig forward to join the posterior branch of the median. In this case the 'cell' enclosed by the hinder median, and its forwardly-directed commissure, will be a 'median-cubital' cell, and not a 'cubital cell' as assumed by Mr. Benjamin Cooke.

On the other hand, as the median vein in Palæodictyopteroids shows little tendency to branch, while the cubitus shows a distinct tendency to branch, we may consider the median vein in the wing-fragment to be a simple vein, undivided throughout that portion of its length which is preserved, and arising in close union with an anterior branch of the cubitus. The cubitus then becomes a double-stemmed structure, the two elements of which unite by a powerful cross-vein in such a fashion as to enclose a basal 'cubital' cell. Notwithstanding the common point of origin of the first two veins under consideration, the latter view seems the more logical one.

A third view is that the median divides at the base, and that the anterior branch of the cubitus goes off forwards to join the inner branch of the median, the latter beyond the junction being therefore a medio-cubital structure.

If these veins be considered from the last-mentioned point of view, the median is a simple undivided vein in the wing-fragment. It arises close to the radius and the anterior branch of the cubitus, the three veins being crowded together for a short distance, beyond which the median bends backwards from the radius, and passes outwards in the direction of the tip of the wing, in an almost straight line. It is separated from the undivided portion of the radius and from the radial sector by an area the width of which is twice that which separates the radius and sub-costa, or that which separates the main stem of the radial sector from the radius.

The anterior branch of the cubitus lies close to the median for a short distance, and then bends sharply inwards from the median, passing back in the direction of the middle of the inner margin of the wing. A rapidly-widening triangular area is thus left between the anterior cubital vein and the median.

The inner cubital vein pursues an oblique course from its point of origin inwards to the wing-margin, and is widely spaced out from the anterior branch. The forwardly-directed twig, which has been already mentioned, forms a sigmoidal curve reaching the anterior branch of the cubital vein about the middle of its present length, probably at the end of the first third of the total length.

Six anal veins are present, all of which pass obliquely downwards to the inner margin. The second and third anal veins fork before reaching the wing-margin. The intercalary venation consists of relatively-large reticulations in the middle areas of the wing, that is, between the median and the cubital veins; while, in the area between the radial sector and the median, the veins cross in curved lines with no very evident reticulation. The intercostal area bears a few faint cross-veins passing obliquely outwards from the sub-costa to the wing-margin.

Affinities.—With so small a wing-fragment, it is not possible to form an accurate idea of the whole structure. It is evident that the radius and the radial sector ran out upon the anterior half of the wing-tip, if they did not occupy the whole of it. The median probably curved inwards, reaching the inner margin near the apex of the wing; while the branches of the cubital and the anal veins occupied most, or all, of the inner wing-margin.

The character of the broad intercostal area and the course of the sub-costa, are very similar to what is found in *Polycreagra elegans* Handlirsch; but the main features of the wing are of a simpler type, and the intercalary venation is wholly different.

The reticulate intercalary venation and the character of the principal veins, which do not show much trace of division in the inner third of the wing preserved, are undoubtedly Dictyoneuroid.

Instead of creating a new genus upon this wing-fragment, it seems preferable to follow the example of Handlirsch in his 'Revision of American Palæozoic Insects' and style the specimen '*(Dictyoneuron)*,' retaining the specific name of *higginsi*.

Type-specimen in the Derby & Mayer Museums, Liverpool.

Locality.—Ravenhead railway-cutting, near St. Helens.

Horizon.—Middle Coal Measures.

PALÆOMANTIS MACROPTERA, gen. et sp. nov. (Pl. III, figs. 3 & 4.)

The late Rev. H. H. Higgins, in his Presidential Address to the Liverpool Field Naturalists' Club, 1871 (p. 18), thus records the discovery of this specimen:—

> 'Perhaps the finest and most remarkable fossil found in the Ravenhead cutting was obtained by a son of Mr. J. P. G. Smith, of Liverpool, who, with a young friend, Mr. Clementson, from Rugby, visited the cutting several times. It was the wing of a large insect, beautifully preserved in a nodule of ironstone.'

This nodule was deposited in the Derby & Mayer Museums at Liverpool, and has been placed in my hands by the courtesy of the Curator, Dr. J. A. Clubb.

The larger half of the nodule has lost a portion of one end, which contained the tip of the right wing. The proximal third of the left wing remains with its dorsal surface uppermost, and its ventral surface closely applied to that of the right wing. It is quite evident that the whole of the two wings were contained in the nodule; but, when the latter was being split open, a thin film of ironstone carried away the middle and distal portions of the left wing. The impression of the dorsal surface of the greater part of the left wing remains upon one half of the nodule, and this, combined with the portion of wing remaining on the other half of the nodule, enables one to determine with accuracy almost the whole of the wing structure.

One unusual feature in the preservation of the wings is that they lie with their ventral surfaces apposed. To bring the wings into this position, one must have become bent under the body, instead of falling sideways or above the back of the insect. The body of the insect would thus, if the wings still remained attached, come to lie between the two. No trace of the body can be seen; but the left wing has a deep inward flexure, such as it would naturally acquire if the body had been carried round with the right wing and pushed up into the anal area of the left wing. Had the insect's body been carried round in the way suggested, the right wing would not coincide in position with the left, but be thrust farther out. This latter is actually the case, the outward displacement of the right wing as compared with that of the left being at least 20 mm.

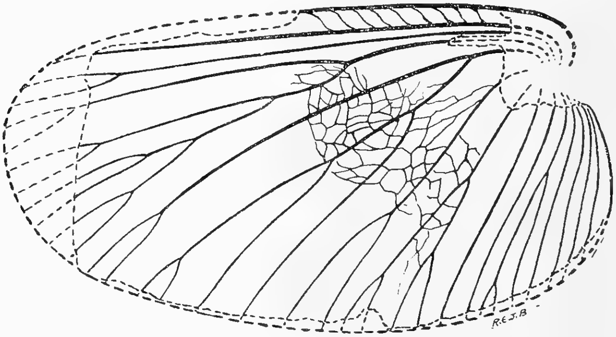
The two wing-fragments are quite sufficient to show that, while the complete structures were comparatively short in length, they were yet remarkably wide from front to back. In this respect they are unlike the wings of any known Coal-Measure insect, and would seem to indicate a heavy-bodied insect, with slow but powerful flight. The frontal third of each wing is supported by strong and fairly rigid veins, which become more slender as they pass outwards. The hinder margins of the wings are more membranous, and were evidently lacking in a rigidity equal to that of the frontal third.

Left wing.—A little more than the proximal third of this wing is present, and in good preservation. It is 42 mm. long, and about the same in width across the anal region. The impression on the other half of the nodule shows all but the tip of the wing. The main trunks of the costa, sub-costa, radius, and median are stout structures, standing out in good relief from the wing-surface. The cubital and anal veins are but half the thickness of the former, and lie sunk in shallow grooves.

The costal vein forms the anterior margin of the wing, which is slightly convex forward, and slopes gently backwards as it passes outwards to the apex of the wing. The sub-costa is separated from the costa by an interval of 4 mm., and passes almost in a straight line outwards to the anterior edge of the wing-tip. The sub-costa gives off a numerous series of small, irregular, and occasionally forked branches, which pass forward to the anterior margin.

The radius arises in close apposition to the sub-costa, and gradually diverges from it as it passes outwards. It throws off a lateral twig on the posterior side before reaching the tip of the wing. The branchings of the radius and the single main stem of the costa occupy the anterior third of the wing-tip. The main stem of the radial sector probably arises from the radius close to the base of the latter, but this cannot be determined, owing to the absence of the inner anterior angle of the wing. The two veins are close to each other proximally, the radial sector keeping parallel with the radius for a short distance and then curving sharply backwards at the end of the first third of its length. At this point it is widely forked, a forward-directed branch passing outwards parallel to the radial sector, and probably forking before it reaches the margin of the wing-tip. The inner branch passes obliquely backwards to the inner angle of the wing-tip, giving off three forward-directed twigs, the first two forking before reaching the apex of the wing.

Fig. 2.—*Restoration of the left wing of* Palæomantis macroptera, *gen. et sp. nov. (Natural size.)*



The median vein is a powerful structure for the first half of the length, beyond which it becomes attenuated. A little beyond its point of origin it breaks up into two main branches, the outer one passing in a broad curve along the median diagonal of the wing, and forking before it reaches the inner margin. The second branch is not so powerfully developed as the first, and follows a course subparallel to the latter, giving off two simple branches on its inner side before reaching the middle of its length, and forming a small fork near the wing-margin. The median and its branches occupy the outer half of the inner wing-margin.

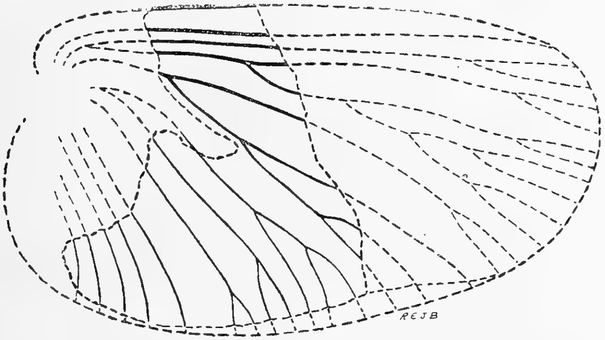
The cubitus is a comparatively weak vein, consisting of two main branches, the outer forking once only, and the inner forking in the middle of its length, each twig forking again just before reaching the margin.

Seven anal veins are determinable, all simple and unbranched, except the third, which forks twice. The anal veins are weak, radiate fan-wise from the base of the wing, and, owing to the great width of the latter, pass almost directly backwards.

The intercalary venation consists of an open meshwork of irregular polygonal cells, feebly defined towards the free margin of the wing. Around the point of attachment of the wing are a few intercalary veins, which run obliquely inwards towards the wing-base.

Right wing.—The right wing, of which less than the proximal half is shown, lies with its under side uppermost under the fragment of the left. The portion exposed is too small to allow of a detailed description of the full character of the veins, but sufficient is seen of the wing to determine that the median vein differs from its fellow in the left wing. But one twig comes off backwards from the second branch, forking at the middle of its length. The outer branch of the cubitus forks twice before reaching the wing-margin, that of the left wing forking once.

Fig. 3.—*Restoration of the right wing of* Palæomantis macroptera, *gen. et sp. nov.* *(Natural size.)*



The greatest depth of the wing is along a line drawn from the costal margin to the middle of the cubital area on the inner margin. The diameter is here 40 mm. The absence of the wing-tip is unfortunate, as it renders the complete outline of the wing a matter of uncertainty. The shape of the ironstone nodule would seem to indicate that very little of the wing is missing, for nodules of this character are usually very uniform in size and outline.

The missing portion can hardly have exceeded 20 to 25 mm. in length. The indications of the terminal forking in the radius and radial sector are usually in close agreement with those of the median, and the latter indicate that only a small portion of the wing-tip is missing. Bearing in mind the probable maximum length of the nodule, and the fact already mentioned respecting the terminal veins, we may fairly assume that the wings were at least twice as long as broad, and had a bluntly rounded tip. Their great breadth is an unusual feature in a Palæodictyopteroid wing, and more typical of those of Blattoids.

The general character and course of the chief veins are most clearly Palæodictyopteroid. The intercalary venation is much like that of *Hypermegethes schucherti* Handlirsch, and forms an open irregular meshwork.

Affinities.—Higgins does not seem to have hazarded any view as to the character and relationship of this wing, although, as already seen, he attempted to determine the relationships of the smaller wing-fragment discovered by himself in the same railway-cutting.

The wing-structure is so clearly Palæodictyopteroid, that its affinities must be sought for in that somewhat generalized group.

In the general course and character of the main veins, the specimen shows a close approximation to *Lithomantis carbonarius* H. Woodward,[1] but differs from all Lithomantidæ in the definite reticulation of the intercalary veins. The latter character brings it into agreement with the Dictyoneuridæ, more especially with *Titanodictya jucunda* (Scudder) Handlirsch. The last-mentioned author has already shown [2] that the wing-structures of the Dictyoneuridæ and Lithomantidæ are so closely alike that the two families might be combined, were it not that in some of the Lithomantidæ the form of the body differs strikingly from that of Dictyoneurids.

The Ravenhead specimen possesses characters peculiar to the two families.

The Dictyoneurid wing is usually quite three times as long as broad, while in the Lithomantids the hinder wings are much broader in proportion to their length. The almost straight posteriorly-directed anal veins of the specimen and the great depth of the wing are alike Lithomantid in character; the wings are markedly membranous in their inner half, and I feel, therefore, justified in assuming that they are the inner of two pairs almost certainly possessed by the insect.

The true relationship seems to lie between the Dictyoneurid genus *Titanodictya* and the Lithomantid genus *Lithomantis*. The specimen cannot properly be included in either, and a new genus is, therefore, necessary. To it I give the name of *Palæomantis*.[3] Its characters may be described as follows:—Wings short, and very broad in proportion to their length. The radius, radial sector, and median are powerful veins with few divisions; the cubitus is a weak vein. Anal veins directed almost straight inwards. Intercalary venation forming an irregular

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[1] Q. J. G. S. vol. xxxii (1876) p. 60 & pl. ix, fig. 1.

[2] 'Revision of American Palæozoic Insects' Proc. U.S. Nat. Mus. vol. xxix (1906) p. 673.

[3] παλαιός = ancient.

meshwork of polygonal cells. The genus is probably one which has been developed from ancestors belonging to the family Dictyoneuridæ in the direction of *Lithomantis.*

To the species I give the name *macroptera,*[1] and define it as follows:—Wings twice as long as broad. Apex bluntly rounded. Divisions of radial sector occupying almost the whole tip of the wing. Cubital and anal veins weak.

Type-specimen in the Derby & Mayer Museums, Liverpool.

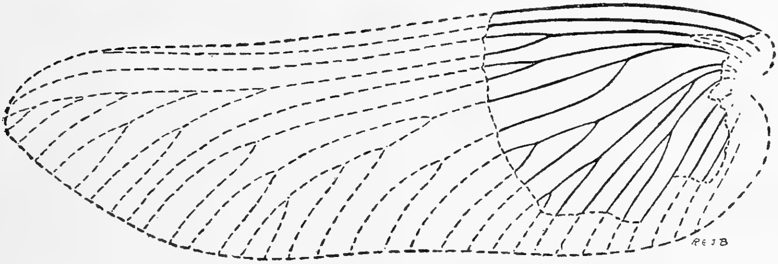
Locality.—Ravenhead railway-cutting, near St. Helens.

Horizon.—Middle Coal Measures.

SPILAPTERA SUTCLIFFEI, sp. nov. (Pl. IV, fig. 1.)

Among the various organisms obtained from nodules from a stratum a little above the Arley Mine in the Middle Coal Measures at Sparth Bottoms, Rochdale (Lancashire), is a small, irregular, micaceous sandy nodule containing the basal portion of an insect-wing. Owing to the coarse granular structure of the nodule, the finer details of the wing-structure are not so well preserved as is usually the case. The chief veins of the wing are robust structures, and these are, fortunately, well marked and clear.

Fig. 4.—*Restoration of the left wing of* Spilaptera sutcliffei, *sp. nov. (Natural size.)*



The portion of wing preserved is 35 millimetres in length along the costal margin. Its greatest width is 27 mm.; but, as the inner margin is not present, the total width of the base of the wing must have exceeded 30 mm. The wing is a left wing. A little more than a third of it is preserved, and the total length of the whole wing (when complete) must have been at least 90 mm. The insect must, therefore, have had a spread of wing of nearly 200 mm., or about 8 inches.

The costal margin is very feebly convex forward, forming, indeed, almost a straight line. The sub-costa runs somewhat parallel to the costal margin, and is sunk in a groove. It gradually approaches the costal margin distally, but to so slight an extent as to render it fairly certain that the sub-costa reached

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[1] μακρός = long; πτερόν = a wing.

almost, or quite, the apex of the wing. The sub-costa gives off a series of straight veins, which pass obliquely outwards to the costal margin. How numerous these veins were it is not possible to say, as the matrix obscures much of the finer detail.

The radius is a strong vein, standing out above the general wing-surface, and keeping a fairly parallel course to the sub-costa and the wing-margin. It gives off the main stem of the radial sector at an acute angle, at about 22 mm. from the base of the wing.

The base only of the radial sector is shown. This arises from the radius at a point about 9 mm. in front of the broken edge of the wing.

The median vein is the most important vein of the wing. It arises close to the radius, and continues parallel to it for a short distance, and then forks into two equal branches, both of which become widely separated from the radius, and one from the other. The anterior branch gives off an outer twig opposite the point of origin of the radial sector, which it approaches very closely. The inner branch of the median passes in a straight line obliquely outwards and downwards in a direction which would bring its ultimate twigs out upon the middle of the inner wing-margin. It gives off, near the base, a posteriorly-directed vein which curves sharply away from the main branch and then passes outwards and backwards parallel to it, the sharp outward curve of the vein causing the formation of a very wide interval between the two.

The cubitus evidently divides quite close to the base of the wing. The outer branch passes backwards and outwards in a gentle double curve, giving off two simple twigs from its inner side. The inner of the two main branches of the cubitus passes obliquely backwards, divided into two twigs near the base of the wing, and the outer of these divides again before reaching the wing-margin.

The anal veins were few in number, remains of four only being left. These all pass obliquely backwards, and the outermost forks before reaching the middle of its length. The remaining three are evidently undivided.

Very few traces of intercalary venation are distinguishable. Allusion has already been made to a few oblique veins, which cross the intercostal area. The only other intercalary veins are a few almost straight and well-spaced cross-veins which bridge over the wide interval between the innermost twig of the median and its fellow.

Affinities.—The mode of division of the radius and the median, the wide area between the inner divisions of the latter and the cubitus, the manifest importance of the median, and the few widely-spaced cross-veins, are all typical Spilapterid characters. The wing cannot be confused with *Stenodictya*, in which the median is much less developed, and the intercalary venation reticulate.

From *Becquerelia* the wing is distinguished by the non-union of the anal veins. I have no hesitation, therefore, in assigning the species to the genus *Spilaptera*, and would add the specific name of *sutcliffei*, in memory of the late W. H. Sutcliffe, who helped so materially to work out the fauna of Sparth Bottoms.

This genus contains three known species. From *Sp. packardi* Brongniart the specimen now described is easily distinguished by the sub-costa being parallel to the costal margin; by the equal separation of the sub-costa, radius, and median in the basal third of the wing; and by the division of the median into two branches quite close to the base. *Sp. libelluloides* Brongniart is only known from the distal half of a wing, in which the cubitus is a smaller vein dividing in a feeble fork some distance out from the base; whereas in *Sp. sutcliffei* the cubitus is much stronger, and divides into two, or possibly three, main branches close to its point of origin. *Sp. venusta* Brongniart is a species established upon little more than the distal half of a left wing. The sub-costa is a much shorter vein than in *Sp. sutcliffei*, and the radial sector comes off from the radius nearer the middle of the wing. In *Sp. sutcliffei* the outward branch of the median forks almost in line with the point of origin of the radius—a feature not seen in *Sp. venusta.*

Diagnosis of species:—Sub-costa subparallel to costal margin; median vein dividing near the base into two branches, of which the outer forks just beyond the point of origin of the radial sector. Cubitus a large and much-divided vein. Anal veins few in number.

Type-specimen in the Manchester Museum, Reg. No. L. 8197.

Locality.—Sparth Bottoms, Rochdale.

Horizon.—Middle Coal Measures.

HYPERMEGETHES NORTHUMBRIÆ, gen. emend. et sp. nov. (Pl. IV, figs. 2 & 3.)

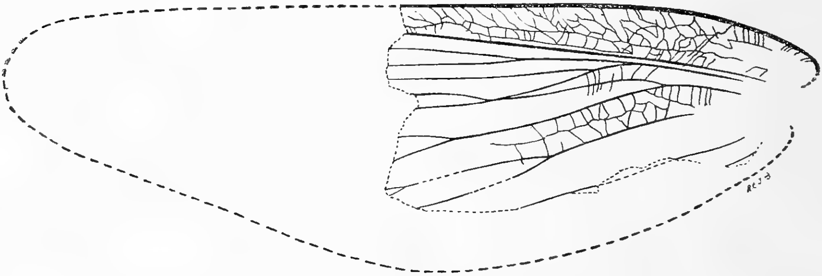
This specimen consists of a portion of the basal half of a left wing, contained in two fragments of an ironstone nodule, of which one bears the impression and the other the wing-fragment. The two do not wholly coincide, and consequently the outline drawing of the wing-fragment is built up from the two halves of the nodule. The inner margin, anal area, and base of the wing have been lost, so that a little less than two-thirds of the outer portion of the basal half of the wing is present. The wing was of great length, the portion remaining being 63 mm. long, with a depth of 31 mm. at its widest part. The whole wing would have a length of about 126 mm., or 5 inches, and the insect a span of wing of close upon 11 inches. The wing shows the basal portions of the costa, sub-costa, radius and radial sector, median and cubitus; possibly there is a trace of a portion of an anal vein.

[My views upon the structure and relationship of this wing have undergone a change since reading the paper before the Society on March 8th. At that time all my efforts to determine the character of the intercalary venation had ended in failure, while

I had been unable to determine the exact condition and course of the veins in the radial sector and median areas. Dr. F. A. Bather afterwards drew my attention to two photographs made of the specimen at the British Museum (Natural History) in June 1914, in which the intercalary venation was clearly shown. The detailed structure of the wing was brought out by the simple expedient of photographing the specimen while it was immersed in water. From a study of the British Museum photographs, kindly lent for the purpose, many of the doubtful points of the wing have been cleared up, and its nearness to *Hypermegethes schucherti* Handlirsch made more certain. The wing is now redescribed in the light of the knowledge thus obtained.—*H. B., March 31st, 1916.*]

The costa is moderately convex from its base to a distance of about 30 mm., beyond which it becomes perfectly straight. Separated from the costa by a very wide area basally is the sub-costa, an extremely feeble and hardly distinguishable vein. It passes straight out to meet the costal margin some distance beyond the middle of the wing.

Fig. 5.—*Restoration of the left wing of* Hypermegethes northumbriæ, *sp. nov. (Natural size.)*



The radius arises close to the sub-costa, and remains parallel to it along its whole length. It gives off two branches posteriorly, the more proximal branch passing obliquely inwards towards the inner portion of the wing-apex; while the second or distal branch arises from the radius a little farther out, and keeps parallel to it. I had formerly considered the proximal branch of the radius as the radial sector, and the distal one as a simple branch of the radius only. If the wing be closely related to that of *Hypermegethes schucherti*, which now seems most probable (as will be seen later) my former view will not hold. It would seem that the proximal branching vein must be regarded as the main stem of the median vein, which has entered into union with the radius, and that the distal branch is the radial sector.

Regarding the proximal branch of the radius as the median vein, I find that it diverges widely from the radius. It gives off a forward twig, which runs parallel to the radial sector, and then continues inwards until it cuts across the next vein, the two veins being perfectly united at the point of intersection. A comparison of this assumed median vein with that of *H. schucherti* is instructive. In the latter species the branching of the main stem of the median vein arises nearer the base of the wing than does the branching-off of the radial sector. It is, therefore, somewhat in the position of the starting-point of the median vein as a free structure in the present wing. The median vein of *H. schucherti* has, however, no union with the radius at all. In that species the main stem of the median runs out towards the wing-apex parallel to the inner branch of the radius, giving off a backward branch which passes obliquely towards, and unites with, the anterior branch of the cubitus. In the middle of its length it gives origin to a twig running parallel to the main stem, and midway between that vein and the cubitus. The course of the median vein in the specimen here described is exactly similar to that of the branch of the median vein in *H. schucherti*, except that the inner branch not only unites with the anterior branch of the cubitus, but continues on the inner side of the latter vein beyond the point of union. The conditions may be summarized by saying that in *H. schucherti* the median vein is free along its whole length, and gives off an inner branch which forks into two twigs, of which the inner unites with the cubitus; while in the specimen here described the median is united with the radius for some little distance, becoming free before the radial sector is reached and then forking, the inner twig uniting with and crossing the cubitus.

The next free vein to the radius is the cubitus. It has a short stout basal stem, which forks into two equal and somewhat widely separated branches, the outer, as I have already noted, uniting with the inner branch of the median. The inner branch shows the beginning of a bifurcation on the broken edge of the wing.

Nearer the inner margin of the wing are traces of two other veins: the first has its basal portion missing, and follows a course parallel to the inner branch of the cubitus. It is strongly forked. The remaining vein is represented by three detached fragments. If Handlirsch's interpretation of the wing of *H. schucherti* is followed, we should regard both these veins as anal. I am, however, of opinion that, while the innermost fragmentary vein may be an anal one, the forked vein, by its position, its forked character, and its stoutness, must be regarded as a portion of the cubitus. I am likewise of opinion that the first, and possibly the second, of the veins marked as anal in Handlirsch's figure of *H. schucherti* ought also to be classed as cubital. Both in *H. schucherti* and in the specimen here described the anal area would have an enormous development and occupy most of the wing-margin if the veins alluded to were wholly anal in character. I feel sure that, if the vein nearest the cubital had been better preserved, it would be found in actual union with the latter at the base of the wing.

The intercalary venation, the knowledge of which I owe to Dr. F. A. Bather, is peculiar, and almost identical with that of

Hypermegethes. The intercostal area is filled by an irregular meshwork of fine veins, with a tendency on the outer and inner sides to a transverse arrangement. Between the median and the cubital the intercalary veins are short, straight, and transverse, and feeble traces of similar veins can be seen in the median area. The cubital area is filled in with a meshed venation, larger and more regular than that of the intercostal area, and this seems to continue into the anal area.

Affinities.—The Palæodictyopteroid characters of the veins of this wing are clear and unmistakable. The general course and branching of the main veins are undoubtedly like those of *Hypermegethes*, and now that the intercalary venation is known, this relationship is put beyond doubt. The points of relationship between *Hypermegethes schucherti* and this wing may be enumerated as follows:—

Intercostal area wide and filled in by an irregular meshwork of subsidiary veins. In each case the radial sector comes off farthest from the base of the wing, the forking of the median next, and the forking of the cubitus nearest the wing-base. The radial, median, and part of the cubital areas are occupied by relatively few transverse veins. The inner half of the wing in each case is filled in by a network of more regular and larger-meshed veins than is the intercostal area. In both cases the median has an inner branch, which enters into union with the anterior branch of the cubitus. The radius, median, and cubital elements are in both cases closely compacted together, with narrow areas, while in the rest of the wing the veins are well spaced.

This assemblage of characters common to *H. schucherti* and the present specimen quite justifies the inclusion of the latter in the genus *Hypermegethes*; but, in order to do this, it is necessary to modify somewhat the diagnostic descriptions of the family Hypermegethidæ and the genus *Hypermegethes*.

I would, therefore, define the family Hypermegethidæ as follows:—

Costa marginal, costal area broad, radius simple, radial sector present, median probably dividing at the base into two or more main branches, the first of which may become united to the radius; cubitus forked near the base, with its branches widely spaced. Anal veins few, and anal area not exceeding a third of the inner margin.[1]

Genus HYPERMEGETHES.

Costal border feebly convex, sub-costa and radius close together along the greater part of their length. Outer median vein fused with radius or separate. Cubitus consisting of two, possibly more, parallel and simply forked branches, dividing near the point of origin. Anal veins few.

The specimen here described differs from *H. schucherti* in the

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[1] The general assemblage of characters found in Hypermegethidæ is, I believe, highly suggestive of the Protodonata, but no definite conclusions can be formulated until the whole wing is known.

close approximation of the sub-costa to the radius along its whole length, in the outer median vein being fused for a portion of its length with the radius, and in distally uniting with and crossing the outer branch of the cubitus. These diagnostic features are sufficiently important to justify the creation of a new species, to which I give the name of *Hypermegethes northumbriæ*.

Type-specimen in the possession of Mr. William Eltringham.

Locality.—Phœnix Brick-works, Crawcrook (Durham).

Horizon.—Shale above Crow Coal.

PSEUDOFOUQUEA CAMBRENSIS (Allen). (Pl. IV, figs. 4 & 5.)

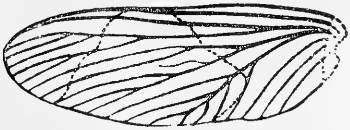
1901. *Fouquea cambrensis* H. A. Allen, Geol. Mag. dec. 4, vol. viii, p. 65, text-fig. on p. 66.

1906. *Pseudofouquea cambrensis* (Allen) Handlirsch, 'Die Fossilen Insekten' p. 125 & pl. xiii, fig. 5.

This is a broken left fore-wing, of which the two parts are preserved upon the surface of two small fragments of black shale. One fragment, bearing the basal part of the wing, is in the Museum of Pactical Geology; the other, containing the outer 28 mm. of the wing, is in the Welsh National Museum, Cardiff.

Allen referred the wing to Charles Brongniart's genus *Fouquea*, comparing it with *F. lacroixi* Brongniart, but drawing attention to the marked difference of the cubitus in the two species and to the greater number of twigs into which the main veins divided in *P. cambrensis*. Handlirsch repeats Allen's figure, and places the species in a new genus, *Pseudofouquea*.

Fig. 6.—*Restoration of the left wing of* Pseudofouquea cambrensis *(Allen).*



[Natural size.]

The total length of the wing remaining is 32 mm., so that 9 mm. have been lost from the tip of the wing in the Geological Survey specimen. The total length is given by Allen as 41 mm. The greatest breadth is 15 mm.

In the costal area are very faint traces of a feeble venation of cross-veins, which bend obliquely outwards. In the area between the sub-costa and the radius the veins in the proximal part are transverse, becoming irregular in direction farther out. The rest of the intercalary venation is now so feebly marked as to be indistinguishable, except between the base of the anal vein and the main stem of the cubitus, where it is irregularly reticulate. This is not shown in Allen's figure.

The costa is fairly convex, most conspicuously so in the proximal half.

The sub-costa is somewhat widely separated from the costal proximally, and gradually approaches it along its outward course. As the costal border dips backwards about the middle of its length, the inner half of the intercostal area is double the width of the outer half.

The radius is a simple vein, giving off the radial sector at the base, and then passing out towards the tip of the wing parallel to the sub-costa, from which it remains equidistant along the whole of its course. The radial sector diverges widely from the radius, and now shows but one posteriorly-directed branch, which forks just as the broken edge of the wing is reached. So widely does the radial sector diverge from the radius, that the area included between them is equal in diameter, immediately beyond the forking of the radial sector, to the whole area lying between the radius and the costal margin at its widest part. Allen shows that two additional undivided twigs were sent off posteriorly from the radial sector, beyond which is now the broken edge of the wing.

The radius and the radial sector occupied almost the whole tip of the wing.

The median vein forks at a quarter of the length of the wing from the base, the outward branch again forking before the middle of the wing is reached. The two twigs so produced pass backwards and outwards to the inner wing-margin, keeping parallel one to the other and to the innermost twig of the radial sector. The inner branch of the median diverges almost in a straight line from the outer branch, so that a wide area lies between them up to the point at which the inner branch forks. The forking of the inner branch occurs farther out than in the outer branch, and forks a second time before the inner wing-margin is reached.

The cubitus is a remarkable vein. For nearly half its length it passes in a broad curve outwards and backwards towards the inner wing-margin, without forking. Beginning at the middle of its length, the cubitus gives off alternate twigs upon its outward and inward sides, those on the inner side being much feebler than those on the outer. The two outward twigs are strongly developed, and sweep in a wide curve outwards and down to the wing-margin. The twigs from the inner side of the cubitus are five in number, and pass directly inwards to the wing-margin, with the exception of the last, which seems a feeble continuation of the main stem, and curves outwards like the two outer twigs; the course of the inner four twigs is therefore much shorter than that of the outer twigs, while the area that they occupy on the wing-margin is also much less. This is a feature entirely unlike anything seen in *Fouquea*.

Four anal veins are distinguishable. The inner two arise from a common base; the remaining two are distinct. This, again, is unlike what is seen in *Fouquea*, where the anal veins branch off regularly from a single stem.

The area lying between the first anal vein and the main stem of the cubitus is very wide, much wider, indeed, than any other area in the wing.

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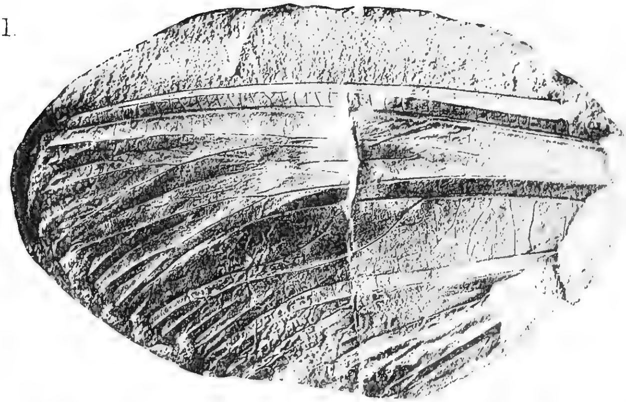

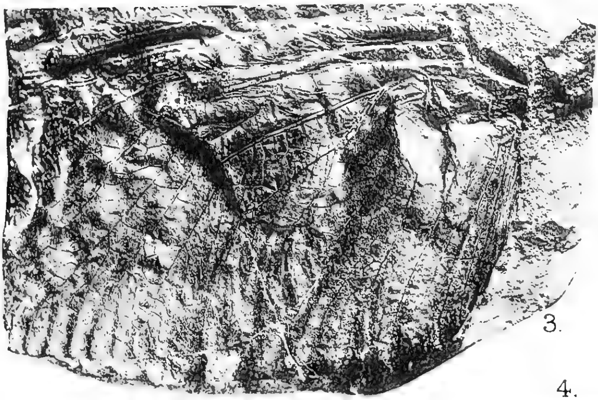

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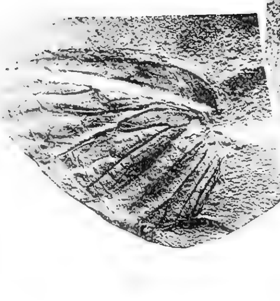

J. W. Tutcher, Photo

Bemrose, Collo., Derby

COAL-MEASURE INSECTS.

(All the figures are of the natural size.)

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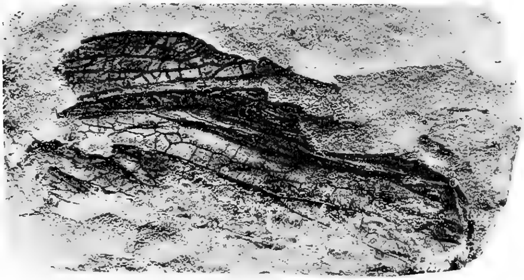

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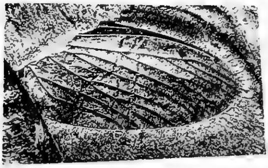

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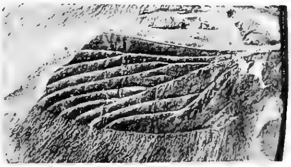

J. W. Tutcher, Photo.

Bemrose, Collo, Derby.

COAL-MEASURE INSECTS.

(All the figures are of the natural size.)

Affinities.—The sub-costal vein reaches the costal margin at about 12 mm. from the apex of the wing—a feature noted in *Fouquea*. The radial sector originates nearer the base of the wing than is shown in Handlirsch's figure. The actual junction is not shown in Allen's figure. It must have been near the base of the wing, much nearer the base than is seen in *Fouquea*. The characters of the cubital and anal veins definitely remove the species from *Fouquea*, as I have already noted; indeed, the character of the cubitus, with its strong anteriorly-directed twigs and its feeble inner branches, is wholly unlike that of any other insect, and would alone suffice to justify new generic rank. So far I am in agreement with Handlirsch; but I regard the enlarged areas between the inner divisions of the radial sector and the cubitus, and between the cubitus and the anal veins, as more suggestive of the Proto-Orthoptera, notably *Thoronysis ingbertensis* Ammon.

More than this cannot be said, and *Pseudofouquea cambrensis* must be regarded provisionally as Palæodictyopteroid, with a possibility of Proto-Orthopteroid affinities.

Holotype specimen: outer half of a wing in the Welsh National Museum, No. 13,120. Middle portion of the same wing in the Museum of Practical Geology, Jermyn Street, No. 7272.

Locality.—Llanbradach Colliery, near Cardiff.

Horizon.—Top of the Four-foot Seam, Lower Coal Measures.

EXPLANATION OF PLATES III & IV.

[All the figures are of the natural size. The photographs reproduced in these plates were prepared by the aid of a grant from the Royal Society.]

Plate III.

Fig. 1. Left wing of *Ædœophasma anglica* Scudder. (See p. 43.)
2. Basal portion of a left wing of *(Dictyoneuron) higginsii* (Handlirsch). (See p. 46.)
3. Left half of an ironstone nodule, showing a left wing-fragment of *Palæomantis macroptera*, gen. et sp. nov., lying upon the right wing, the latter with its underside uppermost. (See p. 48.)
4. Impression, in the right half of an ironstone nodule, of the greater part of the upper surface of the left wing of *Palæomantis macroptera*, gen. et sp. nov.

Plate IV.

Fig. 1. Basal portion of a left wing of *Spilaptera sutcliffei*, sp. nov. (See p. 53.)
2. Left half of a nodule, showing portion of a left wing of *Hypermegethes northumbriæ*, sp. nov. (See p. 55.)
3. Right half of a nodule, showing portion of a left wing of *Hypermegethes northumbriæ*, sp. nov.
4. Portion of a left wing of *Pseudofouquea cambrensis* (Allen). (See p. 59.)
5. Tip of a left wing of the same.

Discussion.

Mr. G. W. Young welcomed the paper as another contribution by the Author on a branch of palæontology but little studied in this country. This was the more to be regretted, as much had been written upon it on the Continent and in America; and he could not help thinking that British entomologists were neglecting opportunities, since we had much excellent material available for study. The species dealt with in the paper showed, as usual, that the Palæozoic insects were so generalized that it was difficult to place them in any of the usually-recognized orders; and they embraced not only the ancestral forms of Orthoptera, Neuroptera, and Hemiptera, but many other types that had not survived beyond Carboniferous times.

Mr. J. H. Durrant also spoke.

5. *On the* ORIGIN *of some* RIVER-GORGES *in* CORNWALL *and* DEVON. By HENRY DEWEY, F.G.S. (Read February 23rd, 1916.)

[PLATES V–VII.]

THE river-gorges here described are situated for the greater part in North Cornwall, between Boscastle and Tregardock, though a few occur in other parts of Cornwall and in Devon. Some of the characteristics of the coastal gorges of Devon have already been described by Dr. E. A. N. Arber,[1] but there appear to be additional features in those of North Cornwall, which are possibly due to their mode of origin.

These gorge-like valleys are more or less restricted to areas of peculiar topography, and their origin is connected with the history of that topography; while they form a sharp contrast with the valley-systems where such a topography does not exist. Thus, the valley-systems of Cornwall are divisible into two groups, each being marked by features peculiar to it; although in some cases the river-valley exemplifies the two types of scenery in different parts of itself.

The difference is in part due to their respective stages of development, but mainly marks a renewal or rejuvenescence of the rivers' activity. The fall of these rivers near Tintagel averages 1 foot in every 13 feet.

The gorges are incised in an upland plain, which truncates all hills at a uniform height of about 430 feet above the level of the sea, while the other series of valleys lies in an area diversified by many irregular hills and buried and submerged estuaries.

THE UPLAND PLAIN.

This feature has become well-known in Cornwall through Clement Reid's[2] descriptions. It is everywhere bounded landwards by a prominent ridge, marking a range of degraded cliffs, which also form the boundary of the hills rising above it to a height of 1000 feet above sea-level. This planation has affected alike rocks of different degrees of hardness, reducing them all to a level surface, and cutting a notch in the higher ground beyond them. When viewed in profile, and especially from places a few miles away, this feature is very conspicuous, as when the Tintagel country is seen from Pentire Head, or the Land's End from Carn Brea.

From Boscastle the plain is continuous for several miles towards the south, where, at Tregardock, the sea has encroached on the

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[1] 'The Coast Scenery of North Devon' London, 1911.

[2] I desire to place on record here how greatly I am indebted to the late Mr. Clement Reid, for valuable hints and encouragement received from him during some seven years of joint field-work in Cornwall and elsewhere.

higher land beyond it; and, although south of this point much of the land rapidly falls, the feature is seen in places both near the coast and inland.

Most of this area is drained by the rivers Camel and Allen, both flowing from north to south in courses roughly parallel to one another and to the coast; but they do not drain all the district, as they are separated by a ridge of high ground from a coastal area drained by streams flowing westwards into the sea. These streams are short and formerly united with another river-valley, now buried beneath the sea, and are thus remnants of a larger drainage-system. One of these valleys runs parallel with the present shore-line, its left-hand slopes forming the sea-cliffs, which are breached by the encroachment of the sea at several points, while its right side is continuous (see Pl. V). Similar sea-breached river-valleys in North Devon are described by Dr. E. A. N. Arber,[1] and others occur in Cornwall and South Devon.

Elsewhere in Cornwall and Devon the upland plain dominates the landscape over wide areas, and more especially near Newquay, on St. Austell Moors, by St. Agnes Beacon, near Camborne, and also in the Land's End and the Lizard. It is conspicuous in Central Cornwall, about Roche and Lostwithiel, and extends along the Tamar Valley towards Launceston.

In South Devon it truncates nearly all the land south of Dartmoor, and has had important effects upon the drainage of that country. East of Dartmoor it is seen especially well about Bovey Tracey, where it has cut into deposits assigned by Clement Reid[2] to the Oligocene Period.

Into the question of the age of this plain I do not intend to enter. Reid adduced evidence to show that the deposits resting upon it are early Pliocene, and I believe most authors agree that they were deposited during some part of the Pliocene Period; but the plain itself may be of much earlier age.

The further question as to the nature of the agency which cut this plain has received the attention of several investigators; but there can be no doubt that the final agent which effected the planation was the sea, as is indicated by the widespread occurrence of the plain, everywhere at the same altitude.

The deposits resting upon it have long been known at St. Agnes, St. Erth, and at the Lizard. They vary from clay to gravel, but, except at St. Erth, do not contain fossils. The character and the depth of the deposits resting on the plain in North Cornwall were tested by some pits dug by the officers of the Geological Survey near Tintagel, which exposed about 12 feet of angular detritus overlying a bed of pebbles of vein-quartz. It is said by local observers that sand containing fossil shells was found when a trench was dug for the water-main many years ago. These sands, however,

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[1] 'The Coast Scenery of North Devon' 1911, pp. 230–39.

[2] 'Geology of the Country around Newton Abbot' Mem. Geol. Surv. 1913, pp. 104–117.

were not traced by the Geological Surveyors. The deposits on St. Austell Moor have been dredged and turned over in search of stream-tin and wolfram, and are everywhere detritus composed of granite, quartz-sand, and clay, but no shells are recorded. The deposits, however, represent a long-continued process of surface-erosion, partly in Pliocene and Glacial, and to some extent in post-Glacial, times.

The evidences of marine erosion are therefore well-marked: namely, the similarity of height of the plain above the sea over wide areas, the degraded sea-cliff, and the beds of pebbles.

This planation repeated a process which had affected the topography of Cornwall and Devon on at least two previous occasions; but the two earlier plains have already been described by Mr. G. Barrow,[1] and reference will only be made to them when necessary.

There are thus two principal types of scenery in Cornwall sharply contrasted one with the other: namely, the upland moors and the rocky gorges—one brought about by prolonged denudation, and the other by acceleration of river-erosion resulting from sudden uplift of the land.

The gorges, however, show in plan sinuous or meandering courses, and thus indicate that, according to current views, the land was not uplifted by a slow continuous process, but rather in two stages. The Tamar exemplifies these two stages when its course is viewed on a map. It flows in a series of loops, often nearly circular, in a deep gorge. The loops were initiated when the river flowed sluggishly across a flat, but on uplift of the land it commenced to dig itself in, and has since continued in its early channel; or else it has followed lines of structural weakness, such as are known to occur in Cornwall and Devon.[2]

Both the planation and the uplift have had important effects upon the drainage of Dartmoor. At the period of emergence Cornwall and Devon probably consisted of a step-like series of wide flats bearing rocky tors, separated one from the other by steep slopes, and drained by sluggish streams. As elevation ensued, the rivers gained acceleration, and cut back into the flats to form gorges. These features are met with repeatedly in Cornwall and Devon, and are especially conspicuous on Dartmoor in the valleys of the Tavy, Lyd, Dart, and Teign.

The Gorges.

Where the plain was undercut by the sea it was bounded by cliffs, and the rivers formed waterfalls when they reached the edge of the cliffs. These falls immediately commenced sawing downwards and backwards into the land, so rapidly in some cases that they led to the formation of gorges.

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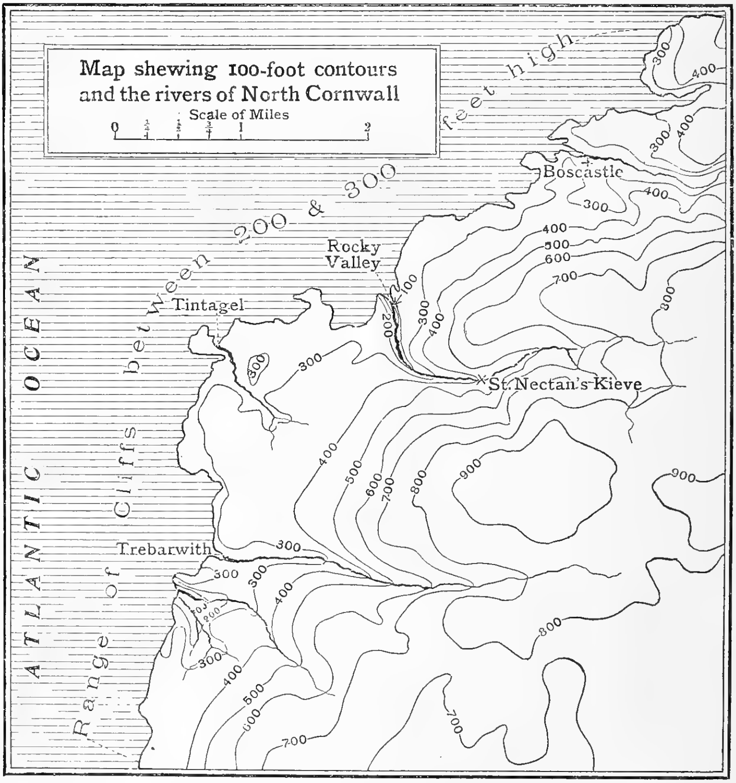
[1] Q. J. G. S. vol. lxiv (1908) pp. 384–400.

[2] See 'The Geology of Dartmoor' Mem. Geol. Surv. 1912, p. 64.

The most conspicuous features in these gorges are the numerous potholes or marmites, and it is not too much to say that they were instrumental in drilling out the chasms where now the rivers flow as cascades and torrents. Of these gorges the most characteristic in Cornwall are near Tintagel and Boscastle, and, inland, those at Lydford, Luxulyan, and the Bovey Valley.

The following descriptions are arranged geographically, commencing in North Cornwall and following the coast southwards, and thence to inland localities.

Fig. 1.



The base of the degraded line of cliffs runs nearly parallel with, and between, the 400- and the 500-foot contours. The cliff is marked by the crowding-together of the contours above 400 feet.

The plateau (see map, fig. 1) near Boscastle covers an area of some 10 square miles, with a coast-line 6 miles long and much indented with bays, havens, and coves. There are five valleys dissecting this plateau, and, although they are several hundred feet deep, their existence would not be suspected if the plain were viewed from a distance; for then it appears simply as a wide expanse of level fields and waste land. The area is divided by these streams into flat-topped blocks of land, where no rock is exposed at the surface, separated one from the other by rocky chasms.

These five valleys exemplify the several stages in the development of gorges, and, when seen from the sea, the degree to which they have been cut down by their streams obviously ranges from the coastal waterfall to a valley accordant with the sea at low tide. Moreover, they possess similar features which characterize them as a group, and differentiate them from the valleys of the country adjoining them on the south. These features are the waterfalls, the cascades and rapids, the potholes, and the bare craggy rocks seaming their slopes.

The first valley in this district, known as Pentargon, is short, and marks an early stage in the development of a gorge; while its stream forms a waterfall over the edge of the cliff. It has cut a sharp gorge in the Carboniferous grits and shales, but this does not extend far inland.

The Valency Valley.

A little farther south is the deep and important valley through which the Valency flows swiftly to the sea. It has sides which are precipitous, with overhanging rocky crags and bluffs, and to it the name gorge well applies. The stream has cut a channel which is swamped at its mouth by the sea at high tide, and forms the little harbour of Boscastle. The valley is of great beauty and in places approaches even to grandeur, especially near the sea, where precipices of sharply-folded beds of grit, veined with threads of white quartz, are undercut by the waves.

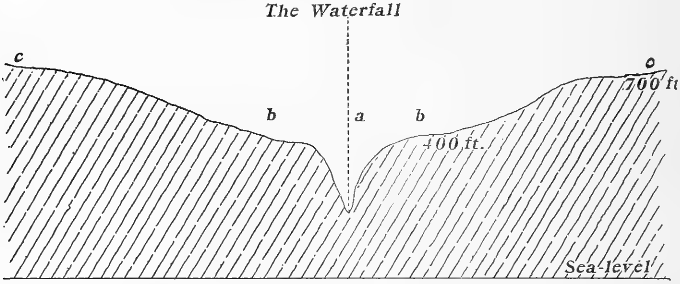
The country, however, between Boscastle and the Rocky Valley is dull and commonplace, except for the magnificent range of cliffs that bounds it; but it enhances the beauty of the next gorge by forming a foil to its mixture of rocks and woodland.

The Rocky Valley.

This gorge owes its origin to the cutting power of what was originally a coastal waterfall, but has how retreated inland for a distance of several miles, leaving numerous evidences of its activity in the walls of the chasm. It commenced its work when the land was uplifted in post-Pliocene times, by cutting a deep gorge into the plateau, and has since continued ripping its way backwards and downwards through the bare rock until it has breached the old cliff-line bounding the plateau. This work has been effected by the formation of a series of large hollows or potholes one below the other, many of which remain in the walls of the gorge; and to this agency I ascribe the formation—at any rate, in part—of all the gorges of the West of England, for similar phenomena are visible at different places in these gorges.

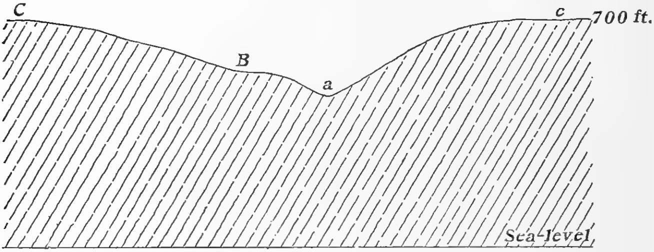
The gorge commences as a vertical wall of rock, more than 40 feet high, and everywhere scarred with potholes. Over the lip of this precipice a fine waterfall leaps clear, and carrying with it its burden of stones crashes down into a large basin 40 feet (see Pl. VI) below, where it immediately commences drilling out the rocky channel of the stream. This basin is thought to resemble a miner's bowl or 'kieve,' and for this reason the locality is known as St. Nectan's Kieve.

Fig. 2.—*Section through St. Nectan's Kieve.*



[Scales: horizontal, 4 inches = 1 mile; vertical, 1 inch = 660 feet.]
a = The gorge. *b* = 430-foot plain. *c* = 750-foot plain.

Fig. 3.—*Section at Trevalga Mill, at a spot on fig. 1 about half a mile east-north-east of St. Nectan's Kieve.*



[Scales: horizontal, 4 inches = 1 mile; vertical, 1 inch = 660 feet.]
a = Present valley. B = 430-foot plain. C = 750-foot plain.

The basin is breached by a hole in its side, through which the waters escape and form a second small waterfall, while remnants of others scar the walls of the gorge, here about 100 feet wide. The stream then races among rocks through the deep ravine for several miles, and thereafter forms a series of cascades and waterfalls, swirling among potholes, until it reaches the sea. The sides of the gorge, which is justly famed for its great charm and beauty, are everywhere nearly vertical, huge crags and bluffs overhanging in many parts.

The accompanying sections (figs. 2 & 3, p. 68) show in profile the way in which the fall has ripped out a chasm in the plateau and also where it has cut a sharp V-shaped recent valley in its ancient wider one. The country-rock is intensely metamorphosed sericite-phyllite, which everywhere weathers into pyramidal stacks and does not easily break down into gentle slopes.

The Trevena or Tintagel Valley.

The next valley presents similar features to the Rocky Valley, but the stream reaches the sea as a waterfall some 40 feet in height. The gorge is lined with rocks, some being volcanic, some more massive dykes, and others phyllites. The stream is small, but has a steep gradient and great cutting power.

South of Trevena Valley the flat extends to Trebarwith, where the same features are repeated, the rushing stream ripping for itself a course through bare rock, and ending in a series of little waterfalls and potholes near the shore, its ravine-like valley studded with pinnacles and crags of bare rock bearing witness to the steep gradient of the stream. At this locality the gorge has been cut to sea-level, in part through schistose lava and ash, and near the sea some instructive examples of miniature cañons, cascades, and potholes are preserved in these volcanic rocks. At Treligga the main valley assumes a cañon-like appearance; but beyond Treligga the sea has worn away all traces of the plateau, and is bounded by the ancient cliff-line. The upland plain reappears, however, near St. Eval, some miles farther south, the feature having been cut in rocks of different degrees of hardness, including the intensely-resistant Staddon Grit.

Inland, the plateau is well seen at Helland, near Bodmin, many miles from the coast. But perhaps the most familiar examples of it are those seen respectively at St. Agnes, where the Beacon rises above the sand and clay-deposits that cover it; at Land's End, and also at the Lizard peninsula. It is conspicuous, too, in the mining regions of Camborne and Redruth, on St. Austell Moors, and near Lanhydrock.

The Luxulyan valley, famous alike for its beauty and for the name that it has given to a peculiar rock, is an example of a gorge incised in this plain. The plateau ends, at some 400 feet above sea-level, as a notch, cutting the higher ground rising above it; and, moreover, this notch is also conspicuous in many of the huge granite-boulders which lie scattered over the surface of the plain. Several of these are upwards of 20 feet high, are rounded on the top, but just above the level of the ground bear a wide basal platform. The river flows through a wooded ravine nearly 100 feet deep, the sides of which are sprinkled over with some big granite-boulders that have rolled down from the plain as the river has eroded its channel. The existence of this gorge is unsuspected until its actual edge is approached, the surface of the adjacent country appearing from a distance as an undissected plain. Beyond the limits of the river's action the plain is covered with stony detritus, which often supports peaty marshes, and contains, locally, pebbles of cassiterite and wolfram. These valuable ores were derived from the kaolinized granite, and are still found in the form of stringers and stockworks threaded through the granite when the china-clay is washed off by hydraulic mining.

These deposits are the residue of a prolonged denudation of the granite, which must have been very active when the tin was rounded into pebbles and swept forward over the plateau, but diminished later and permitted the accumulation of the 'head' and peat.

The rejuvenating effects of the uplift upon the power of the rivers is well represented in the neighbourhood, where some headwaters of the Fowey have cut V-shaped troughs in the wide valleys of earlier streams.

The plain is further traceable over much of the country between Lostwithiel and Launceston, indicating the former extension of the sea far inland. Near Lawhitton and Lifton many of the hills are truncated, and are merely remnants of the plateau; but much higher ground bounds them on the east, and sweeps upwards to the high tors of Dartmoor.

Lydford Gorge.

The importance of the extent of the plateau along the Tamar Valley is best realized by consideration of the great alteration that it has produced upon the drainage-system of Western Dartmoor, including the incision of the deepest gorge in the whole of the West of England, namely, Lydford Gorge.

The gorge has been described by many writers, including Dr. R. L. Sherlock,[1] who called attention to the different resistant powers of metamorphosed and unaltered rocks when attacked by the river, and ascribed to this agency the production of the gorge itself. It is another example of a sunken ravine, which is unseen from the neighbouring country and its existence unsuspected until it is almost entered.

The gorge arose as a result of the diversion of the Lyd to a shorter course and steeper fall,[2] brought about by the breaching of the side of its original valley by another river. Previous to its present course, the Lyd flowed south past Was Tor (as indicated by a broken line on Pl. VII) and along the deep wide valley now drained by an insignificant stream known as the Burn. The water-divide between the Lyd and the Burn is near Lydford Junction, and since its diversion the Lyd has cut at this locality

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[1] 'The Geology of Dartmoor' Mem. Geol. Surv. 1912, pp. 58–59.

[2] The gradient of the Lyd previous to its diversion was 1 foot in 170; whereas afterwards it became 1 foot in 39, as measured from fixed points marked by remnants of the Pliocene plateau near Tavistock and Coryton respectively, and the breached valley near Was Tor.

a ravine exceeding 200 feet in depth. Its abandoned valley is still impressive on account of its depth and breadth, and because of the craggy hills bounding it at Was Tor and Brentor.

The relative period when the diversion occurred is determinable by the relationship of the river to the neighbouring features. The gorge extends from a waterfall (Kitt's Steps) for a distance of some 2 miles, and rests in an older, wider valley. The bottom of this older valley is nearly 700 feet above sea-level; its slopes pass gradually into a general plateau-feature (well shown by the contours on Pl. VII), probably of the age of a similar plateau on Bodmin Moor and described by Mr. Barrow[1] as the 750-foot plateau.

That is to say, the old river had eroded a valley in this plateau to a depth of 50 feet, when its waters gained enhanced cutting-power by an increased gradient arising from a shortening of their journey to the lowlands. So rapidly has the Lyd lowered its bed that a tributary now joins it as a waterfall issuing from a hanging valley (at the point X on Pl. VII) and leaping in two bounds, the last over 100 feet clear into the Lyd valley.

The gorge is merely a narrow cleft or chasm sawn through the grits and shales of the Culm Measures, and in places only a few feet wide. Its walls are riddled with ancient potholes, best seen, perhaps, near Lydford Bridge, and representing the drill-holes made by the river in deepening its channel.

The map (Pl. VII) shows the course of the Lyd before its western bank was breached by the lateral stream. From Lydford a profile view of the ancient valley can be seen. On the west, the slopes of it are conspicuous near Raddon and Was Tor, while the eastern bank extends by Watervale Farm and thence southwards past Black Down towards St. Mary Tavy. The western bank at Lydford Junction is much steeper, on account of its having been undercut by the river impinging against the hard igneous mass of Was Tor. The valley beyond (now followed by two lines of railway) is wide though nearly dry, but is obviously the work of a river much more powerful than the existing puny stream that flows along it.

The recent valley at the gorge is graven in the older one, the bed of the river being nearly 250 feet lower, but following the same course to a point near Was Tor, where it makes a right-angle bend and then trends nearly due west for several miles. At the point where the river turns to the west a **V**-shaped cleft has been cut in the ancient valley-slopes, a feature which is conspicuous when viewed either from the high land near Watervale or from down-stream, looking eastwards up the valley.

Eastern Dartmoor.

On Eastern Dartmoor there are equally significant and conspicuous features indicating the former existence and wide extent

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[1] Q. J. G. S. vol. lxiv (1908) pp. 384–400.

of this Pliocene plateau and the rejuvenescence of the rivers brought about by its uplift. The higher plateaux also form conspicuous flats of marshy land where no rock is seen at the surface, but between these several plateaux the rivers have cut deep gorges, the gorges gradually biting back into the flats and exposing bare and fresh rock on their valley-slopes.

The effect of this rapid erosion is important to the petrologist, for without it he could not have obtained material unaffected by weathering. Now the rivers have ripped through the zone of weathered rock, marked in the mining regions by the 'gossans,' and exposed unweathered rock in which the constituent minerals can be recognized; whereas specimens collected from near the surface only provide material for the study of rock-decomposition.

At the same time, these plateaux are interesting as instances of land that has not suffered glaciation, and is still in the condition of the rest of England in pre-Glacial times. It is covered with débris of a weathered country and graded to a featureless plain.

The Dart.

In the neighbourhood of Ashburton the Dart has cut a deep gorge partly in granite, but for the most part in metamorphosed killas of Carboniferous age. Its present course is remarkable, and results from a series of diversions, with which I do not propose to deal now; but there is sufficient evidence to indicate that its former course was nearly due west from Holne Park, past Ashburton, and thence along the direction and much in the position now followed by the Teign. Reference may be made to the fact that, before entering the sea near Dartmouth, the Dart traverses a wide ridge of land well over 500 feet high, a fact which indicates that in the time when the 430-foot plateau was cut this ridge barred access to the south, and its subsequent breaching must have been effected by a river which afterwards diverted the Dart to its present course. Two of its tributaries:[1] namely, the Eastern and Western Webburn, have cut deep gorges, and are rapidly sawing back into the plateau at 750 feet; and their rejuvenescence is also due to the uplift after the 430-foot plateau was formed.

The Becka Brook.

This river is similar to the others already described, in that it flows sluggishly through peat-flats until it reaches the margin of the 750-foot plateau, down which it forms a magnificent waterfall (the Becka Falls), and flows thence through a deep gorge by Houndtor Wood, to join the Bovey. This river also flows through a gorge, the noted 'Lustleigh Cleave,' and cuts a sharp trench-like valley in the 430-foot plateau, near Pullabrook.

The plateau is well preserved on both sides of the Bovey at this

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[1] See also 'The Geology of Dartmoor' Mem. Geol. Surv. 1912, pp. 69-71.

locality, and, as it is the only wide extent of level ground in the neighbourhood, it has been utilized for the erection of reservoirs. Mr. Reid was of opinion that the flat is cut in the Bovey Beds. The deposits at the locality are mainly sand and gravel, and resemble those found at St. Agnes Beacon.

CONCLUSIONS.

(1) In North Cornwall, near Tintagel, there is an area characterized by peculiar topographical features, namely:—a widespread plateau terminating inland at a height of 430 feet above sea-level, against a degraded line of cliffs, and dissected by deep ravines into flat-topped blocks of land. In these ravines the rivers flow as rapids and cascades, and sometimes end as coastal waterfalls, leaping over the cliff's edge into the sea. Everywhere in the walls of these ravines remnants of 'marmites' are preserved, while the rivers swirl among the existing potholes.

(2) These topographical features are repeated elsewhere in Cornwall, and also in Devon at numerous localities; but such localities are separated one from the other by regions characterized by different topographical features.

(3) Wherever the plateau [illegible] preserved it is dissected by valleys with steep sides, frequently ravines or gorges through which the rivers flow as rapids and cascades and often in potholes.

(4) These facts suggest causal relationship between the two groups of natural features, and, if the development of the valleys be traced, it is seen that they owe their origin to the rejuvenescence of the rivers following upon the uplift of the plateau. In the Tintagel country the rivers fell as waterfalls over the cliff's edge and rapidly ripped out chasms for themselves by means of potholes, many remnants of which are preserved, while others are being formed. In other districts gorges were formed by the shortening of the river-courses owing to the annexation of their head-waters by other streams through breaches made in the valley-sides.

(5) The formation of these ravines is subsequent to the Pliocene Period, and resulted from enhanced erosive powers of the rivers brought about by elevation of the land.

EXPLANATION OF PLATES V–VII.

PLATE V.

A sea-breached valley at Lundy Beach, St. Minver. The valley has been breached by the sea undercutting the cliff, leaving remnants of its western bank. It formed part of a drainage-system, now submerged under the sea, which extended along the northern coast of Cornwall, between the estuary of the Camel and Tintagel. (See p. 64.)

PLATE VI.

St. Nectan's Kieve, the Rocky Valley, near Tintagel. This view shows the waterfall cutting a gorge by means of potholes. The 'kieve' or bowl is behind the hole through which the water issues to form the second fall into the large pothole in the foreground, whence it emerges as a cascade into the valley. The steepness of the walls of the gorge is notable. (See p. 68.)

PLATE VII.

Map illustrating the present and the former course of the River Lyd, on the scale of 3 inches to the mile, or 1:21,120.

DISCUSSION.

Mr. G. BARROW drew attention to the special interest that the phenomena described by the Author had for those who were well acquainted with areas that had been glaciated. In Devon and Cornwall there had been no glaciation in the ordinary sense of the term, yet many of the valleys showed phenomena often held to be distinctive of glaciated areas. The phenomena seen in the South-West of England could be clearly traced to an uplift taking place more rapidly than the rivers could cut back, deepen, and widen their valleys. Prof. Garwood, in a paper read before the Society, had claimed for certain hanging valleys in the Alps that they are not necessarily connected with glaciation, and with his view the speaker agreed. The truth is that a rapid uplift produces conditions similar to some of those that result from the covering of an area with an ice-sheet. Besides producing hanging valleys, the rapid uplift often results in a total change of course of some of the rivers. This is best shown by the Fowey, the oldest course of which was seaward in an easterly direction: later on it flowed west past Gossmoor, to the sea at what is now Newquay Bay; its modern course is southward. The changes took place during the rapid uplift that followed the 750-foot and the 430-foot platforms.

An interesting feature of the whole area is the clear evidence of a pluvial period, or one of especially heavy rainfall, practically contemporaneous with the Glacial Epoch, strongly supporting the modern view that the ice-sheet of the northern areas was largely due to increased precipitation. The Fowey, again, gives clear evidence of this: where it flowed along a specially flat section of the valley, above the 750-foot platform, at the time of the pluvial period, everything but gravel was swept away, and the tin and wolfram-ores concentrated. At the present day, the river is unable to keep the base of the valley open, and fine sediments have accumulated above the gravel to a thickness of over 20 feet.

Dr. R. L. SHERLOCK remarked that he had mapped one part of the region dealt with. He believed the explanation given by the Author of the present course of the Lyd was correct, and that the river formerly flowed along the line of fracture now occupied by the River Burn, a tributary of the Tavy. He was doubtful whether the whole of the 430-foot platform was eroded by the sea, because it extended so far inland up finger-like prolongations: as, for example, at Coryton in the heart of Devon. In the Lydford-Tavistock area the higher platforms were scarcely traceable. Indications of the 1000-foot platform could be seen at Brent Tor and Black Down, but it was very doubtful whether the 750-foot platform was present.

Mr. C. E. N. **Bromehead** said that he had some knowledge of the ground described; the incised meanders of the Tamar near Gunnislake and Calstock reminded him of those of the Wye. The diversion of the Upper Lyd by a tributary of the Tamar could also be paralleled in the upper part of the Wye Valley: near Three Cocks Junction the valley took a sudden right-angle bend towards Hay. The ancient valley of the Upper Wye can be followed past Talgarth and Lake Llangorse until it joins the Usk. The capture of that river by a tributary of the Lower Wye gave a quicker immediate fall to the Hereford plain, as in the case described (where a tributary of the Tamar captured the Upper Lyd). The result was also similar, the gorge of the Wye at Llysarn corresponding to Lydford Gorge.

Mr. R. S. **Herries** commented on the use of the term 'gorge' in the paper. The popular meaning of the word was a deep, steep-sided rocky valley, but the speaker thought that scientifically the use of the word should be restricted to the case of a river which breaches an opposing range of hills. The case of the Avon at Clifton might be the type of such a gorge, and it also fulfilled the popular conception; while the not far-distant 'gorge' of the Cheddar Cliffs was only a gorge in the popular sense. The rivers that flowed from the Weald and cut through the North and South Downs, were gorges in the scientific sense, but would not be so-called by the man in the street.

Mr. E. **Greenly** remarked on the wide bearings of the paper. There were platforms in South Wales and elsewhere about the Bristol Channel. In North Wales, the island of Anglesey was another fragment of such a platform. It was difficult to believe that these platforms could be of widely-different ages, and we might hope that, after a while, it would be possible to begin to correlate them. But there were discrepancies that would need to be reconciled. The platform of Anglesey, for example, was about 100 feet lower than the littoral platform of Cornwall. Perhaps, reconciliation might be possible, if one postulated a true submarine platform passing continuously into a base-level of subaërial waste. In such case a difference of 100 feet would constitute no difficulty at such a distance as that of North Wales and the Bristol Channel.

Prof. W. G. **Fearnsides** agreed that the scenic contrast between the mature topography of the uplands and the vigorous growth of the ravines which are cutting their way back from the Cornish coast is very striking. An equally-abrupt contrast, with similar topographical unconformity along the line at which the ancient valleys 'hang,' can be traced along the nearer hinterland throughout almost the whole western coast of South Britain, both in the glaciated and in the unglaciated districts. Respecting the mature upland topography, the speaker thought that in Cornwall the substantive evidence of the cliff-line at the 430-foot level, and the marine accumulations at St. Erth's and other places below that level, went far towards establishing the platform of marine erosion to which the Author had referred. Farther north along the coasts of Merioneth and Carnarvonshire, of which the speaker had special knowledge, the evidence was not so clear, and it seemed to him that there the Late Tertiary marine platform must be looked for at a much lower level. Nevertheless, in that same district of North Wales, the level to which the new coastal streams have cut back and rejuvenated their courses rises from about 200 feet along the coast of the Western Lleyn to 600 feet at the head of the Vale of Ffestiniog. To the speaker this suggests that the mature topography above the angle of rejuvenation is the surface of subaërial denudation, the planation of which has never been completed. In his opinion, neither the 300-foot nor the 500-foot level, suggested by Mr. Greenly for the platform in Anglesey or Northern Carnarvonshire, could be established as a surface of marine planation, but both must be considered as incidental in the general rise of the margin of the rejuvenated region as the streams have worked their new ravines back into the hills.

In endeavouring to express growth and maturity of topography in terms of stratigraphical chronology, it would be well to bear in mind how much the rate of denudation depends upon the hardness of the rocks. Certainly the rocky ravines of North Cornwall are young, almost in their infancy; but if, instead of the hard Palæozoic killas and volcanic rocks, the rejuvenated streams had worked in such unconsolidated sands and clays as those that compose the Tertiary and Mesozoic formations of the East Coast of England, it might well be that already the district would again have become degraded almost to a peneplain.

Mr. G. M. Part drew attention to precisely the same phenomena of gorges dissecting the edge of a marine plane of denudation that are to be seen on the West Coast of Scotland, and expressed the hope that it would one day be possible to correlate the planes of Cornwall, those of Wales mentioned by Mr. Greenly and Prof. Fearnsides, and others traceable all round the coasts of Britain.

[May 8th, 1917.]

Photo. by H.M. Geological Survey.

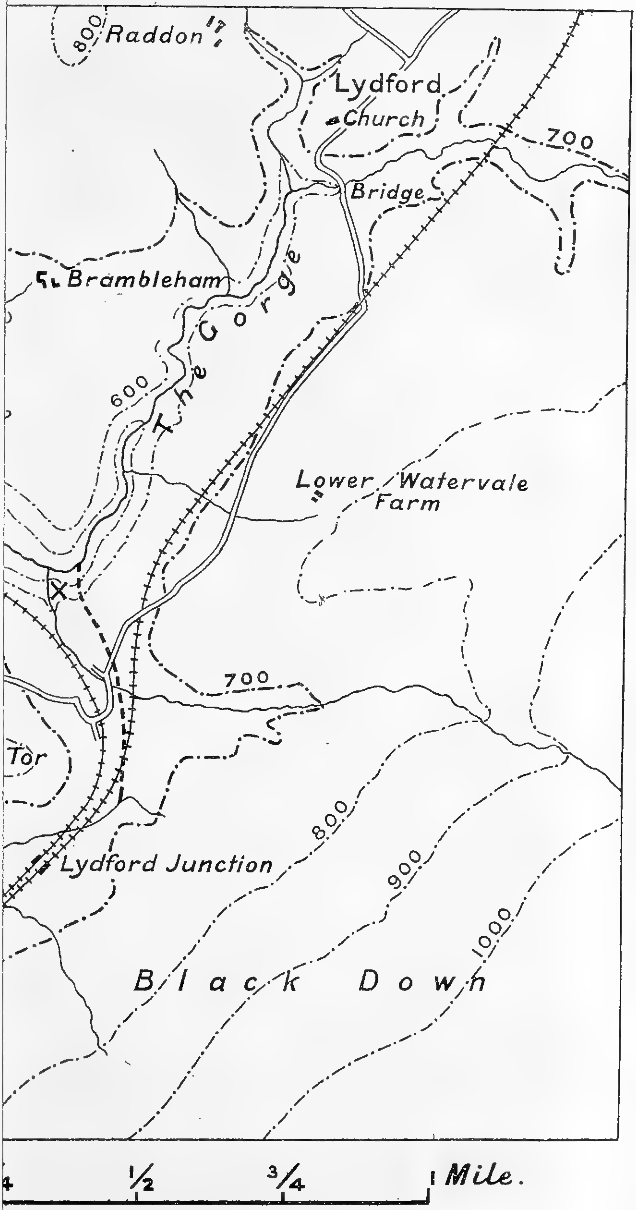
Bemrose Collo Derby.

SEA-BREACHED VALLEY AT LUNDY BEACH, St MINVER.

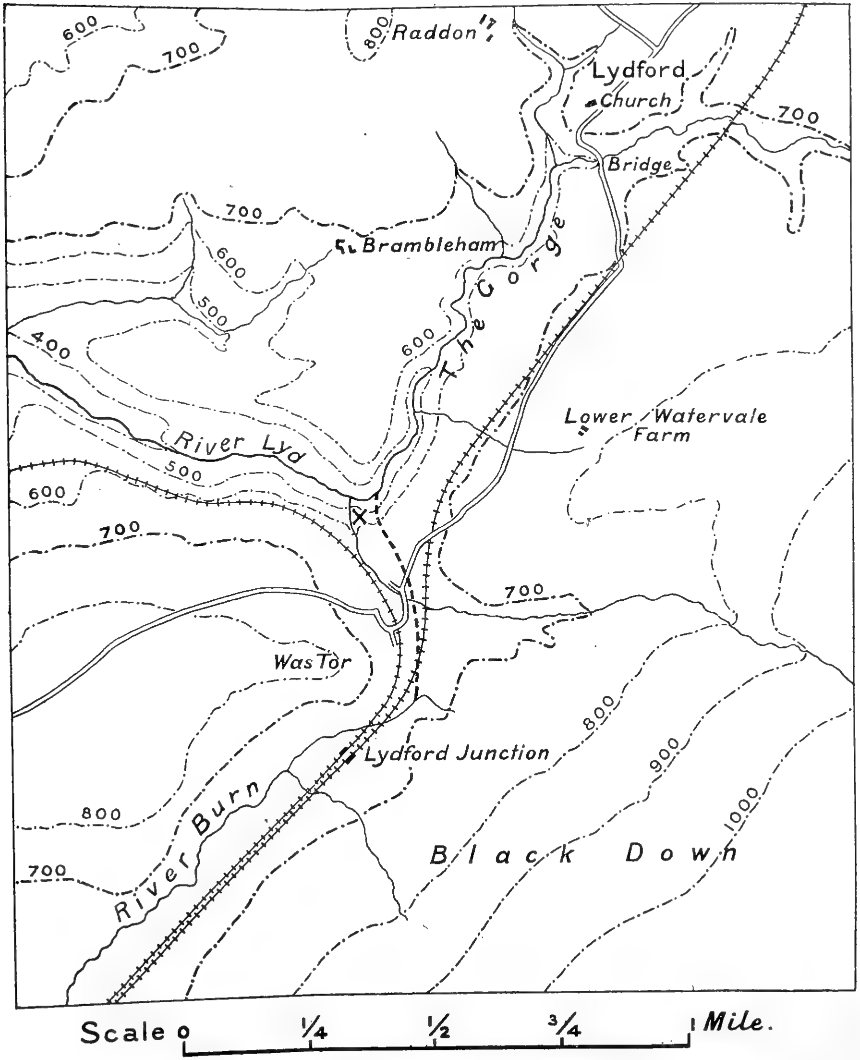
Frith. Reigate.

Bemrose Collo. Derby

ST NECTAN'S KIEVE, THE ROCKY VALLEY, NEAR TINTAGEL.



ATING THE PRESENT AND THE FORMER
URSE OF THE RIVER LYD.



Map illustrating the present and the former Course of the River Lyd.

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⁂ 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. LXXII.
Part 2.

No. 286.

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE PERMANENT SECRETARY.

[With Five Plates, illustrating Papers by Mr. H. G. Smith, Mr. G. W. Tyrrell, and Mr. E. B. Bailey.]

September 10th, 1917.

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SESSION 1917–1918.

1917.	
Wednesday, November	7*—21
,, December	5—19*
1918.	
,, January	9*—23*
,, February (*Anniversary*, Friday, February 15th)	6*—20*
,, March	6—20*
,, April	17*
,, May	1—15*
,, June	5—19*

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

6. *The* LURGECOMBE MILL LAMPROPHYRE *and its* INCLUSIONS.

By HERBERT GLADSTONE SMITH, B.Sc., F.G.S., Demonstrator in Geology in the Imperial College of Science and Technology. (Read May 10th, 1916.)

[PLATES VIII & IX.]

RATHER less than a mile north of Ashburton (South Devon), on the eastern margin of the alluvium of the Yeo, which here flows past Lurgecombe Mill, an excavation has recently been made in the hope of obtaining a workable quantity of road-metal. The rock which formed the object of the working is a biotite-lamprophyre, the existence of which does not seem to have been previously recorded. The dyke is about 9 feet wide, and is exposed for a length of 144 feet in a direction a few degrees north of east; it is intruded into Carboniferous shales (the thrust, as mapped by the officers of the Geological Survey, runs east and west about 100 yards south of the quarry) with which are interbedded occasional cherts. An examination of the country in the immediate vicinity does not reveal any prolongation of the intrusion; it plunges underneath the shales of the rising ground at its eastern end, and disappears under the alluvium on the west. It is not exposed in the bed of the stream, although here the alluvium has been swept away, but it may take a sharp turn and pass under the stream above the weir. The shales in contact with the dyke are merely indurated; no new minerals have been developed in them in consequence of this intrusion, and the locality is outside the aureole of metamorphism of the Dartmoor granite; the nearest outcrop of this granite is nearly 2 miles away.

The intrusive rock is, for the greater part, compact and fine-grained in texture and dark grey in colour. Abundant small flakes of biotite can be recognized, and there are many small patches of a pinkish colour. Weathered surfaces are brown. Towards the margins the rock becomes vesicular, the cavities, sometimes more than an inch long, being filled with a rhombohedral carbonate and quartz, the latter at the centre. In the upper portion of the dyke the cavities are merely in part filled with powdery limonite. Crystals of pyrite are to be seen near the margins of the dyke, and here the alteration has resulted in the development of a dominant green colour, though the biotite is still recognizable.

In thin sections the biotite is conspicuous. It transmits various shades of brown, the deepest colour being exhibited by the basal sections. Many of these are idiomorphic, and are darker brown on the edges; other sections are frayed, and show a cleavage parallel to the length. The mineral is remarkably fresh, but some of the few altered basal sections include acicular crystals (possibly rutile) arranged in three directions as a sagenite web; these directions are at right angles to the edges of the hexagon—the directions of the rays of the pressure-figure of micas. The pleochroism is of the usual character, almost absent in basal sections, and strong in those sections that show cleavage, the maximum absorption taking place when vibrations are parallel to the cleavage. Polarization-colours are fairly bright pinks and greens, and extinction is straight. Basal sections give a pseudo-uniaxial figure, the optic axial plane coinciding with the plane of symmetry.

Small felspar-crystals form the bulk of the rock; they are, however, almost invariably decomposed. They are rectangular, the length being about three times the breadth; they are altered more completely near the centre, the margins being comparatively transparent; they do not clear up when treated with acid. The polarization-colours are the usual first-order greys and yellows. Lamellar twinning is common, but there are cases where twinning is absent. The lamellæ usually extinguish at a fairly high angle, and, as a rule, do not extend to the periphery of the crystal. The outer zone does not show twinning, and extinguishes either in the straight position or with a very small angle. The felspars present are considered to be orthoclase and a plagioclase which is an acid labradorite or andesine.

Small apatite-crystals are fairly abundant. They are recognized by their hexagonal cross-sections, the basal fracture in prismatic sections (which are commonly much elongated), the high refractive index, grey polarization, straight extinction, and negative sign of elongation.

Small magnetite- and pyrite-crystals are common.

Forming a considerable proportion of the rock are large pseudomorphs (preserved in a mixture of rhombohedral carbonate, quartz, and iron oxides) which have the characteristic form of olivine, and are certainly replacements of that mineral. It is these pseudomorphs that show as pinkish areas in hand-specimens. Other accumulations of rhombohedral carbonate are considered by Dr. H. H. Thomas to be pseudomorphous after augite.

A green chlorite is found in interstitial areas bounded by the felspars; it has replaced some ground-mass which in no part of the rock is seen in the original condition. Less frequently the replacement has been effected by quartz. The interstitial chlorite sometimes encloses well-formed rhombs of carbonate, which, in a few cases, show zoning; and occasionally, projecting into the chlorite, rosettes of radiating quartz-crystals are observed.

These minerals, quartz, chlorite, and rhombohedral carbonate, together with idiomorphic orthoclase, in a few cases occur in approximately circular patches (Pl. VIII, fig. 2) which are bounded by biotite-crystals arranged with their length tangential to the circumference of the circle. The minerals of these patches are probably the result of the infilling of cavities which originated after the crystallization of the biotite.[1] The felspar-crystals projecting into these areas, and also those projecting into the interstitial

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[1] See Sir Jethro Teall, 'The Amygdaloids of the Tynemouth Dyke' Geol. Mag. dec. 3, vol. vi (1889) pp. 481–83.

chlorite previously mentioned, are exclusively orthoclase. This fact seems to indicate that they represent only the later stages of felspar growth, and this theory is supported by the zoning of the felspars in the body of the rock.

A fragment of the rhombohedral carbonate from one of the vesicles was found to remain suspended in bromoform with a specific gravity of 2·85; and as, in thin section, this mineral is not stained after treatment with Lemberg's solution, it must be dolomite.

The following analysis (I), made by Mr. J. H. Williams, of the Scientific & Technical Department, Imperial Institute, may be compared with those of the two minettes mentioned below.

The comparatively small percentage of potash makes it undesirable to apply the name of minette to this rock; poverty in silica and richness in alumina are also brought out by the comparison. Although the specimens from which the analysis was made were some of the freshest obtainable, of the three rocks, the analysis indicates that this is the most decomposed.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
SiO_2	44·53	49·14	50·98
TiO_2	1·02	1·81	1·25
Al_2O_3	17·09	14·89	16·13
Fe_2O_3	1·79	1·08	4·20
FeO	4·49	3·88	3·24
MnO	0·11	0·14	0·17
(CoNi)O	trace	0·08	trace
BaO	0·49	0·49	0·20
SrO	trace	nt. fd.	trace
CaO	8·30	5·13	5·50
MgO	7·57	7·07	7·28
K_2O	2·21	5·82	4·82
Na_2O	2·70	2·74	2·99
Li_2O	—	trace	trace
H_2O at 105° C.	0·17	0·15	0·44
H_2O above 105° C.	2·19	1·16	1·46
P_2O_5	0·64	1·49	0·74
FeS_2	0·64	0·32	0·43
CO_2	6·01	4·94	0·58
F	0·05	0·20	—
Cl	0·08	0·05	0·07
Total	100·08	100·58	100·48
Less O for F & Cl		0·10	0·02
Totals		100·48	100·46

I. Biotite-lamprophyre, Lurgecombe Mill, Ashburton (South Devon). (Anal. J. H. Williams.)

II. Minette, railway-cutting near Lemail Farm, 1 mile west of St. Mabyn Church, Cornwall. (Anal. E. G. Radley.) 'The Geology of the Country around Padstow & Camelford' Mem. Geol. Surv. 1910, p. 62.

III. Minette, Gannel Quarry, Pentire, Newquay. (Anal. W. Pollard.) 'The Geology of the Country near Newquay' Mem. Geol. Surv. 1906, p. 61.

One of the earlier thin sections was seen to include a small patch made up of an opaque mineral associated with elongated crystals having a blue colour and a high refractive index. As there was good reason to suppose that the blue mineral was corundum, it was decided to make an effort to obtain additional examples. Two methods were adopted.

A considerable quantity of the rock was crushed and washed by panning. The residue was divided by means of heavy liquids, the last to be used being methylene iodide with a specific gravity of 3·3. Magnetite was extracted from the heaviest residue by means of a bar-magnet, and the remaining constituents were examined under the microscope. Pyrite, commonly as well-formed cubes but occasionally crystallized as a pyritohedron, was the most abundant of these minerals. Far less common were perfect crystals of zircon and fragments of corundum and staurolite. Further particulars concerning these minerals are given later.

The second method employed was the cutting of slices with the wheel. More than 150 of these were cut and examined. Some of these were seen to contain black elliptical patches about a tenth of an inch in diameter, and these slices, together with others not so promising, were sectioned. Fifty sections were made, and of these, twelve contained the minerals foreign to the rock.

Three of these inclusions are selected for description.

Inclusion I. (Pl. IX, fig. 1.)—This consists largely of grains of magnetite, which, for the most part, are black and opaque; but those near the margins of the inclusion are altered to a yellowish oxide. Associated with the magnetite are many elongated crystals transmitting a blue colour, which is irregularly distributed. Some of the crystals are two or three times as long as broad, and have oblique terminations; many of them are almost acicular. They have a refractive index slightly higher than 1·74, show cleavage parallel to the length, and give a pleochroism of blue to colourless with the maximum absorption for longitudinal variations; they polarize in first-order colours, show straight extinction, and have a positive sign of elongation. Crystals which have been isolated are tabular, and viewed at right angles to the tabular faces are isotropic. One of them is bounded by sloping faces which focus alternately on the upper and the lower surfaces, and there is no doubt that they are faces of a rhombohedron. These isolated crystals give a uniaxial figure, and the double refraction is negative. The conclusion is that the mineral is corundum. These thin hexagonal tables, combinations of basal pinacoid and rhombohedron, present points of similarity to the more perfect and larger specimens from Yogo Gulch (Montana) described by Pirsson[1] and Pratt.[2]

This mineral in the section is not in contact with the magnetite; in every case it is surrounded by a zone of colourless mica. The inclusion is not bordered by any definite zone of minerals, but it is

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[1] Amer. Journ. Sci. ser. 4, vol. iv (1897) p. 421.

[2] *Ibid.* p. 424.

possible that some of the biotite on the margin has been formed in consequence of assimilation.

Inclusion II.—In this case the bulk of the inclusion consists of a transparent brown crystal. The mineral has a high refractive index (almost exactly 1·74), shows two fairly well-defined cleavages inclined at about 80°, a pleochroism from pale to darker brown, and polarization in first-order yellow. The fast direction of vibration is also that of minimum absorption. The almost straight isogyre sweeps across the field in such a way as never to coincide with a cross-wire, and this fact, as pointed out by Dr. J. W. Evans,[1] may be taken as indicating the biaxial character of the mineral, which is identified as staurolite. Associated with it, and showing a strong tendency to occur along the cleavages, is a quantity of dark, almost opaque material which is probably magnetite.

Embedded in the staurolite are several crystals of corundum, of the type already described. Also embedded in the staurolite are a few small crystals which have a rich green colour and a high refractive index. These are isotropic between crossed nicols, and are considered to be green spinel.

Surrounding the staurolite is a fairly definite zone of fine-grained colourless material polarizing in first-order colours. In this zone are several crystals of biotite which seem to have a curious influence on the black matter of the staurolite. This black material also tends to occur surrounding the staurolite as a band in close contact with it; and this, when coming on the inner side of the biotite, bends outwards so as to form a lining to a channel (Pl. IX, fig. 2) communicating between the two minerals, staurolite and biotite. It would appear that this biotite has been developed in consequence of a process of assimilation of material from the xenolith.

Inclusion III.—The minerals making up this inclusion are staurolite, corundum, colourless mica, and magnetite. The chief peculiarity is that the whole is surrounded by biotite; and it is suggested that this mineral has been formed in the same way as that associated with Inclusion II, that is, in consequence of the assimilation of a portion of the foreign material.

It is worthy of notice that the emery in the norite of the Cortlandt Series is often surrounded by an abundance of biotite.[2] The phenomena of the Cortlandt Series, however, are on a much bigger scale, and the inclusions described by Prof. A. Lacroix[3] seem to supply cases which are more nearly of the same order of magnitude.

There can be little doubt that these occurrences of corundum, staurolite, green spinel, and associated minerals have been developed

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[1] Journ. Quekett Micro. Club, vol. xii (1915) p. 618.

[2] G. S. Rogers, 'Geology of the Cortlandt Series & its Emery Deposits' Ann. N. Y. Acad. Sci. vol. xxi (1911) p. 77.

[3] 'Les Enclaves des Roches Volcaniques' Ann. Acad. Màcon, vol. x (1893).

in consequence of the addition of material from the country rock, fragments having been detached by the magma during intrusion. One has to imagine that the fusion of the derived fragments resulted in the production of areas of abnormal composition, crystallization taking place according to the laws laid down by Prof. J. Morozewics.[1]

As to the amount of assimilation that has taken place, there must be some uncertainty. That this process has been in operation appears to be indicated by the marginal phenomena of the xenoliths; but the biotite bordering them is not to be distinguished from that of the body of the rock, and the question of the origin of the biotite as a whole at once arises. What proportion of it is due to the absorption of foreign material? The production of the orthoclase during the later stages of crystallization indicates a change in the composition of the magma, a change which has to be attributed either to assimilation or to differentiation.

The facts here put forward are not sufficient to warrant much in the way of generalization, but it would appear justifiable to state that a certain amount of assimilation is indicated, and that much more may have taken place before the magma became sufficiently viscous to leave any record of the process.

My thanks are due to Mr. J. H. Williams for the analysis; to Prof. W. W. Watts for the granting of facilities for conducting the work in the Imperial College of Science & Technology; and to Dr. H. H. Thomas for valuable suggestions at more than one stage of the investigation.

EXPLANATION OF PLATES VIII & IX.

Plate VIII.

Fig. 1. The Lurgecombe Mill lamprophyre. × 28 diameters. (See p. 77.)
2. Orthoclase, quartz, and rhombohedral carbonate surrounded by biotite. × 34 diameters. (See p. 78.)

Plate IX.

Fig. 1. Inclusion in the Lurgecombe Mill lamprophyre. × 25 diameters. (See p. 80.)
2. Tubular connexions between staurolite and biotite. × 80 diameters. (See p. 81.)

Discussion.

The President (Dr. A. Harker) complimented the Author on his paper, and commented upon the various points of interest.

Prof. C. G. Cullis, after congratulating the Author, referred

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[1] 'Experimentelle Untersuchungen über die Bildung der Minerale im Magma' Tschermak's Mitt. vol. xviii (1898) pp. 1–90 & 105–240; also T. A. Jaggar, Journ. Geol. vol. vii (1899) pp. 300–13; see also Sir Jethro Teall on 'The Natural History of Cordierite & its Associates' Proc. Geol. Assoc. vol. xvi (1899–1900) pp. 61–74.

Fig. 1. The Lurgecombe Mill Lamprophyre. × 28.

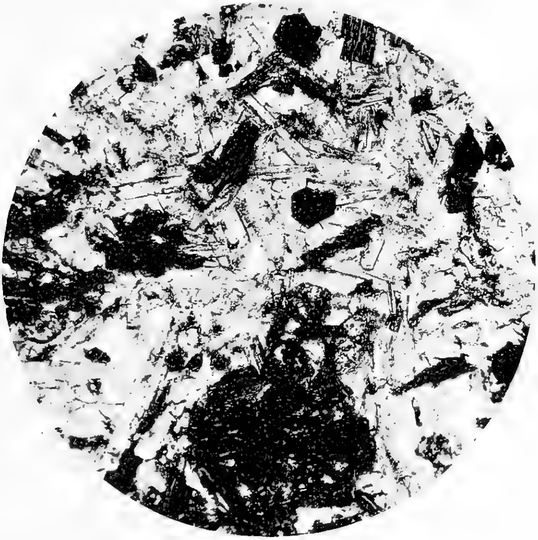
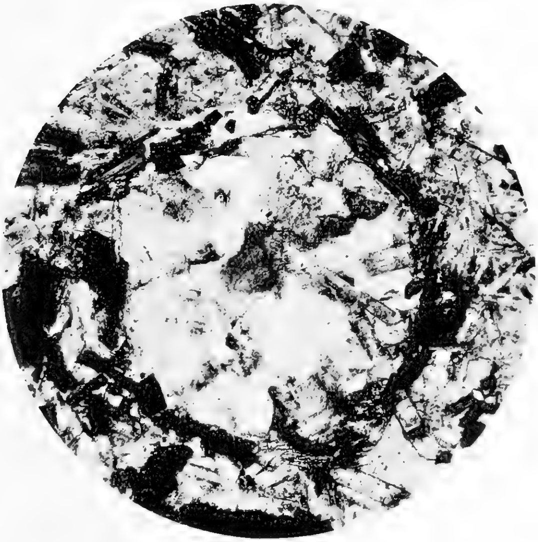


Fig. 2. Orthoclase, Quartz, and Rhombohedral Carbonate surrounded by Biotite. × 34.



H.G.S., Photomicro.

Bemrose, Collo., Derby.

Fig. 1. Inclusion in the Lurgecombe Mill Lamprophyre. × 25.

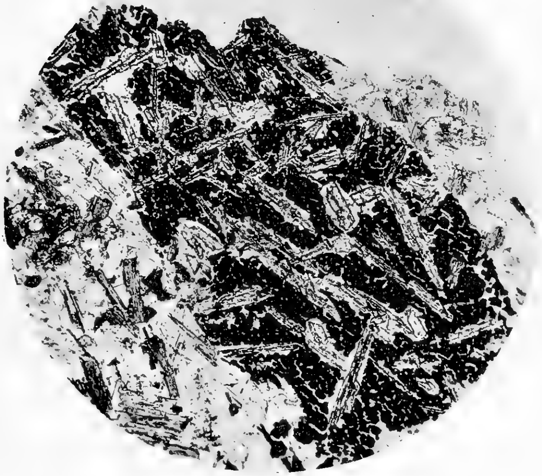
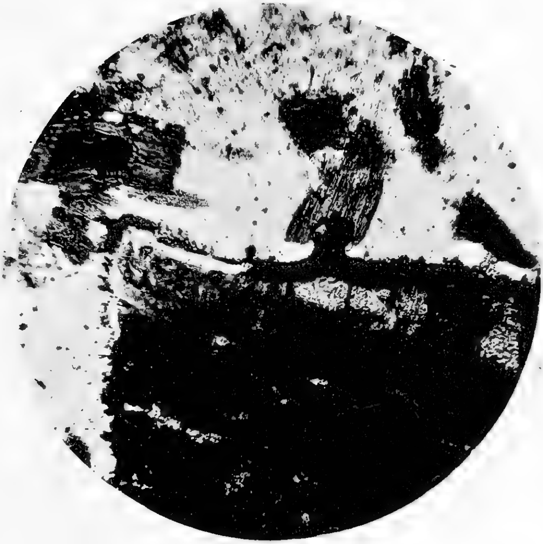


Fig. 2. Tubular Connexions between Staurolite and Biotite. × 80.



H.G.S., Photomicro.

Bemrose, Collo, Derby

to the peculiar chemical composition of the inclusions as indicated by their minerals. They were poor in silica, but rich in alumina and iron, and possibly magnesia. In view of this last constituent, the fact that cordierite had not been observed was noteworthy. Possibly some of the patches now consisting of micaceous aggregates were pinite after that mineral.

Supposing the inclusions to have been shale in the first place—which seemed most likely from the field-evidence—considerable interchange between magma and inclusion must have taken place. Inclusions of Skiddaw Slate in the Threlkeld micrograpite offered a marked contrast to this, having been altered, by the addition of a little boron, merely to tourmaline and secondary quartz, a mineralization involving practically no change in bulk-composition. It would seem that an acid magma, already rich in silica and alumina, had little solvent or metasomatic effect upon argillaceous inclusions, while a more basic magma, deficient in silica but saturated with alumina, had both a solvent and a metasomatic action upon such fragments, the silica being leached out, and its place taken by iron, and to a smaller extent by magnesia, to form such minerals as magnetite and staurolite, while the alumina remained behind in the crystallized condition as corundum.

Dr. J. W. Evans thought that it would not be right to ignore the possibility that the xenoliths might represent iron-ore from a mineral vein traversed by the intrusion, and thus the corundum might be the result of the removal of silica from the magma in combination with oxide of iron. A still more speculative hypothesis was that they might originate from inclusions of sedimentary rocks, containing free hydrates of iron and alumina, and allied in their nature and mode of formation to laterites.

The Author agreed with the President that the included fragments were probably derived from some underlying horizon, but considered it unnecessary to assume that this was very different in lithology from that of the shales now exposed in contact with the intrusion.

In reply to Prof. Cullis, he considered that the micaceous aggregates of some of the inclusions might represent altered cordierite, but was not prepared to go further. He thought also that it was extremely improbable that analysis of the exposed country rock would give any useful information as to the nature of the material caught up by the magma. Although this material was probably argillaceous, its analysis might differ considerably from that of the exposed shales.

Replying to Dr. Evans, he said that the extinctions of the plagioclase cores indicated a composition approximating to that of labradorite. He agreed that the percentage of potash was unexpectedly low—much too low to justify the name of minette. An attempt to incorporate fragments of a laterite would account for some of the inclusions, but in an argillaceous country, probably quite capable of supplying the necessary material, such a mode of origin was only remotely possible.

7. *The* PICRITE-TESCHENITE SILL *of* LUGAR (AYRSHIRE). By GEORGE WALTER TYRRELL, A.R.C.Sc., F.G.S., Lecturer in Mineralogy and Petrology in the University of Glasgow. (Read April 5th, 1916.)

[PLATES X & XI.]

CONTENTS.

I. INTRODUCTION.

THE association of teschenite and ultrabasic rocks (picrite and peridotite) in a single rock-body has now been established for several occurrences in the lowlands of Scotland. The Barnton occurrence, near Edinburgh, has been described by Sir Archibald Geikie,[1] by Mr. J. Henderson & Mr. J. G. Goodchild,[2] and by Mr. H. W. Monckton.[3] At Blackburn, near Bathgate, occurs a picrite, which has been described by the first-named writer as a lava,[4] but has recently been shown to be intrusive and associated with teschenite by the officers of the Geological Survey of Scotland.[5]

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[1] 'Ancient Volcanoes of Great Britain' vol. i (1897) pp. 449–50.
[2] Trans. Geol. Soc. Edin. vol. vi (1893) pp. 297–300 & 301–302.
[3] Q. J. G. S. vol. l (1894) p. 39.
[4] 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 419.
[5] 'Summary of Progress for 1904' Mem. Geol. Surv. 1905, pp. 118–19.

The famous picrite of Inchcolm, in the Firth of Forth, is well known from the descriptions of several observers. Dr. R. Campbell and Mr A. Stenhouse, however, in a recent detailed investigation of the island, have shown that at both the upper and lower contacts the picrite passes into teschenite.[1] On the west coast, Dr. J. D. Falconer has described a picrite-teschenite sill at Ardrossan, intrusive into the Carboniferous Limestone Series: here again the ultrabasic rock occupies the central part of the mass.[2] Recently the late R. Boyle drew attention to still another occurrence at Lugar, near Old Cumnock (Ayrshire). He described the passage of dolerite and basalt [teschenite] through doleritic picrite [theralite] to 'segregated' masses of peridotite or picrite. The ultrabasic rock occurs in the central parts of the mass, and passes gradually to less basic varieties towards both upper and lower contacts.[3] A picrite associated with teschenite has been discovered by Mr. E. M. Anderson at the Inner Nebbock, Saltcoats (Ayrshire).[4]

In the course of an investigation of the Permo-Carboniferous alkalic rocks of the West of Scotland[5] I made a detailed examination of the Lugar sill, and found in it an extraordinary complex of various rocks belonging to the analcite series. This included normal and melanocratic teschenites; a facies with abundant nepheline and ferromagnesian minerals—essentially a melanocratic theralite; and a curious rock composed mainly of analcite and nepheline, with subordinate plagioclase, titanaugite, and barkevikite in very perfect crystals. This unique rock, which it is proposed to call lugarite, has now been found in several localities in the West of Scotland. Extremely fresh hornblende-picrites and peridotites, however, form the major part of the intrusion.

The present paper embodies a complete description of this sill, and attempts an explanation of the processes whereby the different facies have been developed. A comparison with the other occurrences is also instituted. Five chemical analyses have been made in the course of the investigation, and in connexion with these and for the work in general I have to acknowledge the aid of a grant from the Government Grant Committee of the Royal Society. For the analyses I am indebted to the skill of Dr. Alexander Scott, of Glasgow University.

II. Field Relations.

The intrusion which is the subject of this paper occurs near the village of Lugar in Central Ayrshire, near the eastern border of the county. It is intruded as a sill into a crumbling white and yellow

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[1] 'The Geology of Inchcolm' Trans. Geol. Soc. Edin. vol. ix, pt. 2 (1908) pp. 121–34.

[2] 'The Geology of Ardrossan' Trans. Roy. Soc. Edin. vol. xlv, pt. 1 (1907) pp. 601–10.

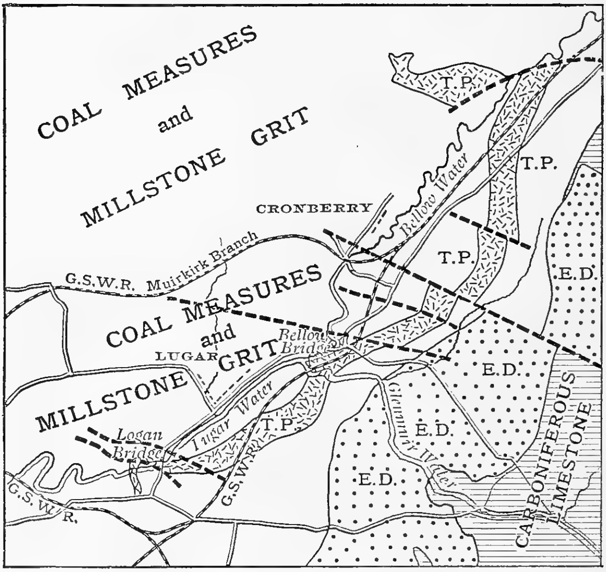
[3] Trans. Geol. Soc. Glasgow, vol. xiii (1908) pp. 202–23.

[4] 'Summary of Progress for 1911' Mem. Geol. Surv. 1912, p. 52.

[5] Geol. Mag. dec. 5, vol. ix (1912) pp. 69–80, 120–31.

sandstone belonging to the 'Millstone Grit.' When the area is re-mapped it is probable that these strata will be incorporated in the Coal Measures. The intrusive nature of the igneous rock is proved by its increasing fineness of grain towards both upper and lower contacts, and by the marginal fringes of hardened sandstone above and below the sill. Definitely transgressive contacts are not seen, although in one place a thin band of hardened sandstone is encountered about 12 feet from the upper margin of the sill. So far as can be ascertained, the intrusion keeps approximately to the same horizon. The whole series dips at about 10° north-westwards, and, from the width of the outcrop, the thickness of the igneous rock is estimated at 140 feet. Apart from small irregularities the outcrop forms a crescent-shaped strip about 3 miles long and a fifth of a mile wide at its widest part. It extends in a general north-easterly direction from Lugar to a mile and a half beyond the village of Cronberry. The Bellow Water with its continuation, the Lugar, cuts through both extremities of the crescentic outcrop, and gives sections at Logan Bridge on the south, and at a spot a mile north-east of Cronberry on the north. The river also cuts through a slight bulge of the outcrop at its confluence with the Glenmuir Water. The latter stream cuts a deep trench in a somewhat different direction through the intrusion at this place. The outcrop is faulted continually towards the south-east

Fig. 1.—*Geological map of the Lugar district, on the scale of 1 inch to the mile, or 1 : 63,360.*



[T.P.=Teschenite-picrite ; E.D.=Essexite-dolerite sill. Broken lines represent faults.]

by a series of six west-north-west and east-south-east faults (see fig. 1, p. 86).. At the north-eastern extremity of the outcrop the sill is cut by a west-south-west and east-north-east fault which severs it from another mass of igneous rock, extending half a mile back towards the west. This mass, however, is on a higher horizon, and has been mapped as separating the 'Millstone Grit' from the overlying Coal Measures.[1] If it be taken as part of the Lugar sill, the total length of outcrop becomes 3½ miles.

The finest sections are found just above the confluence of the Bellow and Glenmuir Waters to form the Lugar Water. Both streams have eroded deep rocky gorges through the sill, the one in a north-easterly, the other in a south-easterly direction. When the water is low, practically every foot of the thickness can be examined either in cliff-section, or in horizontal water-polished areas of rock. In these circumstances the study of the sill can be conducted with facilities unattainable in any of the other occurrences; and the conclusions as to the origin of the different facies arrived at in this case may be considered sufficiently well founded to apply to the other occurrences, in which, although the exposures are not so good, practically the same structure and disposition can be made out.

(1) The Glenmuir Section.

The Glenmuir Water, cutting through the sill in a general north-westerly and south-easterly direction at right angles to the strike, gives the most complete and typical section. The upper contact is seen at the weir, just at the confluence with the Bellow Water. Hardened whitish sandstone occurs overlying a dense basaltic facies, in a steep rocky bank on the south side of the river. The chilling influence of the contact, as shown by fineness of grain, extends down about 12 feet, and has doubtless been strengthened by the inclusion in the sill at this depth of a thin band of sandstone now metamorphosed to a hard white quartzite. The contact-rock is distinctly banded in layers, often confused, wavy, and bifurcating, which differ slightly in colour and texture. The thickness of the bands varies from several inches to very fine linear streaks but faintly indicated by a slight difference of colour. Besides the normal, greyish-black, aphanitic contact-rock, the chief varieties included in the banded material consist of fine-grained, pinkish, and greenish teschenitic rocks, and a very dense, dead-black, glossy, basaltic material, although extremely slight differences of colour and texture serve to bring out the banded structure. These varieties show no sharp contacts with each other, the transition from one to the other taking place quickly but quite gradually. These bands seem to be true schlieren, due to the flow of a slightly heterogeneous magma. In general the streaks are drawn out in bands parallel to the upper margin of the sill. In addition to the banding, the contact-facies is traversed by

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[1] See the Sheets of the 1-inch Map of the Geological Survey of Scotland, Nos. 14 (1868) & 15 (1870).

numerous veins of coarse-grained teschenite with abundant analcite, similar to the rocks described below.

The upper teschenite.—From a maximum depth of 12 feet or so in the mass, the granularity of the rock increases very rapidly towards the interior. The contact-facies passes into a coarse-grained mottled rock, the prevailing tint of which is pink or dark green, according as the felsic or mafic minerals dominate the colour. In thin section the rock is seen to be a typical teschenite, composed of essential plagioclase and analcite, titanaugite, and ilmenite, with accessory orthoclase, olivine, barkevikite, and biotite. The texture is evenly granular, although the felspars sometimes tend to take on a lathy or columnar form. In another variety the augite is conspicuous as long thin black prisms, ranging up to 2 inches in length. A third variety shows very abundant analcite in large pink masses, which are frequently spherical. The rock seems to become richer in analcite as a greater depth in the sill is attained. The thickness of the teschenite cannot be measured in this section, as the contact with the underlying facies is not well seen; but it is usually between 15 and 20 feet.

There are, however, considerable variations in the thickness of this band. Along the western bank of the Glenmuir Water, above the lugarite locality (see p. 91), indurated sandstones and contact-basalts occur less than 20 feet above the picrite. Hence the theralite and teschenite intervening between the picrite and the upper contact must be attenuated, or one of them must be absent in this part of the section.

The theralite band.—Underlying the teschenite is a fine-grained, almost aphanitic, grey rock, which, under the microscope, is seen to have the composition of a theralite. The mafic minerals, olivine and titanaugite, are dominant over the plagioclase and nepheline. Barkevikite, biotite, and iron-ores are rather abundant accessories, and there is often a small amount of analcite. This rock forms a band perhaps 10 feet thick; but in the Glenmuir gorge its outcrop mainly occurs high up in a vertical cliff, although it may also be examined in small exposures on the eastern side of the stream, and in the river-bed when the water is low. In the latter it may be easily distinguished by its smooth, polished, water-worn surface, in contradistinction to the coarse-grained, pitted surfaces of the overlying teschenite and the underlying picrite. Further details of the theralite band are reserved for the description of the Bellow section, where it is much better exposed.

The picrite and peridotite.—By a gradual diminution in the amount of felspar and nepheline, the theralite passes into coarse-grained ultrabasic rocks, composed mainly of olivine and titanaugite, frequently with abundant barkevikite, some iron-ore, biotite, plagioclase, and analcite. These rocks constitute the major portion of the sill, and occupy the interior of the mass. The upper part of the ultrabasic stratum is rich in titanaugite and barkevikite, as well as olivine, and usually contains some plagioclase and analcite. This is a true picrite in the original sense of Tschermak, who applied the term to a melanocratic facies of the Moravian teschenite. In the remainder, however, plagioclase and analcite completely disappear, and olivine becomes the dominant mineral. This rock is a hornblende-peridotite, in which the alkalic tendency is still recognizable by the unusual amount of alkalies contained in the bisilicates. A tongue-like extension of the ultrabasic outcrop occupies the bed of the Glenmuir Water for some distance north-west of the railway-viaduct, the overlying facies forming the cliffs at this point. Good waterworn surfaces can be examined here when the river is low. The rock is remarkably fresh, and shows sharp and irregular variations in granularity. East of the railway-bridge, the ultrabasic stratum forms nearly the whole of a great cliff rising vertically to a height of 90 feet from the north side of the stream. Here, where it is exposed to the weather and is not being continually scoured by the water, it is much decomposed, and weathers to a loose crumbling mass, with spheroidal lumps of harder and fresher rock in places. The north-westerly inclination of the intrusion is well shown in the face of the cliff by the inclination of the joint-planes, but principally by the contrast between the jointing of the ultrabasic rock and the overlying theralitic facies. The former is traversed by a few large irregular joints; but the latter by many, both vertical and horizontal, causing a rude columnar structure. While the transition between the two is not sharp, it is sufficiently well marked to show the general dip of the intrusion towards the north-west. The ultrabasic rock is traversed by a few thin veins of a fine-grained felspathic rock (teschenite-aplite).

The lower teschenite.—A blank of about 30 feet in the section separates the last exposure of the ultrabasic stratum from the underlying facies, which consists of teschenite made up, for the greater part, of the variety containing numerous blade-like or columnar augites. This is exposed in a thick bar across the stream near the second right-angle turn above the railway-viaduct: its thickness is estimated at about 20 feet. It is important to notice that no theralite intervenes here between the picrite and the teschenite. There is little reason to suppose that it is hidden by the blank in the section, for the theralite is the most resistant rock in the complex to ordinary atmospheric weathering.

The lower contact.—The granularity of the lower teschenite declines rapidly, until it passes into the ordinary contact-basalt. The latter shows banding precisely similar to that of the upper contact, and is also traversed by veins of coarse pink teschenite. The two most prominent varieties involved in the banding, which is frequently much confused and contorted, are a fine-grained pink teschenitic rock and a dense black or grey basalt, the two rocks being intimately welded together. Immediately beneath the contact the Carboniferous sediments crop out, dipping westwards at 10°.

This gradual transition from the lower teschenite to a dense basaltic contact-facies can be followed on the eastern side of the stream. On the western side there are much more complicated relations. Here a portion in which the dense basaltic schlieren are dominant over the coarser teschenitic layers may be distinguished from one in which the reverse relation holds. The former abuts against the latter horizontally, and overlies and underlies it. There is also a more or less gradual transition between the two portions. These relations are shown diagrammatically in fig. 2. The coarse-grained teschenitic rock forms conspicuous, waterworn knobs in the bed of the stream. As the stream is crossed to the eastern side the fine-grained basaltic schlieren disappear, and the teschenite passes down normally, as above described, into its contact-facies. This can be traced to a small bar of sandstone seen at low water in the bed of the stream. The relations of the various facies at the lower contact are suggestive of considerable movement in the magma before crystallization had taken place to any extent, for the minerals show little or no alignment in the direction of the banding.

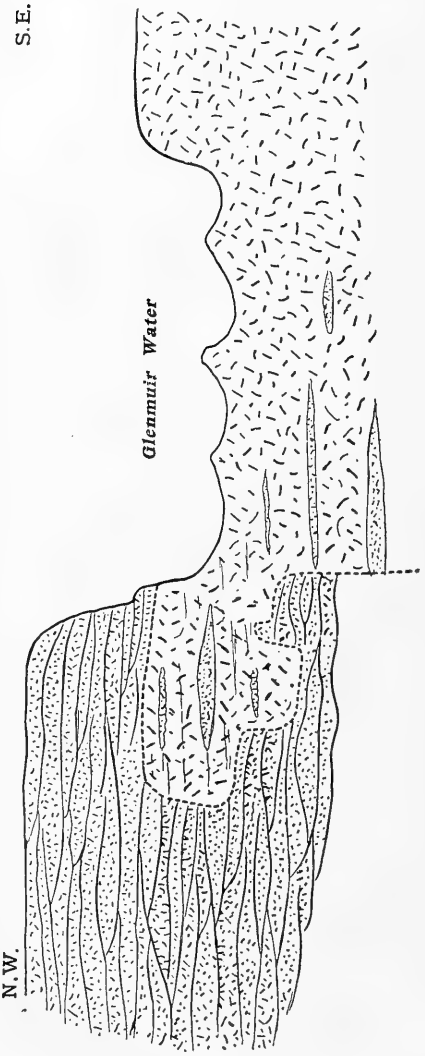


Fig. 2.—*Section across the Glenmuir Water, near the lower contact of the sill, showing the banding of the coarser and finer schlieren. (Scale: 1 inch = 8 feet.)*

The lugarite.—On the west bank of the river, under the railway-bridge and a little to the north side of it, the cliff exhibits a sharp horizontal junction between decomposed picrite and a peculiar rock overlying it. The latter shows a greyish or greenish aphanitic ground-mass, crowded with both stout and slender black prisms. Sometimes small rectangular whitish felspars are seen also. In thin section the ground-mass may be identified as analcite, crowded with needles of apatite, and containing some nepheline. In it are scattered numerous perfectly euhedral prisms of barkevikite, with subordinate titanaugite and plagioclase, also extremely well formed. This rock forms a stratiform mass about 4 feet thick overlain by the theralitic facies. The junction is quite sharp, as the two very distinct rocks can be got within an inch of each other; but the line of demarcation is, in general, not marked by any definite feature on the face of the cliff. The two rocks are intimately welded without any appearance of passage. The long prisms of barkevikite, however, project from the lugarite into the theralite. At places the junction is marked by a thin, fine, horizontal joint-plane, or by a thin layer of slightly decomposed rock. The contact with the picrite is doubtless of the same nature, but the latter is so decomposed that the junction is quite obscured. Some veins of lugarite penetrating the picrite supply further evidence on this point. These veins or small dykes range up to 4 inches in width, and are largely composed of analcite and barkevikite prisms, which are frequently arranged in stellate groups. The contact of these veins with the picrite is an intimate welding, and the barkevikite crystals project from the sides of the veins into the enclosing rock.

The lugarite is also to be found in the Bellow section in the same relative position, but rather poorly exposed. The Glenmuir exposure is only accessible when the stream is low; but south of the viaduct occur numerous fallen blocks from an inaccessible exposure in the face of the cliff. In the other direction the dip of the intrusion carries the lugarite down to the water's edge, where it is lost.

All the available evidence goes to show that this remarkable rock is intrusive in the picrite. The veins of similar material traversing the picrite transgress sharply the different varieties of the ultrabasic rock. There can be no doubt that these veins proceed from the main mass of lugarite, although the junctions have not actually been demonstrated. While the rock is clearly intrusive, it is but slightly posterior to the main phenomenon of intrusion, for the intimate welding and absence of chilled rock at the margins indicates that the ultrabasic rock was still very hot at the time of intrusion.

(2) The Bellow Section.

Although not so complete, this section supplies many details which are missing or obscure in the Glenmuir section. Just above the confluence with the Glenmuir Water, the upper contact of the sill with a soft, yellow, crumbling sandstone is well seen. The contact-facies is a brownish aphanitic rock, with some sporadic flakes of biotite. It is obviously much more decomposed than the corresponding rock in the Glenmuir section. The flow-banding also is not at all prominent.

The contact-facies passes down quickly first into a fine-grained pink and green mottled teschenite, and then into a coarser rock with a conspicuous development of large columnar augites. Although this is the dominant facies there are a few bands of fine-grained material, which are doubtless due to the flow of a slightly heterogeneous magma. Still lower down the rock becomes distinctly more felsic, and shows abundant pink and white spots of analcite. In this variety the augite-crystals are not columnar.

This analcitic facies is in sharp contact with the dark, fine-grained, theralitic stratum beneath. The stream has cleared this contact rather thoroughly, owing to the differential resistance of the rocks to erosion. It slides down a polished waterworn surface of theralite, which is bordered on one side by a low cliff of the coarser and softer teschenite. Hence the contact can be particularly well examined. The theralite is here seen to be shot through or permeated with irregular masses, patches, nests, strings, and anastomosing veins of a pinkish, coarse-grained, felsic rock, resembling the overlying teschenite. These patches and veins do not appear to be intrusive. They have no sharply-defined contacts with the theralitic facies, but the minerals interlock at the margins, welding the two rocks into an intimate union. There is no sign of chilling at the margin of the patches, the normal granularity being maintained up to their edges. There can hardly be any doubt that the theralitic rock and these felsic veins and patches crystallized practically at the same time. The theralitic rock immediately beneath the band of analcitic teschenite is full of these veins and patches, which are also found at lower horizons (although in greatly diminished quantity), until they finally disappear long before the picrite is reached. The overlying analcitic teschenite is not a continuous band, but is developed irregularly, sometimes dying out altogether, in such wise that the augitic facies comes into contact with the theralite.

By the gradual disappearance of the felsic minerals, the theralite passes into picrite, although at one or two places lugarite appears to separate the two rocks. Owing to the conformation of the Bellow gorge, the ultrabasic outcrop has a tongue-shaped lobe directed westwards, which occupies the bed of the stream, while the overlying facies form the sides of the valley. The ultrabasic rocks have precisely the same characters as in the Glenmuir section. At and beyond Bellow Bridge the outcrop widens, but the overlying theralitic and teschenitic facies may still be traced in the steep wooded slopes west of the bridge. At the first right-angle bend of the stream above Bellow Bridge the picrite is intersected by many small crush-planes filled with 'beefy' calcite. At the second bend a large fault-plane is well exposed in the bed of the stream. This, with its fellows, has determined the course of the stream for some distance. It is a fissure about a foot wide, filled with calcite and a yellow flinty material. The rock on both sides of the major fault belongs to the ultrabasic stratum. It is much crushed, splintered, and traversed by numerous thin, anastomosing veins of calcite. Sedimentary rock, however, is exposed on the inner side of the bend, and consists of black shale upturned steeply at the fault. High up in the bank on the west side of the stream, highly analcitic teschenite is exposed, passing quickly into a dense black contact-facies containing sparse flakes of biotite. At the outer edge of the first right-angle bend above Bellow Bridge occurs a black-and-white mottled rock belonging to the lower band of teschenite. At the fault the continuous section of igneous rock ends, and the stream cuts into the sedimentaries. Hence the lower contact is not here visible.

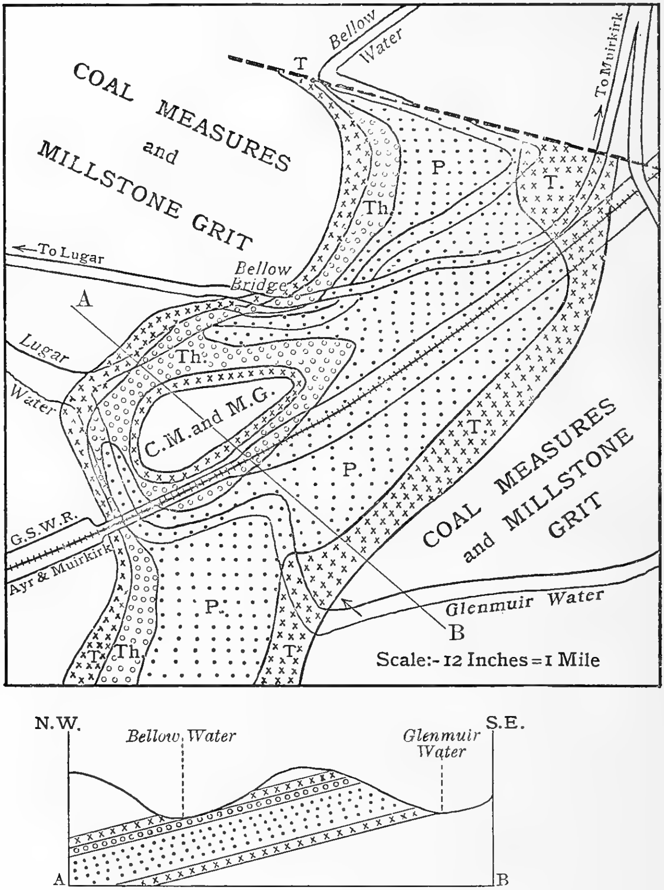
(3) Other Exposures.

Between the Bellow and Glenmuir Waters, near their confluence, rises a knoll of high ground. The Ayr-Muirkirk railway crosses the Glenmuir Water here, and is carried through the knoll in a shallow cutting. As one ascends from either stream, exposures of the theralitic facies and the teschenite are encountered, capped by a small outlier of the 'Millstone Grit' (see map & section, fig. 3, p. 94). The railway-cutting shows nothing but decomposed crumbling picrite.

At the extreme north-eastern end of the sill, a mile and a half north-east of Cronberry, a small exposure is seen in the Bellow Water, here known as the Gass Water. At the south-western end of the section a fine-grained marginal facies of pink teschenite (doubtless the top of the sill) is observed, followed by grey theralite and decomposed picrite towards the north-east. The lower teschenite is not seen; but, so far as it goes, the sequence here is identical with that in the typical exposures. Another section is seen in the Lugar Water at Logan Bridge, at the extreme south-western end of the outcrop. Here the intrusion is quite thin, measuring not more than 15 or 20 feet in thickness, and is wedging out westwards among the sandstones. Both contacts, bordered by hardened white sandstones, are seen. The marginal facies is a decomposed brownish aphanitic rock showing a few flakes of biotite. The interior consists of decomposed teschenite, but there is no trace of the other facies.

A mass of theralite probably connected with the Lugar sill, but with a distinct dyke habit, crosses the Lugar Water in a north to south direction, about 250 yards west of Logan Bridge. The contacts are not seen; but, on the northern bank of the river, the rock forms a small knoll with vertical sides, and has the aspect of a dyke. In appearance and microscopic structure it is identical with the dominant phase of the theralite stratum in the Lugar sill.

Fig. 3.—*Geological map and section of a part of the Lugar Sill.*



[P = Picrite and peridotite ; T = Teschenite ; Th. = Theralite.]

(4) Summary.

It is now possible to attempt a general view of the Lugar sill, and of the structure and disposition of the various facies of which it is composed. This mass, 140 feet thick, was intruded into cold rocks, as testified by the chilled contacts at both upper and lower margins. The upper and lower contact-basalts are identical in composition. The chilling influence of the contact is manifest in fineness of grain to a maximum thickness of 10 feet, after which the rock passes rapidly into a coarse teschenite at both margins.

A movement of the magma has given rise to distinct schlieren, distinguishable by slight differences of colour and texture, at both contacts. The same explanation can hardly be applied, however, to the remarkable differences obtaining in the interior of the sill. Including the contact-basalts and the normal teschenites continuous with them, the rock of the interior is divided into at least three different bands by some process of differentiation or by successive intrusion. First there is a band of ultrabasic rock—picrites and peridotites of coarse texture and remarkable freshness—occupying the major part of the interior, and indeed of the whole mass, and resting on the lower teschenite. The picrite forms the upper part of the ultrabasic stratum and the peridotite the lower. Above the picrite comes a band about 10 to 15 feet thick, of a fine-grained, basic, nepheline-rock belonging to the theralite family, which may be considered as continuous with the picrite and passing into it somewhat rapidly. Between the theralite and the normal teschenite overlying it generally intervenes a thin and variable layer of highly analcitic rock, patches, streaks, and veins of which, or a rock allied thereto, permeate the theralite in its immediate vicinity. Fig. 4 (p. 96) embodies a vertical section of the sill showing the approximate thickness of the various facies, and the map (fig. 3, p. 94) illustrates the surface-distribution of the facies in a limited area at the confluence of the Bellow and Glenmuir Waters.

The differentiation will be dealt with in greater detail, after the discussion of the microscopical and chemical evidence.

III. Petrography.

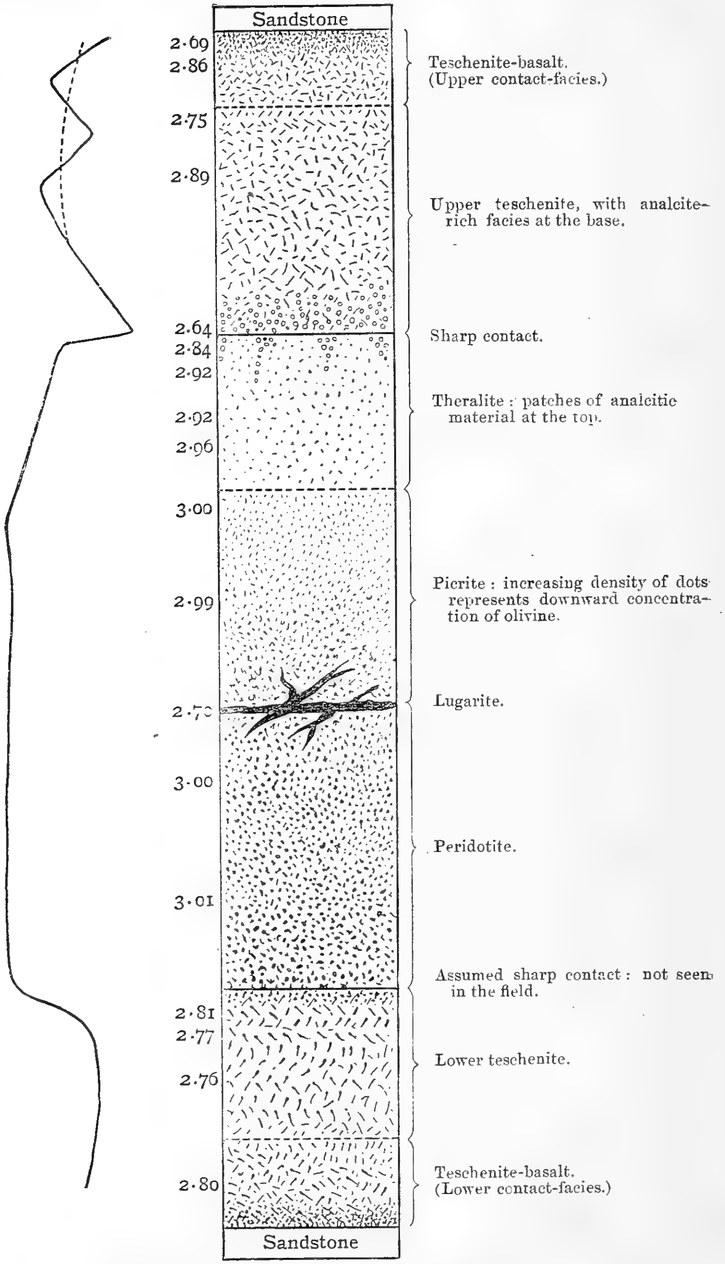
(1) The Contact-Rocks. (Pl. X, fig. 1; Pl. XI, fig. 4.)

The rocks of the upper and lower contacts are identical in all respects, and will therefore be described together in this section. They consist, for the greater part, of a hard, dense, basaltic rock, usually black or dark grey. In several specimens bands or schlieren differing in many subtle gradations of colour and texture are seen. Thin veins of coarse flesh-coloured teschenite, indifferently traversing all the schlieren, are rather numerous.

Microscopically the rock is holocrystalline, on the whole very fine-grained, and shows numerous sharp variations in texture and composition. The minerals observed are plagioclase, augite, biotite, analcite, magnetite, and occasionally olivine. The chemical analysis (p. 104) shows that a considerable amount of orthoclase must be present. A thin section of a rock obtained at the lower contact in Glenmuir Water gives a good general idea of the aspect of both contact-facies, and will accordingly be described in detail. There are several distinct types of rock in the slide (Pl. XI, fig. 4).

(*a*) Starting from one side of the section there is first a schlieren composed of an even-grained aggregate of plagioclase-laths, subhedral prismoids of purplish augite, numerous small ragged plates of reddish biotite enclosing all

Fig. 54.—*Vertical section of the Lugar Sill, on the scale of 22·5 feet to the inch.*



[Figures on the left-hand side represent the specific gravities of the rocks collected approximately at the points indicated. The curve shows the variation of specific gravity with depth in the sill: the zigzags at the top are due to the alternation of schlieren of different densities. The broken-line curve shows the effect of averaging these variations. The division of the sill into three sharply-defined parts is well marked.]

other constituents but analcite, and minute uniformly-scattered cubes of magnetite, all embedded in a limpid, colourless, isotropic base which has the cleavage and low refraction of analcite. The latter is occasionally segregated into small areas comparatively free from the other constituents. A few small patches of serpentinized material occur, which may represent olivine. The extinction of the felspar is between 20° and 30°, but the fine grain forbids exact measurement; it is probably to be referred to acid labradorite. The following is a rough estimate of the mineral percentage:—plagioclase (Ab_1An_1) 45, augite 40, biotite 5, magnetite 5, analcite 5.

(*b*) Adjacent to the above, with a sharp boundary between the two, is a band composed of the same minerals, but distinctly finer in grain. The proportion of augite has increased at the expense of plagioclase and analcite.

(*c*) The next band is still denser. The minerals are the same as above, but are so crowded together as practically to exclude the isotropic base. Magnetite is more abundant, and is sprinkled very uniformly over the field.

(*d*) A coarse vein of teschenitic material separates (*c*) from (*d*), which is the densest of all the bands occurring in the slides. It consists of a crowded mass of minute microlites of augite and plagioclase, with very numerous, small, irregular, poikilitic plates of biotite, all dusted over with magnetite. There are sparse microphenocrysts of plagioclase and purple augite. The felspar has dwindled, and the rock approximates in composition to the monchiquites. The colourless isotropic base is still to be recognized with a powerful objective, and can be definitely identified as analcite, where, in places, it is comparatively free from augite and magnetite.

Apart from the coarse teschenitic veins the four schlieren described above are the principal textural varieties to be found in the slide. But within each of them occur slighter variations in texture and composition, and no fewer than eight distinct varieties of rock occur within the limits of a thin section half an inch long.

These rocks are basaltic in aspect, and in accordance with their occurrence as the contact-facies of a teschenite, they may be called teschenite-basalts. The term analcite-basalt is unsuitable, as it has been used for definite lava-form rocks. Moreover, this rock is practically devoid of olivine, which is abundant in the great majority of analcite-basalts. Some of the schlieren approximate to monchiquites, and others to biotite-basalts.

The contact-facies gradually merges into teschenite by increasing granularity and enlarged proportion of analcite. The following will serve to give an idea of the intermediate fine-grained teschenitic rock. The thin section is from a specimen obtained immediately above the lower contact-facies in the Glenmuir Water. Microscopically the rock is somewhat similar to the coarser schlieren of the contact-facies, but is not banded and is not so rich in ferromagnesian minerals. It consists of numerous, small, euhedral to subhedral prisms of pale augite, with stout plagioclase-laths, some serpentinized olivine, and leucoxenic ilmenite, in a ground-mass of dusty analcite. Associated with the ilmenite are numerous minute scraps of biotite. A few turbid areas have the shape, low double refraction, and general aspect of nepheline as it is more recognizably developed in rocks to be described hereafter. Apatite needles are abundant in the areas of analcite. The rock may be described as a fine-grained teschenite; or if it be desired to emphasize its origin as a contact-facies it may be called teschenite-dolerite.

(2) Teschenite. (Pl. X, fig. 2.)

The differences between the teschenites proper of the upper and those of the lower margins respectively are so slight, that the rocks may be described most conveniently in the same section. The teschenites are rather variable, both in macroscopic appearance and in thin section. Variation occurs in granularity and fabric, but the mineral composition is approximately constant, or, at least, variations in the minerals present or their relative abundance do not carry any of the rocks outside the teschenite group. The dominant type, perhaps, is one which has an effect of very coarse grain, due to the abundance of large, irregular, black prisms or blades of augite ranging up to an inch in length, embedded in an even-grained, apparently-uniform ground-mass consisting of pinkish felspar and analcite. It is noteworthy that the teschenites of the upper margin carry a pink analcite, whereas at the lower margin the analcite is white. The former, therefore, are mottled in black, green (olivine, serpentinous and chloritic alteration-products), and pink; the latter in black, green, and white. The dominant type with columnar augites (Galston type)[1] is interbanded in the upper teschenite with a much finer-grained rock devoid of the pseudo-porphyritic augite. Towards the junction with the underlying theralite the pink analcite becomes increasingly abundant, and forms the dominant macroscopic element in a thin irregular band immediately overlying the theralite. In the lower band of teschenite a fine-grained type occurs, carrying numerous, small, acicular prisms of augite in a white ground-mass of felspar and analcite, with much hornblende and biotite, and a little nepheline (Cathcart type).

In thin section the teschenites consist essentially of labradorite, titanaugite, analcite, olivine, and iron-ores, named in order of abundance. As accessories occur biotite, orthoclase, apatite, nepheline, and barkevikitic amphibole. The last-named invariably occurs as a peripheral alteration-product of the titanaugite. The secondary products are serpentine, chlorite, and leucoxene. The texture is medium- to coarse-grained, and the fabric an interlocking mesh of labradorite and titanaugite in sub-ophitic relations, the large polygonal or irregular interspaces being filled with analcite.

The plagioclase forms broad laths, thoroughly euhedral, and highly zonal. It is a medium to acid labradorite (Ab_2An_3–Ab_1An_1). The crystals are frequently somewhat albitized, and, adjacent to large analcite areas, have been irregularly corroded and replaced by analcite. The cleavage-cracks and the interior of a crystal are occasionally occupied by serpentinous material, which has migrated from adjacent decomposing olivine.

The pyroxene is a feebly-coloured titanaugite, which, in the dominant type, occurs as large, blade-like, or columnar crystals. These, however, although elongated in one direction, are very

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[1] G. W. Tyrrell, Geol. Mag. dec. 5, vol. ix (1912) p. 74.

irregular in shape, owing to their indentation by the terminations of felspar-laths. In some of the rocks, notably the finer-grained varieties, the titanaugite is perfectly euhedral, and is moulded by felspar. The colour is a pale purplish brown, and is very variable and patchy. The most common appearance is of a darker tint towards the margins, but bands alternatively of lighter and darker colour may occur. This zoning coincides with a similar zoning observable between crossed nicols, and frequently also with an hour-glass structure. It is, therefore, connected with slight chemical and optical variations in the crystals. There is occasionally a distinct pleochroism from purplish brown to a pale sepia. A notable feature is that practically all the crystals are hollow. In the prismatic sections elongated cavities occur along the centre-lines, and are filled with calcite, serpentinous alteration-products, and occasionally even analcite. The cavities are more or less equidimensional in the basal sections. They are frequently lined with a highly pleochroic biotite, which extends in ragged indefinite patches throughout the interior of the crystal, and is evidently an alteration-product. The latter frequently has an astonishing pleochroism in shades of brilliant blue, red, and peach-bloom tint, but it is sometimes scarcely more than a discoloration of the augite, so indefinite are its boundaries. The more individualized mica has a more normal pleochroism, but its darker shades have a peculiar 'beetroot' tint. Serpentinous material also occurs within the augite, but its relations show that it has migrated from adjacent olivine, entering the crystal through the cleavage and other cracks. The augite often thus presents a honeycombed appearance in the interior of the crystals, the exterior being almost invariably sound, and free from inclusions and honeycombing.

A red hornblende belonging to barkevikite occurs as an alteration-product upon the margins of the augite-crystals, especially in the fine-grained rocks of the lower contact, where the augite is euhedral. The boundary between the two minerals is always exceedingly indefinite. A rock from the lower band of teschenite above Bellow Bridge is so rich in hornblende that it deserves the designation hornblende-teschenite. This rock is fine-grained and contains nepheline, thereby approximating to the Cathcart type.[1]

A thin band of ægirine-augite or ægirine frequently occurs on the margin of an augite-crystal, especially where it is adjacent to an area of analcite. Small crystals of ægirine are occasionally enclosed in the analcite.

Analcite fills up large and small polygonal spaces between the felspars and augite; but, where corrosion and analcitization of the felspar has occurred, irregular or rounded spaces are formed. It is mostly fresh, showing the cubic cleavage, and occasionally some anomalous birefringence. The commonest alteration is to an extremely-fine, irresolvable, brown dust; but, with a further degree

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[1] G. W. Tyrrell, Geol. Mag. dec 5, vol. ix (1912) p. 74.

of weathering, calcite begins to appear. Beautiful rosettes of a serpentinous mineral are frequently developed in, and apparently at the expense of, the analcite. These enclose flakes of biotite and also the other minerals usually found within the analcite areas. Occasionally the analcite is completely replaced by the fibrous serpentine. These rosettes have been mentioned by Mr. E. B. Bailey in describing the Glasgow teschenites, and he indicates the need for some special explanation of this phenomenon. He suggests that it may possibly originate from 'juvenile' reactions.[1]

The analcite corrodes and replaces the felspars enclosing the cavities in which it has crystallized. The attack has usually spread from the cleavage and other cracks, and the process can be followed from mere incipient analcitization, resulting in a widening of the cleavage-fissures, to complete replacement of the crystal. The latter, however, frequently retains its form; equally often the felspar forms shapeless, irregular masses entirely enclosed in analcite. The final appearance is of a patch of clear or dusty analcite lying in the midst of a large area of partly or wholly analcitized felspars, mixed with serpentinous, chloritic, and other alteration-products.[2] These reactions clearly belong to a juvenile stage in the history of the magma, and may be referred to that late period when the rock was stewing in a hot alkaline solution which ultimately crystallized as analcite.[3] Further evidence as to the original nature of the analcite is afforded by the numerous inclusions of biotite, pyroxenes, apatite, and felspars that it contains; by its association with soda-orthoclase; and by its evident reaction on the adjacent felspars and augite, resulting in the latter case in the formation of a thin layer of a green soda-pyroxene. Pyroxenes which have been entirely enclosed in the analcite have suffered this change to a much greater extent, leading in some cases to complete replacement.

It is remarkable that, while a susceptible mineral such as analcite often remains entirely or comparatively fresh, the other constituents of the teschenites have undergone so much alteration. This leads to the conclusion that the alteration is not so much due to ordinary weathering as to the presence, during the crystallization of the rock, of a hot, intensely-active, alkaline, and water-rich mother-liquor, which crystallized as analcite after effecting much corrosion among the earlier-formed constituents.

Because of the corrosion and replacement effected by the analcite among the earlier constituents of this and other rocks, there is a disposition to regard it as 'secondary' in a certain sense of that term. But it is as definitely a primary consolidation-product of the teschenite magma, inasmuch as its crystallization took place before the cessation of cooling of the rock, as is the allotriomorphic quartz of a granite. Both represent a final magmatic residuum, which

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[1] 'The Geology of the Glasgow District' Mem. Geol. Surv. Scotland, 1911, p. 132.

[2] 'The Geology of the Neighbourhood of Edinburgh' *ibid.* 1910, p. 296.

[3] E. B. Bailey & G. W. Grabham, Geol. Mag. dec. 5, vol. vi (1909) p. 256.

crystallized in the interspaces left among the earlier constituents. Analcite, however, is more active chemically than silica, and, before its consolidation, finds time to attack and partly to replace some of the other constituents. Thus the analcite is not derived from the alteration of the felspar, as held by some petrographers, but the alteration of the felspars is due to the analcite.

Olivine is a constant though never abundant constituent in all varieties of the Lugar teschenites. It is invariably replaced by serpentine, which has crept or spread from the original crystal until the form of the latter has been completely obliterated. The serpentinization may be due to juvenile reactions, as suggested by Mr. Bailey; but it may also be due, as the migration of the serpentine into the surrounding minerals certainly is, to ordinary weathering. Olivine is most abundant in the coarse teschenites of the Galston type, and almost entirely absent from the nepheline-bearing Cathcart type mentioned above.

A constant constituent of the Lugar teschenites is ilmenite in peculiar skeletal forms, and invariably associated with a red highly-pleochroic biotite. These ilmenite-biotite groups are most strongly developed in the Cathcart types. The ilmenite presents a variety of skeletal forms, the commonest, perhaps, being an irregularly-shaped, coarsely-reticulate mass. Another form shows a herring-bone structure, with a central axis from which spring rows of thick, parallel, clubbed rods. Biotite fills up the spaces in the skeletal growth. The ilmenite, as a rule, is anterior in crystallization to the pyroxene, and is also frequently enclosed in felspar. Its decomposition gives rise to a greyish mass of leucoxene, which is often reticulated with three sets of black bars intersecting at angles of 120°.

Biotite occurs in three forms; one, in independent flakes, highly pleochroic from pale straw-yellow to dark reddish brown, is of early consolidation, and is found enclosed in the felspars and analcite. A second form is that described above as occurring in ilmenite-biotite aggregates. The third, which is especially prominent in a Cathcart type from the lower band, is (as described above) an alteration-product of the titanaugite. It occurs as irregular flecks in the interior of the pyroxenes, and also as large, well-formed flakes on their margins. The outer edges of the flakes are quite euhedral, but the interior boundaries with the augite are ragged and indefinite. The biotite is frequently interleaved with chlorite. It often lines a cavity filled with analcite, and serves partly to define the crystallographic form of that mineral.

Orthoclase is a frequent but variable accessory in the teschenites. As the penultimate constituent to crystallize, it is associated and varies in quantity with the analcite. It is generally much altered, and partly or wholly replaced by analcite. Traces of moiré and perthitic structures seem to indicate that it is probably a soda-bearing variety.

A little altered and turbid nepheline, only recognizable by the shape of the pseudomorphs, is to be seen in some of the rocks, notably in the Cathcart type from the lower band of teschenite. It is altered to a highly-polarizing, scaly, micaceous substance. Apatite is abundant, and is enclosed in all the other constituents of the rocks.

The above description covers rocks belonging to the Glasgow, Galston, and Cathcart types. In addition to these are one or two abnormal rocks which may be regarded as highly felsic and mafic varieties of the teschenites. The former occurs as a phase of the variable analcite-rich layer which intervenes between the teschenite proper and the underlying theralite. The orthoclase is approximately equal in amount to the plagioclase, and the rock is clearly leucocratic. Teschenitic rocks comparatively rich in orthoclase are mentioned in Dr. Flett's account[1] of the teschenites of the Edinburgh district. These rocks might be called analcite-monzonites, analogous with the nepheline and leucite-monzonites.

The melanocratic variety also occurs near the junction of the teschenite and the theralite, where the analcite-band is absent. Its mineral composition is defined in Table I, col. v (p. 103). It shows a decided predominance of mafic minerals, and the whole aspect of the rock is ultrabasic. Olivine becomes an essential constituent; augite with hornblende borders is abundant, as well as biotite. Ilmenite, for some unexplained reason, dwindles in this as in all the more basic and ultrabasic rocks of the series. Analcite has decreased considerably in quantity; and, concomitantly, the felspar generally is very fresh. The latter was one of the last minerals to crystallize, fills up the irregular interspaces between the mafic constituents, and shows radiating cracks due to the expansion of serpentinized olivine.

The position of this rock is rather perplexing. It may be interpreted merely as a local, very basic, schlieren; or as due to a small and localized gravity-stratification in the upper teschenite. Its mineral composition shows that it cannot be regarded as a transition-facies from the teschenite to the theralite. The theralites are entirely different, both mineralogically and texturally. A melanocratic teschenite has been described by Prof. W. J. Sollas from New Zealand.[2] That rock, however, is rich in titaniferous magnetite and poor in olivine, thereby differing in these respects from the Lugar rock.

Quantitative Mineral Composition of the Teschenites.

These rocks lend themselves well to micrometric analysis by the Rosiwal method. The chemical compositions calculated from the mineral analyses agree well with the actual chemical composition, as determined by the usual methods of analysis, with the general exception of potash (see Table II, p. 104). This is due to the

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[1] 'The Geology of the Neighbourhood of Edinburgh' Mem. Geol. Surv. Scotland, 1910, p. 294.

[2] 'Rocks of the Cape Colville Peninsula, Auckland (New Zealand)' vol. ii (1906) p. 156.

difficulty of identifying and measuring potash-felspar, when occurring in small quantities in rocks of this kind. Table I illustrates the mineral composition of a number of the Lugar teschenites.

Table I.

	I.	II.	III.	IV.	V.
Plagioclase (Ab_1An_1)	23·2	27·9	28·9	34·5	6·6
Orthoclase	10·2	5·6	...	2·9	...
Analcite	16·1	19·9	13·8	15·5	12·2
Titanaugite	28·1	27·2	39·9	27·3	24·0
Hornblende	...	...	...	...	18·1
Olivine (serpentine)	10·6	7·5	4·6	12·9	32·5
Biotite	3·4	1·5	2·9	2·1	3·7
Titaniferous iron-ore	7·1	9·3	9·9	3·7	1·9
Apatite	1·3	1·1	...	1·1	1·0

I. Fine-grained banded teschenite, near the upper contact, Bellow Water.
II. Teschenite, rich in analcite, upper band of teschenite, Bellow Water.
III. Teschenite, lower band, between peridotite and No. IV, Glenmuir Water.
IV. Teschenite, near the lower contact, Glenmuir Water.
V. Melanocratic teschenite, in the upper band, Bellow Water.

The first four columns show that the mineral composition of the Lugar teschenite is fairly constant. Labradorite averages about 28 per cent., analcite 15 per cent., titanaugite 30 per cent., olivine 8 per cent., biotite 2 per cent., iron-ore 7 per cent., and apatite 1 per cent. Orthoclase is a variable constituent, reaching 10·2 per cent. in No. I, and declining to nothing in No. III. It is probable that a little nepheline occurs in some of the types, but it is hard to detect and harder still to measure. It is probably included with the analcite and orthoclase in the analyses. The fifth analysis is clearly that of a highly mafic variety, with a large increase in the proportion of olivine, and the incoming of 18 per cent. of hornblende, causing a concomitant drop in the proportions of plagioclase and analcite. In respect of the proportions of light and dark constituents (felsic and mafic, or leucocratic and melanocratic), it will be seen that there is a substantial equality in the first four rocks, that is, they are mafelsic. The fifth rock is domafic.[1]

The Chemical Composition of the Teschenites.

Two full chemical analyses of the Lugar teschenites were made for me by Dr. A. Scott; one of the upper contact-basalt, the other of a normal teschenite from the upper band. These are supplemented by analyses calculated from the mineral compositions given in Table I. The minerals of variable composition here are titanaugite, hornblende, biotite, and olivine. It was,

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[1] For an explanation of these terms, see G. W. Tyrrell, 'The Bekinkinite of Barshaw (Renfrewshire) & the Associated Rocks' Geol. Mag. dec. 6, vol. ii (1915) p. 366.

therefore, necessary to know their exact chemical composition in this series of rocks before the quantitative mineral analyses could be utilized. Accordingly, Dr. Scott made analyses of the barkevikite in the lugarite of Lugar, and of the titanaugite in the porphyritic essexite of Crawfordjohn (Lanarkshire), minerals which are optically identical with those of the same species in the Lugar rocks, and occur in rocks belonging to the same petrographic province. For biotite, which occurs in small quantity, an analysis of a biotite from the monchiquite of Horberig, Oberbergen, Kaiserstuhl,[1] was used. From a consideration of the complete series of Lugar chemical analyses it is clear that the olivine also varies somewhat in composition. In the peridotites and picrites it is richer in the forsterite molecule than in the theralites and teschenites. The average composition of the olivine in the different rocks was calculated as follows:—

	Forsterite.	Fayalite.
Peridotite and picrite	4	1
Theralite	3	1
Teschenite	2	1

In the same way the iron-ore was calculated to have the composition

Ilmenite : Magnetite : : 3 : 4 ; or
Fe_2O_3, 39·4 ; FeO, 38·0 ; TiO_2, 22·6.

The chemical analyses by Dr. Scott, and the calculated Rosiwal micrometric analyses are collected together in Table II, with an analysis of teschenite from Mons Hill (Midlothian).

TABLE II.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	44·50	45·26	45·55	44·98	43·41	46·84	42·06	46·06
TiO_2	2·43	3·01	2·91	3·29	4·02	2·06	2·10	2·56
Al_2O_3	15·28	15·74	14·89	15·85	14·89	16·32	8·70	15·94
Fe_2O_3	2·81	2·33	4·06	4·83	5·63	2·65	3·07	2·94
FeO	6·88	7·12	8·23	8·11	9·02	7·30	13·84	7·44
MnO	0·26	0·22	tr.	...	...	...	0·07	0·31
MgO	4·91	5·23	8·03	6·35	7·01	8·53	16·45	4·14
CaO	12·08	8·86	6·98	7·24	8·47	7·93	6·97	7·04
Na_2O	3·94	5·01	5·07	5·78	5·63	5·55	4·59	4·95
K_2O	2·41	2·51	1·94	1·05	0·19	0·63	0·28	2·76
H_2O+	3·09	2·94	1·41	1·67	1·21	1·33	1·15	4·22
H_2O-	0·72	0·68						0·55
P_2O_5	0·24	0·90	0·94	0·84	0·55	0·84	0·75	0·84
BaO(SrO) ...	...	p.n.d.	...	...	...	...	...	0·10
CO_2	1·16	tr.	...	...	...	...	...	0·11
F	...	...	0·05	0·04	...	0·04	0·04	...
FeS_2	...	...	...	...	...	...	...	0·36
Totals ...	100·71	99·81	100·06	100·03	100·03	100·02	100·07	100·32

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[1] H. Rosenbusch, 'Elemente der Gesteinslehre' 1910, p. 300.

I. Teschenite-basalt, upper contact of Lugar sill, Glenmuir Water, Lugar. Chemical analysis by Dr. A. Scott.
II. Banded teschenite, upper teschenite layer of Lugar sill, Bellow Water, Lugar. Chemical analysis by Dr. A. Scott.
III. Banded teschenite, same as II, calculated from Rosiwal analysis No. I of Table I.
IV. Teschenite, rich in analcite, upper teschenite layer, Bellow Water, Lugar. Calculated from Rosiwal analysis No. II of Table I.
V. Teschenite, from lower teschenite layer, Glenmuir Water, Lugar. Calculated from Rosiwal analysis No. III of Table I.
VI. Teschenite, from lower teschenite layer, Glenmuir Water, Lugar. Calculated from Rosiwal analysis No. IV of Table I.
VII. Melanocratic teschenite, from upper teschenite layer, Bellow Water, Lugar. Calculated from Rosiwal analysis No. V of Table I.
VIII. Teschenite, Mons Hill, Dalmeny (Midlothian). Analysis by E. G. Radley, 'Geology of the Neighbourhood of Edinburgh' Mem. Geol. Surv. Scotland, 1910, p. 299.

The teschenitic character of these analyses is at once evident. For a silica percentage averaging 45, and high ferrous iron and lime, the alkalies run to about 7 per cent. The magnesia is comparatively low, indicating the poverty of the rocks in olivine. Combined water, due to the analcite present, is of course high. The analyses obtained by calculation from the Rosiwal analyses are remarkably in accord with the chemical analyses. The greatest discrepancies are in magnesia, potash, and water. The latter may be explained by the fact that no account of the alteration of the rocks was taken in the calculation. The excess of magnesia may perhaps be explained by the complete alteration of the olivine to serpentine in the analysed rocks. The serpentine was analysed as serpentine, but calculated as olivine. The deficiency in potash is due, as explained above, to the difficulty of detecting and measuring orthoclase in these rocks. The analysis of the Mons Hill teschenite shows the essential identity of the Midlothian occurrences with those of Western Scotland.

The richness of some of the Scottish teschenites in potash points to the fact that some of the analcite-rocks are probably to be referred to the monzonite series. With increasing abundance of orthoclase teschenites pass into analcite-monzonites, analogous to nepheline- and leucite-monzonite (sommaite).

The abundance of lime in the teschenite-basalt (I) as compared with the normal teschenite, is due partly to calcite, and partly to a slight enrichment of the contact-rock in augite. The abundance of olivine in the melanocratic type (VII) is shown by a great excess of ferrous iron and magnesia in the calculated analysis.

(3) Theralite. (Pl. X, figs. 3 & 4.)

Three phases of the theralite may be distinguished. A black or dark-grey, compact, doleritic rock forms the main mass of the stratum. The lower part, however, carries abundant hornblende, and is slightly coarser in grain; while, near the junction with teschenite, the rock is veined and shot with patches of a medium-grained, light-grey, analcitic variety.

Microscopically, the theralites consist of essential plagioclase, titanaugite, olivine, nepheline, and ilmenite, with accessory hornblende, biotite, analcite, orthoclase, and apatite. The texture is very fine-grained, and hence the rock might be termed nepheline-dolerite or doleritic theralite. In the principal variety the fabric shows innumerable small, prismoid grains of augite embedded poikilitically in a ground-mass of felspar and nepheline, the whole forming a base in which pseudoporphyritic olivine, augite, and ilmenite is set. The hornblende-bearing variety has the same fabric, only a new pseudoporphyritic element, hornblende, being added. The light-grey veins, however, contain no granular augite, and their abundant analcite gives them a fabric similar to that of the teschenites.

In the principal variety the felspar forms broad, anhedral plates, and seems to have been the last constituent to crystallize, even the nepheline being euhedral towards it. It is extremely zonal, and is crowded with grains of augite. Its composition is consequently difficult of determination, but the evidence points to the usual acid labradorite (Ab_1An_1), with marginal transitions to oligoclase. The plagioclase is liable to decomposition, especially in the central portions of the crystals, and passes into an irregular felted mass of scaly mica.

The augite occurs in two forms: as innumerable prismoid grains embedded in felspar and nepheline; and as larger, pseudoporphyritic, euhedral crystals of a much darker tint than the grains. The colour is a pale purple or lilac, generally darker towards the margins of the crystals. The mineral is often strongly pleochroic, from purplish to pale yellow. It alters, just as in the teschenites, with the production of biotite.

Olivine occurs in large pseudoporphyritic crystals, euhedral originally, but now the angles are largely rounded off, and therefore nearly spherical grains are not uncommon. It is very fresh with, at most, a slight peripheral serpentinous alteration. All the fissures are much blackened by separated magnetite.

Nepheline forms small subhedral to anhedral masses, and appears to be idiomorphic towards the felspar. It is usually altered to a turbid, streaky, micaceous aggregate, the scales of which are arranged parallel to the crystallographic axis of the mineral. It is occasionally quite fresh, and its identification can be made absolutely certain by the usual tests.

Ilmenite occurs in skeletal masses associated with biotite, but not so abundantly as in the teschenites. Biotite also occurs as small independent flakes embedded in felspar or nepheline, or as an alteration-product of augite.

Analcite occurs very sparingly in the principal variety of theralite, but is much more abundant in the veins towards the top of the stratum. Apatite is very abundant, enclosed in all constituents.

A red soda-hornblende, belonging to the barkevikite group, becomes an important constituent in the lower part of the theralite stratum. It usually forms extremely irregular plates, embayed by the earlier constituents, and occasionally enclosing them. It is pleochroic, with colour-extremes of pale straw-yellow and clear red-brown.

The quantitative mineral composition of the main varieties of theralite is set out in Table III, cols. i & ii (p. 109). It will be seen that the mass of the rock is decidedly mafic, much more so than the rocks which have been described as theralite. In addition to the mafic composition, it is characterized by a poikilitic fabric. The light-grey veins, however, are much coarser in grain, are devoid of granular augite and the poikilitic fabric, and show approximate equality between the felsic and the mafic constituents. Containing, as it does, some orthoclase and analcite, this variety closely resembles the true theralites, which are, in general, mafelsic in composition. A mineralogical feature that deserves special mention is the beautiful lilac colour of the augite.

(4) Lugarite. (Pl. XI, fig. 1.)

This rock is found intercalated near the transition between the theralite and the underlying picrite. It has a maximum thickness of 4 feet, and is intimately welded to both the contiguous rocks. It also occurs as irregular, anastomosing veins ramifying through the picrite, and varying in thickness from 1 to 5 inches.

In hand-specimens it presents a striking and beautiful appearance; so much so that it is a matter for comment that the rock has apparently never been noticed before. Boulders of it occur in the bed of the Lugar for a mile or two below the outcrop. It is phanerocrystalline and apparently coarse-grained, consisting of an abundant, continuous, greyish-green ground-mass (analcite, nepheline, and alteration-products) crowded with shining black prisms of barkevikite ranging up to 3 inches in length. The rock of the main exposure also shows equally abundant, more or less equidimensional, black crystals of titanaugite. Occasionally, whitish rectangular felspars may be recognized. Weathered blocks are still more striking in appearance, as the ground-mass becomes white, contrasting effectively with the black prisms embedded in it.

Microscopically, lugarite is a very beautiful rock, owing to the brilliant colours of its mafic constituents and their perfect euhedrism. The rock consists essentially of an abundant cloudy greyish base, partly isotropic, and partly cryptocrystalline because of an extremely-fine dusty alteration-product, clearing occasionally to areas of identifiable analcite. This base is crowded with perfectly euhedral crystals of deep purple titanaugite, red barkevikite ranging up to 3 inches in length, ragged masses of ilmenite passing over to leucoxene, corroded felspars, and innumerable prisms and needles of apatite.

Titanaugite forms well-shaped crystals ranging up to a quarter of an inch in diameter. Its pleochroism is very intense, the scheme being as follows:—

X…………	clear pale brownish yellow.
Y…………	deep maroon or reddish purple.
Z…………	brownish violet.

The hour-glass and kindred zonal structures are prominent, and the exterior zone is always the more deeply coloured and pleochroic. A green coloration frequently appears on the extreme margin. Occasionally, an augite encloses the termination of a felspar-crystal; and in rare cases it is interdigitated with barkevikite, the junction between the two minerals being indefinite, but the exterior margins euhedral. A few crystals are honeycombed by irregular cavities filled with colourless isotropic material, presumably analcite. The titanaugite of this rock is identical in its optical characters with that of the ijolite-dolerite (nepheline-dolerite) of the Lobauer Berg, Saxony.

The barkevikite forms perfect crystals, and is of a deep reddish-brown colour. The pleochroism is intense, with the following scheme:—

X............ pale yellow.
Y............ deep chestnut-red.
Z............ deep brown-red with a tinge of violet.

The maximum extinction-angle in prismatic sections is about 11°. The simple twin parallel to 010 is prominent. The mineral is, therefore, referable to the barkevikite group.[1] It occasionally moulds the pyroxene, and is then evidently an alteration-product; but the great majority of the crystals are entirely independent of pyroxene. On the other hand, the smaller crystals are frequently enclosed in the felspar.

The felspar, where uncorroded, forms well-shaped rectangular laths, and is an extremely zonal plagioclase. Where the extinctions can be measured they indicate a labradorite of composition Ab_1An_2. On the margins, however, nearly straight extinctions are obtained, indicating a transition to oligoclase. The felspar is nearly always corroded, and all stages in its replacement by dusty analcite and isotropic alteration-products can be followed. The replacement begins along the cleavage and other cracks, and advances until large irregular areas in the interior of the crystal are replaced; while, at the same time, the alteration proceeds from the exterior of the crystal in such a way that the felspar remnants are often crescentic in shape, and appear as if large pieces had been scooped or gouged from their sides. The final stage is a complete replacement of the crystal; or, at most, small crescentic fragments of felspar are left. Frequently, however, the crystal form is preserved, and is differentiated from the rest of the groundmass by a slightly paler tint.

Olivine occurs very sparsely as rounded inclusions in the hornblende or augite; and biotite in small flakes, or as an alteration-product of augite. Both minerals may be completely lacking in a slide.

Ilmenite occurs in rather well-shaped hexagonal crystals, and is in process of alteration to leucoxene, giving rise to a marked striation (in black on grey) of three sets of lines in directions intersecting at 120°. It appears to have crystallized in this rock before the hornblende or the pyroxene.

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[1] A. Scott, 'Barkevikite from Lugar' Min. Mag. vol. xvii (1914) pp. 138–42.

Apatite in needles and small crystals is extremely abundant, and occurs embedded in all constituents save ilmenite. The longer needles and prisms show the usual cross-fracture, and are frequently bifid at the terminations.

It is difficult to study the ground-mass, because of its turbidity: it is composed mostly of alteration-products, a fine brown dust, brightly-polarizing zeolites, and 'ghosts' of analcitized felspars; but occasionally it clears to an area of recognizable analcite. Under a high-power objective the fine brown dust resolves itself into clear highly-refracting granules, embedded in a colourless isotropic substance which has a refractive index distinctly lower than that of Canada balsam, and, on the thin edges of the section, a cubic cleavage. It is fairly clear, therefore, that the bulk of the ground-mass is a cloudy analcite. Faint, streaky, paler patches, with an occasional approach to hexagonal or rectangular outlines, are probably to be referred to nepheline. This mineral occurs much more recognizably in a lugarite-like rock in association with the bekinkinite of Barshaw, near Paisley.[1]

Two varieties of lugarite are distinguished. In one, titanaugite and barkevikite are developed in about equal proportions (Table III, col. iii). The distribution of these minerals is, however, very patchy. Some slides contain titanaugite or barkevikite only; others contain both. The veins that penetrate the picrite have barkevikite only (Table III, col. iv), the prisms of which are frequently arranged in a rude stellar fashion.

Quantitative Mineral Composition of Theralite and Lugarite.

These were estimated by the Rosiwal method, and gave fairly concordant results, which are recorded in Table III, below.

Table III.

	I.	II.	III.	IV.
Plagioclase[2]	23·3	16·4	10·5	14·6
Analcite	...	...	42·5	49·0
Nepheline	12·6	16·6		
Titanaugite	36·1	35·9	21·7	...
Barkevikite	...	12·2	17·2	29·5
Olivine	18·6	8·7	...	...
Biotite	3·6	6·7	...	...
Ilmenite	4·2	2·5	5·0	2·7
Apatite	1·6	1·0	3·1	4·2

I. Theralite, Bellow Water, Lugar.
II. Hornblende-theralite, Bellow Water, Lugar.
III. Lugarite, main mass, Glenmuir Water, Lugar.
IV. Lugarite, veins in picrite, Glenmuir Water, Lugar.

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[1] G. W. Tyrrell, Geol. Mag. dec. 6, vol. ii (1915) p. 308.

[2] Ab_1An_1 in theralites; Ab_1An_2 in lugarites.

A little orthoclase has certainly been overlooked in the lugarites and probably in the theralites. Also, in the lugarites the analcite total contains some nepheline. From the chemical analyses it appears that apatite has been considerably over-estimated in the lugarites.

Chemical Composition of Theralite and Lugarite.

No chemical analysis was made of the theralite proper. The rock analysed proved to be nearer to picrite than to theralite, and its composition is set out in Table VI, col. i (p. 114). The lugarite was analysed by Dr. Scott: its chemical composition is unique, reflecting the unique mineral composition of the rock. The chemical compositions, as calculated from the mineral compositions recorded in Table III, are collected here for purposes of comparison, and serve, as do the others already tabulated, to demonstrate the efficiency of the Rosiwal method in suitable cases as an auxiliary to actual chemical analysis.

Table IV.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	42·47	42·75	44·42	46·29	45·56	47·35	43·70	52·73	56·75
TiO_2	2·59	2·68	1·63	2·37	2·53	1·46	0·89	...	0·30
Al_2O_3	14·20	15·19	13·33	17·47	15·92	18·02	19·77	20·05	20·69
Fe_2O_3	3·25	3·50	9·14	2·24	4·04	3·07	3·35	3·43	3·52
FeO	8·73	8·44	6·35	7·07	6·75	5·65	3·47	0·99	0·59
MnO	...	0·05	...	0·28	0·07	0·11	tr.	...	tr.
MgO	12·92	9·47	5·74	2·10	3·02	0·82	3·94	0·17	0·11
CaO	8·26	8·83	10·60	5·82	8·10	7·82	10·30	3·35	0·37
Na_2O	5·33	6·50	5·60	8·69	8·82	9·76	9·78	7·94	11·45
K_2O	0·92	1·37	1·81	1·47	0·04	0·06	2·87	4·77	2·90
H_2O+	0·10	0·21	1·75	5·12	3·53	4·09	0·89	4·85	3·18
H_2O-				0·69				0·69	0·04
P_2O_5	1·18	0·91	0·35	0·70	1·61	1·78	1·34	tr.	...
BaO(SrO)	...	...	...	0·09	...	...	...	0·11	none
CO_2	...	...	...	none	...	...	...	0·93	...
F	0·06	0·04	...	p.n.d.	0·12	0·16	...	...	Cl ·28
S	...	...	0·18	...	...	...	...	...	tr.
Totals	100·01	99·94	100·90	100·40	100·11	100·15	100·30	100·01	100·18

I. Theralite, Bellow Water, Lugar. Calculated from Rosiwal analysis, Table III, No. I (p. 109).

II. Hornblende-theralite, Bellow Water, Lugar. Calculated from Rosiwal analysis, Table III, No. II.

III. Theralite, Flurhubl, Duppau (Bohemia). F. Bauer, Tscherm. Min. u. Petr. Mitth. vol. xxii (1903) p. 281.

IV. Lugarite, main mass, Glenmuir Water, Lugar. Chemical analysis by Dr. A. Scott.

V. Lugarite, main mass, Glenmuir Water, Lugar. Calculated from Rosiwal analysis, Table III, No. III.

VI. Lugarite, veins in picrite, Glenmuir Water, Lugar. Calculated from Rosiwal analysis, Table III, No. IV.

VII. Ijolite, Iivaara, Kuuosamo (Finland). Anal. N. Sahlbom. Quoted from J. P. Iddings, 'Igneous Rocks' vol. ii (1913) p. 306.

VIII. Heronite, Heron Bay, Lake Superior. Anal. H. W. Charlton. Coleman, Journ. Geol. Chicago, vol. vii (1899) p. 435.

IX. Analcite-tinguaite, Pickard's Point, Essex County (Mass.). Anal. H. S. Washington. Amer. Journ. Sci. ser. 4, vol. vi (1898) p. 182.

The correctness of the reference of the first two rocks in Table IV to the theralites, and the general accuracy of the Rosiwal analyses, is shown by the accordance of the calculated analyses with the analysis of Rosenbusch's type theralite from Duppau (Bohemia). The excess of magnesia and the slight deficiency in lime of the Lugar theralites are due to their more highly mafic character; but the alkalies, alumina, and silica correspond remarkably well with those of the Duppau rock.

Turning to the lugarite, the calculated Rosiwal analyses correspond well with the chemical analyses, except in lime, potash, and phosphorus pentoxide. The excess of lime and phosphorus pentoxide is partly due to the over-estimation of apatite, and partly to the overlooking of orthoclase and its measurement as labradorite. The deficiency of about 1 per cent. in potash is, of course, due directly to the latter cause. The lugarite analyses are characterized by a very large content of alkalies along with a comparatively-low silica percentage, and by their persodic character. They fall into the hitherto unoccupied and unnamed persodic subrang of lujavrase (II.7.1.5) of the American Quantitative Classification.[1]

Systematically, these rocks may be described as ijolites in which the place of nepheline is partly taken by analcite, and in which barkevikite occurs as well as, and sometimes to the exclusion of, augite. One of the analyses of ijolite from Iivaara (Finland), corresponds fairly well with that of lugarite (Table IV, No. VII). It is, however, richer in lime and alkalies than the Lugar rock, and contains much less combined water, since nepheline and not analcite is the principal felsic mineral.

The only other rocks hitherto described with an analcite-content of the same order as that of lugarite are the heronite[2] of Heron Bay, Lake Superior, with 47 per cent. of analcite; and the analcite-tinguaite of Pickard's Point, Essex County (Mass.) with 37·4 per cent. of analcite. The chemical analyses of these rocks are set out for comparison in Table IV. Heronite differs from lugarite in containing a large amount (28·2 per cent.) of orthoclase, which is reflected in the large potash-content of the analysis, although the soda-content compares well with that of lugarite. The analcite-tinguaite of Pickard's Point contains ægirine and anorthoclase phenocrysts in a ground-mass composed of nepheline and analcite, is richer in alkalies than lugarite, and is devoid of lime-soda felspar.

(5) Picrite and Peridotite. (Pl. XI, figs. 2 & 3.)

The ultrabasic rock which makes up more than half of the Lugar sill is characteristically felspar-free, and is a typical hornblende-peridotite. Some varieties, however, occurring towards the top of

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[1] G. W. Tyrrell, Geol. Mag. dec. 6, vol. ii (1915) p. 361.

[2] This rock is now regarded as a decomposed tinguaite; see A. E. Barlow, 'Nepheline & Alkali-Syenites of Port Coldwell [Ont.]' Guide-book No. 8 Geol. Surv. Canada, 1913, p. 17.

the mass, contain some felspar and analcite, and are richer in the metasilicates. These are true picrites in the original sense of Tschermak. In hand specimens the peridotite is a fresh, medium to coarse-grained, blackish-green, heavy rock, in which olivine may occasionally be distinguished, and especially hornblende in large, lustre-mottled plates. The rock is variable in granularity, and may be devoid of poikilitic hornblende. The picrites are distinctly finer-grained, and show white or pink specks of felspar and analcite.

Microscopically, the peridotite consists of olivine, titanaugite, hornblende, biotite, and iron-ores in the proportions shown in Table V, col. iii (p. 113). The olivine, which may form 60 to 70 per cent. of the rock, occurs in more or less rounded, subhedral grains, ranging up to half an inch in diameter. It is occasionally quite fresh, but is usually in all stages of alteration to blue, green, yellow, and colourless varieties of serpentine. The coloured serpentines are almost entirely devoid of separated magnetite; but the unaltered olivine and the colourless variety of serpentine contain irregular streaks of magnetite, indicating that the colour of the serpentine depends on whether the iron-oxide is thrown out of combination or not during the process of alteration. The next most abundant constituent is augite, which occurs in polysomatic clusters of small euhedral grains wedged in between the olivines, and where the latter mineral is altered, embedded in serpentine. The granular habit of the augite is distinctive of this type of peridotite, which is accordingly distinguished as the Lugar type. The earliest described picrite or peridotite of the teschenite series, that of Inchcolm, contains titanaugite in large plates which mould and poikilitically enclose olivine.

A red-brown hornblende, belonging, like the amphiboles of the preceding rocks, to the barkevikite group, occurs in large, irregular, poikilitic plates, enclosing small olivines, and groups of granular augite-crystals. It usually forms about 10 per cent. of the rock.

The remaining constituents, biotite and iron-ores, form only about 4 per cent. of the rock. The two minerals are, as usual, closely associated. The rock is almost devoid of apatite: this mineral appears to be associated with analcite, and increases in abundance along with that mineral.

The picrites which occur towards the top of the ultrabasic stratum are divisible into two varieties. One, almost devoid of recognizable felspar, contains much analcite, and very abundant augite. It approximates to the lugarite type, and represents the modification of the peridotite at the contact with lugarite. In thin section this rock consists of numerous, euhedral, purple augites, embedded in a turbid cryptocrystalline or isotropic ground-mass containing zeolites, occasional clear analcite, and 'ghosts' of felspars, identical with the ground-mass of lugarite. Barkevikite occurs in ragged plates exhibiting the poikilitic habit and intergrown with ilmenite. Olivine is comparatively sparse, and is completely serpentinized.

The other variety is an extremely fresh rock, with abundant olivine and some fresh plagioclase. It occurs between the peridotite and theralite in the great cliff of the Glenmuir Water. It differs from the rock described above in the much greater abundance of olivine, in less analcite and turbid decomposition-products, and in the presence of plates of fresh felspar enveloping olivine and augite, and showing the usual expansion-fissures.

Quantitative Mineral Composition of the Picrites and Peridotites.

Table V records the results of the Rosiwal measurement of three of the ultrabasic rocks of the Lugar sill.

Table V.

	I.	II.	III.
Plagioclase ($Ab_1An_1-Ab_1An_2$)	...	5·7	...
Analcite	13·4	8·8	...
Titanaugite	56·6	26·1	20·5
Barkevikite	12·7	8·6	10·0
Olivine	11·1	49·1	65·2
Biotite	...	0·4	2·0
Titaniferous iron-ore	5·1	1·0	2·3
Apatite	1·1	0·3	...

I. Augite-picrite, upper part of ultrabasic stratum, Glenmuir Water.
II. Olivine-picrite, same position and locality.
III. Hornblende-peridotite, main mass of ultrabasic stratum, Glenmuir Water.

It will be seen that the picrites are domafic, and the peridotite permafic. The analcite totals contain a little unidentifiable turbid matter. The diminution in the amount of apatite is a curious feature of the ultrabasic rocks. In the Lugar series, and in the rocks of the Ayrshire petrographical province generally, apatite seems to vary in abundance along with the felsic minerals, especially analcite. A similar but less marked decline in the amount of titaniferous iron-ore also occurs. The order in which the analyses are given is that of increasing depth in the ultramafic stratum. The rapid increase in the amount of olivine illustrates the packing of the olivine-crystals in the lower part of the stratum by settling under the influence of gravity. Along with this there is a decrease in the amount of augite; but barkevikite, a mineral of later consolidation in these rocks, remains practically constant.

Chemical Composition of the Picrites and Peridotites.

Chemical analyses of the augitic type of picrite and of peridotite were made for me by Dr. A. Scott; and these are supplemented by analyses calculated from the quantitative mineral compositions recorded in Table V, above.

Table VI.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	44·47	41·21	42·62	40·35	39·93	42·06	40·32
TiO_2	2·73	3·88	1·58	2·12	1·74	1·93	2·66
Al_2O_3	7·59	8·43	6·41	3·75	2·75	12·18	9·46
Fe_2O_3	6·25	5·22	2·06	3·53	2·49	2·67	4·75
FeO	9·57	11·54	11·27	9·86	13·80	7·89	7·48
MnO	0·49	0·05	0·03	0·20	0·04	...	0·25
MgO	11·93	11·72	25·81	25·69	32·88	11·47	18·12
CaO	10·24	10·10	5·51	4·64	4·16	11·29	10·55
Na_2O	4·27	5·52	3·44	3·14	1·73	5·10	2·62
K_2O	1·46	0·03	0·05	0·80	0·15	1·07	1·10
H_2O+	0·73	1·14	0·76	5·28	0·08	3·08	0·57
H_2O-	0·48			0·83			1·25
P_2O_5	0·54	1·25	0·49	0·25	0·28	0·34	0·68
BaO, SrO	p.n.d.	...	...	0·06	...	...	...
F	...	0·04	0·01	...	...	...	...
CO_2	tr.	...	...	tr.	...	...	...
Incl.	...	...	...	...	...	0·97	0·28
Totals ...	100·75	100·13	100·04	100·50	100·03	100·05	100·09

I. Picrite, transitional to theralite, Bellow Water, Lugar. Chemical analysis by Dr. A. Scott.

II. Augite-picrite, Glenmuir Water, Lugar. Calculated from Rosiwal analysis, Table V, No. I (p. 113).

III. Olivine-picrite, Glenmuir Water, Lugar. Calculated from Rosiwal analysis, Table V, No. II.

IV. Hornblende-peridotite, Glenmuir Water, Lugar. Chemical analysis by Dr. A. Scott.

V. Hornblende-peridotite, Glenmuir Water, Lugar. Calculated from Rosiwal analysis, Table V, No. III.

VI. Limburgite, Hahn, Habichtswald (Hesse-Nassau). Anal. Jannasch. Quoted from J. P. Iddings, 'Igneous Rocks' vol. ii (1913) p. 334.

VII. Nepheline-basalt, Uvalde County (Texas). Anal. W. F. Hillebrand. W. Cross, Bull. U.S. Geol. Surv. No. 168 (1900) p. 62.

These are typical ultrabasic rocks in their large content of magnesia, lime, and ferrous iron, combined with low silica; but they are characterized by comparatively high alkalies, as compared with other rocks of the same category. This results from the persistence of analcite into the ultrabasic end of the series, and from the alkali-content of the pyroxenes and amphiboles. In this respect it is difficult to find phaneric rocks to match with them. Some nepheline-basalts and limburgites approach closely in chemical composition (see Table VI, cols. vi and vii).

IV. Petrology.[1]

The differentiation of the Lugar sill may be explained in two ways, according to whether it is considered as the product of a single act of intrusion or of more than one. Both modes of explanation involve perplexing features. Postulating the former, the

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[1] [Since reading this paper I have, with the permission of the Council of the Geological Society, considerably revised the theoretical discussion of the Lugar sill. I have done this in deference to weighty opinions expressed in the

present heterogeneity of the sill suggests a very complex process of differentiation. Moreover, if it were intruded as a homogeneous body of magma the chemical composition of the contact-rocks should be similar to the bulk-composition arrived at by averaging the analyses of the different parts after weighting them according to their volumes. As will be seen later, this is by no means the case; and, consequently, if the sill is the result of a single act of intrusion, the magma must have been heterogeneous prior to intrusion. The question of its differentiation is then shifted back to an ante-intrusion stage, and its discussion becomes correspondingly difficult.

These complications are avoided, to some extent, if the mass be regarded as a composite sill resulting mainly from two acts of intrusion—the first introducing the teschenite at both contacts, the second bringing in the ultrabasic rock of the interior. All phases within the sill, however, are intimately welded together, showing that the later intrusion must have quickly followed the earlier. Moreover, the mineral and chemical composition of the rocks show that the successive intrusions have very close genetic relations, and have probably arisen by the differentiation of a single body of magma. The problem of the mode of differentiation then becomes the same as that arising from the first hypothesis.

If the sill be thus composite, it shows a surprising lack of xenocrysts and xenoliths, or of veins and dykes, along the main interior contacts. Other features, too, are difficult of explanation on this hypothesis. The subsidiary differentiation observed within the central ultrabasic stratum seems most easily explained by the hypothesis of sinking of early heavy crystals under the influence of gravity, aided perhaps by a concomitant rise of lighter constituents.

The special features of the Lugar sill will now be treated in detail, especially with regard to their bearing on the hypotheses outlined above.

(1) Mineralogical Variations.

Estimations of the modes of twelve types of rock occurring in the Lugar sill are scattered through the foregoing petrographical

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discussion upon the paper, and communicated privately; and also on account of the views on differentiation in general expressed by N. L. Bowen in a recent important paper ('The Later Stages in the Evolution of the Igneous Rocks' Journ. Geol. Chicago, vol. xxiii, 1915, Suppl. pp. 1–91). Liquation theories of differentiation stand in need of drastic revision after the evidence brought forward in this paper, broad-based upon the exact experimental work carried on for many years at the Geophysical Laboratory of Washington, that liquation has never yet been observed in the melts experimented with. Neither has it been observed in lavas, which are Nature's 'quenching experiments.' Whether we can argue from experiments upon the comparatively minute laboratory scale to age-long magmatic processes under natural conditions, is at least open to doubt; and, until that doubt is resolved, it is permissible to use liquation hypotheses, but to assign to other hypotheses more weight according to their correspondence with known facts and conditions.]

descriptions (see Tables I, III, and V). Referring to these it may be seen that lime-soda felspar attains its maximum development, 34·5 per cent., in the teschenites. It dwindles steadily through the theralites, lugarites, and picrites, and is absent from

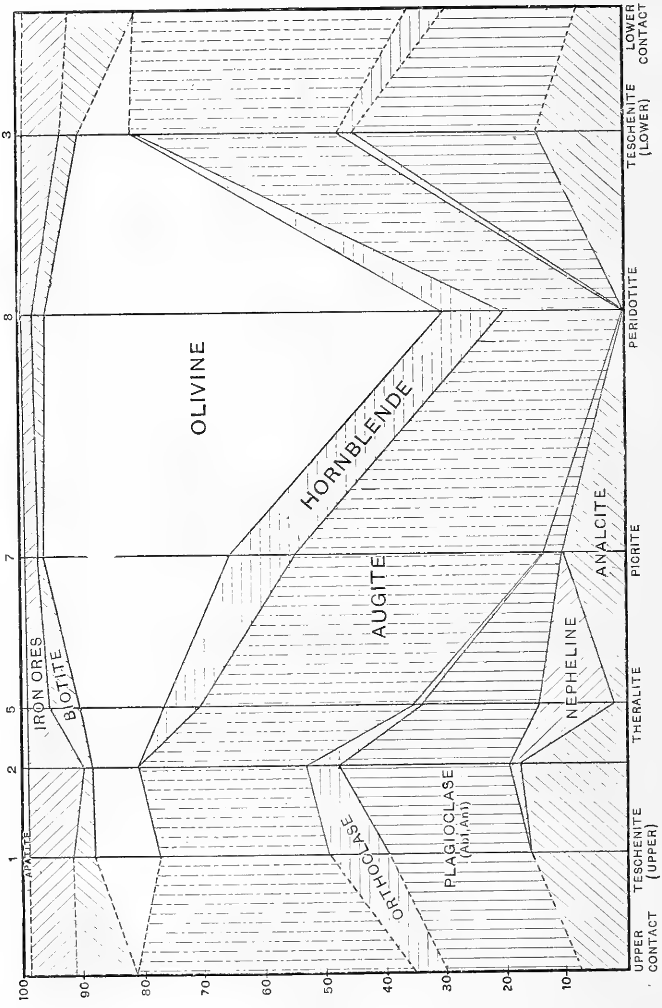

Fig. 5.—*Diagram illustrating mineralogical variation concurrent with increasing depth in the sill.*

the peridotite. Orthoclase occurs most abundantly in the teschenites, but is present in small amount (although unrecorded) in all the other rocks, save picrite and peridotite. It is a mineral hard to detect and measure when associated with abundant lime-soda felspar, but its presence is demonstrated by the potash of the chemical analyses. Analcite is the characteristic mineral of the suite, and is present in all the rocks except the peridotite. It occurs in small amount in the theralites, although unrecorded in the Tables. Where present in notable quantity its amount varies from 30 to 40 per cent. (allowing for the presence of nepheline) in the lugarites, to an average of 15 per cent. in the teschenites. Nepheline occurs in measurable amount only in the theralites (up to 16·6 per cent.), but is almost certainly present in small quantity in the teschenites and lugarites. Titanaugite is the most abundant and constant mafic mineral of the suite. It averages about 30 per cent. in the teschenites, increases to 36 per cent. in the theralites, and attains its maximum development, 55·6 per cent., in an augitic variety of picrite. Red soda-hornblende (barkevikite) is absent from the teschenites, save in a domafic schlieren (Table I, No. 5, p. 103), but is present in amounts ranging from 8·6 to 29·5 per cent. in all the other rocks, the latter amount occurring in veins of lugarite devoid of titanaugite. Olivine averages about 10 per cent. in the teschenites and theralites, is absent from the lugarites, and attains its maximum development in the peridotite, where it may form 70 per cent. of the rock. Biotite averages about 3 per cent. in most of the types, and is most abundant (6·7 per cent.) in the hornblendic variety of the theralite. Iron-ore is most abundant in the teschenites, averaging about 7 per cent., but dwindles steadily downwards through the sill, although it is never entirely absent. Apatite is a comparatively abundant and constant constituent. It averages about 1 per cent. throughout the sill, is absent from the peridotite, and is most abundant in the lugarites, thus illustrating its association with analcite.

The mineralogical variation with depth in the sill may be shown by means of a diagram (fig. 5, p. 116). For this purpose it has been found advisable to average the types (see Table VII, below), thus smoothing over minor mineralogical irregularities.

TABLE VII.

Modes of Rocks in the Lugar Sill.

	1.	2.	3.	4.	5.	6.	7.	8.
Plagioclase (Ab_1An_1 to Ab_2An_3).	23·2	27·9	31·7	28·6	19·9	12·6	2·9	...
Orthoclase	10·2	5·6	1·4	4·7	...	...	...	...
Analcite	16·1	19·9	14·7	16·3	...	} 45·7	11·1	...
Nepheline	...	...	...	...	14·6			
Titanaugite	28·1	27·2	33·6	30·6	36·0	10·8	41·4	20·5
Barkevikite	...	...	...	...	6·1	23·4	10·6	10·0
Olivine (serpentine)	10·6	7·5	8·7	8·9	13·6	...	30·1	65·2
Biotite	3·4	1·5	2·5	2·5	5·2	...	0·2	2·0
Iron-ores	7·1	9·3	6·8	7·5	3·3	3·8	3·0	2·3
Apatite	1·3	1·1	0·6	0·9	1·3	3·7	0·7	...
Felsic constituents	49·5	53·4	47·8	49·6	34·5	58·3	14·0	0
Mafic constituents	50·5	46·6	52·2	50·4	65·5	41·7	86·0	100

1. Upper teschenite (Table I, 1); 2. Analcitic teschenite (Table I, 2); 3. Lower teschenite (Table I, 3, 4); 4. All teschenite, except melanocratic variety of Table I, 5 (Table I, 1, 2, 3, 4); 5. All theralite (Table III, 1, 2); 6. All lugarite (Table III, 3, 4); 7. All picrite (Table V, 1, 2); 8. Peridotite (Table V, 3).

The diagram (fig. 5, p. 116) shows the relation of the mineral constituents to depth within the sill. The depths are plotted as the abscissæ and the proportions of the various mineral constituents as the ordinates, utilizing the averages Nos. 1, 2, 5, 7, 8, 3, in Table VII, in the order given. The break between the theralite layer and the teschenite, where different types occur on opposite sides of a sharp boundary (between 2 and 5), and the similar break between the peridotite and the lower teschenite (between 8 and 3), are clearly shown by the marked changes in the directions of the lines at the points indicated. The sill can thus be divided into three sharply-bounded portions, in each of which a more or less continuous variation may be traced. By far the largest part is that which constitutes the central body consisting of theralite at the top, passing downwards into picrite, and ultimately into peridotite. In this portion plagioclase, analcite, and nepheline show a more or less continuous decrease in a downward direction within the stratum; while olivine rapidly increases in amount, forming about 65 per cent. of the peridotite, and augite and barkevikite find maxima in the picrite and theralite respectively.

(2) Chemical Variations.

The chemical variations within the Lugar sill naturally reflect and follow the lines of the mineralogical variations. Again, as in the preceding section, the variation in 'basicity,' or rather 'maficity' (if one may coin such a term), is the significant variation. In this case, however, it cannot be shown by using the silica percentages as is customary in chemical diagrams, since the silica percentage varies but slightly throughout the series. The percentages of the ferromagnesian oxides show a much more sympathetic

TABLE VIII.

	1.	2.	3.	4.	5.	6.
SiO_2	45·09	42·61	46·40	42·77	40·14	43·16
TiO_2	2·95	2·63	2·12	2·73	1·93	2·66
Al_2O_3	15·49	14·70	17·14	7·48	3·25	10·95
Fe_2O_3	3·72	3·37	3·12	4·51	3·01	3·77
FeO	7·78	8·59	6·49	10·79	11·83	8·97
MgO	6·68	11·20	1·98	16·49	29·29	13·84
CaO	8·63	8·54	7·25	8·62	4·40	7·62
Na_2O	5·16	5·91	9·09	4·41	2·43	4·61
K_2O	1·45	1·14	0·52	0·51	0·43	1·07
H_2O	2·17	0·15	4·48	1·04	3·10	2·69
P_2O_5	0·72	1·05	1·36	0·76	0·26	0·65
Rest	...	0·07	0·28	0·21	0·15	...
Totals	99·84	99·96	100·23	100·32	100·22	99·99

1. Average of teschenites. 2. Average of theralites. 3. Average of lugarites. 4. Average of picrites. 5. Average of peridotites. 6. Average rock of the Lugar sill.

relation to the 'maficity,' and may accordingly be used as abscissæ in a diagram, against which the other oxides may be plotted as ordinates (see fig. 6). Just as in dealing with the mineralogical variations, it has been found necessary and desirable to average

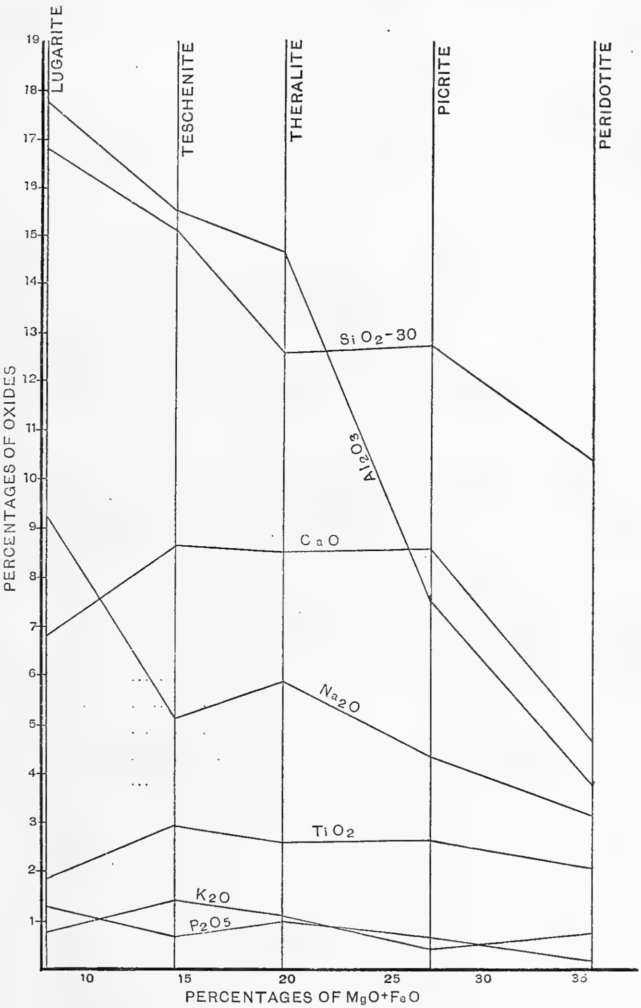

Fig. 6.—*Diagram illustrating variations in chemical composition in the Lugar sill.*

the chemical composition of the various rock-types for use in the diagram. The averages thus arrived at are given in Table VIII. In the calculation of these averages most of the chemical compositions calculated from the graphic analyses have been used, omitting those which duplicate the actual chemical analyses made by Dr. Scott. Thus No. 3 in Table II (p. 104), No. 5, Table IV (p. 110), and No. 5, Table VI (p. 114), have not been used on this score. Furthermore, No. 7, Table II, has been omitted, because it represents merely a small and unimportant schlieren, which would have an effect on the average of the teschenites incommensurate with its size and importance.

The sum of the ferromagnesian oxides being utilized as abscissæ, the diagram shows that the order of increasing richness in these oxides is lugarite, teschenite, theralite, picrite, and peridotite. The most striking feature of the curves (fig. 6) is the rapid and regular fall in alumina from lugarite to peridotite, and the slight fall in silica. Soda also falls; but potash, along with phosphorus pentoxide and titanium dioxide (ignoring small irregularities), remains approximately at a constant level. Lime rises to a maximum in the middle of the series, and drops in the lugarite and peridotite at the extremes. The variation of the curves in this diagram may obviously be correlated with the mineralogical variations which have already been described.

(3) Average Magma of the Lugar Sill.

In the question of the differentiation of the Lugar sill it is of importance to know the chemical composition of the magma before it split up into its present heterogeneous parts. Assuming that the variation has resulted from the differentiation of an originally homogeneous magma, the composition may be calculated by weighting the analyses of the various components according to their bulk, adding, and then dividing by the number of units taken. The average composition of the principal types is given in Table VIII. The proportions have been taken as follows:—

Peridotite (Table VIII, 5)	$\frac{4}{16}$.
Picrite (Table VIII, 4)	$\frac{3}{16}$.
Theralite (Table VIII, 2)	$\frac{2}{16}$.
Teschenite (Table VIII, 1)	$\frac{5}{16}$.
Contact-teschenites (Table VIII, 1) ...	$\frac{2}{16}$.

Since the analyses of teschenite and of the contact-rocks are for all practical purposes identical, seven parts of Anal. 1, Table VIII, have been taken for the last two items. Lugarite is omitted, as it forms an insignificant proportion of the mass of the sill. The result of the calculation is given in Table VIII, 6.

These figures possess significance only if the hypothesis of an intrusion of homogeneous magma, followed by differentiation in place, be accepted. On the hypothesis of successive intrusion it is impossible to assume that the relative volumes of the facies have any necessary connexion with the relative volumes developed within the differentiation chamber. If the former hypothesis be assumed correct the figures show that the original magma must have had a composition intermediate between that of theralite and that of picrite. It had a certain correspondence with that of theralite, but was richer in magnesia, and poorer in lime, soda, and alumina, indicating a greater richness in olivine-molecules and poverty in those of felspars, as compared with theralite; in short, the magma must have been transitional towards the picrite. Consequently, we arrive at the important conclusion that the original magma had a composition different from that of the present contact-rock, and hence, that the sill was heterogeneous when emplaced, and has been shifted since differentiation.

(4) Composition, Identity, and Banding of the Contact-Rocks.

Petrographical examination shows that the upper and lower contacts of the Lugar sill are identical, even down to the smaller microscopical features. Both consist of black, basalt-like rocks, curiously streaked and drawn out in slightly-varying layers, and injected by veins of coarse pink teschenite. They both pass gradually into coarser and more normal teschenites towards the interior of the sill. The upper teschenite becomes more analcitic as it is traced downwards; the lower teschenite remains comparatively uniform as it is followed upwards. These facts show that the teschenite must have been injected into cold rocks, which exercised the chilling effect proper to such contact.

The banding is evidence of considerable movement of the viscous magma during or after emplacement. That the movement and banding took place prior to crystallization is shown by the fact that the textures of the various types are perfectly granular. There is no sign whatever of the parallel arrangement of columnar or tabular minerals such as felspar or augite.

As has been shown in the previous section, the chemical composition of the contact-rock is dissimilar to the average rock of the sill, and consequently the facies cannot be considered as due to the differentiation of an original homogeneous teschenite magma. The fact has no significance if the hypothesis of successive intrusion be accepted. If, however, the sill be considered as due to a single act of intrusion, its heterogeneity must have arisen prior to emplacement. It would have originally had the composition of an ultrabasic theralite or picrite, and contact-rocks of like composition would have been formed. To account for the present disposition of the facies it would be necessary to assume that the intrusion has been moved on from its first position, where it was differentiated, into the position that it now occupies, leaving its picritic contact-rocks behind adhering to the old contacts. This view has some support in the marked flow-banding of the contact-rocks; but it is difficult to understand why this movement did not more seriously disturb the stratified arrangement of the various layers within the sill. This assumption of movement of the sill as a whole, subsequent to differentiation, is not necessary if the alternative hypothesis of successive intrusion be accepted.

(5) Asymmetry of the Sill.

When the arrangement and petrographic nature of the various layers composing the sill is examined in detail, a decided asymmetry becomes apparent. The bands, while generally strictly parallel to the contacts, are not repeated in the same order at the top and at the bottom of the sill. The upper layer of teschenite, becoming richer in analcite downwards, comes to an abrupt end at a sharp junction with fine-grained theralite. The lower layer of teschenite likewise passes very rapidly into the base of the peridotite stratum, although the actual junction is everywhere obscured. The theralite band consequently does not appear in the lower half of the sill (fig. 4, p. 96).

The asymmetry is much accentuated if the densities and sizes of the various bands are taken into consideration. The heaviest and largest layer, the peridotite, is not arranged centrally, but is so situated that its centre-line is well below the geometrical centre-line of the sill. On its upper margin it is flanked by a big mass of the somewhat less heavy picrite and theralite, and on its lower margin by a considerably lighter and smaller band of teschenite. Thus the centre of mass of the whole sill must be considerably below its geometrical centre-line. This, of itself, suggests that gravity must have been the controlling factor in the arrangement, at least in the central ultrabasic stratum. The densities of the layers, bearing out the above facts, are shown in the vertical section (fig. 4, p. 96). When plotted, they form a curve which bulges in an asymmetric manner below the centre-plane of the sill.

(6) Density-Stratification in the Sill.

Apart from the outer sheath of teschenite and its contact-facies, the remainder of the sill, constituting the central ultrabasic stratum, has itself suffered a subsidiary gravity-stratification. This is indicated by the distribution of olivine, which has collected in the lower layers of the mass. The upper portion of the stratum consists of theralite with 14 per cent. of olivine. This passes gradually downwards into picrite with 30 per cent., and finally into peridotite with 65 per cent. of olivine. The inference is that olivine, the earliest constituent to crystallize, has sunk under the influence of gravity to the lower levels of the stratum. This is in accordance with the experiments of Dr. N. L. Bowen,[1] who found that olivine-crystals, forming in an artificial melt approximating in chemical composition to a basic igneous rock, segregated in a dense layer at the base of the crucible in which the melt was contained.

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[1] 'Crystallization-Differentiation in Silicate Liquids' Amer. Journ. Sci. ser. 4, vol. xxxix (1915) pp. 175–91.

(7) Variations in Texture.

Rapid variation in texture is common in alkali-rich rocks, and is highly characteristic of the Lugar sill. These variations are doubtless connected with local variations in the physical and chemical characters of the magma, especially in regard to the gas-content. A textural feature is the comparatively fine grain of the theralite stratum, which is poor in analcite. At the other extreme are coarse-grained teschenites, especially those rich in analcite. The controlling factor is probably the comparative abundance of fluxes, especially water; but the fine grain of the theralite may also be partly due to chilling against the teschenite, as well as to comparative poverty of aqueous residuum. The peridotite is medium- to coarse-grained, but this is assignable to the slow rate of cooling in the centre of the sill. The dense teschenitic contact-facies are clearly due to rapid chilling consequent upon intrusion into cold rocks. The general granularity and lack of parallel orientation among the crystals has already been commented upon.

(8) Segregation-Veins.

Many veins of a coarse pink teschenite cut the dense contact-rocks, and show that a richly-analcitic magmatic residuum remained in a liquid condition long after the consolidation of the contact-rocks. Thin veins consisting largely of analcite and felspar also cut the peridotite. Both types of vein doubtless represent a slight pegmatitic phase in the development of the intrusion. These veins are coarse-grained, and show no signs of chilling at their margins. They were doubtless injected while the rocks were still hot. There are also a few veins of a black fine-grained rock resembling the teschenite-basalts of the contacts. These are probably to be interpreted as injections of teschenitic material at a later stage, when the contact-rocks were colder and able to exercise a chilling effect.

(9) Mode of Intrusion and Differentiation.

Whatever hypothesis of intrusion be adopted, the main differentiation of the Lugar sill must be referred to the stage of its history prior to its emplacement. It is not possible, therefore, to discuss it as fully as might have been done if it had occurred *in situ* at a post-intrusion stage, with all the details clearly displayed. The discussion of the petrography makes it clear that all the different facies are genetically related, and it is highly probable that they have arisen by the differentiation of a single body of magma.

The differentiation appears first to have produced bodies of teschenite and an ultrabasic rock, which may be designated as picrite.[1] The mineralogical and chemical relations of these rocks

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[1] The term picrite was first employed by Tschermak in the sense of a melanocratic derivative of teschenite.

support the view that the gravitational sinking, either of immiscible fractions, or of crystals, was the chief factor concerned in their differentiation. In any case the details of the process are not open to direct inspection, as the magma has been moved since differentiation, and we are, therefore, limited to indirect inference as to its nature. But the gravitational factor receives further support from the phenomena directly observable in the central ultrabasic stratum of the sill, where a gravitational differentiation occurred subsequent to intrusion. This may be regarded as an indication of the process which took place, one stage previously, in the larger chamber whence the Lugar sill was immediately derived.

During the progress of this work I favoured the view that the units of differentiation were immiscible fractions of water-rich teschenite, and comparatively anhydrous picrite, respectively. The sharp interior contact between the upper teschenite and the underlying theralite was regarded as analogous to the sharp contact-plane that is developed between immiscible fractions, such as aniline and water, or various mixtures of metals, which have arranged themselves in order of density. It also became necessary to assume that the sill was the product of a single act of intrusion, and that it was heterogeneous at the time of intrusion. In order to account for the dissimilarity between the teschenitic contact-facies and the bulk-composition of the sill as a whole, the differentiated sill was believed to have received an onward impulse, which pushed it forward into cold rocks, leaving behind its original picritic or theralitic contacts, and establishing new contacts with the succeeding layers of teschenite.

The recent work of Dr. Bowen has discredited liquation theories of differentiation, and has emphasized the importance of crystallization-differentiation, where the crystals are continually removed, either by sinking or zoning, from contact with the liquid in which they were formed.[1] This process receives convincing support from the results of experimental work upon silicate magmas, which has now been carried on for many years in the Geophysical Laboratory at Washington. I am now inclined to ascribe the main differentiation at Lugar to the sinking of heavy crystals in a teschenitic magma. This process is dealt with in greater detail in the next section.

The hypothesis of successive intrusion removes many of the difficulties, and makes unnecessary many of the assumptions, mentioned above. On this hypothesis the teschenite was intruded first into cold rocks, forming fine-grained basaltic facies at both margins. While it was still cooling, but probably solid, a thick mass of picrite magma was intruded along its centre-plane. During its crystallization the ultrabasic layer became stratified according to density mainly by the sinking of olivine-crystals, as

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[1] 'The Later Stages in the Evolution of the Igneous Rocks' Journ. Geol. Chicago (1915) Suppl. pp. 1–91.

described in the next section. This, in its turn, was intruded at a later stage, probably while still partly liquid, by a small mass of lugarite, which spread out as a thin sheet at a horizon about a third of the depth of the ultrabasic stratum from its upper surface.

If the emplacement of the Lugar sill took place in this way, it is difficult to understand why there are no xenocrysts or xenoliths, intrusive veins, or signs of disturbance, along the main interior contacts. The interposition of the ultrabasic magma must have taken place very quietly and gradually, welding itself intimately to the teschenite without wedging off fragments from the contacts. That the teschenite was fractured and comparatively cool before the intrusion of the picrite is shown by the presence of the black veins of basaltic teschenite, which represent teschenitic magma chilled by intrusion into cold, or comparatively cold, rocks.

(10) Sinking of Crystals in the Central Ultrabasic Stratum.

Dr. R. A. Daly and others have shown that the earlier and generally heavier minerals must tend to sink in the ordinary silicate magma. Actual cases of phenocrysts that have sunk (or risen) in lavas have been described by authorities of no less weight than Scrope, Darwin, King, E. S. Dana, and Iddings.[1] In the great quartz-dolerite sill of the Palisades (New Jersey) J. V. Lewis has shown that a concentration of olivine has taken place near the lower contact, giving rise to a stratum of olivine-dolerite.[2] This is interpreted as being due to the sinking of early-formed olivine crystals. Dr. Bowen has shown that olivine- and pyroxene-crystals collect towards the bases of crucibles containing a suitable silica melt, but that olivine sinks more readily.[3] That the process cannot be more often demonstrated in natural occurrences is probably due to the fact that in most small magmas the onset of an inhibitive viscosity, or of crystallization, is too rapid for the gravitational action to take place; and in large magmas the final products of the process are not often exposed by erosion. The sinking of olivine-crystals is believed to have taken place in the central ultrabasic stratum of the Lugar sill, where a downward succession from theralite, through picrite, to peridotite, may be demonstrated, a succession characterized by a gradually increasing proportion of olivine.

Dr. Daly has calculated that a holocrystalline 'basalt' of sp. gr. 3·10 at ordinary temperatures would have a specific gravity of only 2·83 when molten at 1200° C. The figure 3·10 may be taken as a fair average for the specific gravity of picrite, and we may therefore conclude that picrite molten at 1200° C. would have a

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[1] See R. A. Daly, 'Origin of Augite-Andesite' Journ. Geol. Chicago, vol. xvi (1908) p. 411.

[2] Ann. Rep. Geol. Surv. New Jersey 1907, pp. 125, 129–33.

[3] Amer. Journ. Sci. ser. 4, vol. xxxix (1915) pp. 175–91.

specific gravity somewhere near 2·83. Similarly, Dr. Daly has calculated that olivine, which has a specific gravity of 3·40 at ordinary temperatures, would only have a specific gravity of approximately 3·30 when crystallized at 1100° C.[1] The contrast between the specific gravity of crystallized olivine at 1100° C., and that of molten picrite at 1200° C., is sufficiently great to warrant the conclusion that the olivine-crystals, when formed, would sink to lower levels within the magma, and would continue to do so at decreasing speed until the increase of viscosity consequent upon cooling inhibited further movement.

It is conceivable that, under favourable conditions, an almost monomineralic layer might be formed in a magma by the sinking of crystals. The favouring conditions would be early crystallization of a comparatively heavy mineral in a highly fluid magma, unimpeded by the presence of other minerals. The rate of crystallization should be rapid, the sizes of the crystals should be large (as the rate of sinking is proportional to their bulk), and the mineral should appear suddenly in large quantity. Olivine and augite frequently satisfy these conditions, and on sinking they would form, respectively, layers of dunite and pyroxenite. Iron-ores less frequently satisfy the conditions requisite for the formation of monomineralic layers. In most magmas their crystals are small, and the development of the minerals is feeble, though they may be the first to crystallize. Nevertheless, in a few cases, the formation of an iron-ore rock as a result of gravity-settling has been recorded.

The sinking of crystals heavier than the surrounding liquid would probably continue to a diminishing extent, through practically the whole period of crystallization. In this case Dr. Bowen believes that the crystals would tend to sink as a swarm, rather than as individuals, with little tendency to relative movement between the different kinds.[2] The swarm, however, would be dominated by the mineral crystallizing earliest, by the heaviest or largest mineral, or by the mineral crystallizing in the greatest bulk with the greatest speed, according to circumstances. The development of any one mineral within the swarm would be controlled, in general, by a combination of these conditions.

Before the density-stratification of the central part of the Lugar sill can be accepted as due to the sinking of early-formed olivine-crystals, it is necessary to explain why augite and iron-ores are not segregated to the same extent. In the first place, the olivine had a start of the other minerals in crystallization. It is a rapidly crystallizing mineral, and it was forming in large quantity from a richly-magnesian magma. Hence it would form the major constituent of the sinking swarm. Augite, iron-ores, and labradorite began to crystallize somewhat later, and the two first-named would probably participate in the sinking movement. They would find the magma appreciably more viscous, and the field already largely

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[1] Journ. Geol. Chicago, vol. xvi (1908) pp. 404–406.

[2] 'The Later Stages in the Evolution of the Igneous Rocks' *Ibid.* (1915) Suppl. p. 15.

occupied by olivine-crystals. Moreover, the iron-ores are sparsely developed, and would be prevented from sinking to any great extent because of the small size of the crystals. The augite, on the other hand, forms large platy or columnar crystals, shapes, however, which would not facilitate sinking as readily as that of the more compact equidimensional olivine-crystals. Furthermore, the augite tends to form subophitic aggregates with labradorite-laths, a circumstance which would still further hinder sinking. In view of these considerations it is easy to see why olivine should dominate the sinking swarm, and hence why the gravity-stratification in the Lugar sill should be defined mainly by the relative abundance of olivine-crystals. That augite has sunk to some extent is shown by the existence of richly-pyroxenic layers in the picrite part of the stratum, and by the general greater abundance of augite in the picrite than in the overlying theralite (see Table VII, p. 117). This is exactly where one would expect the augite to concentrate, in view of the fact that it is the second heavy mineral to crystallize in bulk. The lowermost layers, on the view adopted here, would be dominated by olivine, a deduction matched by the presence of peridotite in this position.

The hypothesis of sinking of heavy crystals, which is believed to be well attested in the central stratum of the Lugar sill, may be applied to the differentiation of the Lugar magma as a whole. Teschenite and picrite may be regarded as the opposite poles of a gravitative differentiation effected by the sinking of heavy crystals in the magma-chamber whence the Lugar sill proceeded. The teschenite, as the lighter differentiate, would occupy the upper part of the reservoir, and thus, on the application of stress, would probably be injected first, the picrite following as the result of renewed stress. The sunken olivine-crystals might be partly dissolved in depth, and the rounded condition of the crystals in the Lugar peridotite may be cited in favour of this conclusion.

The slight concentration of analcite in the upper teschenite at the junction with theralite (fig. 4, p. 96), may be accounted for by a little settling of heavy crystals in the teschenite, prior to the intrusion of the picrite, aided, perhaps, by a concomitant upward movement of the light aqueo-alkaline material which solidified as analcite. The later history of the sill is mainly that of continued crystallization. After the crystallization and sinking of olivine-crystals had well progressed, the augite, hornblende, iron-ores, and felspars crystallized almost simultaneously, leaving a hot, chemically-active, aqueo-alkaline residuum which finally crystallized as analcite and alkali-felspar. The formation of analcite in this way opens up some interesting magmatic and mineralogical problems, which I do not propose to discuss in this paper.[1] The presence of this residuum is attested by the numerous veins of

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[1] See A. Scott, 'Primary Analcite & Analcitization' Trans. Geol. Soc. Glasgow, vol. xvi (1916) pp. 32–43.

teschenite which pierce the contact-rocks, presumably after the solidification of the latter; and by the corrosion and replacement suffered by the earlier minerals. The origin of the veins, irregular dykes, and sheet of lugarite, is also probably to be referred to this late stage in the history of the sill. This rock, in all probability, represents the extreme analcitic term of differentiation effected in the magma-chamber, injected later along the same channel as the teschenite and picrite.

(11) Comparison of the Lugar Sill with the other Picrite-Teschenite Sills of Scotland.

Including the Lugar sill six picrite-teschenite sills have been described from the Midland Valley of Scotland. The other localities are Ardrossan and Saltcoats in the west; and Blackburn, Barnton, and Inchcolm in the east.[1] Those that have been described in any detail show marked correspondences with the Lugar sill. There is always a central ultrabasic stratum, flanked towards both contacts by teschenite, or by dolerite of teschenitic affinities (save in the Blackburn sill where the base is not seen). The upper band of teschenite is usually the thicker (Lugar, Ardrossan, Barnton). In only two cases, Lugar and Blackburn, is there a sharp contact between the upper teschenite and the ultrabasic stratum; and for these sills some degree of liquation has been postulated. In the others the two types of rocks, where the relation is observable, are said to pass gradually one into the other. The differentiation in this case may be ascribed simply to the gravitational settling of olivine. In the Blackburn, Barnton, and Inchcolm sills, the ultrabasic rock is a picrite in the original sense of Tschermak, an olivinic differentiate from teschenite, and still contains a little felspar and analcite. At Lugar and Ardrossan the gravitational action must have been effective for a longer period, as a felspar-free hornblende-peridotite has been formed, very rich in olivine; and at Lugar, increasing richness in olivine from the upper to the lower part of the stratum has been observed. Flow-banding at both contacts has been observed at Lugar, but at Ardrossan and Inchcolm it apparently occurs only near the upper contact. At Barnton the central picrite shows a rude banding parallel to the contacts.

In two cases, Ardrossan and Inchcolm, the respective observers have postulated heterogeneity in the magma prior to intrusion. At Lugar also, both teschenite and picrite were slightly heterogeneous before intrusion, as shown by schlieren differing in mineral composition or texture. The process of liquation has been invoked to explain a sharp plane of separation between teschenite and an underlying ultrabasic stratum in the Blackburn sill.[2] The influence

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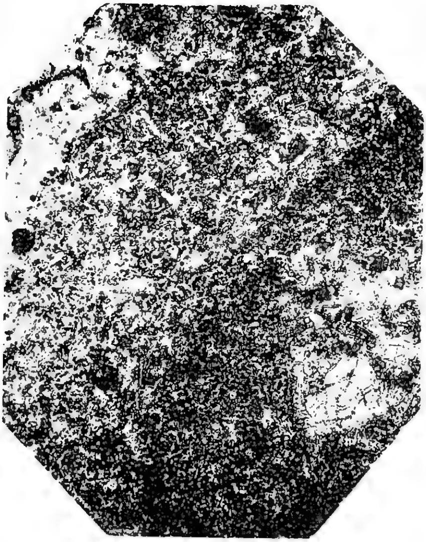
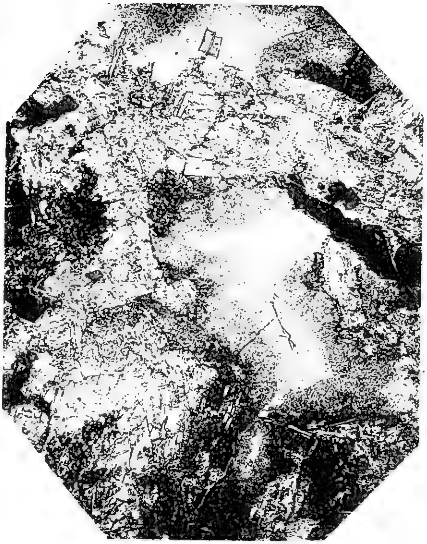
[1] For references, see pp. 84–85.

[2] 'The Geology of the Neighbourhood of Edinburgh' Mem. Geol. Surv. Scotland, 1910, p. 281.

1. × 24



2. × 12



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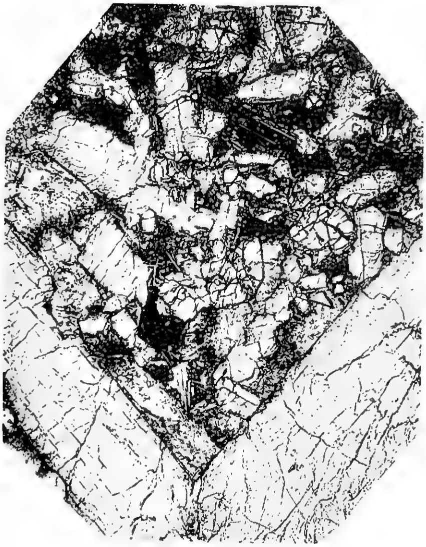

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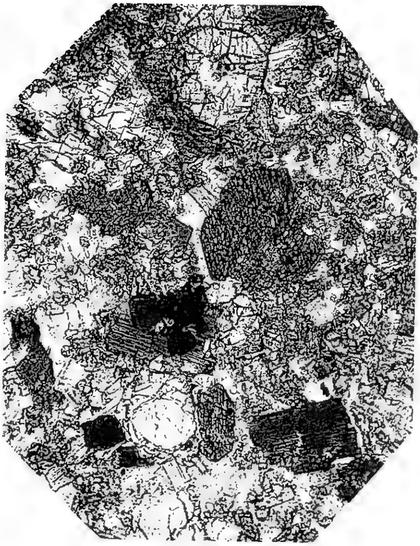
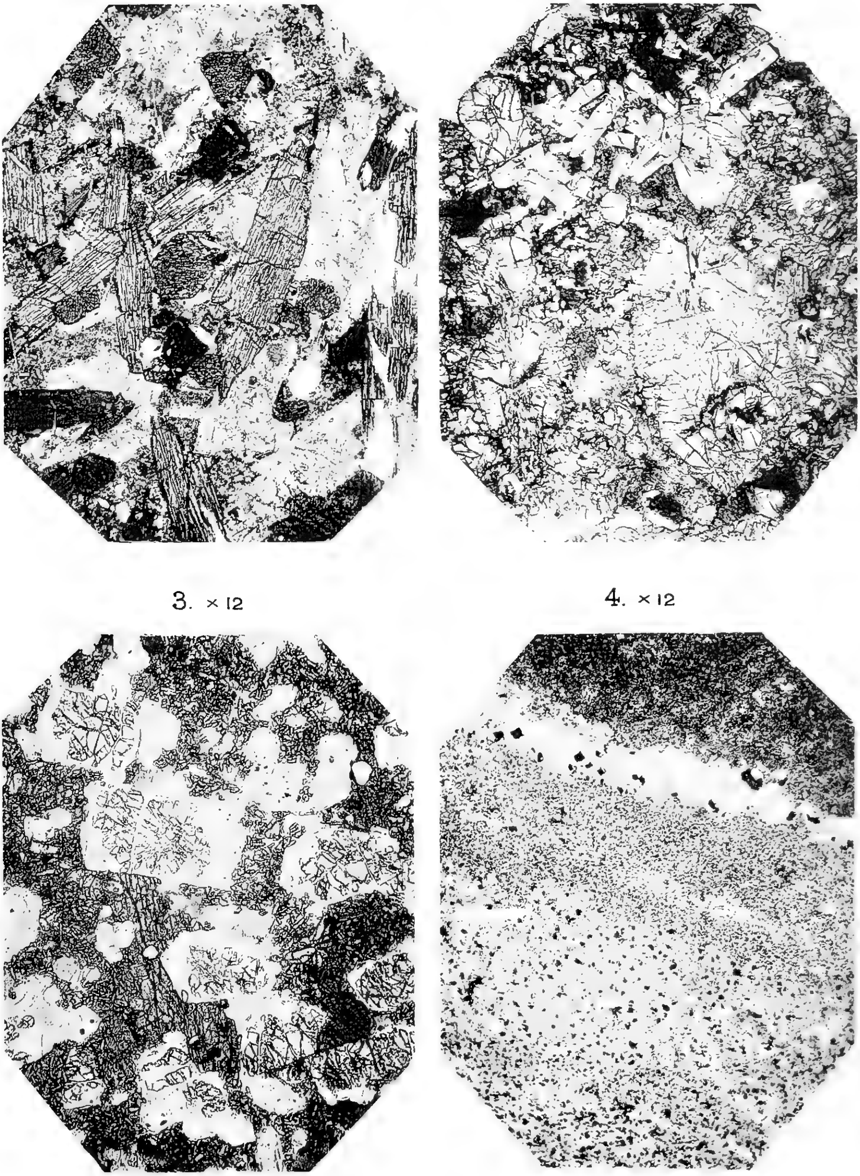


G. W. T., Photomicro.

Bemrose, Collo., Derby

TESCHENITES AND THERALITES.



1. × 12

2. × 12

3. × 12

4. × 12

G.W.T., Photomicro.

Bemrose, Collo., Derby

LUGARITE, PICRITE, PERIDOTITE, AND TESCHENITE.

of gravity in the settling of olivine-crystals has only been appealed to in the case of Lugar, although its effects are clearly demonstrable in the other sills.

EXPLANATION OF PLATES X & XI.

(The slide numbers are those of the collection in the Geological Department, University of Glasgow.)

PLATE X.

Fig. 1. Slide R 1045. × 24. Ordinary light. Upper contact of teschenite, Bellow Water, above Bellow Bridge, Lugar. A felt of minute felspar-laths and grains of augite, with magnetite, and a little interstitial analcite. Note numerous variations of granularity and banding within a small compass. (See p. 95.)

2. Slide R 1044. × 12. Ordinary light. Analcite-rich teschenite, upper band, Bellow Water, above Bellow Bridge, Lugar. Labradorite, augite, and analcite, with numerous flakes of biotite and skeletal ilmenite. Note the central area of analcite with alteration proceeding from the margins. (See p. 98.)

3. Slide PV 249. × 12. Ordinary light. Theralite, augite-rich variety, light-grey patch below the contact of theralite with teschenite, Bellow Water, Lugar. This rock is rich in a beautiful lilac-coloured augite with darker margins. Fresh olivine occurs in small grains about the centre of the field. The turbid interstitial material consists of labradorite and nepheline. (See p. 105.)

4. Slide PV 161. × 24. Ordinary light. Hornblende-theralite, Bellow Water, Lugar. Swarms of minute augite-grains are poikilitically enclosed in a comparatively-coarse ground-mass of labradorite (clear) and nepheline (turbid). Abundant pseudo-porphyritic olivine and barkevikite. The grain of this rock appears deceptively fine, owing to the granular augite. (See p. 105.)

PLATE XI.

Fig. 1. Slide PV 164. × 12. Ordinary light. Lugarite, vein in picrite, Glenmuir Water, Lugar. Large prisms of barkevikite, labradorite (white), ilmenite, and interstitial turbid analcite. This field contains much more felspar than the normal type of lugarite. (See p. 107.)

2. Author's slide. × 12. Ordinary light. Picrite, south of the railway viaduct, Glenmuir Water, Lugar. Consists mainly of augite and olivine, with interstitial turbid analcite, labradorite, and a little barkevikite.

3. Slide R 155. × 12. Ordinary light. Hornblende-peridotite, Glenmuir Water, Lugar. Consists mainly of olivine partly serpentinized, with granular augite, and large poikilitic plates of barkevikite. Note that the augite has the same habit as in the theralite. (See p. 111.)

4. Slide R 1085. × 12. Ordinary light. Lower contact of teschenite, Glenmuir Water, Lugar. Note the varying granularity and the number of different bands within a very small distance. The coarse white band is a later vein of teschenite. (See p. 95.)

DISCUSSION.

The PRESIDENT (Dr. A. HARKER) congratulated the Author on having found so interesting a subject of investigation. His full and careful account of this remarkable composite sill would make a valuable addition to our knowledge. The theoretical discussion based on the facts opened up several interesting questions. The Author had proved that there was a discontinuous variation, with a continuous variation superposed upon it. It had been clearly demonstrated that the latter effect was due to the settling-down of the earlier-formed crystals. With regard to the discontinuity, however, the experiments of the Washington chemists made it difficult to accept any explanation postulating immiscible partial magmas. The speaker would like to see the relations of the various rocks re-examined upon the alternative hypothesis of successive intrusions: the suggestion being that the picrite had been intruded in the midst of an earlier intrusion of teschenite, just as the lugarite was admittedly intruded later in the midst of the picrite.

Prof. W. J. Sollas complimented the Author on a remarkably thorough piece of work, which gained in presentation by the conscientious manner in which fact and hypothesis had been kept distinct. He was inclined to think, however, that the sill had been formed by two separate infillings: that the upper and the lower teschenite were parts of the same intrusion, which followed a widening and reopening of the fissure.

Dr. J. W. Evans welcomed the paper as a valuable contribution to the study of the difficult problem of the differentiation of igneous magmas. He saw no reason for rejecting the supposition that, if it contained sufficient water, a rock-magma might separate on cooling to a certain point into two non-miscible portions, the lighter and uppermost of which contained the greater part of the water, silica, alumina, and alkalies. It was true that no experimental evidence of differentiation had been obtained, when mixtures of silicates had been fused together; but, in the experiments, no considerable amount of water under pressure was present. Continuous gravitational differentiation might be expected to take place in a reservoir of sufficient depth, but the amount of such differentiation that would occur with any particular magmatic composition, temperature, pressure, and depth of reservoir, remained for determination. The succession of the igneous rocks at the Lizard appeared to point to a more or less continuous differentiation from an ultrabasic magma to one with the composition of a dolerite, and then a discontinuous differentiation to a granitic type. The intrusion of the two latter together gave rise to the Kennack gneisses, in which they remained distinct, except where the loss of water before complete consolidation permitted local diffusion. Differentiation as the result of crystallization, in the manner described by Dr. Harker in his 'Natural History of Igneous Rocks,' was now universally accepted.

In the case of the sill described by the Author the possibility of successive injections could not be ignored. If this had happened, the teschenite must have been first intruded and then, before it had completely consolidated, it was followed by still more basic material. This would indicate that the magma had differentiated in a separate reservoir which was tapped near the top. That was contrary to the usual course of events giving rise to deep-seated intrusions: as a result of folding or faulting of the earth's crust, a fluid magma may come to be at a higher level than the adjoining solid rocks, and the reservoir thus formed is then gradually emptied from a point near its base, where there was the maximum hydrostatic pressure; consequently the succession of the intrusions was from basic to acid, as at the Lizard.

Mr. T. Crook joined previous speakers in congratulating the Author on his clear description of this extremely interesting sill. He asked whether the conditions described held true for only a small portion of the sill, or whether they obtained over a considerable area. He raised the question, because of its important bearing on the mode of intrusion. It seemed to him that this sill, so far as the particular portion described was concerned, was best explained by successive intrusions after differentiation had taken place. First, the teschenite was injected; then, before the middle layer of teschenite had completely crystallized, the sill was substantially widened and the peridotite was injected. Finally, and in the same manner, a further slight widening permitted the injection of the 'lugarite' along the median portion of the sill. He considered it impossible to give a satisfactory explanation of the petrology of the sill, except by assuming that the widening of the sill took place in three distinct stages corresponding to the intrusion of the three different rock-types described. The assumption that liquation had taken place after intrusion raised serious difficulties, and seemed to be an unnecessary complication.

The Author, in reply, said that he was much obliged for the kind reception accorded to his paper. He thought that the conditions under which magmatic experiments were conducted scarcely approximated to those obtaining in natural magmas, especially in relation to the content of water and other fluxes. He hoped that liquation might yet be experimentally demonstrated in silicate-magmas. With regard to his interpretation of the differentiation of the Lugar sill, he admitted that successive intrusion offered a plausible alternative to liquation, but thought that observations in the field favoured the latter theory. An almost constant feature of composite sills and dykes was the occurrence of xenoliths and xenocrysts along the interior contacts. No such phenomena were to be observed in the Lugar sill, and there were no veins or dykes springing from the interior contacts. Whether liquation was the true explanation of certain features presented by this sill, or not, he thought that the evidence for subsidence of crystals under the influence of gravity remained overwhelming.

8. *The* ISLAY ANTICLINE (INNER HEBRIDES). By EDWARD BATTERSBY BAILEY, M.C., B.A., F.G.S., Lieut. R.G.A. (Read January 5th, 1916.)

[PLATE XII—GEOLOGICAL MAP.]

CONTENTS.

I. INTRODUCTION.

As compared with the publications of the Geological Survey,[1] the present paper includes the following new features:—

(1) Direct structural evidence is offered of the superposition of the Lower Torridonian sediments of the Rhinns of Islay upon the Lewisian Gneiss of the southern part of that peninsula. Dr. Peach and Mr. Wilkinson were not apparently on the outlook for big inversions, apart from such as are introduced by thrusts, and so their interpretation of the structure required confirmation.

(2) The Loch Gruinart Fault is recognized, and its possible correlation with the Great Glen Fault discussed. No dislocation is suspected in this position

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[1] See Bibliography, § IV, p. 159.

by the Survey authors, but Mr. George Barrow, in conversation, has suggested that an important thrust separates the Rhinns from the rest of Islay.

(3) Collateral evidence is afforded of the existence of the Loch Skerrols Thrust.

(4) The Maol an Fhithich Quartzite is separated from the Islay Quartzite.

(5) The comparatively simple anticlinal structure of North Islay, as illustrated in Sections A & B (Pl. XII), is traced in detail. In the Survey description Dr. Peach and Mr. Wilkinson recognize the anticlinal structure of that part of the district which is included within the horseshoe outcrop of the Dolomitic Group; but they correlate the quartzite beyond this outcrop with the quartzite inside, and assume that the Dolomitic Group is everywhere preserved in synclines. The structural relations, although very clear in the field, are not very satisfactorily represented in the official 1-inch map, since certain of the faults are incorrectly drawn and dip-arrows are for the most part omitted.

(6) The 'Islay Memoir' leaves indefinite the relationship of the Portaskaig and Port nan Gallan Conglomerates, and also that of the North Islay and East Islay Quartzites. The omission is intentional, but does not correspond with any doubt entertained by the writers themselves—as may be judged, for instance, from Dr. Peach's later descriptions of Scarba. I agree with Dr. Peach in considering the rocks of North Islay and East Islay identical in these two instances.

(7) The quartzite of East Islay is shown to be interstratified between the Portaskaig Conglomerate and the Port Ellen Phyllites (Section C, Pl. XII). In the Geological Survey Memoir this quartzite is described as lying in a syncline, and the conglomerates on its two sides, which I distinguish under the names of Portaskaig and Scarba respectively, are correlated, as are also the Mull of Oa and Port Ellen Phyllites.

(8) Satisfactory evidence is given showing that the Portaskaig Conglomerate is younger than the Islay Limestone. Many, if not all, the statements bearing upon this point in the 'Islay Memoir' do not stand examination in the field. It may be added, however, that Dr. Peach's observations in the Garvellachs furnish strong and reliable support to this contention.

(9) The Jura Slates—a minor group, first separated in my official description of Jura—are identified in Islay, where previously they had been regarded as Port Ellen Phyllites exposed along the course of an anticline. The matter is of considerable importance, for on the southern coast of Islay there is very good evidence that these slates are older than the conglomerate and quartzite lying between them and the outcrop of Port Ellen Phyllites farther east. According to my interpretation of the stratigraphy, this points to the Islay Quartzite being older than the Port Ellen Phyllites, whereas in the 'Islay Memoir' the opposite conclusion is arrived at.

(10) Taking the evidence afforded by the archipelago as a whole, one is forced to dissent from Dr. Peach's correlation of the Garvallach and Scarba Conglomerates, and also from his view that the Scarba Conglomerate is the oldest part of the Scarba Quartzite.

(11) The Degnish Limestone is described, in the Geological Survey Memoir that deals with the northern part of the district, as occurring in a syncline with Easdale Slates on both sides. I have failed to find anything to represent these slates on the east side of the limestone.

(12) Particular care has been taken to distinguish clearly between observation and inference. In reading the Geological Survey memoirs dealing with Islay and the islands north of Jura, one is generally at a loss to know whether the folds so frequently mentioned have been traced in the field, or whether they form part of the theoretical interpretation.

The above enumeration of addenda and corrigenda will give a very false impression if it conceals the great obligation under which Dr. Peach and Mr. Wilkinson have placed all who are interested in Highland geology. For my own part, I found their maps and memoirs indispensable for the study of the district in a limited time. [As originally presented, my paper contained a historical introduction, tracing the progress of research from Macculloch's days onward; but this has been withdrawn, as I am advised that it is unnecessary in view of the information already supplied in the Geological Survey Memoirs.[1]]

I may now briefly indicate my own connexion with the district. In 1902 I had the extreme good fortune to receive my Survey training from Dr. Peach, who was at that time engaged upon the investigation of Scarba and the neighbouring islands to the north. The delight of the experience I shall never forget.

In 1907, the year which saw the publication of the Islay Memoir, Mr. W. B. Wright and I were sent to map Colonsay. We were supplied with advance proofs of the Islay Memoir and with the original field-maps, and were instructed to visit the Rhinns in order to acquaint ourselves with its geological structure and succession, because Dr. Peach and Mr. Wilkinson had already established a close connexion between Colonsay and this part of Islay. After a few days spent officially in the Rhinns, we took holidays and separated—Mr. Wright to study the raised beaches, and I, on Dr. Peach's advice, to familiarize myself with the rocks overlying the Loch Skerrols Thrust. I made a complete tour of the coast-sections and many of the inland exposures. As a result, I realized the necessity for modifying the views set forth in the Memoir along the lines indicated in the present paper. I wrote down my conclusions, but deferred publication until I could return to the island and satisfy myself in sufficient detail as to the nature of the faulted western limb of the Islay Anticline north of Bridgend. As chances afforded, I added to my observations in succeeding years, but did not obtain a satisfactory opportunity to work out this particular feature of interest until I took a holiday in the island in 1913. At this time I also revisited the Rhinns, in order to assure myself that the Lewisian Gneiss does really pass below the Torridonian on the north, and is not affected by large-scale inversion.

But to return to the year 1907. I had other districts to visit before following Mr. Wright to Colonsay, and by the time I arrived he had already determined the major features of the geology. Not long afterwards he made the interesting discovery of two earth-movements affecting the cleaved sediments of the island. An account of his researches in this direction is published in the Journal of this Society and in the Geological Survey Memoir dealing with Colonsay.

In 1908 I officially revisited Shuna in company with Mr. Maufe, and we found it impossible to agree with Dr. Peach's view that the Degnish Limestone is separated from the Ardrishaig Phyllites

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[1] Sections 1 and 2 of the Detailed Descriptions, which follow, have also been recast.

by black slates. In 1913 I visited Degnish for the first time, and came to a like conclusion.

In 1910 I was sent by Dr. Horne to Jura to collect material for the Geological Survey Memoir then in preparation. In a fortnight I examined the whole of the coast-sections and various inland exposures.

II. Detailed Descriptions.

(1) Geology of Colonsay and Islay, West of the Loch Skerrols Thrust.

A very brief description of the geology of the western part of the Islay Archipelago will suffice. My observations in Colonsay and Oronsay have already been published, in conjunction with Mr. Wright's, in the Survey memoir on those islands, while my knowledge of the western portion of Islay itself is not sufficient to warrant a detailed account at the present juncture.

Two outcrops of crystalline rocks—a large one in the south of the Rhinns and a small one in the north of Colonsay—have been referred to the Lewisian Complex by Thomson [3, p. 221][1] and Wright respectively. In contact with the Lewisian lies a mass of varied sediments placed by such good judges as Dr. Peach and (subsequently) the late Dr. Clough in the Lower Torridonian System. In both localities the junctions between the Lewisian and Torridonian rocks are much sheared, but this is not a sufficient reason to suspect that the original relationship has been materially altered by thrusting. In fact, Dr. Peach and Mr. Wilkinson have detected what appears to be a true basement-conglomerate at various places near the edge of the Torridonian in the Rhinns. The best exposure of this conglomerate is at Dun Mideir.

From clearly-defined gentle north-easterly pitches which I have observed in traversing the Lower Torridonian sediments lying north of the gneiss-outcrop in the Rhinns of Islay, it seems certain that the gneiss sinks in this direction beneath a covering of Torridonian disposed in a series of sharp but shallow folds (fig. 1, p. 136). I have found north-easterly pitches well marked in the southern part of the sedimentary area, and again between Sanaigmore and Ardnave Point (where shown in Pl. XII). Probably a fairly uniform pitch prevails throughout the whole of the peninsula. It is unfortunate that the lines separating psammitic and pelitic sediments in Sheets 19 & 27 of the Geological Survey map are not drawn with sufficient accuracy to be of assistance in following out the structure; but I am strongly of opinion that the thickness of the sediments in the Rhinns is very considerable, and that the highest stratigraphical horizon is met with at Ardnave Point.

Similar gentle north-easterly pitches continue through Oronsay and the southern part of Colonsay, introducing higher groups, probably, than those encountered in the Rhinns. Mr. Wright and

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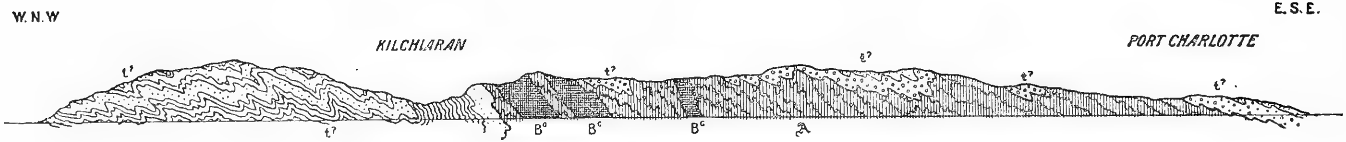
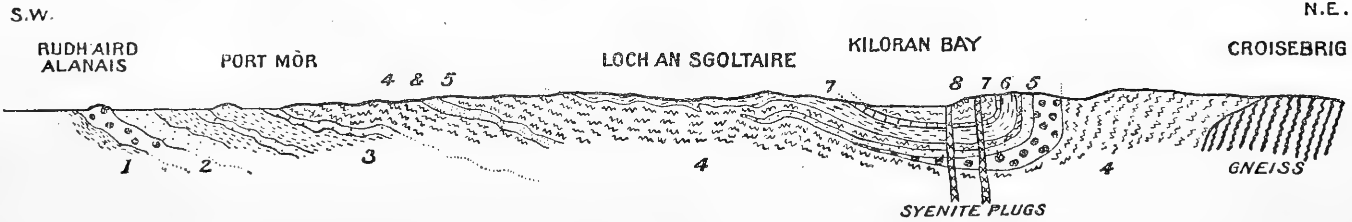
[1] Numbers in brackets refer to the Bibliography, § IV, p. 159.

Fig. 1.—*Generalized section across the Rhinns of Islay (after B. N. Peach & S. B. Wilkinson, 7, p. 20), on the scale of $1\frac{5}{8}$ inches to the mile.*



[A = the fundamental complex of Lewisian; B^G = Basic rocks of the Lewisian; *t* = Lower Torridonian.]

Fig. 2.—*Section across Colonsay (after W. B. Wright & E. B. Bailey, 14, p. 21), on the scale of 1 inch to the mile.*



[Nos. 1–8 refer to groups of the Lower Torridonian, of which 7 is the Colonsay Limestone.]

Note.—Figs. 1 & 2 are reproduced by permission of the Controller of H.M. Stationery Office.

I have traced an upward succession culminating at last in two isolated synclines—the one at Kiloran Bay, the other at Scalasaig. The sediments of Oronsay and Colonsay have been estimated at about 5000 feet in thickness.

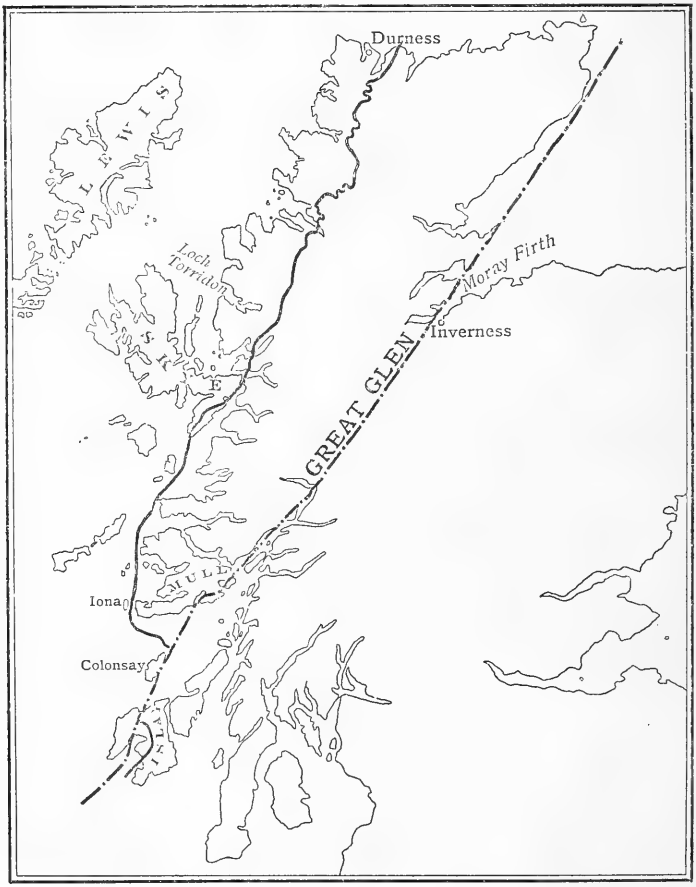
Beyond Kiloran a descending sequence is introduced with very high dips, and before long one meets with the outcrop of gneiss already mentioned (fig. 2, p. 136). It is natural to interpret this gneiss as emerging from beneath the neighbouring Torridonian sediments, and continuous underground with the gneiss of Islay.

When we take into consideration the great thickness of the Lower Torridonian sediments of Colonsay and Islay, we find ourselves bound to postulate an important dislocation along the hollow of Loch Gruinart; for, immediately east of this hollow, we find the Bowmore Sandstone and Islay Quartzite, divisions unrepresented in even the deepest of the Colonsay synclines. For this dislocation I propose the name of the Loch Gruinart Fault. In the Islay Memoir the existence of such a fault is not recognized, and a description is given of what is supposed to be an unbroken contact between the Bowmore Sandstone and the Lower Torridonian on the shore at Gortan. When I visited this section I was unfamiliar with the rocks, and my opinion is consequently of little value; but I am inclined to doubt the Bowmore Sandstone of this restricted exposure. If, however, the correlation be correct, then it would appear that the Loch Gruinart Fault, or a branch of the same, runs slightly to the west of the Gortan foreshore. Otherwise the north-easterly pitch, characteristic of the Rhinns, would carry the Bowmore Sandstone outcrop across the Rhinns long before Ardnave Point was reached.

Without going into details, it seems quite probable that the Loch Gruinart Fault is the south-westerly continuation of the Great Glen Fault. All that is certain is that the Great Glen Fault must pass very close to Colonsay on the one side or the other; and so it is reasonable to connect it with the Loch Gruinart Fault, for both dislocations agree in having a powerful downthrow to the south-east. An additional reason for drawing the Great Glen Fault south-east of Colonsay rather than north-west is illustrated in fig. 3 (p. 138). In the North-West Highlands, wherever undoubted Torridonian rocks are found, they underlie the Moine Thrust. It is probable, therefore, although by no means certain, that the Torridonian rocks of Colonsay and the Rhinns of Islay occupy a similar position. The outcrop of the Moine Thrust was identified by Clough with fair certainty as near Colonsay as the Sound of Iona [C. T. Clough in 14, p. 77]; and, if it is to clear Colonsay after leaving the Sound, it must bend sharply south-eastwards, as shown in fig. 3. According to this interpretation, the Great Glen Fault can scarcely run between the Sound of Iona and Colonsay, for the effect of this fault, with its great downthrow to the south-east, would be to displace the outcrop of the Moine Thrust south-westwards. On the other hand, it does seem likely that the fault passes south-east of Colonsay, since, on crossing the line laid down for it in fig. 3, one finds rocks of the Highland Schist Complex extending south-westwards as far at least as the outcrop of the Loch Skerrols Thrust.

Mention has already been made of the Bowmore Sandstone. As exposed along the shore between Bowmore and Laggan, this group consists of compact, hard, fine-grained sandstone, weathering with brown surfaces, but grey on a fractured face. A very occasional solated pebble of quartz or felspar can be detected, sometimes of air size. The rocks are extremely homogeneous, and therefore the

Fig. 3.—*Suggested continuation of the Great Glen Fault across Islay, with the Moine Thrust on the north-west side perhaps equivalent to the Loch Skerrols Thrust on the south-east side (in Islay).*



bedding is very faintly marked. They are much shattered, as well as considerably sheared. Near Laggan their weathering tints are paler than usual, and some of the group might be styled 'fine felspathic quartzite.' At Blackrock pebbly beds occur, and are represented by slides 6231–6236 in the Geological Survey collection.

As mentioned above, there is often a difficulty in making out the dip of the Bowmore Sandstone. Appearances certainly suggest a very general inclination towards the south-east at angles varying, according to Mr. Wilkinson, between 10° and 40°.

Several competent judges, including Dr. Peach, have been impressed by the resemblance of the Bowmore Sandstone to the Middle and Upper Torridonian. The recognition of the Loch Gruinart Fault does not greatly weaken the correlation which has been based upon this similarity. If, indeed, the Bowmore Sandstone belongs to the southern continuation of the Torridonian, then it is extremely likely that the Loch Skerrols Thrust is the same as the Moine Thrust of the North-West Highlands.

It is well to bring this section to a close on a note of warning. There is something very attractive in the view propounded above that the Lewisian and Torridonian rocks of Colonsay and Western Islay belong to the disturbed foreland up on to which the Moine Nappe has ridden. And also in the further hypothesis that the Moine and Loch Skerrols Thrusts are identical, in which case one must suppose that the Moine Thrust has transgressed from its position in the North-West Highlands under Moine Schists—extending into Mull—until in Islay it lies directly beneath Dalradian Schists of the Central Highlands. There is, however, no abrupt change of metamorphism on crossing the Loch Skerrols Thrust, for the so-called 'schists' of Islay are included in an area of extremely low metamorphism which embraces much of Argyllshire. On this account, Dr. Peach is encouraged to recognize in the Torridonian of Colonsay and West Islay the southward continuation of the Moine Schists in an unmetamorphosed condition, and to refer them to the Moine Nappe rather than to the underlying foreland. This interpretation is, of course, only a part of Dr. Peach's well-known though but partly-published theory, in which he maintains the Torridonian age of the Moine Schists as a whole.

(2) The Loch Skerrols Thrust.

The Bowmore Sandstone passes eastwards beneath the Islay Quartzite. The junction can be followed with approximate accuracy as far south as Bowmore. Beyond this it is completely covered beneath superficial deposits—in fact, it is quite doubtful whether quartzite persists along the eastern margin of the Bowmore Sandstone.

The recognition of the Loch Skerrols Thrust by the officers of the Geological Survey was due in the first place to the marked deformation and mylonitization of the Islay Quartzite and Bowmore Sandstone at their mutual contact. The mechanical evidences are well described by Mr. Wilkinson, who points to the 'drawing-out' of the quartzite along lines varying between west 30° north and north 10° west. The 'drawing-out,' where I have seen it, is of the nature of striation upon shear-planes; at Loch Skerrols it runs north 30° west.

The existence of the Loch Skerrols Thrust can be demonstrated on quite other grounds. It is the purpose of the present paper to show that the Islay Quartzite is folded in an anticline overturned north-westwards. In the heart of the anticline are the Portaskaig Conglomerate, Islay Limestone, etc.; on the south-eastern flanks of the anticline lie the Port Ellen Phyllites. The absence of the last-named group along the west side of the anticline, where the quartzite directly overlies the Bowmore Sandstone, can only be accounted for by invoking a thrust. The north-westward overturning of the anticline above the thrust-plane strongly suggests that the movement along the Loch Skerrols Thrust is in the same sense as that along the Moine and other well-known thrusts farther north. The possible equivalence of the Loch Skerrols and Moine Thrusts has already been touched upon in the previous section.

(3) Rocks above the Loch Skerrols Thrust, as far East as Luing.

The metamorphism of the rocks overlying the Loch Skerrols Thrust is of so low a grade that it is important to have clear evidence of the identity of these rocks and the Dalradian Schists of the mainland. This evidence was obtained long ago by Macculloch [1, vol. ii, p. 159], when he discovered the Portaskaig and Garvellach Conglomerate full of 'granite' (nordmarkite) and 'limestone' (dolomite) boulders, and correlated it with the Schiehallion Conglomerate of Perthshire. The significance of Macculloch's comparisons has of late years been heightened, as a result of Dr. Flett's examination under the microscope of the boulders included in these conglomerates [12, p. 75].

(3 *a*) Maol an Fhithich Quartzite.

This group consists of fine-grained quartzite. A pocket-lens reveals the clastic structure, and further shows that some of the minute quartz-pebbles are blue in colour. Near its junction with the succeeding phyllites the quartzite is intensely sheared. Mr. Wilkinson regarded the outcrop as a faulted outlier of the main Islay Quartzite; but this view may be set aside, as the quartzite and the adjacent phyllites are interfoliated and apparently also, to some extent, interbedded.

(3 *b*) Mull of Oa Phyllites.

These phyllites are prevalently of a dark-grey tint and rather sandy texture. Colour-striping is common, and is especially well seen in the shore-section of the south-eastern corner of Laggan Bay. Grey or greenish phyllites are exposed on the foreshore here, and are constantly interlaminated with very dark seams approaching black.

Cream-coloured sandy dolomites are common in some sections, and may be examined in the cliffs a mile north of the Mull of Oa. The lower[1] bands of the grey Islay Limestone undoubtedly make their first appearance intercalated in the upper portion of the Mull of Oa Phyllites. There are also occasional outcrops of white limestone and associated fine-grained quartzite, which appear to be referable to a like position.

Rough dark-grey, or blackish, slates are quarried at Esknish, and belong to a horizon somewhat below the main mass of Islay Limestone.

The group is much more sheared in the southern part of its outcrop than in the northern, where bedding surfaces are sometimes found glistening with clastic micas.

(3 *c*) Islay Limestone.

The limestone-beds, here classed together, make their first appearance in the upper portion of the Mull of Oa Phyllites, and attain a well-defined maximum at the summit of the group. They are somewhat sandy in composition, and generally dark grey, blue, or black in colour. Oolitic structure is well developed in one or more bands, which have been noted by Mr. Wilkinson at widely-separated points along the limestone-outcrop. Thomson examined the oolites microscopically in the hope of finding fossils, but without success [3, p. 216].

The uppermost bed of the Islay Limestone, near Loch Lossit, is a rather pale-grey rock, which, on testing, proves to be dolomite. I think that dolomite also occurs, north-east of Bridgend, as cream-coloured bands interstratified with the ordinary grey type of Islay Limestone. I did not test them, but they are very similar in appearance to dolomites that occur on higher horizons in the island. Such exceptions, however, do not vitiate the general rule clearly stated by Mr. Wilkinson, that the Islay Limestone is a true limestone; whereas the calcareous beds of the Portaskaig Conglomerate and the Dolomitic Group of the Islay Quartzite are just as definitely dolomite.

Locally—as, for instance, west of Esknish—it appears that certain bands of the limestone become conglomeratic. Fragments of oolitic limestone are crowded together, sometimes cemented in an oolitic matrix. It seems that these beds, if more than one exist, occur near the top of the limestone group. Mr. Wilkinson regards them as belonging to the Portaskaig Conglomerate, and describes their outcrops as outliers; but, as careful search fails to

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[1] The terms lower and upper used in this connexion are justified by structural considerations developed in the sequel.

reveal any bed of the kind at the neighbouring margin of the main conglomerate, I am disposed to regard them as interstratified members of the limestone group.

Mr. Wilkinson has traced the outcrop of the Islay Limestone, in a curve like a horseshoe, from near Bowmore to the Mull of Oa[1]; and has thus demonstrated quite clearly that a fold-axis runs up Central Islay. It is true that the limestone-outcrop, as drawn upon the map, is discontinuous; but many of the interruptions are due to the masking by Drift of portions of the district.

(3 *d*) Portaskaig Conglomerate.

I cannot do better than quote the words with which Dr. Peach concludes his description of the conglomerate as exposed in the Garvellachs:—

> 'The study of the rocks on this group of islands tends to confirm Macculloch's sagacious and far-seeing correlation of this boulder-bed with that of Islay and Schiehallion.'

A very interesting feature of much of the Portaskaig Conglomerate in Islay is its extremely glacial aspect. Large portions of it are unbedded boulder-clay charged with far-travelled boulders. Thomson has urged that it must be of glacial origin, and states that he found a typical striated boulder of quartzite embedded in it [3, p. 211]. I was not equally fortunate, however, although I searched the conglomerate carefully with the same end in view. It is not clear why striated boulders should be difficult to find if the boulder-clay is of glacial origin; for, although the matrix is cleaved, the boulders themselves are often quite unaltered by later movement. There is another difficulty to be faced by the glacial theory: much of the conglomerate is a stratified deposit, and is interbedded with layers of quartzite and dolomite, from which latter it has derived fragments as a result of obviously non-glacial 'contemporaneous erosion.' In the light of these sections one cannot help wondering whether it is necessary to invoke glaciation in order to account for any part of the conglomerate.

Islay.—Splendid exposures of the conglomerate occur both north and south of Portaskaig. The base of the deposit is not seen at the coast in this neighbourhood, but inland sections about Loch Lossit make good the deficiency. Here the grey dolomitic topmost bed of the Islay Limestone, previously mentioned, is overlain by a few feet of dark shale or slate with quartzose ribs, and these by the conglomerate itself. The strata are lying at very

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[1] The coast exposure near the Mull of Oa is disappointing, for the limestone is bleached and reddened in the vicinity of a curious breccia, which, as Dr. Peach suggests, may be a miniature Triassic outlier. Inland exposures, however, even that of the raised-beach cliff, show the grey limestones in characteristic form, and Mr. Wilkinson has recorded oolitic beds as far south as the farm Coillabus.

low angles, and, as Mr. Wilkinson has pointed out, a cake of conglomerate catches on to Beannan Dubh, a little hill rising to the east of Loch Lossit.

The lower portion of the conglomerate is clearly an aqueous deposit, showing obvious bedding, and split up by numerous interstratified bands of quartzite and sandy cream-coloured dolomite. The upper portion, including the main mass, is unbedded, and carries its blocks, boulders, and pebbles promiscuously in a brown, clayey and sandy, somewhat calcareous (likely dolomitic) matrix.

The most conspicuous fragments in the deposit are nordmarkites, of unknown source, and pieces of cream-coloured dolomite—like the dolomite intercalations, only purer. Mr. Wilkinson has described Islay-Limestone pebbles as a feature of the conglomerate, but I spent three days in searching without finding one. It seems probable that his statement has originated on the assumption, already mentioned, that certain conglomeratic limestone-bands belong to the Portaskaig Conglomerate; whereas they appear really to be an integral portion of the Islay Limestone itself. There is no doubt, too, that the dolomite-fragments have often been reckoned as limestone.

Other rocks represented in the Portaskaig Conglomerate have been compared by Mr. Wilkinson with the Lewisian and Torridonian west of the Loch Skerrols Thrust. It is interesting to find gneisses and grits among the boulders, but I think that one should hesitate before assigning them to any particular source.

The Beannan Dubh exposures furnish invaluable evidence in determining the original order of superposition among the sedimentary groups overlying the Loch Skerrols Thrust. The sandy cream-coloured dolomites interstratified in the lower portion of the conglomerate are very prominent in this section. They have been described by Mr. Wilkinson, and their outcrop is indicated on the Geological Survey 1-inch map, Sheet 27, though too small to reproduce in Pl. XII. A careful examination of these beds shows that they have suffered 'contemporaneous erosion,' and have yielded numerous fragments to the conglomerate; and the rule seems to be that the fragments of any particular bed of dolomite enrich the immediately overlying bed of conglomerate.

One of the dolomite-bands is especially noteworthy. It is of a paler tint than usual, and is well exposed for a couple of hundred yards along the south-eastern face of the hill. It rests with an even base upon shales, but is of very irregular thickness, as if its upper surface had suffered from erosion. The overlying rock is a brown, gritty, well-bedded dolomite, which extends downwards into the cavities characterizing the top of the white dolomite below. Moreover, the lower part of the brown dolomite usually contains numerous large fragments of the underlying stratum—in fact, there is often a foot or two of coarse breccia between the two layers, consisting of angular blocks of dolomite set in a sparse, brown, gritty matrix.

Now, this evidence, carefully considered in the field, left no doubt in my mind that the Beannan Dubh succession is right way up. But in Beannan Dubh Portaskaig Conglomerate occurs superimposed upon Islay Limestone. Accordingly, I take it that the index on Pl. XII gives the rock-groups in their original order.

Thus it is proved that the core of the Islay Fold is constituted of the older portion of the Islay Schist succession. It does not, however, follow at once that the fold is an anticline, for in the Highlands we must be prepared to meet with folds affecting inverted sequences, so that additional evidence is required before coming to any conclusion in this matter. Meanwhile, it may be noted that the mapping of the Portaskaig Conglomerate further demonstrates the existence of the Islay Fold, for Mr. Wilkinson has succeeded in tracing the conglomerate intermittently from near Bowmore to Port nan Gallan, east of the Mull of Oa. I may add that I have visited all the known exposures, except the one near Bowmore; between this last and Laggan Bay the solid rocks are completely hidden under superficial deposits.

In the northern part of the island the Portaskaig Conglomerate reaches a thickness of some hundreds of feet. But even here it varies considerably in character, and in some of the outcrops north of Bridgend crystalline boulders are so scarce that one may walk a quarter of a mile before meeting an example; the dolomite-fragments are more universally abundant. In the exposures on the western side of the fold the cleavage is very intense, giving a shaly appearance to the rusty weathering conglomerate.

Followed southwards along the east side of the fold the conglomerate dwindles, and rarely carries conspicuous crystalline boulders. Only in two of the southern exposures is it found richly charged with the typical nordmarkites. These two occur at Beinn Bhan and Port nan Gallan respectively [7, pl. v]. At the former the unbedded, and at the latter the bedded, types of the conglomerate are exposed. Intervening occurrences of the group are as follows from north to south:—

(1) Immediately north-east of a farm, Balvickar (2 miles north-west of Port Ellen), are strong beds of pure cream-coloured dolomite, separated by cleaved, reddish-brown, very fine-grained conglomerate or grit presenting the impure, sandy, argillaceous, slightly calcareous character of the matrix of Portaskaig Conglomerate.

(2) North-east of a farm, Craigabus (2 miles west of Port Ellen), exposures occur showing cleaved, impure, muddy, calcareous, and sometimes slightly gritty rock, occasionally full of fragments of cream-coloured dolomite. A bed of similar dolomite is seen close at hand.

(3) In a road-metal pit south-south-east of a farm, Coillabus (shown on Pl. XII), there is a sandy muddy conglomerate, with quartz-grains and dolomite-pebbles. It is very like the Portaskaig Conglomerate elsewhere, and seems to be underlain by dolomite and quartzose schists.

(4) East of Loch Ardachie (1 mile south-west of Coillabus), the succession just described in (3) is seen to better advantage. A conglomerate with many dolomite pebbles overlies a bed of dolomite which is separated from the Islay Limestone by a band of quartzite.

The Port nan Gallan outcrop has been figured in the Geological Survey Memoir [7, fig. 3, p. 40] to illustrate the unconformity which, according to Dr. Peach and Mr. Wilkinson, exists between the Portaskaig Conglomerate and the Islay Limestone. Unfortunately, the figure is wrongly drawn, for it shows the basal layer of the conglomeratic series obliquely truncating the bedding of the limestone. This is not the case: for, although a plane of discordance separates the two groups, the conglomerate and limestone have identically the same dip. The plane of discordance may, perhaps, have been determined by erosion, as advocated in the memoir; but, if so, the section gives no clue as to which of the two groups is unconformable to its neighbour.

The Garvellachs, or Isles of the Sea.—The oldest rock exposed in the Isles of the Sea is a cream-coloured, white, or pinkish dolomite—or dolomitic limestone—accompanied in places by light-grey slaty beds. Dr. Peach has estimated the thickness of the dolomite as not less that 40 feet. The succeeding rocks are almost all conglomeratic.

On the north-western shore of the main southern island, Eileach an Naoimh, Dr. Peach discovered a beautifully-exposed anticline of the dolomite, surmounted by bedded conglomerate made up exclusively of dolomite fragments, many of them of great size (fig. 4, p. 146). Farther out from the anticlinal axis the dolomite fragments are smaller and enclosed in a dark matrix; while well-rounded boulders of rocks foreign to the islands—nordmarkite, felsite, gneiss, schist, jasper, etc.—make their appearance, sometimes in great abundance. Then follow intercalations of sandy shales, with bands of sandy dolomite and flaggy fine-grained quartzite. These are succeeded by brown-weathering conglomerates charged with dolomite- and nordmarkite-boulders. Pure quartzite is interbedded with the conglomerate, and becomes increasingly prominent at a distance from the anticlinal axis. It contains boulders similar to those that have been enumerated above, but more sporadically distributed.

The main Garvellach dolomite, which yields so many fragments to the Portaskaig Conglomerate in its vicinity, recalls in appearance the dolomite intercalations of the conglomeratic series in Islay, only it is thicker and purer. It is impossible, without boring, to decide whether the Garvellach dolomite is similarly interstratified, or whether it completely underlies the conglomeratic sequence. The interstratified dolomites in Islay, it will be remembered, have suffered from contemporaneous erosion, and therefore the erosion effects in connexion with the Garvellach bed are in keeping with either alternative.

(3 *e*) Islay Quartzite.

North Islay.—The Islay Quartzite is not wholly represented in North Islay, as the top is wanting. In spite of this, North Islay is the most interesting portion of the archipelago from our point of view, for it enables us to realize the anticlinal nature of

Fig. 4.—*Cliff-section, 200 feet high, on the north-western coast of Eileach an Naoimh (Garvellach). See p. 145.*

[Anticline of dolomite, rising to 150 feet, enveloped in Portaskaig Conglomerate. The cliff faces south-westwards. Sketched from a photograph by R. Lunn, 10, pl. iv, p. 32.]

the Central Islay Fold. The following subdivisions are recognized in the Quartzite Series, in descending order :—

Pebbly Quartzite.
Upper Fine-Grained Quartzite.
Dolomitic Group ('Fucoid Beds' of the Geological Survey Memoir), with often a massive quartzite intercalation ('Pipe Rock' of the Memoir) near the base.
Lower Fine-Grained Quartzite.

In regard to the two lower subdivisions and their relations to the Portaskaig Conglomerate, the above is in agreement with the succession as stated by Mr. Wilkinson. But, whereas he believes that the Dolomitic Group is the highest stratigraphical division preserved in the island, I propose to show that it is overlain by much the greater portion of the Islay Quartzite.

The structure and succession of the district can be determined equally well along the coast or inland. The coast-section furnishes a good introduction, and will be considered first.

Coastal traverse from Portaskaig to Loch Gruinart.—The Lower Fine-Grained Quartzite succeeds the Portaskaig Conglomerate with an even, moderate northerly dip in two clear sections (repeated by normal faulting) on the shore north of Portaskaig. The quartzite here is very fine-grained, pure though slightly felspathic, vitreous, well-bedded, and ripple-marked. It must be some hundreds of feet thick. In the northern exposure thin conglomeratic seams occur towards the top, one bed containing pebbles of nordmarkite, quartzite, and shale.

I have seen specimens from the Islay Quartzite which could be placed right way up with confidence, because they carried narrow-crested broad-troughed ripple-marks. During my earlier visits I had not realized the value of ripple-marks in determining the original order of superposition of a little-altered series of sediments. On my last visit my time at Portaskaig was unfortunately too short to enable me to investigate the point satisfactorily. There is no doubt, however, that this line of research is a very promising one in Islay and elsewhere.

The succeeding Dolomitic Group consists, in the Portaskaig sections, of the following subdivisions, in descending order :—

Thick zone, very largely made up of buff-weathering, banded, impure dolomitic beds, with a very small proportion of grey or blue limy seams; also dark and silky-grey, impure quartzose slates; and, towards the top, important beds of pure, cream-coloured and white dolomite.

Minor band of well-bedded, massive, fine-grained quartzite, about 100 feet thick.

Grey silky phyllites, sandy-grey flags, banded, flaggy, fine-grained quartzite (one pebbly layer has been noticed), alternating with calcareous or dolomitic flags and fine-grained quartzite. Almost every bed ripple-marked.

Some of the flags are sun-cracked in the manner that is so common among the Orcadian Flags of Old Red Sandstone age. This feature was remarked upon by Thomson, as also the presence of

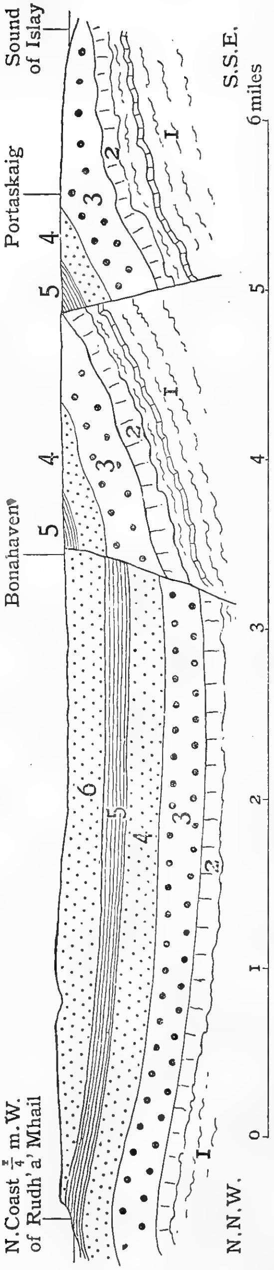

Fig. 5.—*Section from Portaskaig to the northern coast of Islay (thicknesses exaggerated).*

[1=Mull of Oa Phyllites (with limestone-band); 2=Islay Limestone; 3=Portaskaig Conglomerate; 4=Lower Fine-Grained Quartzite; 5=Dolomitic Group; 6=Upper Fine-Grained Quartzite.]

possible worm-tracks and rain-pits. In the massive quartzite Dr. Peach records worm-pipes similar to the 'small pipes,' 'ordinary pipes,' and 'trumpet-pipes' characteristic of the three zones of the 'Pipe-Rock' of the Durness Quartzite. I could not find these worm-pipes during the time at my disposal, and it must be remembered that structures suggestive of worm-pipes are sometimes open to a variety of interpretations. I have seen small, rounded, sandy bodies interrupting the bedding of the Islay Quartzite about 2 miles south-west of Beinn Bhan (South Islay), which strongly recall the choked openings of worm-pipes; but I was never able to trace pipes down from them into the rock below. Similar 'small rounded concretions on the weathered surfaces' of some of the quartzite near the western coast of Scarba have been called 'pseudopipes' by Dr. Peach because of their 'simulating the so-called "pipes."'

The Dolomitic Group clearly dips off the Lower Quartzite division in both sections along the coast north of Portaskaig. The more northerly exposure is terminated by the Bonahaven Fault. So far there is no difference of opinion in regard to the structure of the coast, and the part of fig. 5 south of Bonahaven is little more than a copy of a section given in the Survey Memoir.

The Bonahaven Fault introduces the Upper Fine-Grained Quartzite—a pure, slightly-felspathic, well-bedded quartzite with vitreous fracture;

it is immensely thick and very white, whiter probably than the Lower Quartzite.

The authors of the Geological Survey Memoir on Islay regard all the quartzite of the island as belonging to the subdivision under the Dolomitic Group, and, therefore, refer to the Bonahaven Fault as having 'a downthrow to the east.' A glance at the map, however, shows that the fault, all along its inland course, has an important downthrow to the north-west. Thus it appears that the quartzite introduced into the coast-section by the Bonahaven Fault structurally overlies the Dolomitic Group.

The superposition of the Upper Fine-Grained Quartzite is still more obvious on the northern coast, west of Rudh' a' Mhail, where the Dolomitic Group makes its appearance as an isolated inlier with gentle anticlinal dips.

The quartzite west of the inlier continues with westerly dips, averaging about 35°, until truncated by a fault, inclining steeply to the east, and excellently exposed for over 100 feet in the cliffs of the raised beaches. Just east of the fault on the foreshore the quartzite includes a conglomeratic bed with lumps of quartz in a quartzitic matrix. It has been described as carrying granite-pebbles also, but I do not feel confident that such is the case. The authors of the Geological Survey Memoir confused this conglomerate with the conglomerate already described as occurring at the top of the Lower Quartzite; and, not noticing the fault, imagined that a normal passage existed from it up into the Dolomitic Group, for the latter appears immediately on the west.

The Dolomitic Group, which occupies the shore west of the fault, undulates at low angles until, passing over an anticline, it dips somewhat steeply westwards at an average angle of about 40°, and once more passes beneath the Upper Fine-Grained Quartzite. The rocks near the junction on the foreshore are broken by a shatter-belt, and this has led to the insertion of a fault on the Geological Survey map. But the apparent superposition of the quartzite over the Dolomitic Group cannot be explained away by a fault, since the actual contact of the two groups may be seen intact where a path goes behind an old sea-stack of the raised beach.

This is the last appearance of the Dolomitic Group on the coast. The whole of the northern cliffs to the westward are fashioned out of quartzite dipping north-north-westwards at angles of about 45°. At Gortantoid Point, east of Loch Gruinart, the Upper Fine-Grained Quartzite passes under Pebbly Quartzite, distinguished by numerous layers of quartz-pebbles, of rather small size and often blue in colour, and by scattered, big, rounded pebbles, also quartz. The pebbly layers and pebbles are merely features in a prevalently fine-grained quartzite exactly like that of the underlying group.

Three important results follow from the coastal traverse detailed above :—

(1) The groups—Portaskaig Conglomerate, Lower Fine-Grained Quartzite, Dolomitic Group, Upper Fine-Grained Quartzite, Pebbly Quartzite—are in

ascending structural sequence; this proves conclusively that the fold, running up Central Islay and determining the horseshoe outcrops of the Islay Limestone and Portaskaig Conglomerate, is an anticline.

(2) In the central or axial belt, where well-defined stratigraphical groups crop out along the seashore, constant repetition by isoclinal folding is non-existent, although there is important repetition by open folding and faulting. One cannot hope to determine structure with like certainty in the waste of uniform, well-bedded, fine-grained quartzite between the westernmost outcrop of the Dolomitic Group and the first appearance of the Pebbly Quartzite at Gortantoid Point. I could, however, find no evidence for isoclinal repetition of this fine-grained quartzite (the example, fig. 5, p. 51, of the Geological Survey Memoir is based on an illusory appearance), and I feel confident that the group is some thousands of feet thick on both sides of the Islay Anticline.

(3) The Upper Fine-Grained Quartzite is stratigraphically distinct from the Lower, as may be seen from its superior position and greater thickness, and more especially from its passing under the Pebbly Quartzite at Gortantoid Point. In order to clinch the matter, it may be stated in advance that the Gortantoid relation is precisely reproduced on the opposite side of the Islay Anticline in Jura.

Inland exposures in the axial district of the Islay Anticline.—On the west side of the inland continuation of the Bonahaven Fault, the Lower Fine-Grained Quartzite dips in a general northward direction away from the Portaskaig Conglomerate. The junction of the two groups is often hidden, and the bedding of the quartzite is sometimes rather difficult to make out; consequently it is fortunate that additional evidence, leaving nothing to the imagination, is afforded by the upward passage of the quartzite at gentle angles under the Dolomitic Group. A traverse along the southern boundary of the latter, from Loch Staoinsha (2 miles south-west of Bonahaven) to beyond Giur-bheinn, reveals a simple anticlinal arrangement[1] of the beds, affected by a regular northerly pitch, and complicated to some extent by faulting. The fault, which runs through Loch Giur-bheinn (a small loch immediately east of Giur-bheinn), is bordered at the loch by steeply-inclined beds along its western side. Although these beds are on the upthrow side of the fault and dip towards it, they appear to be inverted. Be this as it may, the effect is strictly local, and the dip speedily rights itself.

It is interesting to note, in passing, a recurrence of conglomeratic conditions towards the top of the Lower Fine-Grained Quartzite in these inland exposures [7, p. 43], just as in the coast-section already described. The bed or beds contain nordmarkite and other pebbles like those of the Portaskaig Conglomerate, but the matrix is sometimes a pebbly quartzite. West of Giur-bheinn considerable outcrops of gritty slate are shown in Pl. XII as belonging to this conglomeratic position; it is not certain, however, that they do not belong to the Dolomitic Group. In the neighbourhood of Giur-bheinn the massive quartzite intercalation ('Pipe-Rock' of the

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[1] Reference is made to this anticline in the Geological Survey Memoir on Islay (p. 49) as 'by far the most conspicuous example of the system of folding,' and evidence for it is given in some detail.

Geological Survey Memoir), which occurs towards the base of the Dolomitic Group on the coast, is strikingly developed, and serves as an excellent index.

In most of the inland tract under consideration the existence of the Islay Anticline is very obvious, because, just as in the coast-section, the dips are practically all normal. About a mile south of Giur-bheinn, however, the western limb of the anticline becomes steeply overturned.

The Dolomitic Group has a double outcrop in the western limb, as a result of repetition by faulting. In the more easterly of these two outcrops the quartzite intercalation ('Pipe-Rock' of the Survey Memoir) is often traceable, but in the other outcrop I could not be certain of its presence. In their northern portions both outcrops afford quite typical exposures of the Dolomitic Group; towards the south, especially in the western outcrop, exposures are mainly limited to massive beds of very pale-grey dolomite.

It is a curious feature in the tectonics of this western limb that the two outcrops of the Dolomitic Group remain equidistant when followed from the district of normal dips into that of steeply-reversed dips. It looks as though the fault, repeating the group, is of comparatively low inclination in the southern part of the region. East of Loch Cam the outcrop of the fault bends abruptly south-eastwards, and very clearly truncates the Dolomitic Group (with the quartzite-band so often mentioned) and also the whole of the underlying Lower Fine-Grained Quartzite, throwing them against Portaskaig Conglomerate and Islay Limestone. The inclination of the rocks thus brought together is very steep, and, as the fault is running transversely to their strike, its existence is easily demonstrated. From this point north-north-eastwards for 4 miles the fault has been mapped parallel to the strike of the beds, merely so as to account for the observed repetition of the Dolomitic Group. A mile north-north-west of Giur-bheinn it becomes self-evident once more, for quartzite on the west of it is seen aiming directly at dolomitic rocks on the east.

In the more westerly of the two main outcrops belonging to the western limb of the Islay Anticline, all the groups between the Islay Limestone and the Upper Fine-Grained Quartzite deteriorate greatly south of Loch Cam. It is doubtful how far this is a feature of original sedimentation, and how far due to mechanical thinning connected with the Loch Skerrols Thrust. The Upper Quartzite is itself mechanically thinned out, more or less completely, in this neighbourhood and on the south.

It is unnecessary to point out in detail the evidence that the quartzite outside the cordon of dolomitic outcrops, reaching from the Bonahaven Fault to near Bridgend, must belong to a structurally overlying group—sharing, of course, in the steep inversion of the western limb of the Islay Anticline. The mapping may be allowed to speak for itself, but it should be added that the superposition of the outer quartzite is clear in the neighbourhood of the Margadale River (west of Bonahaven) and has been recognized in the Geological Survey Memoir on Islay, where, however, it is interpreted as a local inversion.

Jura.—A full statement of my observations in Jura has been published in the Geological Survey Memoir on Knapdale, Jura, and North Kintyre. Of this a short résumé is given below.

The following succession has been recognized in the Islay Quartzite as developed in Jura, where, unfortunately, the base of the formation is not exposed. The sequence is stated in descending order:—

Scarba Conglomeratic Group.
Jura Slates—black above, grey below.
Non-Vitreous Pebbly Quartzite with seams of Black Slate.
Non-Vitreous Pebbly Quartzite with Flags, except in the south.
Vitreous Pebbly Quartzite (Pebbly Quartzite, North Islay).
Vitreous Fine-Grained Quartzite (Upper Fine-Grained Quartzite, North Islay).

As indicated in Pl. XII, two important faults pass northwards across the Sound of Islay into Jura: the more westerly merely touches the western shore of Jura; the more easterly—the Beinn Bhan Fault of Islay—runs inland for a short distance. The position of these two faults in the coastal cliffs is indicated by pronounced shattering. Between the two faults one meets with an upward succession from the Vitreous Fine-Grained Quartzite into the Vitreous Pebbly Quartzite—in fact, the same sequence exactly as one encounters along the northern shore of Islay west of the anticlinal axis.

The Beinn Bhan Fault has not been followed in the inland part of its course, where, indeed, exposures are rather unsatisfactory. It probably joins its western neighbour on re-emerging upon the coast, for there is great shattering of the quartzite at the place where the two faults are mapped as coming together; while no marked shatter-belt is seen in the coast-sections farther north.

The Vitreous Pebbly Quartzite seen west of the fault—or, at any rate, a rock of identical character—continues northwards along the coast to the mouth of the loch that almost divides Jura into two. After the interruption due to this loch, the group is seen again for some 3 miles, when it passes below the sea, to reappear once more in Scarba.

Dipping off the Vitreous Pebbly Quartzite comes the most characteristic division of the Islay Quartzite as developed in Jura—namely, the Non-Vitreous Pebbly Quartzite with Flags. It is an immensely thick group, and in the south consists almost uninterruptedly of pebbly quartzite, which, in a northerly direction, is increasingly split up by cleaved grey sandy shales (or mudstones) and flags, more or less evenly distributed throughout. In some cases, as Dr. Peach has pointed out, the flags are crowded with worm-casts.

The next group, the Non-Vitreous Pebbly Quartzite with seams of Black Slate, has only been differentiated in the north of Jura, where its most obvious feature is an absence of the flags so characteristic of the much thicker group on the west. The quartzite is massive and not very pebbly, and has no conglomeratic tendencies. In the Survey Memoir I correlated this band with the Conglomeratic Group of Scarba; but, on further consideration, I feel convinced that the conglomeratic pebbly quartzite south-east of the Jura Slates is the true representative of the Scarba Conglomerates.

The Jura Slates, in their typical development, include a western portion of grey slate or phyllite and an eastern portion of black slate. Except in certain exposures half way up the coast, the grey slates are quite subordinate, and in the extreme north they fail altogether. In the north the black slates are accompanied by thin beds of dark-grey or black limestone, some of them pebbly.

The Scarba Conglomeratic Group, according to the correlation now adopted, dips off the Jura Slates, and consists of pebbly quartzite of an unusually coarse texture, and often of a dark-grey or black hue. These coarse pebbly quartzites everywhere carry intercalations of black slate, which, so far as one can judge, increase in importance northwards.

The pebbles are generally quartz and felspar, ranging up to the size of a pigeon's egg. At a few points, indicated by dots in Pl. XII, fragments of grit and slate occur, imparting to the rocks a definitely conglomeratic facies. From the appearance of the matrix, and from the quite abnormal size of the associated quartz- and felspar-pebbles, I have no hesitation in regarding these rock-fragments as products of erosion: they have not resulted from crushing connected with the folding of the schists.

East Islay.—The following succession has been determined in East Islay:—

Scarba Conglomeratic Group.
Jura Slates, black above, grey below.
Quartzite, prevalently pebbly above, non-pebbly below.

It has already been pointed out that the Portaskaig Conglomerate can be recognized at intervals from Beinn Bhan to Port nan Gallan, near the Mull of Oa. A little to the east of its course one might expect to meet with the Dolomitic Group of North Islay. Unfortunately, however, only a single rather doubtful outcrop has so far been found. It occurs on Beinn Bhan, where it was recognized by the officers of the Geological Survey. The persistent non-appearance of the Dolomitic Group elsewhere may, perhaps, be due to an untraced continuation of the Beinn Bhan Fault; it is more likely, however, a result of a deterioration of the Dolomitic Group in a southerly direction.

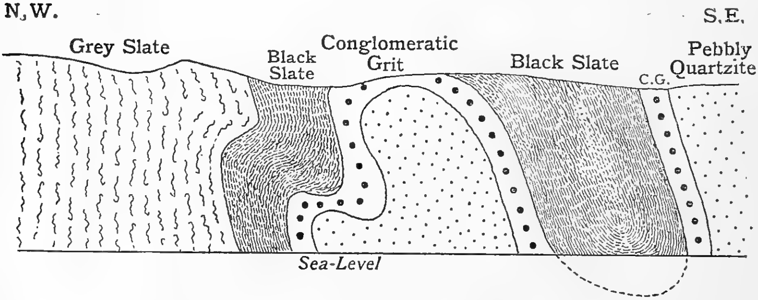
The great mass of quartzite lying north-west of the Jura Slates in East Islay is susceptible of a rough division into a lower group with few pebbly bands, and an upper group which is very generally pebbly. All the quartzite east of the Beinn Bhan Fault belongs to the pebbly group.

The Jura Slates are best exposed on the southern coast, where a broad band of grey slate is followed eastwards by a thin belt of intensely black slate. It is interesting to note how close an agreement exists between this exposure and those of Jura, save only that the grey slates are relatively more important in the south.

The Scarba Conglomeratic Group, as in Jura, is represented by pebbly quartzite, generally of extreme coarseness and sometimes definitely conglomeratic. The pebbles are quartz and felspar, along with occasional fragments of quartzite and slate. The rock-fragments are evidently a result of 'contemporaneous erosion'—the slate, no doubt, in most cases derived from interbedded seams of slate, generally grey, sometimes black.

The interbanding of quartzite and slate in parts of the Conglomeratic Group has been interpreted in the Survey Memoir on Islay as an example of incessant repetition by folding of the conglomeratic edge of the Islay Quartzite and the neighbouring pelitic rocks of the Port Ellen Phyllites. The slate-fragments have accordingly been taken as conclusive evidence that the Islay Quartzite is of later date than the Port Ellen Phyllites. But, as a matter of fact, the supposed repetitions can nearly always be distinguished one from the other on the score of minor characters, such as colour, composition, or texture; wherefore it seems certain that they are mostly due to recurrences of type in an originally alternating series of arenaceous and argillaceous deposits. At the same time, with the incoming of softer strata between the quartzite-beds there is a marked increase of buckling, such as is illustrated in fig. 6, above.

Fig. 6.—*Cliff-section, 200 feet high, on the southern coast of Islay: interfolded Jura Slates and Scarba Conglomeratic Group.*



A particularly interesting section of that portion of the Scarba Conglomeratic Group which comes next to the Jura Slates is furnished by the cliffs of the southern coast of Islay. The black slate of the Jura Slates is here seen folded with the succeeding quartzite of the Conglomeratic Group in the manner indicated in fig. 6. The quartzite, where it approaches the black slate, is markedly coarse in texture, blackish, and charged with black-slate fragments. It is, therefore, exceedingly likely that the Scarba Conglomeratic Group is later than the Jura Slates. This deduction has already been drawn from the exposure, and is stated in the Geological Survey Memoir on Islay (p. 36). Unfortunately, however, the authors of that memoir regarded the Jura Slates as merely Port Ellen Phyllites, brought to the surface along an anticline, and accordingly they thought that the section showed the Islay Quartzite to be later than the Port Ellen Phyllites. On the interpretation of the stratigraphy advanced in the present paper, exactly the reverse conclusion is attained.

Scarba, Lunga, etc.—The following succession of groups has been recognized from west to east in the Islay Quartzite as developed in Scarba. Dr. Peach, to whom we owe the classification and also the recognition of worm-casts in certain of the groups, is of opinion that the succession is probably a stratigraphical one—not reduplicated by folding,—and that the Conglomeratic Group is the oldest group of the series. I agree with Dr. Peach, except that, in the light of the evidence from Islay, I think that the Scarba Conglomerates are probably the latest members of the series :—

Scarba Conglomeratic Group.
? Jura Slates (not recognized as a group by Dr. Peach, and for the greater part cut out by the Scarba Fault).
Pebbly Quartzite with numerous Flags (sometimes crowded with worm-casts).
Massive Quartzite, sometimes pebbly, with quartz and felspar.
Fine-Grained Quartzite, with concretions resembling the infilled mouths of worm-pipes.
Quartzite with Flags (sometimes crowded with worm-casts).

It seems not improbable that the western Quartzite with Flags of Scarba may belong to the upper part of the Dolomitic Group of Islay. The eastern Quartzite with Flags is, of course, the continuation of the Jura Flag Group; while the Massive Quartzite on the west of it belongs to the belt of vitreous quartzites which occupies the western coast of Jura for about 7 miles.

The eastern Quartzite with Flags is bounded on the east in Scarba by an important fault, recognizable also in the islands on the north, where it increases considerably in downthrow. In those portions of the northern islands that lie west of the Scarba Fault (leaving out of consideration the Garvellachs and Dubh-fheith, which I have described as constituted wholly of Portaskaig Conglomerate), Dr. Peach believes that he can recognize the Massive Quartzite of Scarba and also (in Lunga) the eastern Flag Group.

It seems that the Jura Slates are wholly faulted out in Scarba, unless represented for a short distance by a strip of black slate, noted by Dr. Peach on his field-maps along the course of the Scarba Fault. In Lunga it is not impossible that the group has been locally removed by 'contemporaneous erosion,' since a fairly important outcrop of what appears to be the eastern Flag Group of

Scarba occurs in this island in the midst of the conglomeratic beds east of the Scarba Fault.

The Conglomeratic Group, as developed in Scarba and the islands on the north, is of exactly the same type as in Jura and Islay, but with the conglomeratic tendency more marked. While much of the deposit consists of coarse pebbly quartzite, it is common to find beds containing unrounded blocks of pebbly quartzite, black slate, and limestone—some of them several feet long. There are no igneous boulders such as are commonly met with in the Portaskaig Conglomerate, and the equally characteristic white dolomite-pebbles of the latter are also absent.

(3 *f*) Port Ellen Phyllites.

East Islay.—The prevalent rock-type is silvery-grey sandy phyllite and slate, with some beds of flagstone. Certain members of the group are calcareous. The metamorphism is rather higher than in Central Islay.

The Port Ellen Phyllites are the seat of an extraordinary number of epidiorite sills, probably in some measure repeated by isoclinal folding.

South-East Jura.—The Port Ellen Phyllites of South-East Jura are, for the greater part, an extremely sandy set of grey phyllites, associated with many sheared grey sandstones. Purer phyllites occur in bands, especially in the eastern portion of the exposures, where they are much invaded by epidiorite-sills. Many of the rocks are slightly calcareous, and a few seams of limestone have been noted. Layers of black slate or phyllite are intercalated in the western part of the group.

(3 *g*) Laphroaig and Ardmore Quartzites.

A quartzitic group, to which the above title may be applied, follows south-east of the Port Ellen Phyllites. Epidiorite-sills are common throughout, while the south-eastward dip which is characteristic of the Port Ellen district is maintained very uniformly.

The first oncomings of the group are best described as fine-grained 'poor' quartzites ('Laphroaig Quartz-Schists' of the Geological Survey Memoir on Islay, p. 28). They are so much interbedded with phyllitic material, that it is probably impossible to map them out consistently.

The portion of the group cropping out farther east consists largely of pebbly quartzite, as at Ardmore and in Texa, the island south of Laphroaig.

There is a bed of conglomerate on the western shore of Loch an-t-Sailein (3 miles east-north-east of Laphroaig), and a few little bands of dolomite are interbedded with the quartz-schists a short distance inland on the eastern shore of the same. These rocks lie west of the pebbly quartzites of Ardmore type.

(3 *h*) Scarba Transition Group.

East of the Conglomeratic Group in Scarba lies a thick succession of interbedded black slates, quartzites, and limestones. The black slates, which are of Easdale type, are the dominant members of the group. The interbedded quartzites are often pebbly, and resemble the quartzite of the adjoining Conglomeratic Group. The yielding nature of the slates has permitted the development of much obvious crumpling.

There is scarcely room for doubt that the mixed slate and quartzite group of Eastern Scarba represents a Transition Group connecting the Islay Quartzite with the Easdale Slates. The relation of this Transition Group to the Port Ellen Phyllites and the Laphroaig and Ardmore Quartzites cannot definitely be settled, owing to lack of exposure; but it seems probable that the two sets of rocks are roughly equivalent, as one would expect from their relations to the Scarba Conglomeratic Group. Such an interpretation is in keeping with the growing importance of black slate in the Jura Slate Group which followed northwards: in the south of Islay the Jura Slates are mainly grey, whereas in the north of Jura they are entirely black.

(3 *i*) Easdale Slates.

The Easdale Slates which build up Luing and its associated islands are carbonaceous, quite black, and very pyritous. Quartzose intercalations are rare, but thin black limestones common.

As might be expected from their composition, the Easdale Slates are thrown into numberless small-scale folds.

(4) Rocks of Degnish and Shuna.

The schists of Degnish and Shuna probably belong to the Loch Awe rather than to the Islay region. They are dealt with in the present paper, so as not to leave a gap between the district here described and that already discussed in the Journal of this Society (vol. lxix, 1913) under the title of the Loch Awe Syncline.

(4 *a*) Degnish Limestone.

Dr. Peach has traced a very well-characterized dark sandy limestone through Degnish and Shuna into Reis an-t-Sruith—an island off Craignish Point. Much of the limestone is mottled with round aggregates of dark calcite, in large crystals, embedded in a sandy calcareous matrix.

Dr. Peach describes a narrow belt of Easdale Slates as generally recognizable in Degnish and Shuna, separating the limestone from the adjacent Ardrishaig Phyllites: in this I think that he has been mistaken. After careful re-examination I consider that the rocks in contact with the limestone are members of the Ardrishaig Group, that the junction is a normal sedimentary one, and that no Easdale Slates occur anywhere in Degnish or Shuna.

(4 *b*) Ardrishaig Phyllites.

The Degnish Limestone is followed eastwards, both in Degnish and in Shuna, by a set of greenish-grey phyllites with many thin intercalations of white limestone, and also, in the eastern part of Shuna, of fine-grained quartzite. Lithological character and geographical position assign these rocks to the Craignish Phyllite Group, which Mr. J. B. Hill[1] several years ago correlated with the Ardrishaig Phyllites of Loch Fyne, on the other side of the Loch Awe Syncline.

III. CONCLUSION.

The object of the present paper has been to give an account of the stratigraphy and structure of the Islay district. The main results are graphically expressed in Pl. XII. The map and sections of this plate speak for themselves, but a few words may be useful in regard to the explanations.

The Raised Beaches of the Loch Gruinart hollow and the lavas of Old Red Sandstone age north of Degnish are altogether later than the rocks dealt with, and are designated by black-and-white symbols.

The epidiorite-sills have no stratigraphical significance, and are shown in an isolated tablet.

To the rocks of Shuna and Degnish are assigned a separate index, because it is suspected that they may be resting upon an important thrust, separating them from the Islay succession below. The Degnish Limestone is placed under the Ardrishaig Phyllites, because it is so arranged in fact; but whether the limestone is older or younger than the phyllites is an open question.

The long index at the left-hand side of the plate represents the succession in Islay above the Loch Skerrols Thrust, and also its continuation in the islands on the north. The upper part of the index is split, in order to indicate the probable equivalence of the Port Ellen Phyllites and the Laphroaig and Ardmore Quartzites in the south to the Scarba Transition Group in the north. There is very good reason to believe that the index represents the rocks in their original order of superposition, with the oldest at the bottom.

The Bowmore Sandstone is given an index to itself, on account of its structural isolation.

The rocks of the Rhinns of Islay and Colonsay are cut off from the rest of the district by the Loch Gruinart Fault They are shown in a single index, but with the unconformity between the Lower Torridonian sediments and the Lewisian Gneiss quite clearly indicated.

Finally, it may be pointed out that the Loch Gruinart Fault is probably the Great Glen Fault of the mainland, while the Loch Skerrols Thrust is not unlikely the Moine Thrust of the North-West Highlands (see fig. 3, p. 138).

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[1] 'On the Progressive Metamorphism of some Dalradian Sediments in the Region of Loch Awe' Q. J. G. S. vol. lv (1899) p. 479.

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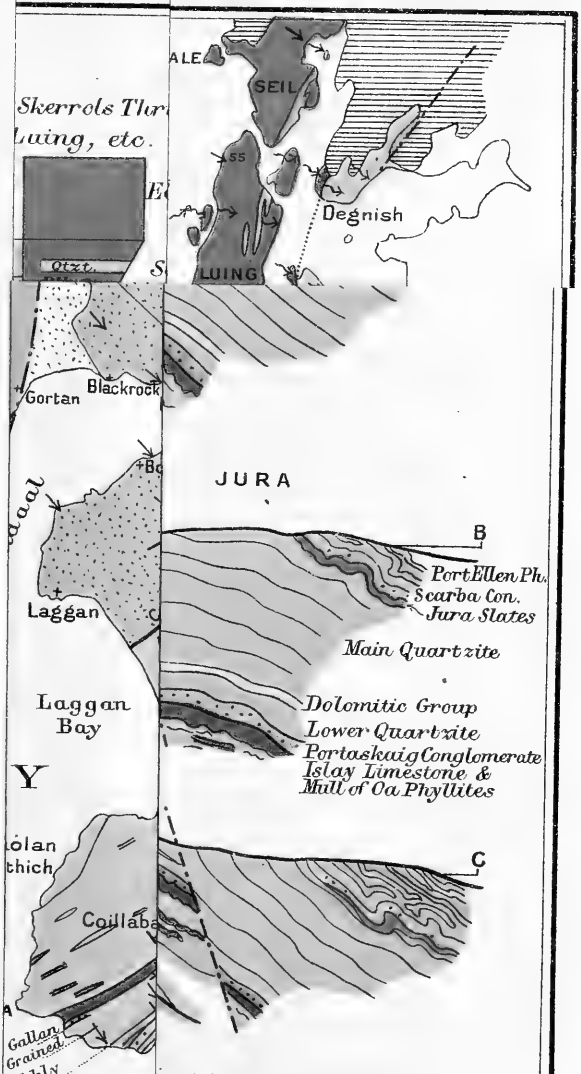
inor modifi of Scotland),

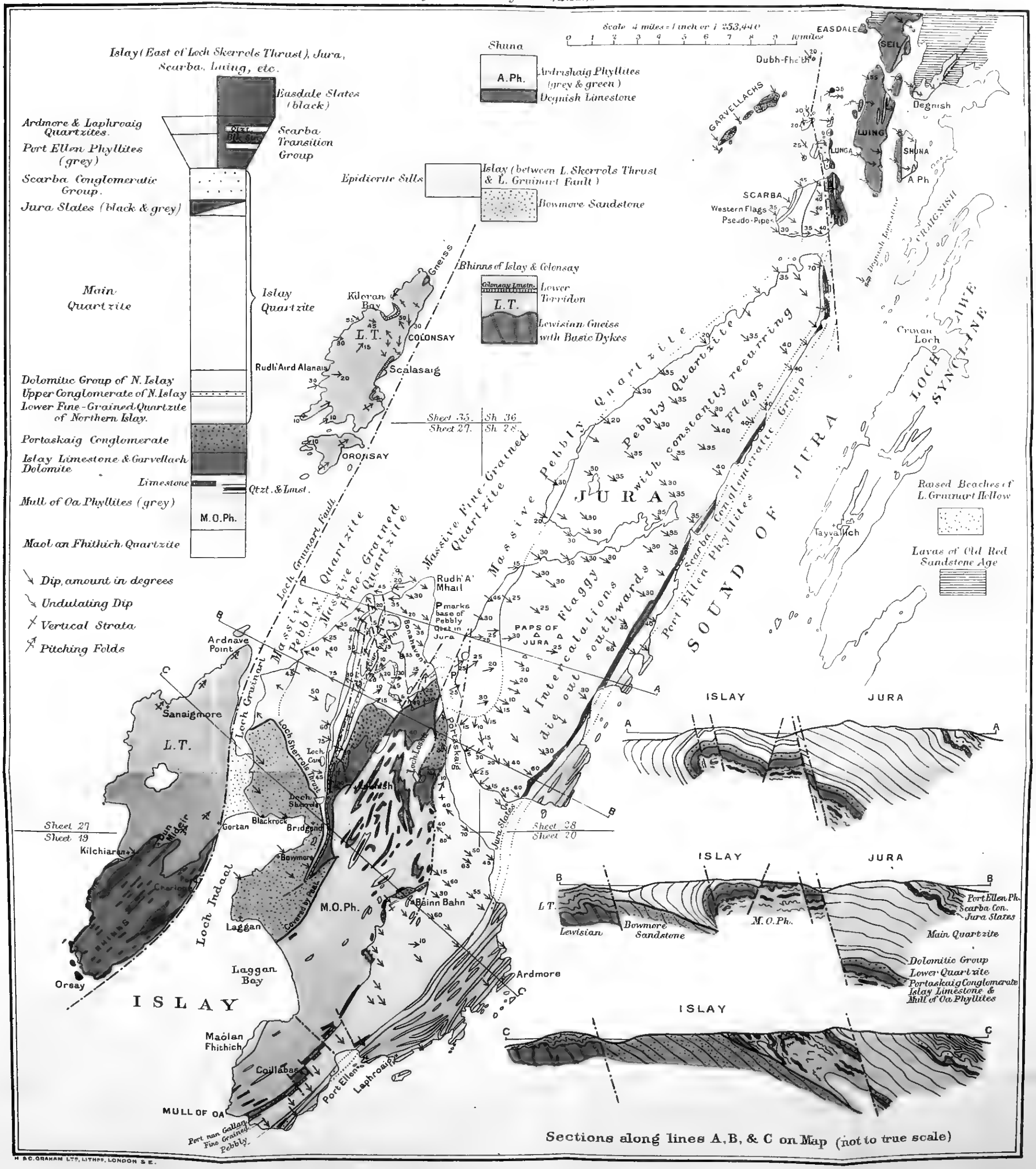


not to true scale)

GEOLOGICAL MAP OF ISLAY, JURA, etc.

(based, with minor modifications, upon Sheets 19, 20, 27, 28, 35, & 36 of the 1-inch Geological Survey Map of Scotland),

by E. B. Bailey, M.C., B.A., F.G.S.



H. & C. GRAHAM LTD, LITHRS, LONDON S.E.

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2. R. I. Murchison & A. Geikie.—'On the Altered Rocks of the Western Islands of Scotland & the North-Western & Central Highlands' Q. J. G. S. vol. xvii (1861) p. 171.
3. J. Thomson.—'On the Geology of the Island of Islay' Trans. Geol. Soc. Glasgow, vol. v (1873–76) 1875, p. 200 (a short account was communicated to the British Association in 1871).
4. One-Inch Geological Survey Map of Scotland, Sheet 20,[1] 1896.
5. One-Inch Geological Survey Map of Scotland, Sheet 19, 1898.
6. One-Inch Geological Survey Map of Scotland, Sheet 27, 1900.
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8. W. B. Wright.—'The Two Earth-Movements of Colonsay' Q. J. G. S. vol. lxiv (1908) p. 297.
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12. 'The Geology of Knapdale, Jura, & North Kintyre (Explanation of Sheet 28 with parts of 27 & 29)' Mem. Geol. Surv. Scotland, 1911.
13. One-Inch Geological Survey Map of Scotland, Sheet 35, 1911.
14. 'The Geology of Colonsay & Oronsay, with Part of the Ross of Mull (Explanation of Sheet 35 with part of 27)' Mem. Geol. Surv. Scotland, 1911.

The authorship of the above-mentioned Geological Survey publications—so far as it concerns the subject of the present paper—is, in the main, as follows:—4, 5, and 6: S. B. Wilkinson. 7: B. N. Peach & S. B. Wilkinson. 9: S. B. Wilkinson (Jura) & B. N. Peach (northern end of Jura, Scarba, etc.). 10: B. N. Peach. 11: S. B. Wilkinson. 12: E. B. Bailey. 13 and 14: W. B. Wright & E. B. Bailey.

EXPLANATION OF PLATE XII.

Geological map of Islay, Jura, etc. on the scale of 4 miles to the inch, or 1:253,440; with sections across those islands (not to true scale).

[*For* 'Beinn Bahn', *read* 'Beinn Bhan'; *for* 'Coillabas' *read* 'Coillabus'; *for* 'Dubh-Fheth' *read* 'Dubh-fheith.']

Discussion.

Mr. G. Barrow drew attention to the wide range of the Author's observations; with regard to the Moine Thrust, its position on the published maps rendered its occurrence close to Islay impossible. He agreed with the Author that there was a great break between the main part of Islay and the western and almost detached part. But, although there might be a fault as well, the changes seen in the condition of the strata as regards crystallization were due mainly to the thrust that passed along the Great Glen of the Caledonian Canal and continued through the Islay area. As in the case of the Moine Thrust, little-altered or non-crystalline rocks on the south-east side of the Thrust were driven over or on to rocks that are highly crystalline. Referring to his paper published by the Geologists' Association, and accompanied by a map in which the Highland

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[1] The corners of these Sheets are shown on Pl. XII.

rocks are shown to be divisible into zones of increasing and decreasing thermal alteration, the speaker pointed out that the thrust drives the outer zone, in which there is no crystallization, on to a zone of high alteration; the absence of crystallization in a considerable part of the Highland rocks of Islay is thus no proof at all of newer age—it is natural to the thermal zone, to which they belong. The limestone is so little altered, that its original oolitic structure is locally preserved despite its great age.

He agreed with the Author that the rocks in Western Islay were of Lewisian age; but, in addition, they were part of the Highland rocks, or the series of sediments of which the Moine Gneisses formed a part, and had the more common strike of the Highland folding, north-east and south-west.

The speaker complained of the introduction by the Author of new names for rocks which had long-established names. Thus, in the south-east of the island the 'Port Ellen Phyllite' has long been known to be the 'Ardrishaig Phyllite' or 'Canlochan Schist.' This band of shale is known to continue across Scotland, and emerges on the coast to the south-east of the Portsoy Quartzite. It is more of a true shale in the latter area, and contains thinner if not fewer sandstone-bands than in Islay. Similarly, the quartzite is the well-known Highland Quartzite, which again crosses the country to Portsoy; it is also finer and thinner at Portsoy, thicker and coarser in Islay.

Again, the limestone is the Blair Athol Limestone, which also occurs on both coasts; the course of it and the Quartzite are fairly well shown on the most recent edition of Sir Archibald Geikie's 10-mile to the inch geological map of Scotland. The limestone in Islay also is affected by changing conditions; while the associated dark schist is, for the greater part, more sandy and lighter-coloured than in areas to the north-east.

With regard to the stratigraphy of the area, it is known that the side of the Quartzite on which the limestone occurs is the opposite to that on which the Ardrishaig Phyllite (Port Ellen) occurs. This was proved many years ago, although the evidence has never been published. Inspection of the map already mentioned will show that the Blair Athol Limestone crops out, more or less continuously, for many miles on the north-west side of the first outcrop of the Quartzite. On the south-east side of it another persistent outcrop occurs, of the limestone known as the Loch Tay or Pitlochry Limestone. For many years these were thought to be the same limestone; but, after a short period of mapping, the speaker found that this could not be the case, and, after a considerable 'argument,' Sir Archibald Geikie was satisfied that the new view was correct, and that they were stratigraphically on opposite sides of the Quartzite. There was no question of their not being different limestones—that was settled; it then became incredible that there could be these two limestones continuing for miles, each confined to one side only of the Quartzite, without their being stratigraphically on opposite sides of that rock. These results were embodied in Sir Archibald's Presidential Address to the Geological

Society in 1891. No one has since questioned the fact of their being separate limestones, and it is doubtful whether there is now a single modern official Survey publication in which the Loch Tay Limestone is not taken to be below the Quartzite. Had these facts been published at the time, the remarkable discussion about the Quartzite being at the top of the Series could not have taken place—it is an obvious absurdity.

Thus on the eastern side of Islay the top and the base of the Quartzite occur: the latter (as usual) is the coarser, the top being finer, often very fine and often remarkably white; this fine margin occurs on the side next the Blair Athol Limestone, and there must be in the Highlands altogether many hundred outcrops of this white margin, though, except by the speaker, they are rarely if ever mentioned. The usual erosion occurs below the limestone, and, being in a folded area, it causes the outcrop of the bed to approach and recede from the margin of the Quartzite in the usual characteristic manner seen on most modern maps. When the limestone is followed round, it is seen that the Quartzite is all one quartzite; and this is confirmed by the frequent occurrence of the typical white margin in the area some distance west of Loch Finlaggan. It is now seen that the Boulder Bed (Portaskaig Conglomerate) of this area has exactly the same relations with the limestone and quartzite as at Schiehallion, placing the identity of the various beds beyond serious doubt; the limestone is the Blair Athol Limestone. (The speaker here placed on the table the Geological Survey 1-inch maps, Sheets 27 & 55, so that the Fellows might satisfy themselves as to this identity.)

In view of what has been stated, the theory advanced by the Author that the ground between the two outcrops of quartzite is an anticline seems impossible: if, as shown, the limestone is above the fine margin of the Quartzite, it must be a tilted syncline, the structure being identical with that at Portsoy in the East of Scotland. The white margin is well seen on the ground, where the so-called 'Fucoid Beds' are shown to terminate on the map; the speaker found no trace of Fucoid Beds at the places indicated. The statement that the Author disagreed with the view that the Portaskaig Conglomerate was not the Scarba Conglomerate is not well put: the ground was mapped by Mr. Wilkinson, who held no such view, but his opinion was ignored; further, Mr. Wilkinson had no doubt that the two conglomerates are on opposite sides of the Quartzite, but he doubted whether the side on which the limestone occurs was the top.

Turning now to the sandstone south-west of the so-called 'Loch Skerrols Thrust,' the speaker thought these crucially important; he doubted the existence of the thrust at all, and believed that these sandstones are brought on by pitching of the folded Quartzite, and that small patches cross the so-called thrust and are infolded with the margin of the Quartzite. These beds, as also their relation to the limestone and Quartzite, are better seen in the Bowmore area. One now sees that these sandstones have the persistent flaggy habit and the curious persistent dip in one direction, due to singularly perfect isoclinal folding, that characterize the Moine Gneisses; from a study of the maps, the speaker felt that there was a possibility of the original rocks, from which the more massive types of felspathic Moine Gneiss were formed, being found in this part of Islay, and this was the cause of his visit to the area. He had now little doubt that these sandstones are the rocks in question. They are practically free from any trace of crystallization, present all the characters that the unaltered representatives of the Moine Gneiss should possess, and the Bowmore area shows that they are on the fine margin of the Quartzite and, so far as the folding will allow us to see, they are between the limestone and the Quartzite: that is, they are in the position assigned to them in the speaker's paper published by the Society. Far from being of any great thickness, they were probably quite a thin group originally. Islay is thus one of the most encouraging areas in the Highlands for further examination, and is worth mapping with the minutest detail.

Dr. B. N. Peach, in the following written communication to the Secretary, stated that, while making criticisms, he would wish at the same time to state that he considered the view put forth by the Author—that the dolomitic 'Fucoid'-like beds are not the highest rocks in the Islay succession, as held by the Geological Survey, but are in turn overlain by the main quartzite, the Jura Slates, the Scarba Conglomerate, and Port Ellen Phyllites, in upward sequence—to be worthy of the closest consideration, although he felt that the Author had not brought forward sufficient evidence to establish thoroughly his contention. If this could be done, many difficulties left unsolved by the Geological Survey would be cleared up:—

'The important feature in the paper is the evidence which the Author adduces to prove a further extension of the anticlinal arrangement of the strata in Islay, east of the Loch Skerrols Thrust. This structure, in a modified form, was previously recognized by the Geological Survey. In the Memoir on 'The Geology of Islay,' it was shown that the Islay limestones, black slates, and phyllites form the core of a compound anticline extending from the Mull of Oa north-eastwards to Kiels, near Portaskaig. It was also pointed out that, between Loch Finlaggan and Port a' Chotain in Northern Islay, the strata, including five subzones, ranging from the Portaskaig Conglomerate up to the Fucoidal Beds with massive bands of dolomite, are arranged in a compound arch.

'In his paper the Author contends that the dolomitic group, which resembles the Fucoid Beds of Cambrian age in Sutherland and Ross, is not the highest member of the sequence in Northern Islay, but is overlain by an upper quartzite on the eastern and western limbs of the compound arch. On the eastern limb this upper quartzite runs from Rudh a' Mhail to Bonahaven, on the western limb from Rudh a' Bholsa to Loch Skerrols in the south. He also holds that there is an ascending sequence from his upper or main quartzite of Islay, Jura, and Scarba, to the black slates of Scarba, Lunga, and Easdale.

'I submit the following criticisms on these opinions:—

'1. In proof of the superposition of the upper or main quartzite on the east limb of the compound arch in Northern Islay, the Author states that, west of Rudh a' Mhail, the dolomitic group appears as an inlier with gentle anticlinal dips passing below the upper quartzite of Rudh a' Mhail and Port a' Chotain. In my opinion, the evidence shows that the dolomitic group does not there form an inlier, and that the Port a' Chotain quartzite underlies the dolomitic group. The horizon of the latter quartzite is proved by the occurrence in it on its west side, of the characteristic band of conglomerate containing granitoid pebbles near the top of that zone. The fault separating the Port a' Chotain quartzite from the dolomitic beds on the west does not affect this reasoning. If there is an upward succession from the dolomitic group into the main quartzite from this supposed inlier, it can only be found on its eastern margin, where the dolomitic group with a south-eastward dip is exposed on the beach followed by the quartzites of Rudh a' Mhail. But here the dolomitic beds and the quartzites are traversed by shear-lines, showing that the original relation has been disturbed by movement.

'The evidence at the western margin of the dolomitic group of an upward passage into the quartzites of Rudh a' Bholsa on the western limb of the compound arch is also unsatisfactory—because near the margin of the quartzite the section is interrupted by a fault forming a wide shatter-belt. East of this fault, pebbly quartzites occur for a few yards in contact with the dolomitic group; but, in my opinion, these pebbly quartzites may represent the boulder-bed near the top of the lower quartzite.

'As regards the Author's statement that the Islay Anticline is apparent from the dips in his main quartzite-belts, too much reliance ought not to be placed on this line of evidence in so highly folded a region. In his own map and sections he is obliged to invoke inversions of the strata north of Loch Skerrols, where his so-called 'main (upper) quartzites' dip south-eastwards as if passing, in normal sequence, below the dolomitic group!

'2. According to the Author's hypothesis, his main quartzite is overlain by the Jura black slates, and these in turn by the Scarba Conglomerate Group in Islay, Jura, Scarba, and Lunga. If there is a succession upwards from the main quartzite in Islay and Jura, it does not extend into Scarba. For, in Scarba and Lunga, the Scarba Conglomerate contains large masses of the black slates, limestones, and pebbly grits lying to the east of it. If the black slates of Scarba and Lunga belong to the Luing and Easdale black-slate group, there can be no upward succession from the Scarba quartzite into the Easdale black slates.

'3. The Author states that black slates do not occur in the island of Shuna, between the Craignish phyllites and the Shuna limestone. Black slates occupying this position were officially mapped by him at the southern end of the island, though now repudiated by him. In my opinion, black slates occupying this position occur not only at the southern end of the island, but in the middle and at the northern end, where they were formerly wrought.

'4. In the quartzite-belt north of Loch Skerrols, and in the belt between Port nan Gallan and the Sound of Islay, the lower and upper (or main) quartzites are represented in his map and sections as coming together, without the intercalation of the dolomitic group. No explanation of this feature is given by the Author.

'5. As regards the Maol an Fhithich Quartzite, which is supposed by the Author to underlie the Mull of Oa Phyllites, I think that his conclusion is erroneous: for the junction, where exposed at the northern end, is certainly a line of fault. In my opinion, it is merely a faulted portion of the same quartzite as that which overlies the Loch Skerrols Thrust, north of Bridgend.

'6. The Author refers to the Bowmore Sandstones south-east of Loch in Daal as a fine-grained series, but in that very area there are marked pebbly bands to which reference is made in the Islay Memoir (p. 27).

'7. The occurrence of Bowmore grits and sandstones west of Loch in Daal has been questioned by the Author. These grits are to be found on the shore near Gortan schoolhouse, 1 mile north of Bruichladdich, where they show the same stage of deformation as the other rocks of the Rhinns, facts which have an important bearing on the position of his supposed Loch Gruinart Fault.

'8. Regarding the Author's suggestion that the Loch Skerrols Thrust may represent the Moine Thrust of the North-West Highlands, I wish to call attention to the fact that the rocks above and below this line of disruption in Islay are in the same low grade of metamorphism—a feature quite unknown in any region where the Moine Thrust has been mapped.

'Dr. Clough's view that the Lewisian gneiss and unaltered Torridonian rocks of Iona are separated from the highly crystalline Moine Schists of the Ross of Mull by the Moine Thrust is quite in accordance with the phenomena connected with this line of movement in the north.

'I also agree with Dr. Clough's suggestion that the position of the Great Glen Fault lies between the Ross of Mull and Colonsay, on the ground that the strata on the downthrow side of the fault are in a low grade of metamorphism, compared with the Moine Schists of the Ross of Mull and Morvern, which existed as crystalline schists before the intrusion of the igneous rocks by which they are now traversed.'

The contributions by Mr. Barrow and Dr. Peach were forwarded to the AUTHOR, who sent the following reply:

'I believe that there is good foundation for some of Mr. Barrow's views regarding the equivalence of rock-groups found in Islay and Perthshire respectively. In fact, a comparison was early initiated by Macculloch. On the other hand, I think that Mr. Barrow employs a very dangerous method when he confidently interprets the Islay structure and succession in the light of his Perthshire experience. He comes to the conclusion, for instance, that Central Islay is of synclinal structure, although, in my opinion, it is easy to demonstrate the reverse in the field. He also regards the Islay Limestone as of later date than the Quartzite, although this, too, is contrary to the local evidence.

'I do not think that the complexity of the Highland problem has been sufficiently appreciated in the past. Before a satisfactory general solution is attained, I am convinced that we shall have to accumulate careful field-observations for several years to come.

'The points raised by Dr. Peach are best considered *seriatim*:—

1. I consider the sections along the northern coast of Islay to be quite convincing in regard to structure and succession; and I believe that the descriptions given in my paper will be found to be accurate. In answer to the criticism that I have to invoke inversions north of Loch Skerrols, I should like to point out that this is not a part of the district where one would attempt to decide the anticlinal or synclinal structure of the Islay Fold as a whole. It is on a flank, whereas the northern coast exhibits the axial region.

2. Dr. Peach's second criticism is based upon the claim that the source of certain boulders contained in the Scarba Conglomerate in Scarba and Lunga can be identified on the local evidence. As a first suggestion, I think Dr. Peach's interpretation of Scarba excellent; but, in the light of the fuller evidence afforded by Jura and Islay, I am convinced that it now needs modification.

3. I mapped black slates as occurring in Shuna when I accompanied Dr. Peach to that island within a few months of my joining the Geological Survey. Dr. Peach at the time told me that a particular belt consisted of "bleached black slate." Since then I have revisited Shuna, and compared the rocks in question with such small areas of bleached black slate as are sometimes found immediately adjacent to outliers of Old Red Sandstone farther north, and am convinced that a mistake was made.

4. The reason why a detailed explanation is not given, is that it is impossible to decide between the various alternatives that are available.

5. The evidence upon which my conclusion is based is given in my paper.

6. All along the Bowmore shore the sandstone is thoroughly fine-grained, as stated in my paper.

7. It is not denied in my paper that the Bowmore Sandstone may have been rightly identified on the shore near Gortan schoolhouse. The discussion of the evidence for the Loch Gruinart Fault explicitly includes this possibility.

8. The absence of highly crystalline schists immediately above the Loch Skerrols Thrust is emphasized in my paper, and is taken into account in considering the possible equivalence of the Loch Skerrols and Moine Thrusts.'

[September 10th, 1917.]

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Vol. LXXII.
Part 3.

No. 287.

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE PERMANENT SECRETARY.

[**With Nine Plates, illustrating Papers by Dr. W. R. Jones, Prof. S. J. Shand, and Dr. A. Holmes.**]

November 23rd, 1917.

LONDON:

LONGMANS, GREEN, AND CO.

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SESSION 1917–1918.

	1917.	
Wednesday	December	5—19*
	1918.	
,,	January	9*—23*
,,	February (*Anniversary,* Friday, February 15th)	6*—20*
,,	March	6—20*
,,	April	17*
,,	May	1—15*
,,	June	5—19*

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

9. *The* ORIGIN *of the* SECONDARY STANNIFEROUS DEPOSITS *of the* KINTA DISTRICT, PERAK (FEDERATED MALAY STATES).

By WILLIAM RICHARD JONES, D.I.C., D.Sc.(Lond)., F.G.S., A.I.M.M., Late Assistant & Acting Government Geologist to the F.M.S.

(Read June 23rd, 1915.)

[PLATES XIII–XV.]

CONTENTS.

I. INTRODUCTION.

IN September 1910, Mr. J. B. Scrivenor, Government Geologist to the Federated Malay States, described certain deposits (the Gopeng Beds) in the Kinta district as being 'the remains of a very ancient tin-field that formed part of Gondwanaland,' and as having been transported by glaciers or sheets of floating ice.[1] This theory of their origin has also been maintained by its author in later publications,[2] and in an article in the 'Geological Magazine' for July 1914, p. 309, he states that the Glacial theory 'best explains the facts in the field.'

The presence in these 'clays and boulder-clays' of rich deposits of tin-ore, the bulk of which, according to Mr. Scrivenor,[3] is derived from Gondwanaland, gives very great economic importance to the question of their origin; and its importance from a scientific point of view becomes immediately apparent when it is realized that these clays are stated to have furnished 'a more valuable horizon on climatic evidence than can be afforded by limited

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[1] 'Report on Prospecting Work at Gopeng by the Government Geologist, No. 13' Kuala Lumpur, 1910, p. 3.

[2] 'Geology & Mining Industry of the Kinta District, Perak (Federated Malay States)' Kuala Lumpur, 1913, pp. 27–46 & map; see also 'The Geology & Mining Industries of Ulu Pahang' Kuala Lumpur, 1911, pp. 49 & map.

[3] 'Geology & Mining Industry of the Kinta District' 1913, p. 35.

collections of fossils in rocks far removed from Europe'[1]; that they have been correlated with the Talchir Beds of India; and have been used as the horizon on which to base the geological age of rocks that cover over a quarter of the surface of the Malay Peninsula.[2] If they are of glacial origin and of the same age as the Talchir rocks they should extend under the 'younger Gondwana rocks' mapped by Mr. Scrivenor, and consequently other extensive tin-fields would remain to be discovered in the Malay Peninsula.

The object of the present paper is to show that all the tin-ore found in the 'clays and boulder-clays' of the Kinta Valley has been derived from rocks now *in situ* in the Kinta district; that it is unnecessary to bring in glacial agency to explain any of the features which led Mr. Scrivenor to adopt that theory of their origin; to point out that these deposits cannot be considered of the same age as the Talchir Beds of India; and to show that a simple interpretation may be given to the geological phenomena of the Kinta district.

Evidence will be advanced to show that these 'clays and boulder-clays' are in some places alluvial deposits and in others the result of weathering *in situ* of phyllites and schists, which have afterwards either subsided on the dissolving metamorphosed limestone that everywhere has been proved to underlie them, or slipped down the valley sides. It will be shown that the richest tin-ore deposits occur, without exception, near to granite or to granitic intrusions proved to be cassiterite-bearing, and that the deposits farthest from these igneous intrusions contain no tin-ore. All the features which led to the adoption of the glacial theory of the origin of these deposits will be shown to be the results of intense weathering in a moist tropical climate, such as have been described in other tropical countries.

All the types of rock and mineral present in the supposed 'glacial clays' have been proved *in situ* in the older rocks of the district; and, in the case of the tin-ore, these sources will be shown to be sufficient to account for all the ore in these clays.

II. General Description of the Kinta District.

The Kinta District is in the centre of the State of Perak, and is bounded on the east by that part of the watershed of the Main Range which lies between Gunong Kerbau (7160 feet above sea-level) on the north-east and Gunong Pergantong (4740 feet) on the south-east. On the west the Kledang Range forms the boundary, except between Siputeh and Tronoh where the range disappears. The northern boundary is the rising ground north of Chemor, and the southern boundary extends westwards from

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[1] 'The Geological History of the Malay Peninsula' Q. J. G. S. vol. lxix (1913) p. 353.

[2] *Ibid.* p. 370 & pl. xxxv.

Gunong Kinjang (4780 feet) to the Sungei Tumboh, as shown on the accompanying map (Pl. XV).

The chief river of the district, the Sungei Kinta, flows practically along the whole length of this part of the country, from north to south, and is joined on the north-west by a small stream, the Sungei Pari. On its left bank it receives, as tributaries, the Sungei Raia, the Sungei Kampar, and two or three other small streams.

The granite of the Main Range on the east occupies roughly half of the entire area, and on the west the granite of the Kledang Range covers a stretch of country about 25 miles long and, on an average, well over 2 miles wide.[1] It is evident, therefore, that a considerable part of the district is occupied by granite. The granite of the Main Range, as will be pointed out later, is known to be stanniferous in a very large number of places; while that of the Kledang Range has proved, especially at Menglembu and Chendai, where it has been extensively crushed, to be highly stanniferous.

The floor of the Kinta Valley, as the low-lying part of this district may be called, has been shown, in a very large number of opencast tin-mines, to consist of a metamorphosed limestone with a very irregular surface.

Where the feature formed by the granite of the Kledang Range disappears in the southern part of the valley, granitic intrusions in the limestone are common—for example, between Siputeh and Tronoh, between Tronoh and Kamuning Jawa, and farther south at Tanjong Toh Allang. Intrusive veins of pegmatite, aplite, and quartz traverse the limestone, and frequently carry tin-ore; masses of granite, forming distinct features, are also known: these are shown on the accompanying geological map (Pl. XV).

Between Lahat and Papan the granite is in contact with schists and phyllites: these latter rocks, as will be shown, prove to be veined with granitic intrusions carrying tin-ore, and are almost certainly connected with the granite of the Kledang Range. On the east at Tekka, Ulu Gopeng, Tanjong Rambutan, and other places, the decomposed schists contain cassiterite-bearing granitic intrusions; and the rocks near the granite-junction, in numerous other cases in the Kinta district, have been worked for tin-ore occurring in them as stockworks.

With the exception of a few patches in the caves in the limestone cliffs, to which reference will be made later, and those of the foothills and granite ranges, the tin-ore deposits of the Kinta district are found in the valley between the two ranges. In the north this valley (the Kinta Valley) is only about 6 miles wide, but it opens out southwards until it becomes twice that width between Pusing and Gopeng. It is a flat-bottomed valley with steep eastern

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[1] J. B. Scrivenor, 'The Geology & Mining Industry of the Kinta District' 1913: see sketch-map at the end, and also the map accompanying this paper (Pl. XV).

and western boundaries,[1] and there is a very small gradual rise from south to north.

West of the Kinta River, from near Lahat to Tanjong Toh Allang, a distance of more than 12 miles, there is, however, a stretch of undulating ground at a higher level than the rest of the valley and skirted by the road from Tanjong Toh Allang to Batu Gajah, being cut through by it at Rotan Dahan, between Batu Gajah and Pusing Lama. Exposures of the rock composing this stretch of ground may be seen at Kacha, Rotan Dahan, in numerous places at Batu Gajah, and it forms the bed-rock in the small watercourses on the Harewood and Kinta Valley Estates.

At Kacha the rock is a decomposed mica-schist, dark blue in places. The schist preserves its foliation, and contains granitic intrusions carrying tin-ore. Tourmaline-corundum rocks are found here *in situ*, and small kaolin-veins are common. Pits have been sunk in the schist, and small leaders, carrying tin-ore, have been followed. Two such pits reached a kaolin-vein in which the kaolin was perfectly white, and had all the characters of a kaolin-vein *in situ*. The dark-blue clay in a mine at the foot of Kacha Hill can be traced from a typical soft structureless clay, through clay exhibiting traces of foliation, to partly-decomposed phyllites and schists showing distinct foliation-planes.

At Red Hills, which forms a distinct feature in the Kinta Valley, on account of the rising ground and the dark-red colour of its numerous cuttings, the phyllites exposed in parts are dark blue; but in many localities the disseminated pyrite has been oxidized, and the rock is heavily ferruginized. Granitic intrusions are numerous, and these have been found in places to carry workable amounts of cassiterite. Parts of the phyllites are barren of tin-ore. Tourmaline-corundum rocks are numerous, and are found here *in situ*.

This feature is continued into that part of Rotan Dahan which lies on the north side of the road from Batu Gajah to Pusing; and south of the road it has been cut through by the drainage-system of the valley.

Numerous exposures of the phyllites and indurated shales which form this high ground may be seen on the eastern flanks at Batu Gajah, on the Harewood and Kinta Valley Estates; and a very good exposure showing the high angle of the foliation-planes may be seen along the bridle-path from Batu Gajah to Siputeh, near the Batu Gajah end. The more shaly parts are jet-black, and have been mistaken by some observers for coal; these are well exposed in the drains running through the cocoanut plantation below the Batu Gajah Club.

Separated from this stretch of high ground by the Kinta River are two other prominent masses, one on each side of the Sungei Raia. The northern area contains the Pinji and the Sengat Rubber Estates, and the southern the Kellas Estate. The two

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[1] See the accompanying section across the Kinta District (Pl. XV).

masses are composed of phyllites, indurated shales, and some quartzite bands, and in places bear great resemblance to the area previously described.

Standing out in isolated grandeur above the general level of the valley, and forming very striking natural features, are numerous limestone cliffs with bare light-coloured faces which immediately arrest attention. They are most numerous in the north-western part of the valley, but the biggest mass of all is half way between Gopeng and Kampar; it is more than 4 miles long.

As previously noted, the bed-rock underlying the tin-ore deposits has proved, in a large number of mines in various parts of the valley, to be a metamorphosed limestone, and to have a very irregular surface. It is the custom in Malaya to refer to the prominences in this irregular floor as pinnacles, and to the masses standing above the level of the valley as cliffs or hills. That nomenclature will be followed in this paper.

III. Geological History of the Kinta Valley.

Fossils are practically absent in the metamorphosed limestone of this valley; but at Changkat Pari, near Ipoh, Mr. Scrivenor[1] found great numbers of what were 'probably once crinoid-stems and other organisms.' These, however, proved to have 'no homotaxial value.' On the other side of the Main Ridge he found 'the same limestone, but less altered and containing recognizable fossils.' These having been examined, Mr. Scrivenor arrived at the conclusion that the most that could be said was that the limestone was Carboniferous, and that it was the oldest rock known *in situ* in the Federated Malay States.

Lying immediately upon the metamorphosed limestone are the so-called 'Gondwana Rocks,' and above them are the recent deposits.

The granite of the Main Range on the east of the Kinta Valley, of the Kledang Range on the west, and of the neighbouring outcrops, is a pale porphyritic granite of an acid type. It contains tourmaline and muscovite in abundance, and frequently carries tin-ore. From the petrological, mineralogical, and geological points of view the granite in all the outcrops of the Kinta Valley seems to be of the same age, which must be later than that of the limestone that has been metamorphosed by it. For several reasons Mr. Scrivenor has come to the conclusion that it is a Mesozoic granite and probably Cretaceous.

Taking the limestone, then, as Carboniferous or Permo-Carboniferous, and the granite as Mesozoic, we have the following sequence in the Kinta district:—

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[1] J. B. Scrivenor, 'The Geology & Mining Industry of the Kinta District' 1913, p. 22.

According to Mr. Scrivenor.	According to the present writer.
4. Lignites and recent deposits.	4. Alluvial deposits derived from (2) and (3), and containing lignite, peat, and tin-ore.
3. Mesozoic granite, probably Cretaceous.	3. Granite. Age not definitely determined.[1]
2. Gondwana Rocks: (Older than the granite). Younger { Schists, phyllites, quartzites, and shales. (Metamorphosed by the granite) Older { Clays and boulder-clays correlated with the Talchirs of India. These latter contain tin-ore, 'the bulk of which is derived from some mass of tin-bearing granite and rocks altered by it, but distinct from and older than the Mesozoic granite.'	2. Schists, phyllites, quartzites, and indurated shales metamorphosed by the granite of the Main Range and of the Kledang Range, and containing in places, notably near the granite junctions, granitic intrusions with tin-ore *in situ*. These rocks have subsequently suffered in places decomposition to considerable depths.
1. Carboniferous Limestone metamorphosed by Mesozoic granite.	1. Limestone. Carboniferous to Permo-Carboniferous, metamorphosed by the above granite.

The main question on which I disagree with Mr. Scrivenor is that of the original source of the 'clays and boulder-clays,' and of the tin-ore which they contain. He includes these in his Gondwana Rocks, whereas I class them as alluvial deposits.

Mr. Scrivenor is of opinion that some of the tin-ore is derived from the granite and granitic intrusions now *in situ* in the district, and that certain rich patches in the 'clays and boulder-clays' have received 'secondary enrichments' from these intrusions; but he believes that the bulk of the tin-ore in his 'Gondwana Rocks' is derived 'from an ancient tin-field quite unconnected with the granite now *in situ* in the district.' In other words, the Kinta district is stated to have furnished the remarkable phenomenon of two tin-fields, one superimposed on the other, the latter being of Permo-Carboniferous age, and the former of a much later geological age.

Limestone cliffs.—It is very important, in dealing with the geological history of the Kinta district, to understand how the limestone cliffs which stand well above the general level of the valley have been formed. If it can be shown, as I endeavour

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[1] I consider that there is strong evidence in favour of the view that the granite of the Main Range of the Federated Malay States is a prolongation southwards of that of Burma and Siam, and that it extends, with some breaks, through Johore to Banka and Billiton. That of Burma is known to extend across the borders of China, and in these areas it is, like that of Malaya, of a very acid type and cassiterite-bearing. Further investigation may show that this part of the world is occupied by some of the largest masses of granite, intruded at the same period, on the earth's surface, and that the igneous activity resulting in the intrusion of this granite determined the subsequent main structure-lines of that part of the Far East.

to do, that they are the result of simple denudation of a strongly-jointed limestone, then the position of most of the tin-ore deposits at the foot of these cliffs, and resting on the weathered surface of the limestone, makes it impossible for them to be as old as the neighbouring granite ranges which form the sources of the streams that denuded the limestone. The greater part of the deposits are obviously of alluvial origin, and any doubt on that point is settled by the fact that the beds of the streams which carried them to their position are still being worked, in numerous cases, for tin-ore on the slopes of the hills and mountains directly overlooking the positions of these deposits. The streams, after reaching the valleys, are frequently deviated in order that their beds may be washed for tin-ore, and quite recently a great scheme was propounded to work the bed of the Kinta River itself.

Some of the tin-ore deposits near the foot of these limestone hills are not, however, alluvial in the sense of having been transported by running water, but are the result of the weathering *in situ* of phyllites and schists, which afterwards subsided on the dissolving metamorphosed limestone that has everywhere been proved to underlie them at small depths. It was the failure to appreciate the effect of the extensive weathering of these rocks in a moist tropical climate, where the water flows for some miles over decomposed granite, and is hence rich in alkalies, that seems to have misled Mr. Scrivenor. He recognized, however, that the position of these deposits at the foot of the cliffs was difficult to reconcile with their Permo-Carboniferous age. He states that 'simple denudation alone might account for them (the limestone hills) if we were to regard the beds overlying the limestone floor at the base of the cliffs as being recent alluvium'[1]; but concludes that they 'owe their origin primarily to faulting,' and that the main fracture that brought about their formation coincides with the junction between the granite and the older rocks. No reason is given for the absence of similar hills on the west side of the valley, although the junction between the granite and the limestone there has also been described[2] as a fault-junction.

These limestone hills are very irregular in plan, and, in a diagram[3] in his memoir on the Kinta district, Mr. Scrivenor has reduced them to their simplest forms, in order to show the directions of the faults which formed them. The least possible number of faults is sixteen, and these show fault-planes in twelve different directions. In order to form isolated hills like these by faulting, the movement round each particular hill must have been simultaneous, and so as to explain this it is stated that they are 'huge blocks of the crust that sank on to the granite magma relatively less than the surrounding rocks when the Main Range anticline broke up.'[4] If this sinking movement occurred, then it is reasonable to conclude that the amount by which the limestone floor of the valley sank

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[1] 'The Geology & Mining Industry of the Kinta District' 1913, p. 14.

[2] *Ibid.* p. 18.

[3] *Ibid.* facing p. 16.

[4] *Ibid.* p. 18.

into the granite, relatively less than the isolated hills, would be equal to the present height of these hills above the general level of the valley-floor, which is formed of the same limestone. Two of these hills are well over 1500 feet above the limestone floor, so that it must be presumed that the valley sank into the granite magma at least that much more than did the limestone constituting these hills. No reason is given why the limestone floor of the valley should sink into the granite magma, and leave these limestone-hills as isolated heights.

That a granite magma is able to incorporate huge blocks of limestone, several hundreds of feet thick, over an extensive area is a highly controversial postulate; but, where no evidence is given of the presence of large quantities of calcic minerals in the granite, even in the neighbourhood of the limestone, the explanation cannot be considered satisfactory. Moreover, the presence here of numerous big veins of pegmatite, aplite, and quartz, which represent the later phase of the granite intrusion, seems to show that the residual magma had not incorporated great masses of limestone.[1] This interesting question of magmatic stoping need not, however, be further discussed here.

Most of these hills are on the east side of the Kinta Valley, and there is not a single limestone hill on the west side. It is a very significant fact that, practically without exception, these hills lie between two or more rivers or streams, and that there is an intimate relationship between the position and form of these hills and the drainage-system of the valley. Taking the masses from north to south, we note the following sequence :—

(*a*) Gunong Kantang (1087 feet) is between a tributary of the Sungei Pari and Sungei Kantang. [‘Sungei’ is Malay for ‘river’ or ‘stream.’]

(*b*) Gunong Kuang is between Sungei Kuang and Sungei Kantang.

(*c*) The cliffs north of Ipoh (Gunong Lang, Gunong Tungun, Gunong Santan, and Gunong Tasek) are between Sungei Pari and Sungei Kinta.

(*d*) Gunong Temiang is near the confluence of Sungei Kinta and its tributary Sungei Choh.

(*e*) The cliffs east of Ipoh are between Sungei Choh, Sungei Ulu Piah, and Sungei Kinta.

(*f*) The Gunong Lanno mass, near Pulai, is between Sungei Raia and Sungei Tekka.

(*g*) The largest mass of all, including Gunong Gajah, Gunong Nasi, and Gunong Tempurong north-east of Kuala Depang, is between Sungei Kampar, Sungei Depang, and Sungei Siput.

On the west side, where the watershed of the Kledang Range is only from 3 to 4 miles from the valley-floor, there is but one stream, the Sungei Jahan, and this is a very small one. The absence of limestone cliffs and of streams on this side of the valley,

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[1] J. J. Sederholm, C. R. Congrès Géol. Intern., 12ème Sess. (Toronto, 1913) 1914, p. 319; and J. P. Iddings, ‘The Problem of Vulcanism’ Yale University Press, 1914, pp. 200, 201.

and the presence of both on the east side, is not a mere coincidence. The rivers flowing over the beds which once covered the limestone formed definite courses before cutting down to the latter, and these courses they continued to keep and to deepen after reaching the limestone, eroding it in their beds and leaving it on their banks protected by the deposits which still, in places, cap the limestone. It seems reasonable to assume that on the east the limestone reached a higher level than on the west of the valley, for the effect of the granite of the Kledang Range on the west, in forming an anticline, would be considerably less pronounced than that of the enormous igneous mass forming the Main Range and reaching twice the height of the Kledang Range. The presence of metamorphosed limestone flanking the Main Range for some considerable height (it very probably once extended over the range in places, and was continuous with the metamorphosed limestone on the other—the Pahang side—of the range) lends strong support to this view.[1]

The evidence on the formation of strikingly similar cliffs in other parts of the Malay Peninsula is very clear. M. De la Croix describes those of the River Tui district in Pahang as being due to denudation, and adds that there is evidence on that side also that the limestone 'has overlain even the top of the Main Dividing Range.' The same writer, in another paper,[2] describes a limestone cliff near Gapis (in Pahang), and compares it with those of the Kinta district as follows:—

> 'Il est fort probable que cet îlot calcaire n'est pas aussi isolé qu'il paraît, et qu'il existe dans son voisinage et en d'autres points de la plaine de Pérak d'autres masses qui ont dû être nivelées par les phénomènes d'erosion et recouverts par les alluvions, ainsi qu'on peut l'observer dans la vallée de Kinta.
>
> 'Ces mêmes caractères se retrouvent dans la vallée de Kinta; au nord à Gunong Jalong et à Gunong Plias' . . .

In the memoir on Ulu Pahang, Mr. Scrivenor states that the limestone cliffs on the east side of the Main Range have been formed by the 'process of denudation acting unequally on masses of strongly jointed and tilted beds of limestone.' A comparison of the photographs of Bukit Goa Sar in that memoir[3] with that of the cliff near New Tambun Mine,[4] in the Kinta district, will show the striking similarity between the cliffs on both sides of the Main Range.

At Batu Caves, near Kuala Lumpur, a fracture-plane is clearly seen to be continuous from one cliff-face into the other. It would be an extraordinary coincidence to find that these two cliffs had been faulted with exactly the same throw. The evidence in

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[1] J. B. Scrivenor, 'The Geology & Mining Industries of Ulu Pahang, Federated Malay States' Kuala Lumpur, 1911, p. 33.

[2] J. E. De la Croix, 'Le Royaume de Pérak' Bull. Soc. Géogr. Paris, ser. 8, vol. iv (1883) pp. 342–48.

[3] 'The Geology & Mining Industries of Ulu Pahang' pl. iv, facing p. 34.

[4] 'The Geology & Mining Industry of the Kinta District' 1913, pl. viii, fig. 2.

that part of Malaya which is on the same side of the Main Range as the Kinta district, that the cliffs are the result of uneven denudation, is particularly clear.

In the Kanching Valley in Ulu Selangor, a valley which is remarkably like that of Kinta in its topography and geological structure and, for its size, quite as rich in tin-ore, two limestone cliffs appear. Like those of Kinta they lie between two streams, and, isolated as they seem from one point of view, they are, nevertheless, part of a ridge that can be clearly seen from Ulu Kanching.

This seems the proper place, before leaving the geological history of the district, to deal with Mr. Scrivenor's contention that the tin-ore deposits at the foot of these cliffs could not have been deposited by the streams because, on account of the recession of the sea, 'for some time back the grade of the rivers has been increasing: *i. e.*, they had farther and farther to fall from source to outlet, which again postulates erosion of the valley-floors.'[1] It seems difficult to understand why a river, the course of which is stated to be lengthening, can, on that account alone, be said to be increasing in erosive power, for the opposite is generally the case. The courses of all the chief rivers in the Malay Peninsula[2] are markedly meandering for several miles from their mouths, and it is impossible to understand how such rivers could in the past have had a lower gradient than they now have. The Kinta River has a fall of only 85 feet from Batu Gajah, in the centre of the Kinta district, to the sea—a distance of about 20 miles. If the Kinta River and its tributaries have never had 'the opportunity of depositing alluvium,'[3] it may be asked by what agency were the thick beds of lignite and sand, described by Mr. Scrivenor as recent alluvium and filling the big limestone-cups, carried to their present position? How also did the alluvium shown covering the whole surface in the diagram on p. 49 of his Kinta Memoir accumulate? It remains to add that the Kinta River and its tributaries have cut deep valleys in the Main Granite Range, and in the past must have removed thousands of feet of the strata which, of course, once covered the granite. With a source thus obviously lowered by thousands of feet, and a bed considerably raised towards its mouth, where a thickness of 150 feet of alluvium was proved in a boring by the Public Works Department, the statement that the grade of the Kinta River is increasing cannot be accepted.

Ordinary denudation in the higher parts of the rivers and deposition of alluvium in the valleys not only appear to explain the presence of the limestone-hills and the clays at their foot, but also offer an immediate explanation of the numerous horizontal grooves

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[1] 'The Geology & Mining Industry of the Kinta District' 1913, p. 18.

[2] W. R. Jones, 'The Geology & Mining Industry of Ulu & Kuala Selangor' now in the hands of the Government Printer, Kuala Lumpur, F.M.S.

[3] J. B. Scrivenor, 'The Geology & Mining Industry of the Kinta District' 1913, p. 49.

on the cliff-faces; of the very irregular outline, not only at their base, but from top to base, of these cliffs; of the sometimes vertical faces (due to joint-planes); of the overhanging faces (due to undercutting); of the frequent gently-sloping faces showing terraces; and of the alluvial tin-ore deposits found in caves in these cliffs at various heights, sometimes hundreds of feet above the valley-floor, and formed in the past by streams flowing from over the stanniferous granite of the Main Range.

IV. Alluvial Origin of the Stanniferous Clays and the 'Boulder Clays.'

The 'Gondwana Rocks' of Kinta are mapped by Mr. Scrivenor under the following headings:—Gopeng Beds, Clays with Tourmaline-Corundum Rocks, Clays with Corundum Boulders, Phyllites and Quartzites, Shales and Quartzite. It is stated, however, that this is not to be taken as their sequence, but as a means of showing the distribution of the beds in various parts of the district.[1] For reasons which will appear later, the phyllites, quartzites, and shales are said to represent the 'younger members of the Gondwana Rocks of the Kinta District, and include mica-schists, tourmaline-schists, shale, and carbonaceous shales.'[2] Now, these schists are near, or at, the granite-junctions, and are frequently veined with granitic intrusions carrying cassiterite. They are being worked for tin-ore, occurring in quartz- and pegmatite-veins and stockworks, at Tanjong Rambutan and Ulu Gopeng on the east; at Lahat, Kacha, Papan, and Tanjong Toh Allang on the west; and at several other places on both sides of the Kinta Valley.

The reason given by Mr. Scrivenor for regarding these rocks as being younger than the 'clays and boulder-clays' is that

> 'the ground immediately above the limestone is composed of the clays and boulder-clays or the remains of them, and the highest ground in the valley, apart from the limestone-hills, is formed of the quartzites, etc.; while there is no evidence of the clays and boulder-clays having been derived from the quartzites and phyllites when the latter formed, as they might have formed, a land-surface.'[3]

The position of these clays and boulder-clays at a lower level than the quartzites and phyllites, and resting on the irregular bed-rock of the valley, is, however, perfectly consistent with the alluvial origin of the greater part of them, the rest being the result of the decomposition *in situ* of the schists and phyllites, which, in places, sank on the underlying dissolving limestone. Evidence will now be adduced to show that all these tin-ore deposits are derived from rocks proved to be *in situ* in the district.

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[1] J. B. Scrivenor, 'The Geology & Mining Industry of the Kinta District' 1913, p. 28.

[2] *Ibid*. p. 44.

[3] *Ibid*. p. 45.

(*a*) Weathering of Phyllites, etc., into Clays.

At Kacha, Tambun, Lahat, and Papan the 'clays and boulder-clays' can be definitely traced in the tin-mines, from a structureless clay through a clay showing traces of foliation, into partly-decomposed phyllites exhibiting distinct foliation, and occasionally containing granitic intrusions which carry cassiterite and tourmaline.

The remarkable rapidity with which rocks weather in tropical countries is well known; but, where the process is helped by heavy evenly-distributed rainfall in a country covered with dense vegetation, it becomes so intense that within a few weeks freshly-exposed surfaces of phyllites and shales are weathered into a soft clay. Where, however, phyllites and schists are heavily veined with silica they become friable, but continue to preserve their structure in places for a long period.

Dr. J. W. Evans, in describing[1] the weathering of crystalline rocks of the Malnād ('rainy area'), west of Mysore, states that they have been converted down to a considerable depth into a reddish or brownish clay-like material, which might be mistaken for a Tertiary or Quaternary formation, were it not that it is traversed occasionally by a quartz-reef which alone resisted the forces of corrosion, and igneous rocks of the Nilgiri Hills are seen to weather into a similar soft material. The same author describes the conversion to a considerable depth of the Palæozoic slates of Bolivia into a deep-red or brown clay.

Van Schelle[2] states that the argillaceous sandstone in the river Bojan (Western Borneo) is weathered into clay to a depth of $8\frac{1}{2}$ feet, and is then indistinguishable in its upper layers from alluvial clay; and Th. Posewitz[3] wrote that

> 'the weathering of the eruptive rocks is also very great, a fact which was impressed upon me during my ascent of the mountain Pararawen in Southern Borneo.'

He found nothing but a completely decomposed rock, the nature of which it was impossible to determine; and even from a depth of several feet he obtained only a very altered rock, which was provisionally referred to granite.

In the mica-schists of Fatoya (New Guinea), Prof. Lacroix[4] states that borings were pushed to a depth of about 200 feet without reaching the fresh rock, the weathered rocks being unctuous to the touch and friable when dry.

Sections in which granite has been weathered into a soft friable earth to a depth of 40 or 50 feet are very common in numerous road-cuttings in Malaya, where small veins of silica and fracture-planes can be seen continuous from the fresh to the weathered rock. In some cases, as on the Pahang road, the rock is seen

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[1] 'The Wearing-Down of the Rocks' Proc. Geol. Assoc. vol. xxv (1914) p. 238.

[2] Neues Jahrb. vol. ii (1880) pp. 19 & 28. Quoted by Posewitz.

[3] 'Borneo' transl. by F. H. Hatch, London, 1892.

[4] L. L. Fermor, 'The Work of Professor Lacroix on the Laterites of French Guinea' Geol. Mag. dec. 6, vol. ii (1915) pp. 36, 37.

weathered to a depth of 60 feet and more; and, near Peretak, in Ulu Selangor, granite has been weathered *in situ* to a depth exceeding 100 feet.

The conversion, therefore, in a moist tropical climate, of rocks such as schists, phyllites, and indurated shales into a fat clay, in a valley where all the rivers have just flowed for many miles over a decomposing granite, and the waters of which may be presumed to be rich in alkalies, is not remarkable.

Where the water continues to flow along the sloping junction of the granite, that part of the beds which overlies the limestone becomes converted into a soft structureless clay, and, helped by its sinking movement on the gradually-dissolving limestone underneath, it loses its structure, whereas the overlying beds may still preserve some of their structure. Such cases, which were recently well illustrated in Siputeh, Lahat, and Serendah Valley, account for the presence, in places, of a soft clay between the limestone and the phyllites and schists. These clays in many cases, as, for instance, at Tambun, Lahat, and Tronoh, have been definitely traced into weathered phyllites showing foliation-planes (see Pl. XIV).

Where the decomposed phyllites and indurated shales are veined with granitic intrusions, mostly quartz-veins, the sinking movement of such beds on the dissolving limestone breaks up the continuity of the veins, and results in a fine clay containing angular boulders; and, where the granitic intrusion was tin-bearing, the ore preserves its angularity. A section illustrating this was particularly well exposed recently at Siputeh Mine.

The conversion of such beds into clay, resulting, in some cases, in landslips and soil-creep down steep slopes, also accounts for angular boulders in a fine clay, and the process is common in Malaya.

The weathering process is particularly intense in alluvial deposits where the waters, rich in alkalies, can percolate with ease through the beds in various directions. At Kanching and other places in Ulu Selangor, and at Gopeng, Kramat Pulai, Lahat, and many other mines in Kinta, beautifully-rounded pebbles of different types of granite have become so thoroughly decomposed that they can be powdered into a fine sandy clay with ease between the fingers.

R. A. F. Penrose[1] observed the same phenomenon in the locality which first suggested to Mr. Scrivenor the existence of glacial deposits:—

> 'Sometimes beds of coarse granite pebbles and boulders, forming the substratum of the tin-alluvium, have decayed *in situ* in the same manner as the surface of the original rock; and it is not uncommon to see rounded granitic fragments converted into a soft putty-like mass, which, when broken up, gives rise to angular particles of the original quartz of the rock and a soft clay resulting from the decay of the felspar. Hence angular quartz may often be found in deposits that have been transported long distances. Such an

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[1] Journ. Geol. Chicago, vol. xi (1903) p. 143.

occurrence is seen on the property of the Gopeng Tin Mining Company, where the tin-bearing stratum consists of a more or less ferruginous deposit of sandy and gravelly material occupying a ridge on the side of a small stream and underlaid by a pebbly stratum like that just described. In the creek-bed below, near the native town of Gopeng, tin-alluvium washed down from the ridges is extensively worked by the Chinese.'

Deposits such as these, when subjected in the mine to water under great pressure for hydraulicking the beds, leave exposed faces which certainly bear resemblance to a cutting in glacial clays; for, not only does the water destroy any structure that the beds previously preserved, but the pebbles are broken up, and, when the talus at the foot of the face is washed by powerful jets of water, the broken pebbles are hurled against the working-face. The photograph, for example, illustrating Mr. Scrivenor's article in the 'Geological Magazine' for July 1914 (p. 310), was taken in my presence, and is of a working-face that had been subjected to water from a monitor under a pressure of 80 lbs. to the square inch. In the photographs in the memoir on the Kinta district (pl. iii, fig. 1) it will be noticed also that the boulders are much more sharply angular than those usually associated with glacial deposits.

At the Tekka Ltd. Mine a boulder of tourmaline-schist, obviously part of the tourmaline-schist occurring *in situ* a few yards away, was found completely surrounded by the supposed glacial clays! This proved conclusively that the clays could not be older than the granite which gave rise to the tourmaline and associated minerals. The boulder was cemented with chalcedony, which enabled it to preserve its structure.

At Gopeng the beds contain numerous boulders of schists, and, in places, notably near the large kaolin-vein recently sampled by me,[1] these boulders, although friable, still preserve distinct foliation-planes, and occasionally contain small veinlets of tourmaline and cassiterite traversing individual boulders.

(b) The Rocks and Minerals present in the Clays occur *in situ* in the Schists, Phyllites, etc. The Relation between their Distribution and the Drainage System.

It is agreed that tourmaline-corundum rocks are found in the clays and 'boulder-clays' only of the west side of the Kinta River, but Mr. Scrivenor does not regard the river in any way as the cause of the fact that it divides the clays containing tourmaline-corundum rocks from those which do not, but looks upon it

'as a remarkable accident, but one that enables us to conveniently distinguish the clays with tourmaline-corundum rocks as the western boulder-clays, as opposed to the eastern boulder-clays of Gopeng, Pulai, etc.'[2]

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[1] W. R. Jones, 'Clays of Economic Importance in the F.M. States' Kuala Lumpur, Government Printing Office, 1915, p. 3.

[2] J. B. Scrivenor, 'The Geology & Mining Industry of the Kinta District' 1913, p. 28.

When it is remembered that the Kinta River flows from north to south through the middle of the Kinta Valley, and that it carries the whole of the valley-waters, it becomes, indeed, a remarkable accident that the tourmaline-corundum rocks should coincide absolutely with the western half of the drainage-system of the valley. It would be reasonable to expect that clays and boulder-clays, which had been transported by ice moving from west to east from Gondwanaland, would during their long journey of several hundred miles have every opportunity of becoming mixed up to form a heterogeneous deposit. But the coincidence becomes still more remarkable when it is pointed out that pure corundum-boulders are found on the east of the Kinta Valley, and that they have never been found on the west.[1] These facts alone, namely, that tourmaline-corundum boulders occurring in clays supposed to be of glacial origin and of Permo-Carboniferous age are confined to the western drainage-area, that the corundum-boulders are confined to the eastern drainage-area, and that both have never been found together in a valley which came into existence in post-Cretaceous times, present, in my opinion, an insuperable objection to the glacial theory of the origin of these beds. The explanation which is suggested for this extraordinary coincidence is quite inconsistent with what is known of glacial deposits in any other part of the world. It is stated that

> '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.'

This means that a glacier, or a sheet of ice, laden with corundum- and tourmaline-corundum rocks carefully selected the east side of the valley for the deposition of the former, and the west side for the deposition of the latter, and that the dividing-line between supposed Permo-Carboniferous deposits of the east and those of the west coincided with the present main drainage of a valley which was not then in existence, but was formed in much later geological time. It will be instructive at this juncture to compare the descriptions given by Mr. Scrivenor of these eastern and western clays.

Western clays and boulder-clays.	Eastern clays and boulder-clays.
Contain tourmaline-corundum rocks.[2]	Do not contain tourmaline-corundum rocks.[2]
Do not contain pure corundum-rocks.[2]	Contain pure corundum-rocks.[2]
Show little signs of bedding.[3]	Show 'for the most part a fairly distinct bedding.'[4] 'On the east stratification in the clays has been preserved.'[5]
'The boulders all of the same sort are more massed together on the west than on the east.'[3]	The different kinds of boulders are mixed together.[3]

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[1] 'The Geology & Mining Industry of the Kinta District' 1913, p. 28.
[2] *Ibid.* p. 28. [3] *Ibid.* p. 39. [4] *Ibid.* p. 32. [5] *Ibid.* p. 41.

It seems clear, therefore, that the distribution of the eastern and western 'clays and boulder-clays' is directly related to the present drainage, for Mr. Scrivenor has taken the Kinta River as the dividing-line between these two clays.

The tourmaline-corundum rocks have been found *in situ* at Kacha, Redhills, and Batu Gajah on the west of the Kinta Valley, and it is to be expected that they should be found in clays which are at lower levels and on the same drainage-side of the valley.

Large blocks of pure corundum have not been, so far as is known at present, discovered *in situ*, but small veins carrying corundum are common at Tekka Ltd. Mine on the east; also at Kramat Pulai large corundum-boulders are very plentiful in recent alluvium overlying the beds of lignite, and are obviously derived from the schists near the granite-junction about 300 yards away. The presence in these 'clays and boulder-clays' of tourmaline-corundum and pure corundum-rocks seems to offer a very definite proof that they are derived from rocks metamorphosed by the intrusion of the Mesozoic granite.[1]

It is clear, therefore, that the characteristic rocks present in these supposed glacial clays on the west of the Valley are known to be *in situ* in many places in the Kinta district, and that, before being metamorphosed by the granite of the Main Range and the Kledang Range, the original rocks (described by Mr. Scrivenor as having been deposited 'under conditions similar to those when radiolarian cherts' were deposited elsewhere[2]) differed very sharply from the Gondwana Rocks of India, the bulk of which have yielded terrestrial forms only, and even from the supposed Gondwana Rocks of Ulu Pahang (F.M.S.): for, in the geological map of this latter locality, the Radiolarian Chert Series is excluded[3] from the deposits mapped as Gondwana Rocks. Indeed, it is stated[4] that an unconformity exists between the two.

It is significant that no rocks or minerals not present *in situ* in the district (unless the large corundum boulders be taken as an exception) have been found in the 'clays and boulder-clays.' The complete list[5] of boulders found at Gopeng and Tekka is as follows:—

Quartz, abundant; sandstone, probably weathered quartzite; sandy schists with white mica, abundant; phyllite, rare; hornstone, rare; hornblende-schist, rare; tourmaline-rock, generally blue, abundant; quartz-muscovite rock, abundant; quartz-tourmaline-muscovite rock, abundant; quartz-kaolin

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[1] J. B. Scrivenor, 'The Tourmaline-Corundum Rocks of Kinta' Q. J. G. S. vol. lxvi (1910) p. 439 & pls. xxx–xxxi; also Geol. Mag. dec. 6, vol. i (1914) pp. 309–11.

[2] Q. J. G. S. vol. lxvi (1910) p. 439.

[3] J. B. Scrivenor, 'The Geology & Mining Industries of Ulu Pahang' Kuala Lumpur, 1911, pp. 35–37 & sketch-map.

[4] J. B. Scrivenor, Q. J. G. S. vol. lxix (1913) p. 349.

[5] J. B. Scrivenor, 'The Geology & Mining Industry of the Kinta District' 1913, p. 33.

rock, common; small masses of kaolin, not very common (kaolin-veins are common): brown tourmaline-schist, often veined with quartz and white mica, abundant; granite, some porphyritic, not common; tourmaline-granite, not common; corundum, rare at Gopeng, but common as large and small boulders in one part of the Tekka Ltd. Mine.

It will be noticed that all the rocks and minerals are those that would be expected near the contact of an acid granite with schists and phyllites.

Localities where the schists and phyllites have been, and are still being, worked for tin-ore occurring definitely *in situ* have already been mentioned, but attention is drawn to the following as being of particular interest. At the beginning of July 1914 a remarkably rich deposit of tin-ore was found on Mining Lease 6973, at Papan in the west of the Kinta district. It was in a much decomposed phyllite, which still, however, retained in places distinct traces of foliation; and the ore occurred as a vein, keeping a very definite course, varying from 335° to 340°. It was definitely *in situ*, and beautiful crystals, with sharp edges and brilliant faces, were collected by Mr. W. A. Naish, A.R.S.M., Inspector of Mines, and myself. Granite is exposed a short distance away, and the junction may be within about 200 yards of this spot. Similar veins, very rich in tin-ore, and keeping definite courses for short distances, have been found on several occasions traversing the schists in this locality.

(*c*) The Deposits richest in Tin-Ore occur near the Granite-Junctions and Granitic Intrusions.

One of the most striking and conclusive proofs of the origin of the tin-ore in the clays of the Kinta district is, however, the fact that those properties that have produced, and are still producing, the richest yield of tin-ore are all found near the granite-junction of the two granite ranges or near a granitic intrusion; and that the deposits farthest from the granite-junction and granitic intrusions, namely, those towards the central parts of the valley, contain too little tin-ore, or tin-ore in too fine a state of division, to be worked. This fact is clearly brought out by the coloured Government Survey map, in which the land given over to agriculture is coloured green and the mining land red.

It is not suggested here that all the agricultural land contains no tin-ore, but it contains too little to be profitably worked. Most of the rubber-estates in the Kinta Valley have been planted during the last few years, during which time it has been the practice of the Mines Department not to recommend the alienation of any land for agriculture in the Kinta district until it has been proved, by the sinking of pits or boring, to contain too little tin-ore to be workable.

The following is a list, supplied by the courtesy of the Warden of Mines for the Kinta district, of the twenty largest tin-mines in this district and their outputs for the year 1913. (1 picul, or pkl., = $1\frac{1}{3}$ lbs.):—

(1) Tronoh Mines 33,730 pkls., (2) French Tekka, Gopeng, 11,566 pkls., (3) Lahat Ltd. 8604 pkls., (4) Tambun Mine 7582 pkls., (5) Tekka Ltd., Gopeng 5772 pkls., (7) Ulu Piah 5590 pkls., (7) Penkalan 5239 pkls., (8) Gopeng Consolidated (old section) 4870 pkls., (9) Menglembu Lode 4726 pkls., (10) Malayan Dredging Company 3780 pkls., (11) Kinta Tin-Mines 3546 pkls., (12) Kramat Pulai 3436 pkls., (13) Tronoh South 2899 pkls., (14) Gopeng Consolidated (new section) 2874 pkls., (15) North Tambun 2620 pkls., (16) Chendai Meru 2359 pkls., (17) Kledang 2080 pkls., (18) Pusing Bharu 1490 pkls., (19) Sultan Idris 1455 pkls., and (20) Siputeh 1186 pkls.

Total = 114,634 pkls., or more than 6823 tons.

The positions of these mines are indicated on the accompanying map (Pl. XV) by the number corresponding to their place in the above list, and it will be noticed that the maximum distance of any of them, with one exception, from granite or from a granitic intrusion[1] is less than a mile, and that nearly all are within a few yards of an igneous intrusion. No fewer than seventeen of these mines are situated either actually at the junction of the stanniferous granite of the Main Range and the Kledang Range, or are traversed by granitic intrusions proved to contain tin-ore *in situ*. The presence here of these acid igneous rocks is not disputed, for Mr. Scrivenor has himself described their existence.[2]

The theory that these stanniferous deposits are of glacial origin and of greater antiquity than the granite and granitic intrusions of Kinta involves its author in very serious difficulties.

The position of the clays at Tronoh Mines, for example, does not fit in with the glacial theory, as they are (in many places) underlain by sandy beds containing lignite and carrying rounded grains of tin-ore. They appear to be alluvial deposits filling a huge solution-trough in the limestone. Mr. Scrivenor, however, describes the solution-cavity as

> 'being filled, in part at any rate, with Gondwana boulder-clays, lignite, and sand, and ending abruptly on the west side against a reversed fault.'

This reversed fault must, according to the section given, have a throw of some hundreds of feet. In a previous description of the same mine the beds were stated to be altered sedimentary rocks, granite, and pegmatite, and Mr. Scrivenor writes

> 'I have seen both pegmatite and altered sediments *in situ* underground in Tronoh, and also veins of quartz with cassiterite . . . This clearly points to the small hill as the source of the tin-ore.'[3]

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[1] By 'granitic intrusions' are meant the veins of aplite, pegmatite, and quartz which are intrusive into the schists and phyllites and the cassiterite-bearing quartz-veins that traverse the metamorphosed limestone of Kinta.

[2] 'The Geology & Mining Industry of the Kinta District' 1913: see geological sketch-map.

[3] 'The Geologist's Report of Progress, 1903–1907' Kuala Lumpur, 1907, p. 40.

In an article by him in the 'Geological Magazine' for July 1914 (pp. 309–11), the object of which was 'to present further evidence on the relative age of the clays and the granite,' a remarkably good photograph is shown of the junction of the schists and granite at the French Tekka Mine, and there it is stated that these clays possibly escaped metamorphism, although they are in contact with an enormous mass of granite intrusive into them. This question will be further dealt with on p. 186; but the point to notice here is the similarity between the section in this photograph of French Tekka and the section given of Tronoh Mines, and the totally different interpretations assigned to them.

M. Joseph Roux-Brahic describes[1] the tin-ore of French Tekka as being derived from the rock *in situ* on the property and in the immediate neighbourhood, and this has later been verified by me.

The presence in the clays at Ulu Piah Mine of big blocks of white to colourless fluorspar and of large lumps of scheelite, practically unknown in most of the mines of the district, and the fact that scheelite, fluorspar, and tin-ore have been found *in situ* in veins in the limestone on this property, seem to place the question of the origin of, at least, this part of these clays beyond dispute.

Despite the fact that at Gopeng Mines and at Ulu Gopeng tin-ore has been, and is still being, worked *in situ* in many places, and that granitic intrusions are very common in these mines, Mr. Scrivenor definitely states that the bulk of the ore has been transported here by ice from an ancient tin-field situated somewhere to the west of the present position of the Malay Peninsula.

Gopeng is famous, among other things, for the remarkable purity and extent of its kaolin-veins,[2] and the association of these veins and other granitic intrusions with the richest deposits of tin-ore is quite clear and, in places, strikingly obvious. Such a case, occurring at the Kinta Mines, Gopeng, is described in the Kinta Memoir by Mr. Scrivenor as follows:

> 'Only a few yards away from this vein [kaolin-vein] a very rich mass of tin-ore was found that constitutes an excellent example of a secondary supply of tin-ore from the Mesozoic granite.'[3]

This would imply the secondary enrichment by granite, stated to be of Cretaceous age, of a tin-ore deposit of Permo-Carboniferous age!

Overlooking the western part of the Kinta Valley, between Menglembu and Lahat, are the Menglembu Lode Mine and the Chendai Lode Mines. The hard undecomposed granite worked here is traversed by innumerable small stringers, rich in tin-ore.[4] For the purposes of this paper it is sufficient to point out that, in this locality, overlooking the Kinta Valley, is granite which, when

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[1] 'Étude du District Stannifère de Tekka' 1913, p. 6.

[2] W. R. Jones, 'Clays of Economic Importance in the Federated Malay States' Kuala Lumpur, 1915, p. 33.

[3] 'The Geology & Mining Industry of the Kinta District' 1913, p. 57.

[4] [W. R. Jones, 'Mineralization in Malaya' Mining Magazine, Oct. & Dec. 1915, pp. 6 & 7.]

crushed and washed, yielded in one mine, the Menglembu Lode Mine, for the year 1913 no less than 4726 pkls. or 281 tons of tin-ore.

At Kramat Pulai a section was exposed, in which a kaolin-vein was supposed to be intrusive into 'boulder-clay' containing tin-ore: this was regarded as proving definitely that the 'boulder-clay' was older than the kaolin-vein, and hence that the tin-ore in the 'boulder-clay' was older than the present granite. My own recollection, combined with what I have subsequently seen at numerous other mines, of the above section (which I examined with Mr. Scrivenor), is that the variation in colour in different parts of the deposit was due to the presence in some parts of much oxide and hydroxide of iron and to its absence in other parts, and that the so-called 'boulder-clay' and the 'kaolin-vein' simply represent different colours.

Mr. Scrivenor describes a similar case at the Pusing Bharu mine as follows:—

> 'Once a vertical pipe of pale-coloured mottled clay was found in the darker clays. This was not a kaolin vein, but probably marked the bleaching action of the slow current of water either from above or from a spring in the limestone.' [1]

Kramat Pulai Mine supplies a very definite proof of the origin of its tin-ore deposits, for recent developments have conclusively shown the presence of beds of lignite and peat resting under the supposed 'glacial clays' and directly upon the limestone. The decayed wood is unquestionably recent, and the explanation advanced in other cases that trees fell down long-forgotten excavations, subsequently filled in by detritus,[2] cannot even be suggested for a definite bed of lignite (see Pl. XIII).

At Siputeh boulders of quartz with tourmaline and cassiterite are very frequently observed in the clays, and quartz-veins carrying these minerals are occasionally found intrusive in the limestone bed-rock. The localized presence of these boulders has, on three definite occasions, enabled me to presume the proximity of a vein, which has, with the help of the manager, been subsequently located. In one case the vein carried tin-ore *in situ*.

A feature of the ore from this mine is its coarseness and angularity, and Mr. Scrivenor photographed some of it to illustrate[3] the difference between this supposed case of angular ore from Glacial Clays and the rounded ore from alluvial deposits. The fact, however, that a lode was worked on this very mine about ten years ago, when under the management of Mr. F. E. Mair, A.R.S.M., and that Mr. Scrivenor now agrees[4] that ore has been recently

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[1] 'The Geology & Mining Industry of the Kinta District' 1913, p. 65.

[2] J. B. Scrivenor, 'The Gopeng Beds of Kinta' Q. J. G. S. vol. lxviii (1912) p. 150.

[3] 'The Geology & Mining Industry of the Kinta District' 1913, pl. iv, fig. 3.

[4] 'The Deposits of Tin-ore in Limestone, Ipoh' Times of Malaya Press, 1914, p. 8.

proved there *in situ*, gives an immediate explanation of its angularity.

In three mines, out of the twenty largest mines enumerated on p. 182, granitic intrusions have not been discovered, but they furnish evidence which, instead of supporting the glacial theory, offers very strong arguments against it. One of these, the Malayan Dredging Company's Mine, is in a part of the Kinta Valley mapped by Mr. Scrivenor as not containing any glacial clays. Of the other two, Tronoh South Mine has lignite throughout most of its deposits and the ore at Pusing Bharu Mine is in rounded grains. In his description of Pusing Bharu Mr. Scrivenor writes[1]:—

> 'The floor of the Pusing Bharu Mine is limestone. Several well-marked "cups" have been uncovered, lined with Gondwana boulder-clays and filled with sand and lignite, and elsewhere the limestone surface is very irregular and broken up by pinnacles . . . The sand contains tin-ore, sometimes as much as 3 katis (4 lbs.) to the cubic yard, and in some sections I have seen small boulders of tourmaline-corundum rocks in lignitic sand close to the junction with the boulder-clays . . . From time to time sections have been exposed in the Pusing Bharu Mine for which it has been difficult, to say the least, to find any clear explanation. The late General Manager, Mr. W. M. Currie, thought that the clays had been to some extent rearranged by recent river action, and brought forward as evidence the tin-ore, which he thought to be distinctly waterworn. I cannot see, however, that the ore is more worn than in the glacial beds generally, and think that the sinking of the clays on to the dissolving limestone may be the cause of the difficulties referred to. It would, for instance, be possible in this way to account for the fragments of wood and patches of sand being found in clay immediately above the limestone, as, during the sinking movement, some of the younger lignite and sand might become mingled with the older Gondwana Clays.'

The explanation given for the New Tambun Mine is, however, totally different, for it is stated[2] that the relation there of the younger Gondwana Rocks to the glacial clays

> 'is obscure, but the latter are clearly faulted down against the limestone, and it is possible that the younger rocks in turn have been faulted down against the clays.'

Without enumerating the large number of other mines in the district, I will now state the general conclusion, namely, that well over 90 per cent. of the ore derived from the Kinta district is from mines situated within a distance of less than a mile from the junctions of the granite of the Main Range and the Kledang Range, or from granitic intrusions contemporaneous with the granite of these ranges; and that over 80 per cent. of the ore is derived from mines where granite, or a granitic intrusion, has actually been proved on the property.

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[1] 'The Geology & Mining Industry of the Kinta District' 1913, p. 65.
[2] *Ibid.* p. 59.

(*d*) Absence of Metamorphism in the 'Glacial' Clays.

If the clays and 'boulder-clays' are of Talchir age, and therefore much older than the Cretaceous granite with which they are in contact, and if they lie, as averred, between metamorphosed limestone below and phyllites, schists, and quartzites above, why were they not metamorphosed to the same extent as the rocks between which they lie? Mr. Scrivenor states that

> 'They show no trace of hardening as a whole, or of mineral alteration away from the granite-junction and veins. They might have been quite recently deposited, so far as their physical condition is concerned.'[1]

To account for the absence of metamorphism, he gives two explanations. One is that the clays, owing to their great plasticity, escaped metamorphism; and the other, that, if they did suffer metamorphism, they have now lost all signs of it. It seems quite impossible to reconcile the statement[2] that the absence of regional metamorphism in these clays

> 'is probably due to the 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,'

with his other statement[3]

> 'that there seems to be a gradual passage upwards from the clays and boulder-clays to the phyllites and quartzites.'

What evidence is there that the clays below those converted into phyllites were so much more plastic than the latter that they were able to escape metamorphism? The only reason given is that the unmetamorphosed clays are rich in kaolin[4]; kaolin, however, is characterized as a clay, not by its plasticity, but by its non-plasticity. These unmetamorphosed clays are supposed by Mr. Scrivenor to be of Permo-Carboniferous age, and in that case must have been covered by thousands of feet of strata when the Mesozoic granite-magma, now forming the two granite ranges flanking the valley (and only about 10 miles apart), was intruded. It is inconceivable that any clays, wedged between two subsequently-intruded enormous granite ranges, and lying between beds highly metamorphosed by the granite, could possibly have escaped metamorphism, especially within a few yards of the granite-contact,[5] whatever their nature.

In support of the alternative explanation that they may have lost all signs of metamorphism, Mr. Scrivenor draws attention to the following extract from the Rev. W. Howchin's paper on the glacial clays of Australia:—

> 'The beds which give evidence of glacial origin may be described as consisting mainly of a grand mass of unstratified, indurated mudstone, more or

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[1] 'The Geology & Mining Industry of the Kinta District' 1913, p. 40.

[2] 'The Gopeng Beds of Kinta' Q. J. G. S. vol. lxviii (1912) p. 146.

[3] 'The Geology & Mining Industry of the Kinta District' 1913, p. 45.

[4] *Ibid.* p. 41.

[5] *Ibid.* See geological map.

less gritty . . . It is, in every respect, a characteristic till . . . In places the beds become highly siliceous and very close in grain, probably owing to the introduction of silica-charged waters, which have given rise to much quartz-veining at some points.' Again: 'When the till is of an earthy, or non-siliceous, nature, it frets away rapidly by weathering, and sometimes forms cavernous shelters in the faces of cliffs. Under such circumstances, with a friable and freshly-exfoliated surface, its resemblance to the Pleistocene Boulder-Clay of Europe is very striking.'[1]

It is then pointed out that, in the case of the Kinta Valley clays, the deposits have for a long time been exposed to agencies possessed of great power to dissolve quartz, and that there seems to be no need to postulate a great sinking movement over the limestone in order to account for the recent appearance of the clays, but that they may have been largely silicified at one time, the hardening silica having been since removed by ground-water.

That silicified beds can become desilicified in the tropics is abundantly proved in numerous cases in Malaya and elsewhere. But silicification is not the only effect of metamorphism that one would expect to have taken place in clays older than the granite, situated in a narrow valley bounded by granite-ranges of immense mass, intruded into by numerous granitic veins, and interbedded between rocks which themselves have been highly metamorphosed.

The Australian deposits described by the Rev. W. Howchin cannot be considered a parallel case, for the latter are not situated in a metamorphosed area, no igneous rock being shown in any of the sections illustrating that paper, although three of them extend over 15, 30, and 60 miles respectively.[2]

At the junction of the clays with the underlying limestone signs of metamorphism might reasonably be expected, both being supposed to be older than the granite; but, as Mr. Scrivenor remarks, 'the limestone is generally separated from them by ironstone.'[3] In places, the junction between the so-called 'glacial' clays and the limestone is remarkably free from any signs of interaction.

V. Mode of Faulting of the Clays.

The presence of faults in the 'clays' is advanced as evidence of their greater antiquity than the granite, and the impossibility that they could be recent deposits.[4] Two faults are mentioned: one at Rotan Dahan, in which the clays showed distinct slickensiding, and one at Tekka, where a 'remarkable fault-breccia occurred.' The bed-rock at both these places is limestone.

Now, this bed-rock of metamorphosed limestone in the Kinta Valley has been attacked by ground water to an extraordinary degree, and big 'cups' and 'troughs' separated by 'pinnacles' are

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[1] Q. J. G. S. vol. lxiv (1908) p. 239.
[2] *Ibid.* pp. 236, 256, 257.
[3] 'The Geology & Mining Industry of the Kinta District' 1913, p. 31.
[4] *Ibid.* p. 37.

found practically over the floor of the whole valley. The 'cups' are sometimes very deep, one at Siputeh exceeding over 130 feet in depth, and into these cups the clays have sunk.

That the limestone floor of the valley was in places exposed by denudation and then partly covered by recent alluvium is conclusively proved by the fact that occasionally it still forms the surface-rock, and that in other localities the limestone has, resting directly upon it, clays, sands with rounded pebbles, and beds of lignite, partly carbonized wood, and leaves. These beds also contain rounded grains of cassiterite—as at Tronoh South, Lahat, etc. The limestone, even when covered by these beds, is still being dissolved away, and this accounts very simply for the fact that beds of undoubted alluvial origin show clear evidence of faulting down into the enlarged limestone cups directly underneath. Indeed, in the Serendah Valley, in Ulu Selangor, I was able to foretell the presence of a big limestone cup in one mine by the presence of small faults (having a throw of a few feet only) in the exposed face of the overlying alluvium.

But a more striking example was seen at Penkalan Mine in the Kinta Valley, about two years ago. A circular patch of the surface had suddenly subsided from 3 to 4 feet, and further work on the mine showed that directly underneath was a limestone cup. Another such subsidence on a bigger scale occurred recently on the Government road at Lahat, and was supposed, for good reasons, to be due to the presence directly underneath of a limestone cup out of which the water had drained into the deep workings of the Lahat Mine.

In that mine a very interesting case of faulted alluvium was seen recently. That the deposit was alluvium was shown by its sandy nature, and the presence of partly decayed wood and occasional lumps of vegetable gum in the faulted beds. The bed-rock has proved to be limestone, and it is probable that a limestone cup will be found underneath. The top of a limestone 'pinnacle' has already been exposed here.

At Kanching, in Ulu Selangor, alluvium containing very well-rounded pebbles of granite, aplite, and pegmatite was seen to be faulted, and limestone cups are known to be numerous here. I was fortunate in coming across another clear case of faulting in alluvium at Kanching, when in Mr. Scrivenor's company.

VI. Absence of Glacial Characters.

There is no other case on record, so far as I have been able to ascertain, where deposits known to be of glacial origin have not yielded some polished and striated boulders. In the 'clays and boulder-clays' of the Kinta Valley, however, Mr. Scrivenor states that

> 'No clear evidence has been seen on the boulder or on the limestone bed-rock of ice-action, such as the polishing and striations frequently seen in glaciated regions.' ('The Geology & Mining Industry of the Kinta District' 1913, p. 39.)

It is true that marks of glaciation cannot be expected on limestone bed-rock which has been attacked to such an extent that any glaciated pavements that it may have once formed would have disappeared long ago. But boulders in clays, which are stated to have preserved their angularity owing to transport by ice and not by water, would be reasonably expected to have preserved some signs of polished surfaces and striæ. The absence of angular corners due to subsequent solution could be understood; but the circumstances which enabled the boulders in a glacial clay to preserve their angularity, and yet to lose their polished surfaces and striæ, are difficult to imagine.

Fine clay in glacial deposits, being formed by the powdering of the minerals of the rocks over which the ice has passed, would be expected to carry, in a finely comminuted state, representatives of such minerals as are especially resistant to weathering. Where, consequently, a mineral such as cassiterite is present as a coarse material in glacial clays, it is to be expected that it is present also as a fine flour. Cassiterite is brittle, comparatively soft, and as insoluble as silica, which is present in the supposed rock-flour, so that glacial clay rich in coarse angular tin-ore should give, in its finest parts, chemical reactions for tin. Several tests which I carried out on this fine material have failed to reveal tin.

The Restricted Areas to which the supposed 'Glacial Clays' are confined, even in the Kinta District.

If the 'clays and boulder-clays' belong to the Lower Gondwana Rocks (they have been correlated with the Talchir proper), and hence are older than the phyllites, quartzites, and indurated shales, it is reasonable to expect them to underlie most of these latter rocks at least in the Kinta district, for in India the Talchir proper (the actual glacial bed) is the most widely spread of all the Gondwana divisions.[1] A reference, however, to Mr. Scrivenor's map will show that they have been proved only in a few restricted patches, even in the Kinta district; and it is of the greatest significance, bearing in mind their great economic importance, that these supposed glacial stanniferous clays have never been discovered underlying the 'younger Gondwana Rocks' in the numerous cuttings in the district, except near the foot of the granite ranges, where, according to my contention, they are the result of weathering *in situ* of the schists and phyllites.

Absence of Glacial Tin-Ore Deposits in other parts of Malaya and in the Neighbouring Countries.

No tin-ore bearing clays in Malaya, in the neighbouring countries, nor in the Far East, have been claimed to be of glacial origin, except those of the Kinta district.

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[1] E. V. Vredenburg, 'Summary of the Geology of India' 2nd ed. Calcutta, 1910, p. 52.

In Ulu Pahang (Federated Malay States), where younger Gondwana rocks are presumed to occur, Mr. Scrivenor writes:

> 'Apart from the Machi tin-field, all the tin-ore being won in Ulu Pahang to-day is clearly derived from the granite of the Main Range.'[1]
>
> 'The Machi tin-field is remarkable in that there is no known outcrop of granite in the immediate vicinity of the mines, although there is good reason to believe that it exists not far from the surface. The ore worked is alluvial, the pay-dirt being sandy with little or no impurities.' (*Op. cit.* p. 22.)

Of the tin-field north-west of the Kinta district in Larut, Perak, Patrick Doyle wrote[2]:—

> 'All the land at the foot of these ranges is more or less stanniferous. Its level is even now being altered by the alluvium brought down from the hills by a rainfall which exceeds 150 inches per annum. All the ore worked up to the present time has been found in the alluvium derived from the mountain-ranges, *i. e.* in mining language, in stream-works. The ore has been traced up to veins in the rocks, but these have not hitherto been worked. . . . . There can be no doubt that these beds have been formed by degradation of the mountains; these, as has been stated, consist of granitic rock, in which the tin-stone associated with iron-ore occurs in veins.'

Mr. Scrivenor describes[3] this same area as consisting of a

> 'vast alluvial flat, from which has been extracted that wealth of tin-ore which has made the district of Larut justly famous';

and, in discussing the origin of tin-ore at Ayer Kuning in this neighbourhood, he states[4]:

> 'Now these facts can only point to one conclusion, and that is that the white overburden and the karang with the cassiterite have been derived from the small changkat on which the hospital stands; and further, judging from the nature of the alluvium, it may be concluded that the changkat owes its existence to a hardening of the shale and sandstone series, over and above whatever may have been effected in this direction by the main granite mass, consequent on the intrusion of a mass of pegmatite, isolated on the surface, but certainly connected in depth with the other igneous rocks of the Taiping Range.'

In Ulu Selangor, which has always contained some of the most productive tin-fields of Malaya, the following paragraph from my report is incorporated in the Geologist's Annual Report for 1913 (§ 25, p. 3):—

> 'Too much importance cannot be attached to the fact that the ore of Ulu Selangor is derived from rocks now *in situ* in that district, and this fact should guide prospecting in that part of the Peninsula. Where the valleys are rich in tin-ore the hills should be very carefully prospected right up to the source of the streams running into the valleys. In the case of every valley in Ulu Selangor I have been able to find in this way, tin-ore *in situ* in the granite. Local enrichments with angular ore should be very carefully examined, and the bed-rock itself tested for ore by crushing and washing.'

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[1] 'The Geology & Mining Industries of Ulu Pahang' Kuala Lumpur, 1911, p. 23.

[2] Q. J. G. S. vol. xxxv (1879) p. 229.

[3] 'A Preliminary Report on the Geology of the Neighbourhood of Taiping, Perak' Kuala Lumpur, 1904, p. 1.

[4] *Ibid.* p. 7.

In the famous valley round Kuala Lumpur, the numerous well-rounded pebbles in the deposits may be cited as only one of several pieces of evidence which show conclusively that the beds are of alluvial origin.

The tin-ore of Negri Sembilan (Federated Malay States) occurs in alluvial deposits and as stockworks in phyllites and schists, and the granite has proved stanniferous in places. The same is true of such tin-ore as is found in Johore.

The deposits of Banca and Billiton,[1] and the few deposits of Sumatra [2] are alluvial and occur near exposures of granite. Those of Siam lie close to granite outcrops and are of alluvial origin; and those of Burma [3] have been shown by the officers of the Geological Survey of India to be alluvial deposits of post-Tertiary age.[4] In French Indo-China,[5] and in Yunnan,[6] the tin-ore is derived from the breaking-down of rocks near granite or granitic intrusions.

VII. THE 'GLACIAL CLAYS' OF THE KINTA DISTRICT CANNOT BE CORRELATED WITH THE TALCHIR BEDS OF INDIA.

In the absence of proof that the stanniferous clays of Kinta are of glacial origin, the most important, if not the only, grounds on which they have been correlated with the Talchir Beds of India have been removed, for 'climatic evidence' is stated to have furnished for this purpose a more valuable horizon than palæontological evidence.

Further difficulty in accepting the correlation is experienced by the remarkable difference in sequence of the supposed Gondwana Rocks of Malaya and those of India. In Malaya beds at the base of the 'Older Gondwana Rocks' are stated to pass up gradually into those of the 'Younger Gondwana Rocks,' and the junction between them is said to be 'so obscure that it is impossible to draw a line between them.' [7] Now, the Younger Gondwana Rocks of

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[1] P. Van Diest, 'Banca & its Tin Stream-Works' transl. by C. Le Neve Foster, 1867; S. Fawns, 'Tin-Deposits of the World' 1905, p. 35; J. A. Phillips & H. Louis, 'A Treatise on Ore-Deposits' 1896, p. 610.

[2] 'A Treatise on Ore-Deposits' 1896, p. 610; also 'The Alluvial Tin-Deposits; Siak, Sumatra' Trans. Am. Inst. Eng. vol. xx (1892) pp. 50–84.

[3] [Subsequent to the reading of this paper I have spent many months at Tavoy (Burma) and have familiarized myself with the occurrence of wolfram and tin-ore in that district. Almost the whole of the wolfram is obtained from rocks decomposed *in situ*, or from lodes traversing granite, mica-schists, and phyllites. Tin-ore is found associated with wolfram in the lodes and detrital deposits, and is occasionally found in alluvial deposits which, owing to the extremely perfect cleavage into thin flakes of wolfram and to its instability in a moist tropical climate, carry relatively very little of this latter mineral.]

[4] Rec. Geol. Surv. India, vol. xxii, pt. 3 (1889) p. 188.

[5] L. Gascuel, 'Gisements Stannifères au Laos Français' Ann. Mines, ser. 10, vol. viii (1905) pp. 321–31.

[6] 'Tin-Mining in China' Mining Journal, vol. cix (1915) pp. 397, 439.

[7] J. B. Scrivenor, 'The Geology & Mining Industry of the Kinta District' 1913, p. 45.

Malaya are tentatively stated to be the 'equivalent of the Mahádeva Group, or possibly the Pánchet Group of the Indian Gondwanas,'[1] so that between the glacial clays and the Younger Gondwana Rocks of Malaya, the rocks of the Karharbari sub-stage and of the whole of the Damuda Stage are entirely absent. This would mean that a very important unconformity existed in Malaya, representing well over 8000 feet of strata in India, and yet an unconformity so obscure that in no section has it been possible to decide where it exists!

Palæontological evidence shows also that, even if the clays were of glacial origin, they could not be correlated with the Talchir Beds of India. As Mr. T. H. D. La Touche remarks,[2] it is difficult to understand how glacial deposits lying above the *Glossopteris* Beds can be equivalent to the Talchirs of India, which are older than the *Glossopteris* Beds.

VIII. Summary and Conclusion.

More than half of the Kinta district is occupied by granite which has proved to be stanniferous in a very large number of places, both in the Main Range and in the Kledang Range.

The isolated limestone hills are the result, not essentially of faulting, but of unequal denudation on a strongly jointed limestone; hence the position on the valley-floor of the stanniferous clays and 'boulder-clays' (other than the clays formed from the weathering of the schists and phyllites *in situ*) makes it impossible to regard them as being of Talchir age, or indeed as anything but alluvial deposits derived from the weathering-down of the neighbouring rocks.

The theory of the glacial origin of these deposits involves a number of improbabilities, among which may be enumerated:—

(*a*) Simultaneous faulting, over an extensive area, with fault-planes in various directions and throws of several hundreds of feet.

(*b*) Magmatic stoping, on an enormous scale, over selected areas only.

(*c*) The deposition of supposed Permo-Carboniferous glacial clays, containing different types of rock, in adjoining areas, the dividing line between them being coincident with the chief drainage-course of a valley of post-Cretaceous age.

(*d*) The superposition of two important tin-fields, one of Permo-Carboniferous age and the other of post-Cretaceous age, in one and the same district; and in the former case, in a very restricted part of that district.

(*e*) The absence of metamorphism in clays lying between highly metamorphosed beds and in contact, in places, with enormous masses of granite.

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[1] J. B. Scrivenor, 'The Geological History of the Malay Peninsula' Q. J. G. S. vol. lxix (1913) p. 356.

[2] *Ibid.* pp. 370, 371.

Tin-ore has now been proved *in situ* in the Kinta district:—

(1) In the stanniferous granite of the Main Range and the Kledang Range, which flank the Kinta Valley, and in several places are being exploited for tin-ore.

(2) In other stanniferous granite outcrops, almost certainly connected with the granite ranges, outcrops which have yielded, and are still yielding, tin-ore.

(3) In the schists, phyllites, quartzites, and indurated shales towards the granite-junctions, which in numerous places are worked for the ore occurring in them as stockworks, and in the granitic veins connected with the granite.

(4) In the large number of granitic intrusions traversing the limestone floor of the Kinta Valley, and forming an important source of ore.

The angularity of the boulders and tin-ore in a clayey matrix in the supposed glacial deposits is due in places:—

(*a*) To the weathering of phyllites, etc. into clay which sank gradually on the dissolving limestone underneath, resulting in the breaking-up of the veins of quartz and pegmatite traversing the phyllites.

(*b*) To soil-creep effecting the same result.

(*c*) To the breaking-up of the much-weathered tin-bearing pebbles in the alluvium.

Tin-ore has been found *in situ* either on the mine or on the property immediately adjoining it in eighteen out of the twenty largest tin-mines in the Kinta district.

Over 90 per cent. of the ore worked in the district is obtained from mines situated at less than a mile from granite or granitic intrusions, and over 80 per cent. of the ore is won from mines where granite or a granitic intrusion has actually been proved on the properties. Yet it is contended by Mr. Scrivenor that the tin-ore in these supposed glacial deposits was derived from another and distant source outside the Malay Peninsula.

It has now been shown that all the rocks and minerals present in the 'Gondwana clays and boulder-clays' of the Kinta district must have been derived originally from a cassiterite-bearing granite and from schists, phyllites, etc., metamorphosed by such a granite: in other words, that the 'clays and boulder-clays' must have been derived originally from an area containing rocks bearing striking and peculiar resemblance to those now *in situ* near the granite-junctions in this district.

At the same time, it has been shown that the acceptance of a glacial origin for these 'clays' implies that in a district in which tin-ore is being worked *in situ* at more numerous localities than in any other district in the world, the bulk of the ore in the clays in the lower part of the valley was brought by ice from an ancient tin-field hundreds of miles away to the west of the Malay Peninsula.

An alluvial origin for the clays, or their formation by weathering *in situ*, necessitates, on the other hand, only the postulate that the processes of weathering now actively at work in the Kinta district have continued over a long period.

EXPLANATION OF PLATES XIII–XV.

Plate XIII.

View of Kramat Pulai Mine, Kinta (F.M.S.): a band of lignite interbedded with the 'clays and boulder-clays.' Corundum 'boulders' and tin-ore occur in the clays above and below the lignite.

Plate XIV.

View of Lahat Mine, Kinta (F.M.S.). On the left the mica-schists are seen in contact with the granite of the Kledang Range. On the right the deposits are of alluvial origin. The limestone bed-rock is seen cropping out at the bottom of the mine.

Plate XV.

Geological sketch-map of the Kinta district on the scale of 3 miles to the inch, or 1 : 190,080; and section across the Kinta district from Gunong Irau to Gunong Hijau on the same horizontal scale.

Discussion.

The President (Dr. A. Smith Woodward) compared the phenomena described by the Author with those observable on the coast of Brazil, especially in the neighbourhood of Rio de Janeiro, where the deposits originally supposed to be of glacial origin were really the decomposition-products of the granitic rocks *in situ*.

Dr. J. W. Evans remarked on the sharp opposition between the views put forward by Mr. Scrivenor and those advanced by the Author. The former had done very valuable work in the Malay Peninsula, but the speaker thought that the latter had made out a strong case. His explanation of the structure of the country had the advantage of simplicity in comparison with that adopted by Mr. Scrivenor, and received strong support from the evidence adduced of the relation of the distribution of the minerals in the Gopeng Beds to the occurrence of the same minerals in the adjoining intrusive and metamorphosed rocks. The suggestion that the unstratified character of these deposits was the result of landslips was in accordance with the speaker's own experience in South America. When the rocks of steep slopes were converted into soft clay-like products by tropical weathering, there came a time when the weight of the altered material became too great to be supported by the cohesion at the surface of the unaltered rock, and it slid forward into the valley below.

Prof. W. W. Watts congratulated the Author on the results of his three years' work in the Federated Malay States. The exhibited specimens, maps, and statements seemed to make out a very good case for his explanation of the origin of the tin in that region—an explanation which appeared to be in accordance with what was known of stanniferous deposits elsewhere. He hoped that the Author would follow up his researches on tropical weathering. It was possible that weathering under subtropical conditions in the latitude of Great Britain might explain some phenomena hitherto unexplained in this country.

Prof. W. G. **Fearnsides** further congratulated the Author on the good case that he had made, and commented upon the Kinta district as an important source for the supply of those tungsten-ores that are now so much in demand for the manufacture of 'high-speed' steel. He enquired whether the Author had found it possible to draw any sharp chemical distinction between the clay-like residues which he attributes to the weathering *in situ* of felspathic rocks in a tropical climate, and the true china-clays or kaolins which, like the tin-lodes, are generally attributed to the pneumatolytic action of the granite.

Mr. T. **Crook** expressed appreciation of the paper, and agreed with previous speakers that the interpretation of the Kinta Valley sequence given by the Author was simpler, and, judging the evidence as a whole, more acceptable than that given by Mr. Scrivenor. However, as that writer was not present to defend his view with reference to the age of the boulder-beds, and as the discussion had revealed an overwhelming opposition to him on this question, it might be worth while to call attention to one or two observations to which Mr. Scrivenor had apparently attached some importance.

With regard to the origin of the alluvial tin-ore in the Kinta Valley, Mr. Scrivenor himself admitted that it had been derived in part from the Kinta granite-intrusions and from the disintegration of the limestone and other rocks that had been veined and impregnated as a result of this intrusion. But he also claimed that the boulder-beds containing detrital tinstone were in existence at the time of the intrusion. In support of this view, Mr. Scrivenor had definitely stated that the Kinta granite exists in intrusive relation with the boulder-beds. He stated further that the intrusive granite was a factor in the impregnation of these beds with tinstone, and that these later impregnations were of a type that could be clearly distinguished from the detrital tin already existing in the beds. These observations by Mr. Scrivenor had an important bearing on the question of age, and they apparently had largely contributed towards leading him to the conclusion that the boulder-beds were older than the granite intrusion.

Mr. A. E. **Kitson** remarked that, from the evidence adduced, the view advanced by the Author regarding the origin and age of the deposits appeared to be the correct one, and he congratulated him on his paper. He said that Mr. Scrivenor's description of the locality was published some time ago, and it seemed probable that since then local mining operations had disclosed evidence disproving his view of the glacial origin of the deposits. Among others, the absence of striæ on the pebbles was a strong reason for doubting such an origin. The photographs of the limestone cliffs and isolated blocks appeared to indicate that they were due to denudation and slipping of masses along master-joint planes, while the general character and disposition of the pre-granite deposits did not support the supposition of extensive faulting. The occurrence of tinstone on each side of the valley, but not in the middle of it, indicated its genetic connexion solely with the bordering intrusive granite. The peculiar weathering of rocks in the wet regions of the tropics was remarkable. In railway- and road-sections in the Gold Coast Colony he had seen thick masses of decomposed biotite-gneiss, of thin phyllites and altered sandstones, and of altered sandy mudstones which had changed into sandy clays, so similar as to be indistinguishable one from the other. The lamination of the rocks in large portions had disappeared entirely, and all of them might easily be mistaken in many places for clays of a late period.

Dr. Herbert H. Thomas regretted the absence of Mr. Scrivenor, but thought that the Author had presented to the Society mature conclusion based on careful observation. It was important to bear in mind that, when the Author commenced work in the Malay States, he was evidently inclined to regard the glacial origin as the only possible explanation of the peculiarities of the Gopeng Beds; but, as his work progressed, he came to regard the previously-accepted view as untenable. The speaker hoped that the Society would publish the paper, in order that it might be more fully discussed than was possible at the moment.

The Author, in the course of his reply, said that the study of British rocks by anyone familiar with weathering in a moist tropical climate would, as Prof. Watts suggested, be a useful piece of investigation, especially with respect to beds deposited during the prevalence of a tropical or subtropical climate. Prof. Fearnsides had raised the question of kaolinization, which was full of interest to him, for he had been fortunate in seeing the chief kaolin-deposits of China, some of those of Japan, and he had described elsewhere[1] those of the Federated Malay States. Kaolinization seemed to be the result of atmospheric weathering near Kingtehchen in China, and of both atmospheric weathering and pneumatolysis in Malaya. The kaolin resulting from the former cause was found, in several tests, to be less soluble in dilute sulphuric acid than similarly-treated kaolin from veins where pneumatolytic agents had obviously played an important part. He hoped to publish shortly the results of his observations on kaolinization, observations carried out in exceptionally favourable circumstances.

In answer to a question on the absence of a glaciated floor in the limestone underlying the clays of the Kinta Valley, it was necessary to point out that, although in India (near the village of Irai, along the banks of the Pem near its confluence with the Wardha) the Kadapah Limestone underlying the Talchir glacial clays is described as being deeply grooved, it should be remembered that the percolating water in the Kinta Valley, after flowing over

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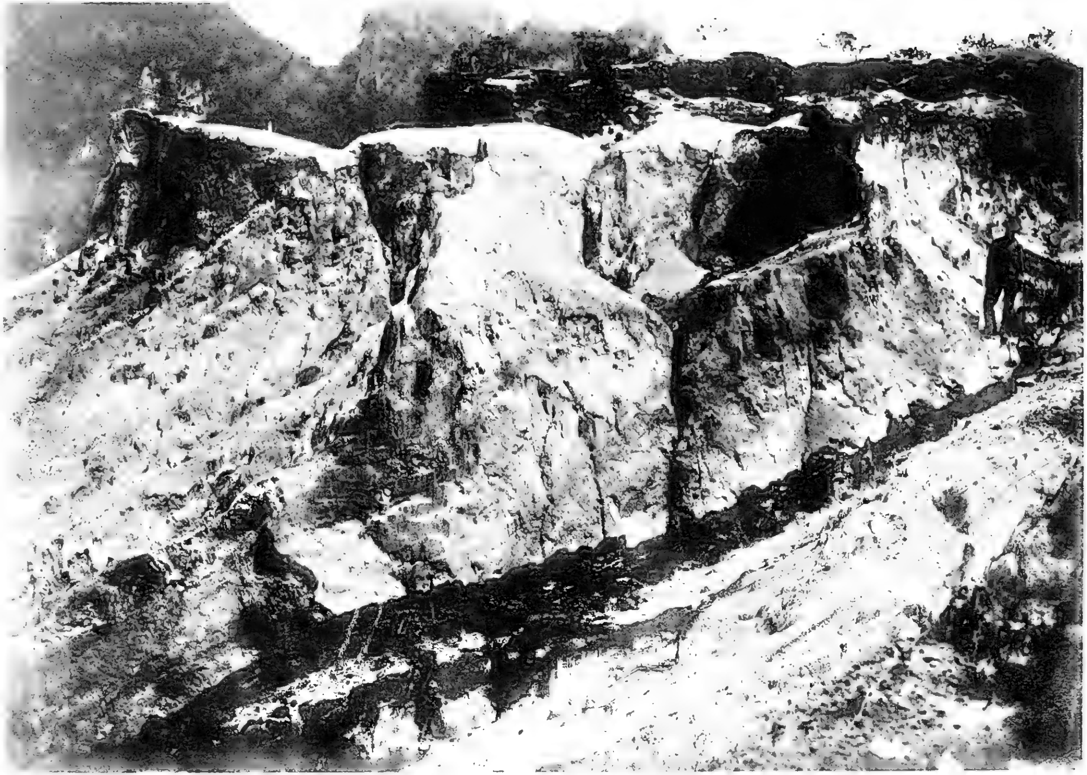
[1] W. R. Jones, 'Clays of Economic Importance in the Federated Malay States' Government Printing Office, Kuala Lumpur, 1915.



W.R.J., Photo.

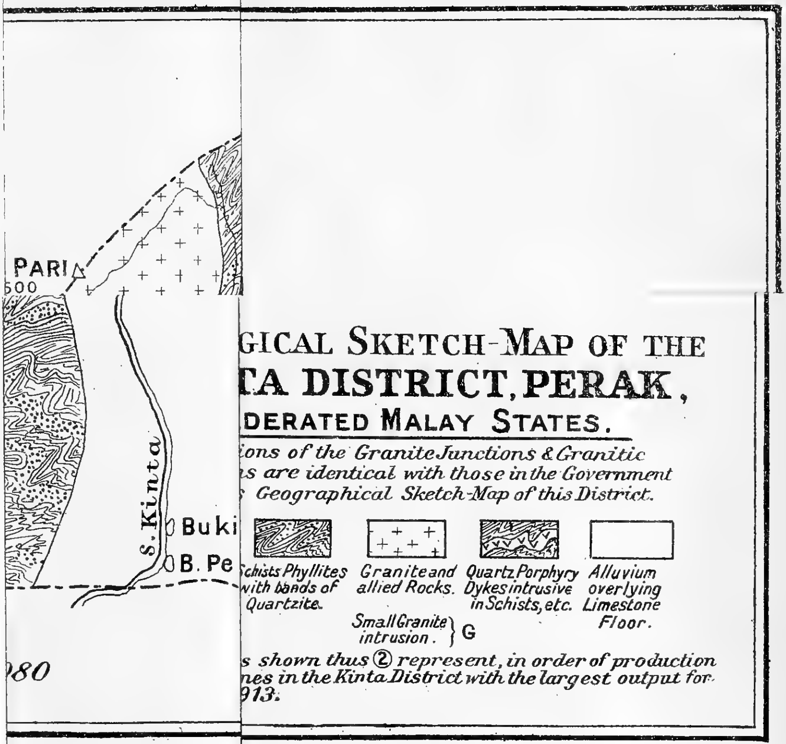
Bemrose, Collo, Derby

KRAMAT PULAI TIN-MINE, KINTA (F.M.S.).

W. R. J., Photo.

Bemrose, Collo, Derby.

LAHAT TIN-MINE, KINTA (F.M.S.).



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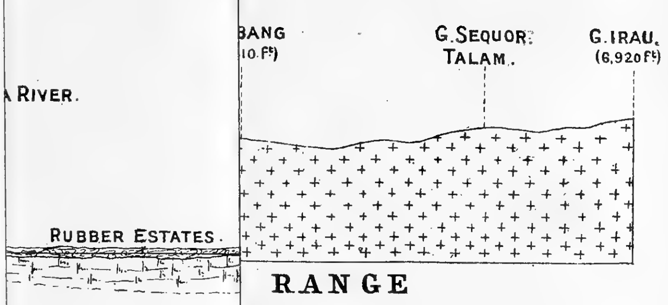

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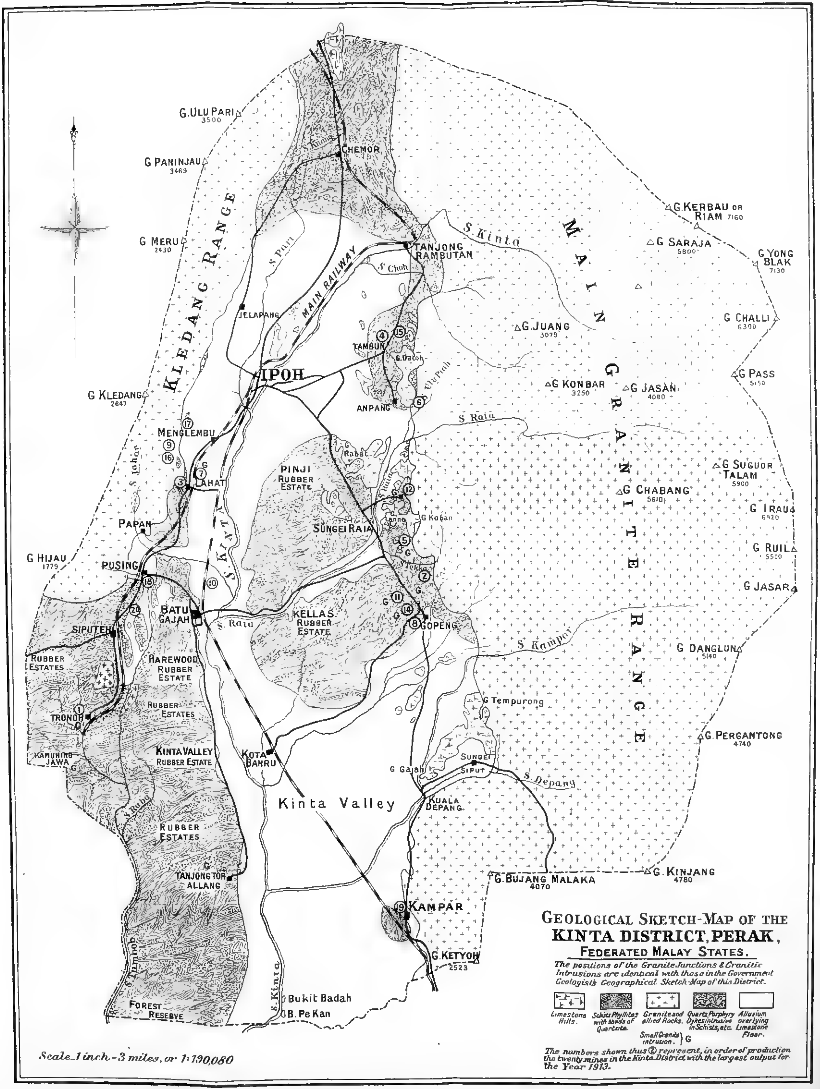
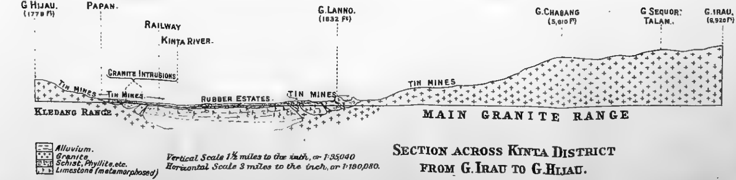


GEOLOGICAL SKETCH-MAP OF THE
KINTA DISTRICT, PERAK,
FEDERATED MALAY STATES.

The positions of the Granite Junctions & Granitic Intrusions are identical with those in the Government Geologist's Geographical Sketch-Map of this District.

The numbers shown thus ② represent, in order of production the twenty mines in the Kinta District with the largest output for the Year 1913.

Scale 1 inch - 3 miles, or 1:190,080



Vertical Scale 1½ miles to the inch, or 1:95,040
Horizontal Scale 3 miles to the inch, or 1:190,080.

SECTION ACROSS KINTA DISTRICT
FROM G. IRAU TO G. HIJAU.

H. & C. GRAHAM Ltd. LITHrs.

two steep granite-ranges, would probably dissolve the limestone to such an extent that no glaciated pavement would exist. He agreed with Mr. Scrivenor that no importance should be attached to the absence of such a glaciated pavement.

It was very difficult, as Dr. Thomas pointed out, to realize at first what tropical weathering could do; and only after great familiarity with the rocks in the field could one confidently offer an opinion. The speaker's mapping of the Ulu and Kuala Selangor districts had afforded him much help in understanding the structure of the Kinta district.

The only difference stated to exist, between the tin-ore in the 'clays and boulder-clays' and that in the admittedly alluvial deposits, is that in the former it is more angular. Mr. Scrivenor published a photograph, in his memoir on the Kinta district, to illustrate this point. It was significant, however, that the angular ore there figured came from a mine (Siputeh) where a lode was worked some years ago, and where cassiterite was definitely found *in situ* in 1914 by the manager and the Author. Mr. Scrivenor, in a lecture on 'Tin-Ore in Limestone'[1] agreed that tin-ore had been found recently *in situ* at this mine.

Mr. Kitson was correct in stating that later developments had yielded much information that was previously unobtainable. Mr. Scrivenor still, however, believed in his theory; his memoir and map of this district were only published in 1913, and in a recent paper in the 'Geological Magazine' (July 1914, p. 309) he stated that the glacial theory is the one that best explains the facts seen in the field. In the Annual Report of the Geological Department of the Federated Malay States for 1913, he (the speaker) wrote that in Ulu Selangor he had, in every case, traced the tin-ore from the valleys, up the streams, to schists and granite where tin-ore was definitely *in situ*.

With regard to the boulders, Mr. Scrivenor stated that not a single boulder showing undoubted glacial striæ had ever been found. Boulders were being continually washed out of the stanniferous clays, and excellent opportunities were given for examining thousands of them in the dump-heaps.

He thanked the Fellows for the kind manner in which they had received his paper, and for the interesting points raised in the discussion.

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[1] See 'Times of Malaya' Ipoh, 1914, & F.M.S. Chamber of Mines publication of this lecture.

10. *The* PSEUDOTACHYLYTE *of* PARIJS (ORANGE FREE STATE), *and its* RELATION *to* 'TRAP-SHOTTEN GNEISS' *and* 'FLINTY CRUSH-ROCK.' By S. JAMES SHAND, D.Sc., F.G.S., Professor of Geology in the University of Stellenbosch. (Read March 22nd, 1916.)

[PLATES XVI–XIX.]

CONTENTS.

I. INTRODUCTION.

IN the year 1913 I received from a former student of mine, Mr. P. H. S. De Wet, a consignment of rock-specimens from the neighbourhood of Parijs (O.F.S.). Among these were many pieces of a dense black rock, which, I was informed, occurs very abundantly in veins and networks in the granite. The characters of this rock seemed so remarkable that I took an early opportunity of visiting Parijs myself, in order to study the phenomena in the field. As a result of my observations, I formed the opinion that the black veins were intrusions of basic magma which had entered the granite by a process of stoping, accompanied by corrosion and solution; and a paper embodying this conclusion was communicated to the Geological Society in November 1914, an abstract of it appearing in the Proceedings of the Society for that month (No. 964). After the manuscript had left my hands, I became aware for the first time of the work of Sir Thomas Holland and his colleagues of the Geological Survey of India on the 'trap-shotten gneiss' of Salem, Madras, and I could not fail to be struck by the resemblance between some of the phenomena there described and those observed by me. My attention was next turned to the 'flinty crush-rocks' of the Cheviot Hills and other parts of Scotland, which were also at one time held to be of igneous origin. By the kindness of Dr. Flett, the late Dr. Clough, and Mr. E. B. Bailey, I was enabled to study hand-specimens and sections of a large number of these rocks; and although, on comparing them with my own material, I found the differences to be at least as numerous as the resemblances, it became clear that I must reconsider the features of the Parijs occurrence in the light of the evidence derived from other regions. Parijs was accordingly revisited during 1915, and such fresh information and illustrations as were gained have been embodied in the account which is now presented.

It should be explained that the name pseudotachylyte has been adopted in recognition of the fact that these rocks have a great similarity to tachylyte, also that such rocks have been mistaken for trap and tachylyte in Scotland and India as well as in South Africa, and for the further reason that no more suitable name is in existence. 'Trap-shotten gneiss' denotes the entire complex of intrusion and intruded rock, and is misleading in view of the fact that the intrusive part is not certainly 'trap' at all; while 'flinty crush-rock' begs the question—as regards the Parijs rocks, at least.

II. Occurrence in the Field.

The township of Parijs lies upon the northern portion of the Vredefort granite-mass and on the southern bank of the Vaal River. The granite, which has an outcrop of some 400 square miles, has generally been regarded as Archæan (that is, pre-Witwatersrand), and appears as such on Dr. F. H. Hatch's map of the Transvaal; but Dr. Molengraaff, and more recently Mr. F. W. Penny, have held that this granite is in reality intrusive in the Witwatersrand System. No detailed survey of the region has yet been made.

The 'granite' in the neighbourhood of Parijs is a streaky granitic gneiss, composed of red and grey elements. Sometimes the red forms patches and streaks within the grey, elsewhere the grey matter is similarly enveloped by the red, or again the two elements may constitute alternate bands. The red matter often forms veins and bands of coarse pegmatite which run parallel to the direction of foliation of the grey rock, but in other cases such veins cut sharply across the foliation. These pegmatites are occasionally very coarse-grained graphic granites. When extensive exposures are studied, it becomes evident that the red portion is of later consolidation than the rest of the rock. Isolated 'floaters' of banded grey paragneiss can be found embedded in the red granite; and, to my mind (although I have not made a special study of the gneiss-granite), the matter is susceptible of one interpretation only, as follows:—the grey facies of the granitic gneiss results from impregnation, metamorphism, and eventual assimilation of sedimentary country-rock by the ascending magma, while the red is the residual portion of the same magma. Probably neither part reproduces the initial composition of the magma exactly.

The red bands are composed essentially of quartz and felspar, with a very small proportion of biotite. Cleavage-pieces of the red felspar show it to be a true orthoclase; the red coloration is unevenly distributed, and is especially intense in the neighbourhood of cracks. The larger crystals often pass externally into micropegmatite. The grey bands contain much oligoclase with practically straight extinction, also a variable but generally large proportion of biotite which often exceeds 50 per cent. I have not observed any hornblende in the few slices that I have cut; but at the weir, 2 miles above the township, bands of a bright-green amphibolite occur in the granite.

The special interest of the district attaches, not to the granite-gneiss, but to a remarkable system of veins of apparent tachylyte which intersect the granitic rocks everywhere throughout the area north of Vredefort. Of the southern portion of the area, where exposures of the granite seem to be much less numerous, I am unable to speak. The best exposures are seen in the bed and banks of the Vaal, where the scour of the running water cleans and smooths the rock-surfaces; the veins then show up jet-black and exhibit a highly polished surface, thus affording a strong contrast to the rougher grey surface of the granite. Elsewhere they weather grey or greenish, and are then difficult to distinguish from the granite. On each of my visits I took a large number of photographs of these veins, but many of the exposures were so difficult to 'catch' (on account of their awkward situations, irregular surfaces, slight colour-contrasts, and so on) that I found it desirable to supplement my photographs by scale-drawings, some of which are reproduced herewith.

The highly irregular, branching intrusion of Pl. XVI was exposed in a deep cutting made for one of the piers of the new bridge; the rock-face shown is about 7 feet high, which will give a measure of the dimensions of the intrusion. This cutting has since been filled up. The photograph reproduced in Pl. XVII, fig. 1 was obtained in another excavation near the first; it shows a vein turning from a vertical to a nearly horizontal plane and thinning out. The width of the vein is 6 inches at the centre of the photograph. The detail of the blind end of this vein is shown in text-fig. 8 (p. 203). Pl. XVII, fig. 2 shows a large block which has been thrown out by blasting operations at the weir, above the town; the entire block is only a portion of a wide dyke of pseudotachylyte. The floaters of granite which are embedded in the dark base are so numerous and so perfectly rounded that the rock resembles in appearance a sedimentary conglomerate. This is a most remarkable specimen, and, despite its weight, which must be about a ton, one would like to see it removed entire to a museum.

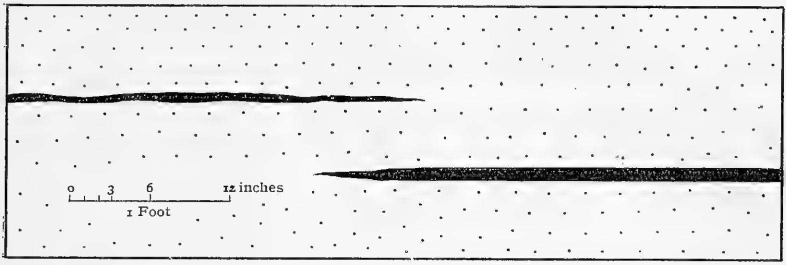
The characteristic features of the intrusions, as seen in the field, are summarized in the following paragraphs:—

The veins are utterly irregular in form, direction, and thickness (text-figures 6, 7, 10–13; Pl. XVI).

They have every inclination from vertical (Pl. XVI) to horizontal (Pl. XVII, fig. 1), and they strike towards all points of the compass.

They change their direction again and again, and often follow sinuous

Fig. 1.—*Blind veins, above the boathouse.*



[The one on the right can be traced for about 7 feet; it runs perfectly straight, and is 1 inch wide. Within 5 inches it thins out and terminates.]

Fig. 2.—*Branching, and a blind vein, seen near the boathouse.*

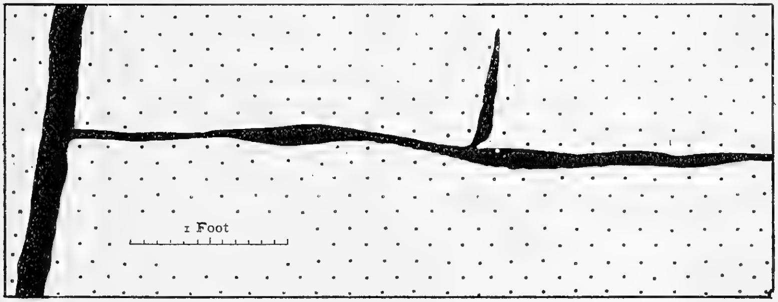
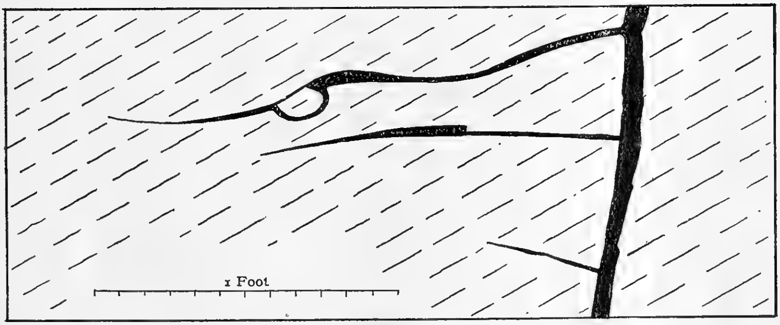


Fig. 3.—*Branching and blind veins, near the boathouse.*



[The broken lines indicate the foliation of the granite.]

Fig. 4.—*A thin vein* ($\frac{1}{8}$ *to* $\frac{1}{4}$ *inch*) *of pseudotachylyte following the margin of a pale band in granite-gneiss, in part breaking across it and sending venules into it; 200 yards above the boathouse.*

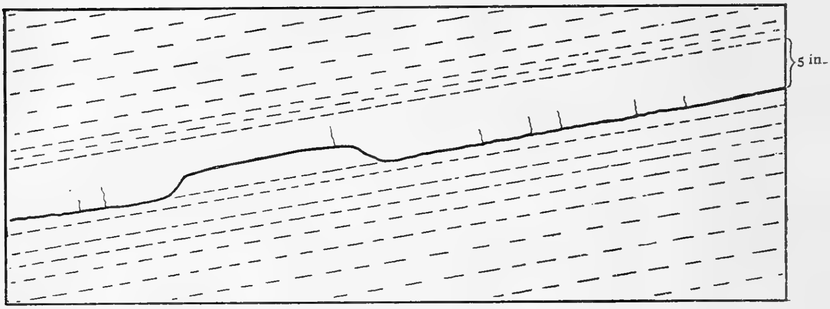


Fig. 5.—*A pegmatite vein faulted 2 inches by the pseudotachylyte.*

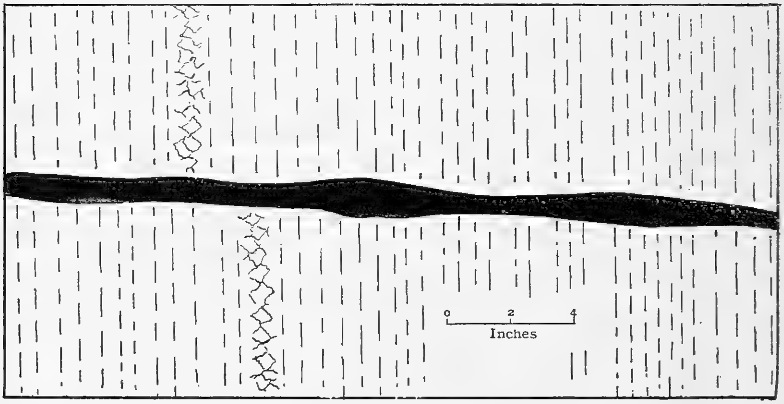
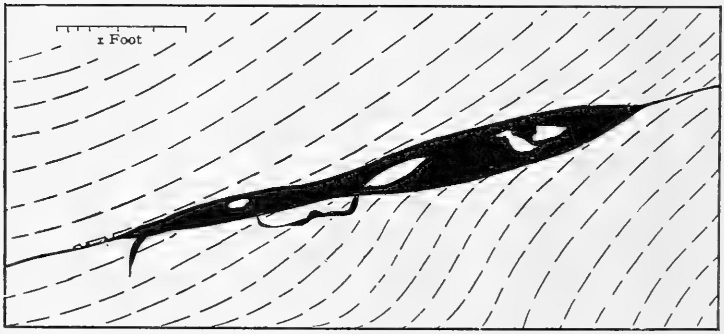


Fig. 6.—*Pseudotachylyte a quarter of a mile below the bridge.*



[The broken lines indicate the foliation of the granite.]

Fig. 7.—*Pseudotachylyte a quarter of a mile below the bridge.*

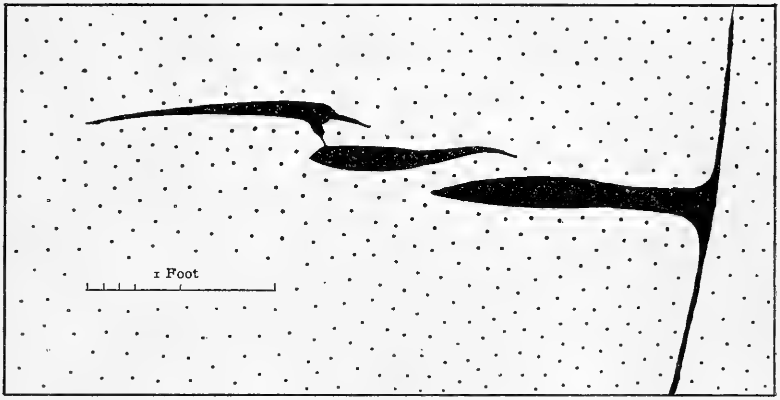
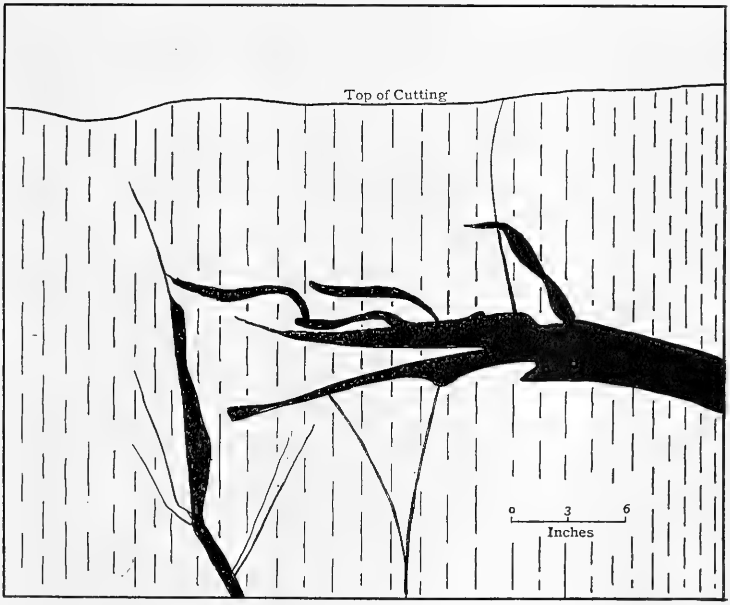


Fig. 8.—*The vein shown in Pl. XVII, feathering out at its end. Cutting below the bridge.*



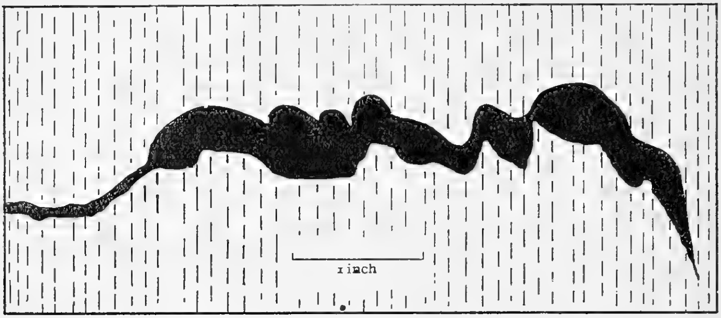


Fig. 9.—*A wavy band cutting across the foliation of the gneiss, at the end of the blind intrusion illustrated in Pl. XVII. Vaal River Bridge.*

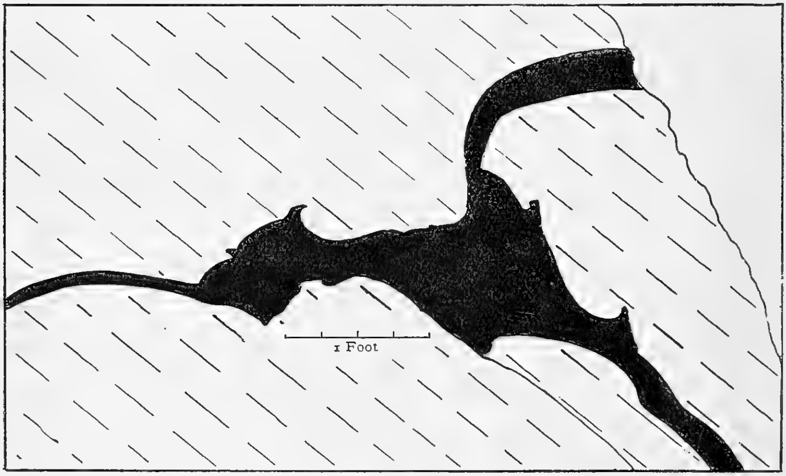
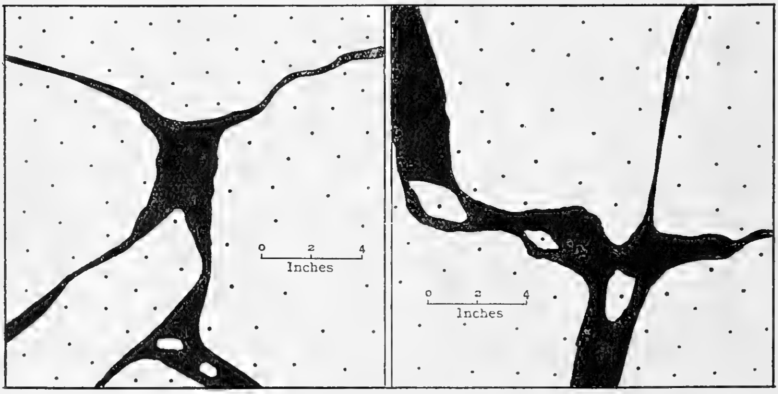


Fig. 10.—*Vein seen below the bridge.*

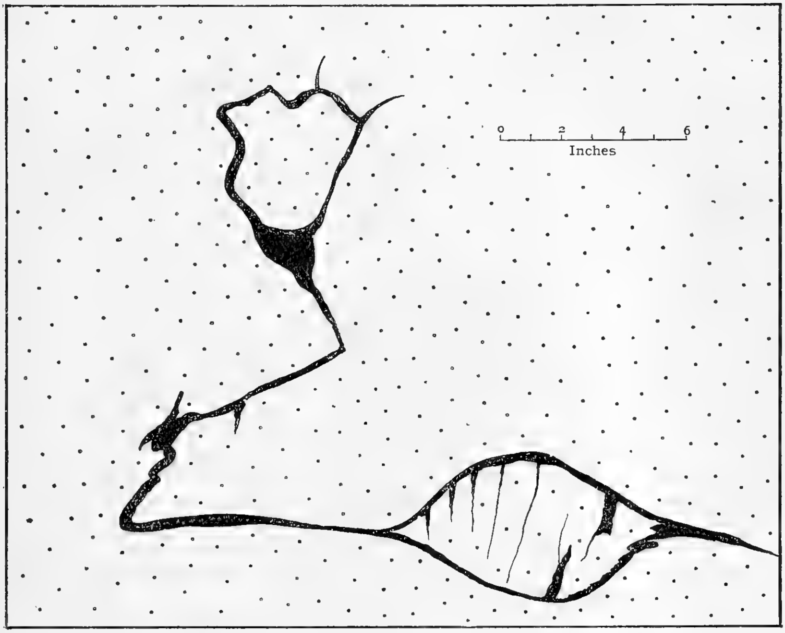


Figs. 11 & 12.—*Veins seen 200 yards above the boathouse.*

11.

12.

Fig. 13.—*Pseudotachylyte 200 yards above the boathouse.*



courses (text-figures 2, 3, 9–13) and their direction is entirely independent of the foliation of the granite (text-figures 3, 5, 6, 8, 10).

They thicken and thin repeatedly and rapidly (text-figures 6, 7, 9, 10–12), give off branches at high and low angles (text-figures 2–4, 7, 8, 10–12), and often anastomose in the most complicated way (text-figures 10–12).

In innumerable cases they thin out and terminate blindly (text-figures 1–3, 7, 8, & Pl. XVII, fig. 1).

The contact with the surrounding granite, as seen with the naked eye, is perfectly abrupt. The granite is never sheared parallel to the course of the veins, its texture remains unchanged, and the felspars continue to show large bright cleavage-faces and straight twinning lamellæ, right up to the surface of contact (Pl. XIX, fig. 1).

The junction-line is often nearly straight for distances of many feet, especially in the case of those veins which are not more than a few inches thick (text-figures 1, 2, 4, 5, & Pl. XVII, fig. 1); in other cases it is strongly serrated (Pl. XVI).

The veins vary in width from a fraction of an inch up to 2 or 3 feet; but in the thicker veins there are always numerous inclusions or floaters of granite which occupy a large proportion of the stated width, and the black base is often reduced to the rôle of a mere cement for the floaters (Pl. XVI, & Pl. XVII, fig. 2). The floaters range from boulders a couple of feet in diameter down to minute grains, and they are far more frequently rounded or turbinate than angular (Pl. XVII). In an average sample about 20 or 25 per cent., but in some cases (Pl. XVII, fig. 2) as much as 80 per cent., of the contents of a vein consists of boulders and fragments visible to the naked eye.

The black base in which the granite floaters are embedded is a compact black rock, like a microcrystalline basalt or tachylyte, capable of taking on a high polish. Apart from grains of quartz and felspar derived from the granite, no constituent of the black rock can be recognized even with a lens, nor is it possible to say whether the rock is crystalline or vitreous.

It is in most cases quite impossible to determine whether the veins act as faults. Sometimes a movement of one side of the vein, amounting to not more than 2 inches, can be proved (text-fig. 5, p. 202), but no proof of great displacements was found. Some of the boulders illustrated in Pl. XVI have been shifted only an inch or two from the walls which furnished them.

III. MICROSCOPIC CHARACTERS OF THE PSEUDOTACHYLYTE.

Sections of most of these rocks must be cut very thin, in order to secure even moderate transparency. The photomicrograms shown were taken by electric light, with exposures up to 2 minutes, yet the base of the rock appears perfectly black, and only the inclusions exhibit detail. The opacity of the base is due to a multitude of minute black specks (of magnetite), which not only stop a great deal of light, but also make it extremely difficult to determine the nature and properties of the transparent components of the ground-mass. Examination of a large number of slides, all made by myself, has shown that three types of ground-mass are represented, as described below. The inclusions are alike in all cases, and will be described afterwards.

Type 1.—This is the most opaque type of all, and is found generally in the thinner veins, those less than a couple of inches wide. Clouds of magnetite-grains of irregular shape obscure all detail. Behind these grains one sees a structureless background, which is not perfectly isotropic, but gives dull-grey tints between crossed nicols. The mass is not homogeneous, since different parts do not extinguish at the same time, but boundaries between the different portions cannot be made out; the appearance is not in the least suggestive of a powder. Some specimens are nearly isotropic, of very dark colour, and show a concentration of the black colouring-matter at many centres. A slight streakiness of the colouring-matter, suggestive of flow-structure, is rarely seen. Fragments of these black rocks, free from visible grains of quartz and felspar, were picked out and placed in bromoform (specific gravity = 2·8); they all floated.

Type 2.—In this type a certain amount of crystallization has taken place. The magnetite-grains are in part tiny octahedra, and are accompanied by swarms of grains and scales which are pleochroic from yellowish green to pale grass-green (Pl. XIX, fig. 3). These are so minute and so abundant that in the thicker parts of the slides, as also in the specimens of the finest grain, one has merely an impression of greenness over all. Sometimes the prisms form definite collars or mantles around the xenocrysts. The length of the largest prisms does not exceed 0·08 millimetre, and the average is much less; the breadth is from 0·02 mm. downwards. The extinction of the prisms lies between 10° and 20°; they have high refraction and low birefringence (first-order colours), and they show a perfect cleavage parallel to their length. I am not able to distinguish cleavage in cross-sections, but of all the common rock-minerals the characters just enumerated clearly indicate a hornblende. Tiny scales of brownish-green biotite are also present in less abundance. Through the clouds of magnetite, hornblende, and biotite-grains, one sees again a feebly polarizing background which is either indeterminable, as in type 1, or else passes over towards type 3.

Type 3.—This type of ground-mass is found in some of the widest veins, but also in some thinner ones, which are not externally different from the others. It does not seem to constitute entire veins, but to occur in patches within rocks which also show type 2. Considering the invariable blackness of the rocks, it is surprising to find that the section often shows very little of dark or opaque minerals, but consists either of a honeycomb of polygonal spherulites of a dark-brown colour, showing a perfect cross between crossed nicols (Pl. XIX, fig. 4), or of a felt of felspar-microlites with a subordinate amount of magnetite-dust and a few green scales in the interstices (Pl. XIX, fig. 5). The microlites rise to 0·05 mm. in length and 0·01 in width. They are all twinned, and, although their small size makes the determination difficult, it seems that both Carlsbad and albite twins are present. The extinction is always straight or practically so, and it is probable that both orthoclase and oligoclase are represented. The arrangement of the microlites is generally radial, not parallel, and it is thought that the stellate groups of microlites have developed out of spherulites.

The granite-walls and inclusions.—I have cut various sections across the junction between granite and pseudotachylyte, and I find that in general the granite shows no change which can be traced farther than 1 or 2 mm. from the edge. In some cases this junction is absolutely sharp, and the granite betrays no change whatever. Such a junction is shown in Pl. XIX, fig. 1, where a single plagioclase crystal is seen to be cut sharply across, as if by a knife; a few tiny cracks are observed at right angles to the fractured surface, and along these there has been a very slight faulting of parts of the crystal; but, with this exception, the twinning lamellæ are perfectly straight, showing that there has been no shearing of the granite parallel to the vein. This is not an isolated instance—I have observed the same feature in several slides. The general conclusion as to the absence of shearing in the granite holds rigidly for every case that I have studied in the field or in the laboratory. In one case a crystal of titanite was found, half of which is embedded in the granite-wall, while the other half projects well into the tachylyte-vein; here is proof positive of the absence of shearing.

In other cases the quartz- and felspar-crystals of the granite, within a space of 1 or 2 millimetres from the edge, are considerably cracked, show a very irregular extinction, and are invaded by tongues of pseudotachylyte. Fragments of quartz and felspar actually enclosed in the vein-rock are much cracked, the quartz-grains in particular showing a beautifully minute mosaic structure between crossed nicols. This granulation is unaccompanied by schistosity, and is such as might have been caused by rapid heating of the crystals. Pl. XVIII, fig. 2 shows granitic fragments floating in tachylyte just at the margin of a vein. The shadowy grains are felspar, the clear white grains are quartz. All the grains show fretted, embayed outlines, and the suggestion of active corrosion by the black base is very strong. Actual proof of melting of felspar is contained in Pl. XVIII, fig. 1 & Pl. XIX, fig. 2, which are taken from the margin of a large vein. In these photographs the quartz-grains stand out in clear relief from a matrix of half-melted felspar which shows viscous flow-structure.

Sometimes the included felspars are red, and present a compact, felsitic appearance. Slices cut through these red felspars show that the whole substance is minutely granulated, and that in part the felspar has been fused and has afterwards crystallized in the form of perfect spherulites.

It is remarkable that only the quartz and felspars of the granite appear among the inclusions; in no single instance is the biotite preserved. In view of the evidence of high temperature shown by the melted felspar, this becomes intelligible: biotite is decomposed by moderate heat, and its decomposition has furnished the abundant magnetite of the base of the rock. Although felspar is more abundant than quartz in the granite, yet among the inclusions quartz is more noticeable than felspar. In one case an inclusion of amphibolite was discovered in one of the veins. The bright-green hornblende shows no granulation, and is quite unchanged save at the very edge of the inclusion, where it loses its well-developed cleavage and takes on a fibrous appearance, although keeping its pleochroism and its uniform extinction. Round about the inclusion the pseudotachylyte is coloured green, hence solution is again indicated.

The only other xenocrysts that I have observed are a few unchanged crystals of zircon, sphene, and magnetite. The pseudotachylyte is always perfectly fresh, and no hydrous secondary minerals have been observed in any case.

IV. The Case for the Igneous Origin of the Veins.

The evidence which suggests an igneous origin for these veins, and led to their being regarded as tachylytes in the first instance, may now be summarized:—

(1) The mode of occurrence in the field, as described above—which is quite consistent with an igneous intrusive origin, but difficult to reconcile with any other known manner of formation.

(2) The abrupt contacts between vein-rock and granite, and the absence of shearing in the granite.

(3) The common occurrence of blind intrusions.

(4) The presence of rounded boulders and fragments in the veins, as also the microscopic evidence of corrosion and even fusion of these and of selective destruction of the constituents in a definite order.

(5) The presence of spherulitic and microlitic structures that find their nearest analogues in vitreous dyke-rocks and lavas in which crystallization has taken place subsequent to consolidation as glass.

(6) The sharp distinction which exists between the inclusions and the matrix.

(7) Although unquestionable igneous intrusions are not often seen in the granite, yet there is at least one basic dyke of the largest size in the very heart of the area, thus demonstrating the presence of basic magma in depth. This is a dyke of granophyric quartz-dolerite, nearly 600 yards wide, which is exposed in a shallow valley at the weir, above Parijs. Mr. J. W. Penny has described basic intrusions in the Lower Witwatersrand Beds which overlie the granite.

V. Comparison of the Pseudotachylyte with 'Trap-Shotten Gneiss' and 'Flinty Crush-Rock.'

The term trapshotten (that is, trap-injected) gneiss was employed by W. King & R. B. Foote for parts of the gneiss of Salem (Madras), which they describe as being 'very largely impregnated or shot with strings of dark green or bluish-black compact trap.' The supposed trap-veins of this area were subsequently studied by Sir Thomas Holland, who found them to consist of an indurated black dust, through which fragments of quartz and felspar are disseminated. He was able to imitate the material by heating powdered gneiss to white heat in a furnace, and he concluded that the production of the veins was due to the brecciation of the gneiss along certain lines, but not to injection of trap; the black colour and indurated nature of the material he ascribed to the action of heat produced during the violent brecciation of the rock.

The manner in which these dark veins occur in the field, as described and illustrated by the above-mentioned writers, recalls many of the features of the Parijs occurrence. Important points of difference, however, are that the so-called 'trap-shotten' bands occur in roughly parallel belts which coincide with lines of dislocation, and that they are often associated with true igneous intrusions of a basic nature. With regard to microscopic characters, the difference is fundamental; in no single instance that I have observed can the matrix of the Parijs rocks be described as a 'black dust' or powder.

In Scotland rocks of somewhat similar characters to the above have been described as 'flinty crush-rocks' and mylonites. Many references to such rocks occur in the Geological Survey Memoir on the North-West Highlands, and attention may be drawn especially to the descriptions on pp. 124, 221, and 249. It is again significant that the veins are found only in highly dislocated regions—especially along, or in the neighbourhood of, well-marked fault-planes and zones of crushing. In most cases the flinty material is associated with bands of a more clearly granulitic or mylonitic character, and it has been suggested that by the intensity of the crushing sufficient heat may have been generated to fuse small portions of the rock. Some of the specimens in the Geological Survey collection show the occurrence of black flinty material as streaks within ordinary mylonite, apparently confirming the above view; a good example of this is Slide 12933.

Dr. Harker has described crush-lines in granite near Broadford (Skye), and notes that the most marked effects are restricted to the vicinity of faulted boundaries. The flinty crush-rocks of the Cheviot Hills, discovered by the late Dr. C. T. Clough, also occur along crush-lines in granite. Sections of these rocks, which Dr. Clough kindly permitted me to examine, show the clearest evidence of shearing; but they range from obvious mylonites, consisting of angular fragments of quartz and felspar, to very dense, structureless, black bands the origin of which might have remained obscure if they had not been associated with coarser granulitic material. Dr. Clough informed me that these veins were at one time considered to be of igneous origin; in my view, however, their true nature is unquestionably clearer than that of the Parijs rocks. The specimens that exhibited the nearest approach to the characters of the pseudotachylyte of Parijs came from Cunyan Crag (Cheviots). Dr. Clough also showed me a flinty crush-rock from South Ben Lee, North Uist (Hebrides), which, in regard to the extreme opacity of its base, almost defying microscopic resolution, resembled the densest examples of my Parijs type 1.

Dr. Clough, Mr. Maufe, & Mr. Bailey discuss flinty crush-rocks at some length in their paper on the cauldron subsidence of Glen Coe, and give a convenient summary of some of the literature mentioned above. They show that at Glen Coe dark, apparently tachylytic, rocks have been produced by the shearing of various types of rock, quite independently of igneous action. Of especial interest is their observation that in some cases 'the flinty crush-rock has been injected as a fluid away from its source of origin.' By the courtesy of Dr. Flett and the late Dr. Clough and Mr. Bailey, I was enabled to study a large number of hand-specimens and sections from this area, as well as from other parts of Scotland. I found that the majority of them were unmistakable mylonites, or eyed gneisses on a microscopic scale; but there seemed to be a representative of every stage between these and a type with almost unresolvable dense base, which may show flow-structure or may lack every trace of orientation. Only the most extreme examples of the latter type are comparable to the Parijs rocks, and none of them showed anything similar to the crystallization of felspar and hornblende seen at Parijs. The points in which these rocks begin to resemble those of Parijs are the following:—

(1) The base of the rock is sometimes structureless and opaque, and full of tiny black grains, which are in part euhedral crystals of magnetite.

(2) Larger fragments are sometimes rounded, and have what look like reaction-rims, or their margins may appear to have been corroded. Internally they may exhibit a mosaic structure.

(3) In rare cases there are beginnings of crystallization in parts of the base, and in one instance (Meall Riabhach, Ross-shire) typical trichites are developed.

Out of all the material that I examined I was able to select only four specimens of which I could fairly say that they showed a close approach to my Parijs rocks of the first type.[1]

Typical flinty crush-rocks are developed on a very large scale in the province of Olavarria (Argentine Republic), where they have

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[1] The sections in the Geological Survey collection bear the numbers 12332, 13402, 13403, 12934, 4281.

been studied by H. Backlund. In his memoir on the subject, Backlund traces the mechanical alteration of a coarse porphyritic granite into a black horny rock with relics of felspar-phenocrysts. Optical deformation of the brecciated fragments is said to be visible in every preparation, and as there is no obvious recrystallization it is concluded that the breccia has not been submitted to any very high temperature. Backlund compares these rocks with Scottish flinty crush-rocks, which they appear to resemble closely. Four chemical analyses are tabulated, two of different facies of the granite-gneiss and two of mylonites. The analyses of mylonite do not differ more from the analyses of granite than do the latter one from the other, and, in particular, the analysis of a 'dense black mylonite with red spots of microcline' corresponds almost exactly to the mean of the two analyses of granite-gneiss.

The only other part of the world from which I have been able to obtain useful information regarding crush-rocks and pseudotachylytes is Little Namaqualand, the north-western corner of the Cape Province. I am indebted to Dr. A. W. Rogers for the following note on the subject:—

> 'The trap-shotten rocks in Van Rhyn's Dorp and Namaqualand are massive gneiss and occasionally the mica-diorites of the copper-bearing intrusions. The cracks are rarely half an inch wide, usually less than a tenth of an inch. They—or, rather, the instances observed—are in groups several feet long, and the individual cracks give off branches and join up with their neighbours. Though they have no constant direction, the cracks in any one group are parallel in a rough way, and at Jubilee Kop and on Mining Lease 81 they cross the foliation of the gneiss approximately at right angles. The strings are black.'

In sections of one of these black veins from Flamink Vlakte (Namaqualand) I was able to determine the following characters. Under a low magnification the appearance seen is that of a powder consisting of sharp angular grains of quartz and felspar of all sizes, with a sort of cement of green scales. Even the highest magnification fails to reveal anything of the nature of a glassy, spherulitic, or microlitic base. The quartz and felspar fragments are mostly free from cracks, and give a perfectly uniform extinction, while the plagioclases show normal twinning lamellæ. The green scaly substance lying between the colourless grains is made up of shapeless scales of biotite, with perhaps a few scraps of hornblende of the same colour. This biotite seems to be mainly detrital, just as the quartz and felspar are, but some of it may conceivably have crystallized in place. There is absolutely no suggestion of corrosion, melting, or recrystallization of the quartz or felspar, and nothing whatever to indicate that the temperature was high. Magnetite, which renders the Parijs rocks so dark and opaque, is nearly absent. A few grains of zircon are visible, some of them being enclosed in the larger biotite-scales.

As an illustration of this mylonitic type of crush-rock, which appears to be the standard type in all the regions above described, except Parijs, I include a photomicrograph of the rock of Flamink Vlakte in Pl. XIX, fig. 6. The essential difference between pseudotachylyte and flinty crush-rock is impressively shown when this photograph is compared with Pl. XVIII, fig. 2.

The facts that have been established so far may conveniently be tabulated in the following form:—

(*a*) Black rocks are composed of crushed material without recrystallization or any evidence of elevated temperature: Argentine; Namaqualand; most Scottish and Indian localities.
(*b*) Black rocks are composed of crushed material, but with evidence of high temperature approaching the melting-points of some of the constituents, and with beginnings of crystallization: some Scottish localities, especially Glen Coe, Meall Riabhach, and North Uist; some Indian localities (?).
(*c*) Black rocks hold inclusions of fragmental material, but lack proof of origin by crushing; the temperature exceeded the melting-point of felspar, and spherulitic and microlitic crystallization took place: Parijs.

Regarding the evidence from a purely qualitative standpoint, it would seem that we have a complete series of rocks connecting up the pseudotachylyte of Parijs with ordinary mylonite, the various links in the series being as follows:—

mylonite → fritted mylonite or flinty crush-rock → fused mylonite or pseudotachylyte (type 1) → recrystallized pseudotachylyte (types 2 & 3).

Arguing on these lines, it is possible to maintain the view that pseudotachylyte is simply an extreme form of flinty crush-rock, the production of which involved a greater generation of heat than usual.

Against this view of the origin of pseudotachylyte there are some very weighty arguments. The supposed series of rocks connecting pseudotachylyte with mylonite, although qualitatively complete, is very imperfect when examined quantitatively. In all the regions that have been mentioned here, except Parijs, the first member of the supposed series is abundant, the second member much scarcer, the third member is limited to a few minute or even microscopic occurrences, while the fourth member does not occur. At Parijs, on the other hand, the first and second members are entirely absent (at least a close search has failed to reveal them), while the third and fourth members occur in great abundance throughout a large area. These considerations cast the gravest doubt upon the actual continuity of the supposed series. In fact, the only conclusion that the study of flinty crush-rocks entitles us to draw is that products similar to pseudotachylyte can be, and in rare cases have been, produced by crushing and heating associated with movement along planes of dislocation.

Further objections to the comparison of pseudotachylyte with flinty crush-rock are as follows:—

(1) The absence of shearing and cataclastic phenomena in the granite. This can only be accounted for by supposing the fractures to have been produced by sudden snapping of the granite in response to a sudden stress; but how, unless there was long-continued friction, could the quantity of fine dust necessary to fill the fissures be supplied?

(2) The common occurrence of blind veins seems positively to exclude the possibility of long-continued friction; the blind veins do not differ in texture or composition from the others.

VI. THE CHEMICAL COMPOSITION OF THE PSEUDOTACHYLYTE.
(See also Appendix, p. 217.)

When I first examined these rocks, I had no means of making a chemical analysis of the material. Subsequently, when the question of the origin of the pseudotachylyte was reopened, my assistant, Mr. R. A. Page, kindly undertook to perform the necessary analyses, and the figures given below are due to him. In justice to Mr. Page, I must state that the work was performed under very unfavourable conditions, with a deficient supply of platinum vessels, with acetylene burners and a spirit blast-lamp for ignition, and without reagents of special purity; consequently, it was not expected that a high degree of accuracy could be attained. The summation of the analyses is low; but, as we are concerned rather with the general chemical character of the rock than with the very precise determination of individual constituents, the result has proved quite serviceable, and I desire to record my great indebtedness to Mr. Page for his careful labour. The figures are given in the first two columns below; those in the third and fourth columns refer to Backlund's analyses of black mylonite and grey mylonite respectively, the minor constituents being omitted:—

	I *a*.	I *b*.	II.	III.
SiO_2	62·03	62·66	65·75	68·24
TiO_2	n. d.	n. d.	0·66	0·01
Al_2O_3	16·57	16·26	15·56	16·08
Fe_2O_3	2·51	2·51	0·64	0·81
FeO	2·90	2·89	3·30	2·20
MgO	0·39	n. d.	1·77	0·40
CaO	3·39	3·99	3·75	3·42
Na_2O	6·37	5·88	3·11	3·34
K_2O	3·41	2·75	4·11	3·99
H_2O-	0·16	0·96	0·08	0·08
H_2O+	0·72		0·69	0·83
CO_2	0·00	...	0·74	0·59
Totals	98·45	97·90		

TiO_2, ZrO_2, MnO, and P_2O_5 were present in small quantities, but were not determined by Mr. Page.

The rock chosen for analysis shows a combination of the characters of types 2 & 3 as above described—that is, it contains both felspar-laths and hornblende-prisms, with magnetite. The average diameter of grain is 0·01 millimetre, and the usual quartz- and felspar-inclusions are present in comparatively small amount in the hand-specimen, although well-rounded inclusions are very numerous under the microscope. An apparent discrepancy exists between the abundance of hornblende in the ground-mass of the rock and the rather low figure for magnesia in the analysis; but it is possible that the place of magnesia is largely taken by ferrous oxide, and that the amphibole is rich in the grünerite molecule.

The norm of this rock, as calculated from the first analysis, is as follows:—Quartz 9·72, orthoclase 37·81, albite 28·82, anorthite 11·12, diopside 5·02, hypersthene 1·49, magnetite 3·71. The rock, therefore, falls into persalane, subrang pulaskose (I, 5, 2, 3).

Conclusions to be drawn from the analyses.—It was recognized from the beginning that a chemical analysis would probably prove inconclusive as regards the origin of the veins, because (*a*) it is not possible to separate the ground-mass of the rock from the minute granitic inclusions which occur all through it, and (*b*) whatever theory of the origin of the veins one may favour, it is certain that some part of the granite—especially the biotite, but also some of the felspar—has already been incorporated in the ground-mass. The analysis, therefore, gives the composition of the ground-mass *plus* that of innumerable quartz- and felspar-inclusions.

No analysis has been made of the granite-gneiss in which the veins occur: this is a composite banded gneiss in which different bands show a very wide range of composition, and no single analysis could give a fair idea of the average composition. From the mineralogical examination of the various facies of the gneiss, however, one may describe the rock-complex as a whole as having the composition of a granodiorite. The real utility of the above analyses, therefore, lies in showing that the composition of the pseudotachylyte is such as might result from the commingling of fragments derived from the different leucocratic and melanocratic bands of the gneiss.

My original assumption, that the dykes consist of basic igneous material (approximately of the composition of basalt) which has acidified itself by solution of granite, is now seen to be scarcely tenable. The figures for alkalies and magnesia, in particular, are such as no mixture of granite and basalt could give. Again, in order to account for the proportion of silica alone, it would be necessary to assume that our hypothetical basaltic magma took up in solution and suspension from one and a half to three times its own weight of granite, since, according to Dr. Daly's figures, the average silica of basalts is 49 per cent. and that of granodiorites and granites from 65 to 69 per cent. The actual proportion of suspended granite-fragments (that is, inclusions) in the analysed rock was determined by geometrical measurement of four thin sections; the results were 25·3, 26·4, 28·2, and 43·5 per cent. respectively, giving an average of about 30 per cent. Hence, in order to account for the observed composition of the pseudotachylyte, we should be driven to the assumption that the supposed basaltic ground-mass had actually dissolved and completely assimilated about its own weight of granite. But a simple calculation based on the known values of the specific heat and latent heat of fusion of the common silicate-minerals shows that a magma, to dissolve its own weight of foreign rock, would need to have an initial temperature enormously in excess of any temperature known to be realized in the higher zones of the lithosphere.

If, then, the participation of an igneous magma is to be assumed at all, it must be a magma considerably richer in silica and alkalies than basalt. But here we are faced by the fact that the only body of magma that is known to underlie the granite-gneiss in this region is the body which gave rise to the enormous dolerite-dyke at the weir above Parijs, and to the various 'diabases' in the Lower Witwatersrand rocks. The analysis, therefore, deprives the igneous theory in its original form of an important buttress. If we try to modify that theory by assuming that the invading magma was of andesitic or dacitic composition, we merely beg the question.

VII. The Case against an Igneous Origin.

So long as no other than an igneous origin suggested itself, certain peculiarities of structure and composition exhibited by the pseudotachylyte could be overlooked; but, with an alternative solution in the field, these points of singularity must be regarded as evidence against the igneous theory. The main points militating against the acceptance of the igneous theory are as follows:—

(1) The total absence of macrocrystalline equivalents of the pseudotachylyte.
(2) The total absence of differentiation between the central and the marginal portions of the veins.
(3) The general absence of flow-structure.
(4) The extreme opacity of the most glassy-looking rocks, and the abundance of powdery magnetite in them.
(5) The absence of perfect isotropism, even in the most structureless types.
(6) The low water-content of the rocks. Mr. R. A. Page determined for me the total loss on ignition in the case of one of the most nearly glassy rocks (type 1); it amounted only to 0·83 per cent., which is much lower than the average figure for pitchstones.
(7) The melting (as distinct from dissolution) of felspar contacts. This is a phenomenon for which I can recollect no parallel among igneous rocks; it seems to demand a temperature higher than one can concede to a thin tongue of magma far from its source.
(8) The analogy between these rocks and the rare semi-vitrified crush-rocks of Scotland, and through these with other Scottish occurrences of flinty crush-rocks and with the mylonites of Argentina, India, and Namaqualand.

VIII. Conclusion.

There are two explanations before us of the origin of these pseudotachylytes: one is, that they represent end-products of the same process as that by which flinty crush-rocks have been produced; the other, that they are true igneous intrusions. I have stated the evidence for and against both hypotheses without prejudice. I must now add that the result of my study of flinty crush-rocks has been to make me chary of reasserting the normal igneous origin of the pseudotachylyte. The only point as to which I am really satisfied is the intrusive relation of the material to its walls. Before rejecting the igneous theory, however, on account of the evidence which has already been cited against it, we may pause to consider whether a melt of granite, produced within the granite itself by mechanically-developed heat, would not differ in its properties from a normal granitic magma owing to the absence of the usual volatile constituents of a magma. Such a melt, being in all probability extremely viscous, might be unable to undergo differentiation or to crystallize as a magma would; hence the absence of differentiation and of phanerocrystalline products, although hardly compatible with consolidation from a magma, is, perhaps, not incompatible with consolidation from a rock-melt. That the pseudotachylyte is the product of such a rock-melt, as distinct from a magma, is the hypothesis that best explains the facts. It depends, however, on the assumption that the heat necessary to fuse the granite on the large scale which the intrusions indicate is capable of being produced by the sudden rupture of the granite without long-continued friction or shearing. The validity of this assumption, as well as the properties of such a rock-melt under high pressure, can only be guessed at. Granted the necessary postulates, then this hypothesis adequately explains the phenomena.

Should the above assumption not prove acceptable, there is still one possibility left. Prof. Stanislas Meunier and others still believe in the causation of earthquakes by deep-seated explosions.[1] The conditions at Parijs are not such as Prof. Meunier postulates, but there is abundant evidence that the sub-crust of these parts of South Africa has in the past contained highly explosive material: witness the hundreds of tuff-filled pipes which have been drilled through the crust in the Orange Free State, the Transvaal, and the adjacent parts of the Cape Province. The extrusion of the great dolerite-dyke at Parijs itself demands an expulsive force of enormous power. The form of the pseudotachylyte veins indicates that the granite was shattered by a sudden gigantic impulse or series of impulses. If this impulse were of the nature of an explosion in the sub-crust, it would have as a necessary consequence the outrush of incandescent gases through all the fissures of the granite. In these circumstances fusion of the walls of the fissures might well ensue. Sir Andrew Noble's experiment, in which cordite was exploded in steel cylinders and the gases allowed to escape through a small hole in a granite stopper, will at once recur to the memory. Here is not only a possible source of the vein-material, but an explanation of the high temperature to the action of which that material testifies. I hardly dare offer this as a serious hypothesis, since it takes us away from known causes altogether; but, when one is dealing with an extraordinary phenomenon, no possibility is too extraordinary to be worthy of consideration.

In brief, the material of the pseudotachylyte seems to be melted granite—this is indicated by the chemical characters, and is consistent with the microscopical evidence; it behaves towards the granite like an igneous intrusion—this is established by the field-observations. The source of the heat and the mechanics of the intrusive process remain obscure.

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APPENDIX [September 1916].

Some fresh Analyses of the Granite and Pseudotachylyte of Parijs, made by Dr. H. F. Harwood.

Through the kind mediation of Dr. Arthur Holmes, Dr. H. F. Harwood, of the Imperial College of Science & Technology, has lately been induced to undertake the analysis of the granite and pseudotachylyte, in order to settle the question of the origin of the latter. For this purpose I supplied him with:—

(1) the residue of the material already analysed by Mr. R. A. Page and described by me in the foregoing pages, and

(2) a large block from the locality shown in Pl. XVII, fig. 1, consisting of part of the tachylyte vein (2 *a*) and part of the granite wall (2 *b*).

The analytical results are tabulated below under these numbers:—

	(1)	(2 *a*)	(2 *b*)
SiO_2	64·87	66·95	67·72
Al_2O_3	15·62	15·06	15·79
Fe_2O_3	1·90	1·58	1·04
FeO	2·50	2·18	2·33
MgO	1·77	1·38	0·99
CaO	3·73	3·25	2·93
Na_2O	4·29	4·32	4·49
K_2O	2·92	2·85	2·21
H_2O+	0·57	0·51	0·68
H_2O-	0·08	0·12	0·11
TiO_2	1·32	1·75	1·36
P_2O_5	0·27	0·07	0·11
SO_3	none	none	none
S	0·06	0·12	0·02
MnO	0·05	0·03	0·02
SrO	trace	none	0·03
BaO	0·01	0·05	0·01
Cl	trace	trace	trace
Totals	99·96	100·22	99·84
Less O	0·02	0·05	
	99·94	100·17	

The analysed specimen of the granite-gneiss is distinctly banded in hand-specimen, the individual bands of alternately light and dark colour being 1 to 2 mm. thick and neither regular nor persistent when examined minutely, yet sufficiently so to give a distinct grain to the rock. Both white and flesh-red felspars are seen, the latter being the larger and tending to produce eyes. Both orthoclase and oligoclase are present, with biotite as the only dark silicate. Grains of apatite are rather abundant, with some ilmenite and titanite, and large irregular patches of quartz make up about a quarter of the rock. The chemical and microscopical characters determine the rock to be essentially a granodiorite; but, as I have already expressed the opinion that the whole mass is a hybrid granite-gneiss the composition of which varies greatly from place to place, there is no need to lay stress on the name.

The analysed specimens of pseudotachylyte are of my type 2, passing towards 3—that is to say, they contain abundant hornblende-needles and magnetite-grains; but in places, and especially round the larger inclusions, felspar-laths are also prominently developed.

Comparing the figures for the two kinds of rock, it is evident that they are so nearly identical as positively to exclude the participation of a foreign magma in the production of the pseudotachylyte. The greater content of potash, magnesia, and iron in the pseudotachylyte, as compared with the granite, doubtless arises from the fact that biotite is the first mineral to fuse. In preparing the powder of 2 *a* for analysis, the larger fragments of quartz and felspar were probably rejected (at least, that was my own procedure); but no biotite was rejected with them, hence the enrichment of the base in the constituents of biotite.

All three analyses fall, in the quantitative classification, into lassenose (I, 4, 2, 4)—a group containing many plagioclase-granites and dacites.

The conclusion to which my re-examination of the rocks, coupled with Mr. Page's analysis, had already led me is, therefore, completely confirmed by Dr. Harwood's work. The pseudotachylyte has originated from the granite itself through melting, caused (as I have shown) not by shearing but by shock, or, alternatively, by gas-fluxing.

I wish to offer my warmest thanks to Dr. Harwood for his kindness in performing the above analyses, and thus enabling the investigation of these remarkable rocks to be completed; and also to Dr. Holmes for so kindly interesting himself in the matter.

EXPLANATION OF PLATES XVI–XIX.

Plate XVI.

A large vein of pseudotachylyte exposed in a cutting made for one of the piers of the new bridge below Parijs (Orange Free State).

Plate XVII.

Fig. 1. A vein coming up vertically, turning over to a nearly horizontal plane, and thinning out. Thickness of the vein = about 6 inches in the middle of the photograph. Exposed in a cutting at the bridge. (The detail of the blind end of this vein is shown in text-figure 8, p. 203.)

2. A boulder from one of the large veins, thrown out during blasting operations at the weir, above Parijs: shows rounded floaters of granite and gneiss. A foot-rule has been placed alongside, in order to give the scale.

Plate XVIII.

Fig. 1. Melted felspar at the margin of a vein. The clear white areas are quartz-grains. × 15 diameters. (See p. 207.)

2. Section near the margin of a vein: it shows granite fragments being detached, apparently corroded, and floated away. × 15 diameters. (See p. 207.)

Plate XIX.

Fig. 1. Margin of a vein, showing a plagioclase-crystal which has been broken but not sheared. Crossed nicols. × 15 diameters. (See p. 207.)

2. Melted felspar at the margin of a vein. The clear colourless areas are quartz-grains. × 15 diameters. (See p. 207.)

3. Pseudotachylyte with ground-mass of type 2, full of minute hornblende-prisms. × 45 diameters. (See p. 206.)

Fig. 4. Spherulitic ground-mass, type 3. × 80 diameters. Crossed nicols. (See p. 206.)

5. Ground-mass of felspar-microlites, type 3. × 100 diameters. Crossed nicols. (See p. 206.)

6. Flinty crush-rock from Flamink Vlakte (Namaqualand). × 15 diameters. (See p. 211.)

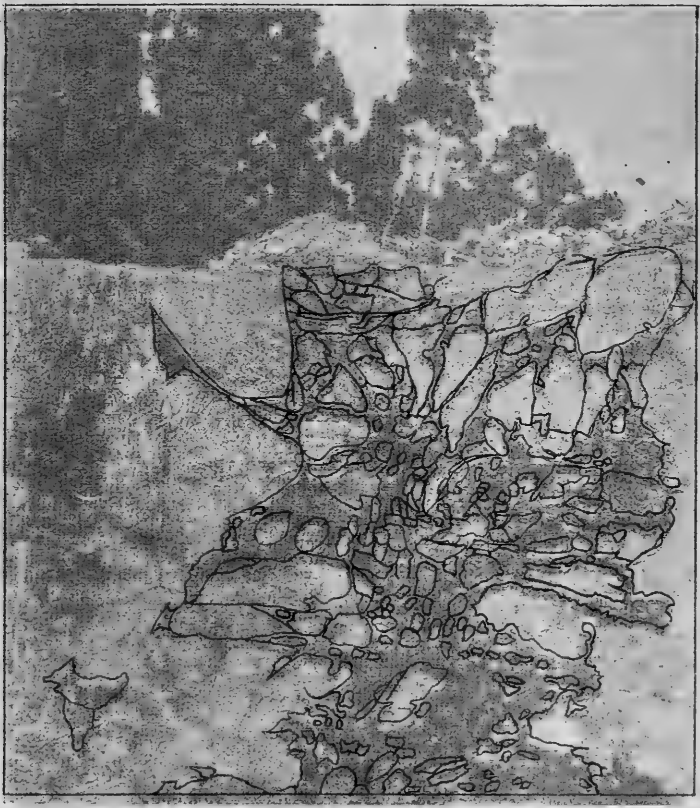
Discussion.

Sir Jethro Teall considered that the paper was an important contribution to a most interesting and difficult subject. The facts had been very clearly described by the Author. He (the speaker) had examined many specimens of 'flinty crush' from Scotland, and had been much puzzled to account for the phenomena. The bits of quartz and felspar which often formed a large part of the rock showed marked signs of crush and strain, while the dark matrix rarely exhibited any signs of crystallization. The flinty material occurred in thin veins which sometimes anastomosed. He found it very difficult to understand how the material was produced, and how it came to be distributed in this way through the rock from which it was largely if not entirely produced.

Mr. J. F. N. Green said that, whatever might be the case with the occurrences which had been quoted from India and other places outside South Africa, there did not appear to be any evidence for crushing in the description that had just been given. Except for the character of the country-rock, the macroscopic phenomena were of a kind familiar to students of the volcanic areas of this country. He placed on the table two specimens from the Lake District showing, on a small scale, brecciation, comminution, blind veins, etc., closely resembling the photographs and drawings exhibited.

Mr. E. Greenly drew attention to some specimens and slides of 'flinty crush-rock' from the Lewisian Gneiss of Scotland that were exhibited on the table, and had been kindly lent by the Geological Survey. When he first met with these veins in the Loch Maree country, five-and-twenty years ago, he certainly supposed that they could be nothing but igneous injections. Soon afterwards, however, on the other side of the lake, he found that the same kind of material, appearing first as veins in almost uninjured gneiss, increased rapidly in quantity towards a powerful zone of crush near the lake-side, until, in that zone, the gneiss was permeated by it in all directions. The dynamic origin of the material (already advocated by Dr. Clough) was here unquestionable. One of the slides on the table showed microlithic structure in a vein-rock, another showed crushed gneiss of the lake-side zone breaking down and passing into 'flinty' matter.

Dr. A. Holmes said that, having now heard the revised version of the Author's paper, he was still inclined to support the original suggestion that the pseudotachylyte veins were of igneous origin. The form of the intrusion could be paralleled in Mozambique, where the speaker had seen irregular veins of granulitic granite penetrating gneiss in an equally intricate fashion. If the pseudotachylyte were the result of crushing *in situ*, then every gradation



S. J. S., Photo.

Bemrose, Collo, Derby

VEIN OF PSEUDOTACHYLYTE EXPOSED IN CUTTING BELOW PARIJS (O. F. S.).

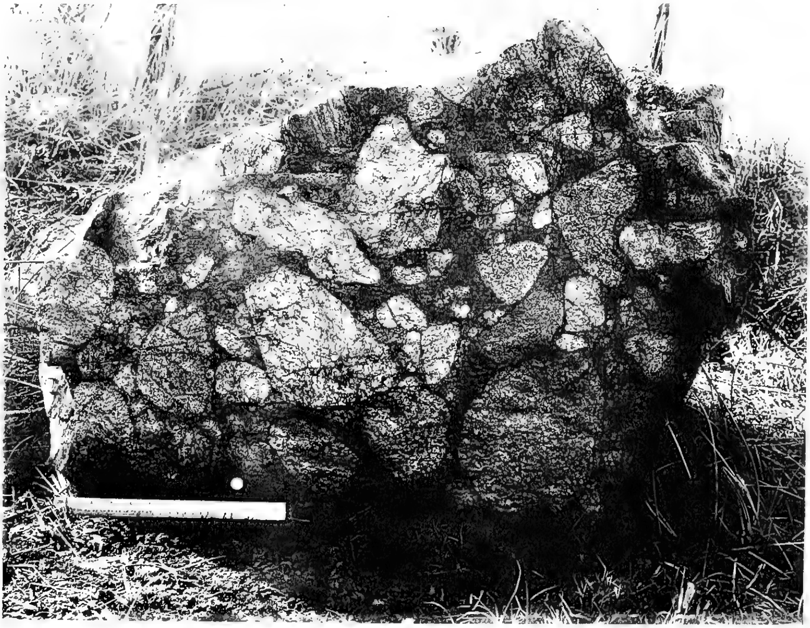
S. J. S., Photo. Bemrose, Collo., Derby.

VEIN OF PSEUDOTACHYLYTE EXPOSED IN CUTTING BELOW PARIJS (O. F. S.).

FIG. 1. VEIN OF PSEUDOTACHYLYTE NEAR PARIJS (O. F. S.).

S.J. S., Photo.

FIG. 2. A BOULDER FROM ONE OF THE LARGE VEINS OF PSEUDOTACHYLYTE NEAR PARIJS.



S.J. S., Photo.

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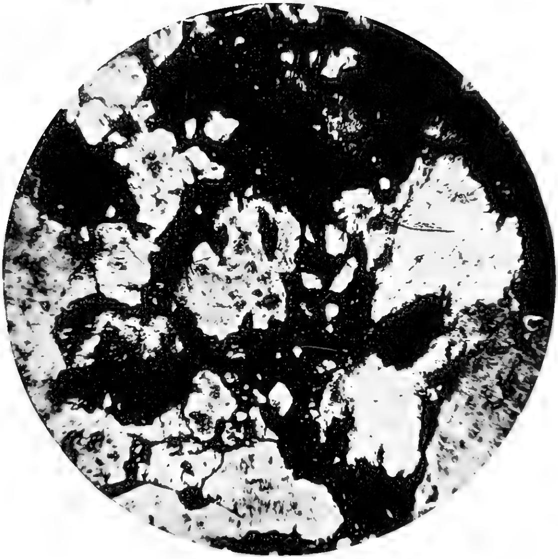
1. × 15

2. × 15



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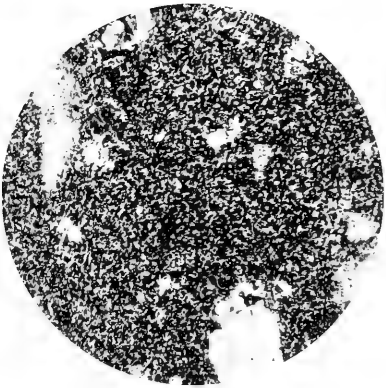
PSEUDOTACHYLYTE OF PARIJS (O.F.S.).

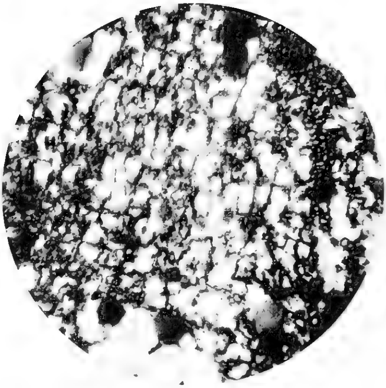
1. × 15

2. × 15

3. × 45

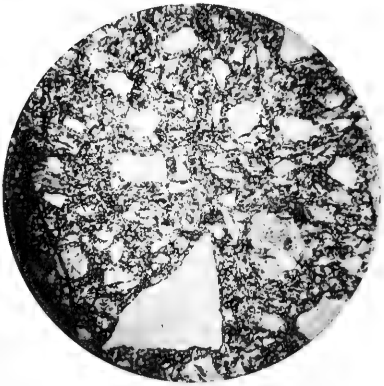


4. × 80



5. × 100

6. × 15



S.J.S., Photo.

Bemrose, Collo., Derby.

PSEUDOTACHYLYTE OF PARIJS (O.F.S.), ETC.

between fused material and mylonite ought to be represented. There did not appear to be such a gradation; while, on the other hand, there was abundant evidence that the material had possessed a sufficiently high temperature to fuse the minerals of the invaded rocks. The question then arose: why had the black rock crystallized so badly? One explanation might lie in the assumption that the intrusion was feebly supplied with volatile fluxes; and such a condition would naturally arise if some deep-seated rock that had previously crystallized and lost its fluxes, were again to be raised to its melting-point—by severe crushing, or rise of the geotherms, or any other cause.

The Author stated, in the abstract of his paper, that the composition of the rock was practically that of a granodiorite, and that it might correspond to an average of the granite-types in which the veins occurred. The speaker said that he could not agree with either of these statements, for the analysis showed about 10 per cent. of alkalies, with soda nearly twice as abundant as potash. The speaker suggested that, if the Author could have specimens of the pseudotachylyte and of the red and grey granites sent to England for analysis, the results could not fail to throw more light on the origin of this most puzzling of rocks.

Dr. J. W. EVANS thought that it was clear, in the majority of cases, that the material of pseudotachylyte had been injected into the rock in a fluid or pasty condition, as the result of pressure at right angles to the general direction of injection. It did not appear to be derived from an extraneous magma, but at least in some cases, including that described by the Author, the matrix had been in a molten state. It was doubtful whether the heat produced by earth-movements was ever sufficient to cause an appreciable rise in temperature, and the speaker was inclined to attribute the melting to a regional rise in temperature which did not melt the granite because this had lost its magmatic water. The intrusive material may have been formed from a basic segregation, more easily fusible on account of the larger proportion of iron and alkalies. Such segregations would in many cases determine planes of weakness in the rock. The brecciation of the granitic material included in the veins might, in some cases, be attributed to the forcible injection of the latter.

11. *The* TERTIARY VOLCANIC ROCKS *of the* DISTRICT *of* MOZAMBIQUE. By ARTHUR HOLMES, D.Sc.(Lond.), D.I.C., A.R.C.S., F.G.S. (Read June 28th, 1916.)

[PLATES XX & XXI.]

CONTENTS.

Introduction.

I. HISTORY OF EXPLORATION.

THE Portuguese East-African District of Mozambique was, until recently, one of the least known of the East-African coastlands. Livingstone explored the regions on the south-west (1865) and north (1874), but Mozambique itself he did not touch. Sadebeck (1879) was the first to give a geological description of the sedimentary rocks that fringe the coastal plain of the mainland north and south of Mozambique[1] Island. This work was followed up by Choffat (1903) in an important palæontological memoir on the Cretaceous formations of Conducia Bay. Exploration beyond the coastal zone was initiated by Lieut. H. E. O'Neill, who made a number of successful journeys westwards across the mainland during the years 1881–1884. In his papers (1882, 1884, 1885) he

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[1] The name Mozambique has been used indiscriminately for (*a*) Portuguese East Africa, (*b*) the district lying between the Luli and Ligonia Rivers, (*c*) the Island of Mozambique, and (*d*) the city of Mozambique.

gives a very complete and faithful account of the natives and their customs; but, beyond the suggestion that the prevailing rocks are gneisses and granites, he makes no reference to the geology of the territory. In 1887, Mr. J. T. Last made a journey from Blantyre to the Namuli Peaks, which had for long been considered to be of volcanic origin. This view he disproved (Last, 1887), describing the summit as 'an almost perpendicular mass of white stone.' I have since learned from Mr. Last that he referred in this expression to the grey granite and gneiss which builds up the Namuli Peaks, as it does the other mountainous masses of the country.

Thus, until a few years ago, Mozambique, with the exception of part of the Cretaceous coastal fringe, was practically a *terra incognita* to geologists. In 1910, a prospecting and surveying expedition was organized by the Memba Minerals Ltd., under the leadership of Mr. E. W. E. Barton. The coastal belt was investigated during the first season with Memba as the base of operations; but, owing to the hostility of the natives, little progress was made inland. Early in 1911, a fresh party was formed with headquarters at Mosuril, and Mr. E. J. Wayland, Mr. D. A. Wray, and myself, were appointed as geologists to the expedition. A short account of the geographical work accomplished, together with the map made during the two seasons' work, has already been published (Reid, 1913), and in two papers introductory to the present more detailed treatment Mr. Wray and myself have described the geography of the country and the outstanding features of the geology (Holmes & Wray, 1912 & 1913; see also Wray, 1915).

The present paper deals with the Tertiary volcanic rocks of Mozambique, and will be followed by one describing the Pre-Cambrian rocks.

II. General Features.

With the exception of a coastal zone of variable width, formed by a narrow belt of Cretaceous and Tertiary sediments and flanked on the west by later Tertiary volcanic rocks, the whole territory consists of a complex of gneisses and other foliated rocks with granitic and other intrusions belonging to at least two different periods. Although we proceeded inland for 250 miles, as far west as longitude 37° E., we met with no signs of unmetamorphosed sedimentary rocks, once the coastal zone had been left behind. The oldest rocks lying on the basal complex are of Lower Cretaceous age, and consequently there is no close stratigraphical evidence for the age of the complex.

The petrological details and architecture of the complex suggest for the greater part of it a Pre-Cambrian age, and in a subsequent paper an attempt will be made to show that this view is justified: for a direct measurement of the age of the gneisses, and that of one of the later granites, by the radioactive method, proves that an approximate correlation can be made between the older rocks of Mozambique and those of other countries far removed from the tropics.[1]

[1] A. Holmes, Proc. Geol. Assoc. vol. xxvi (1915) p. 305.

The geological sequence in Mozambique may be summarized as follows:—

Recent Deposits.	Overlying drifts, lateritic deposits, coral reefs, and raised beaches.	
Tertiary.	2. Volcanic rocks.	Post-Oligocene.
	1. Mozambique Limestone and Mochelia Conglomerate.	Oligocene.
Cretaceous.	3. Conducia and Monapo Beds.	Upper Cretaceous.
	2. Mount Meza Beds.	Middle Cretaceous.
	1. Fernão Velloso Beds.	Lower Cretaceous.
Pre-Cambrian Complex.	4. Pyroxenites.	
	3. Granites and pegmatites.	
	2. Gneisses, amphibolites, and eclogites.	
	1. Schists and crystalline limestones.	

III. The Coastal Belt.

The narrow Coastal Belt is formed essentially of Mesozoic deposits, and extends intermittently along the whole East African coast, broken only where the sea has eaten away the sedimentary formations and reached the more resistant rocks beyond. Throughout the length of Mozambique, no sediments older than Cretaceous are known along this zone, but on the north, in Portuguese Nyasaland and in the German (1914) and British areas, Upper Karoo and Jurassic formations are also found.

In Mozambique the coastal zone varies in width up to 10 miles. The shore itself is fringed with loosely-cemented coral-rocks and raised beaches. The underlying sedimentary rocks extend almost continuously from the Lurio in the north to Moginquale in the south, and are nearly all of Cretaceous age. Mozambique Island and the outlying parts of the adjoining mainland are unconformably capped with Tertiary sediments, which were referred by Sadebeck (1879) to the Upper Eocene or Oligocene.

Mr. Wray has divided the Cretaceous formations into three main groups, the succession of which, with their lithological characters and distribution, is expressed in the following table:—

Name.	*Age.*	*Lithological Character.*	*Distribution.*
3. Conducia and Monapo Beds.	Senonian.	Limestones, calcareous shales and sandstones, with a calcareous conglomerate at the base.	Mokambo Bay to the Mikati River.
2. Mount Meza Beds.	Albian to Aptian.	Sandstones, often felspathic, with calcareous bands.	Mount Meza and the adjoining district.
1. Fernão Velloso Beds.	Neocomian.	Alternating limestones and shales.	South of Fernão Velloso Harbour to Memba.

The prevailing dip is southward or south-eastward, except north of Mokambo Bay, where the Conducia Beds appear to be brought up by a syncline. Folding, however, wherever seen, is very gentle. Evidences of movements of a vertical type are more common, and small north-and-south faults have broken up the Monapo Beds along the northern shores of Mokambo Bay. Mr. Wayland determined their junction with the gneissose rocks on the west to be a faulted one. The Conducia Beds south of Sokoto Hill are faulted against the gneissose rocks, for the conglomerate basement-beds are not seen, and marine limestones are brought to a level with the older rocks. Mr. Wray considers that Fernão Velloso Harbour, with its rugged gneissose cliffs on the west and low-lying limestones and shales on the east, represents a line of fault picked out by marine erosion between the Cretaceous sediments and the Pre-Cambrian complex. On linking up all our observations, it seems clear that a series of nearly north-and-south faults has slowly displaced the Cretaceous beds, generally dropping them down on the eastern side, and locally cutting them off sharply from the ancient rocks beyond. It is a significant feature that the average direction of these faults is parallel to the general trend of the adjoining coast-line and to the basaltic dykes associated with the Tertiary volcanic rocks. The strike of the foliation and banding of the gneisses is truncated obliquely by the coastal belt, and the coast has therefore a typically Atlantic character.

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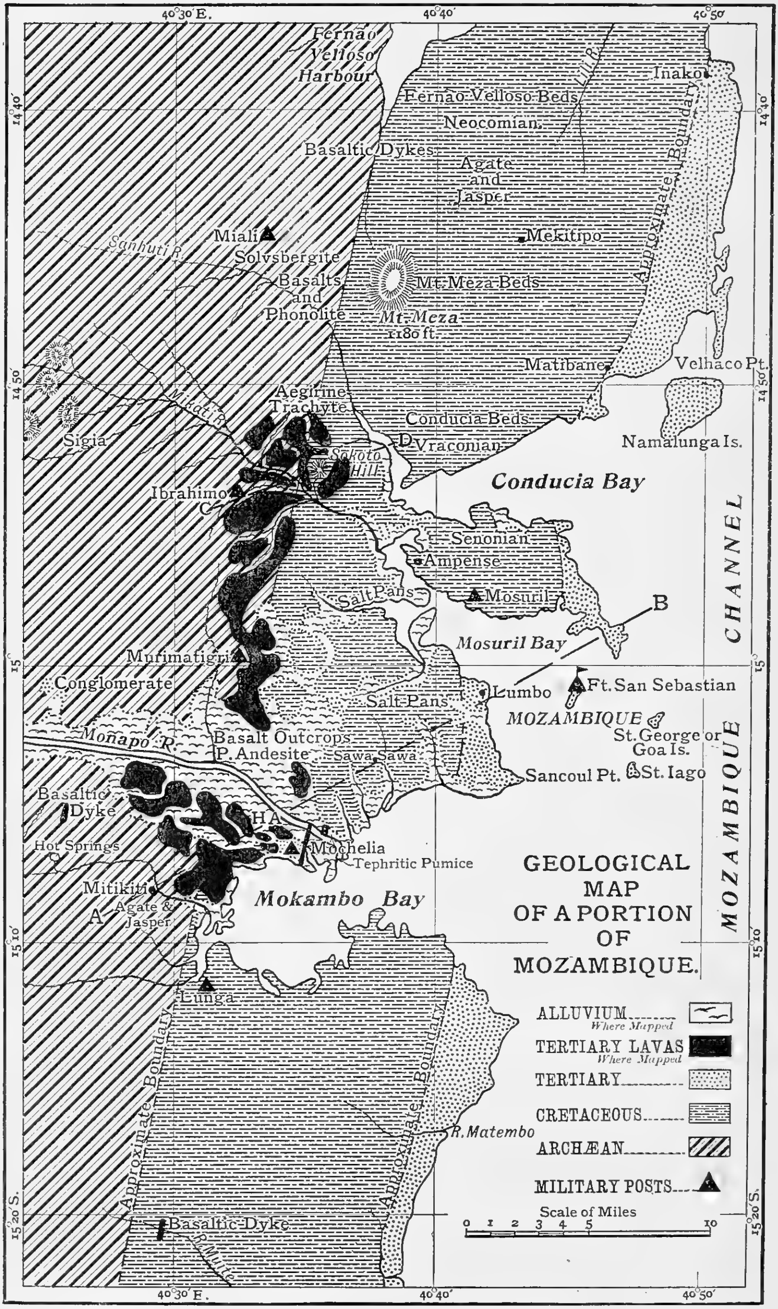
Fig. 1.—*Map illustrating the distribution of the volcanic rocks of Mozambique.*



[Based on the topographical survey by the staff of the Memba Minerals Ltd., 1910–11 (Geogr. Journ. vol. xlii, 1913, p. 112) and on geological observations made by Dr. A. Holmes, Mr. E. J. Wayland, and Mr. D. A. Wray.]

Fig. 2.—*Section AB, from the Mitikiti River to Mosuril Bay.* (*Length = 25 miles.*)

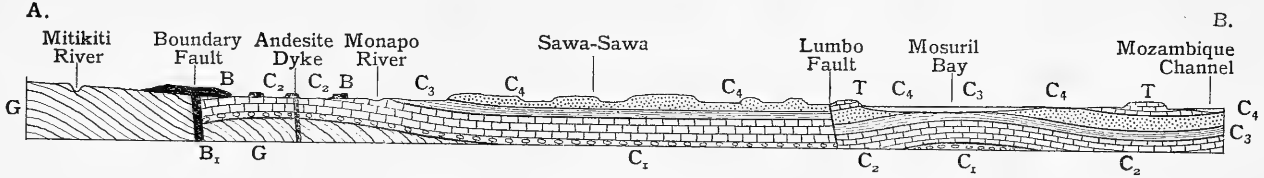
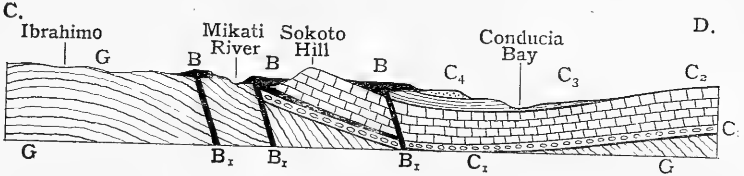


Fig. 3.—*Section CD, from Ibrahimo to Conducia Bay.* (*Length = 11 miles.*)



B. Basalt-flows,
B_1. Basalt-dykes, } (Post-Oligocene).
T. Limestone (Oligocene).
C_4. Sandstone,
C_3. Shale,
C_2. Limestone, } (Cretaceous).
C_1. Calcareous conglomerate,
G. Gneiss, granite, pegmatite, etc. Pre-Cambrian complex.

The Volcanic Area.

V. THE DISTRIBUTION AND FORMER EXTENT OF THE LAVAS.

The volcanic rocks of the district of Mozambique occur along a narrow belt of country which extends from Mokambo Bay to beyond the Sanhuti River, following a line approximately parallel to the general direction of the coast (see map, fig. 1, p. 226). The boundary-fault between the sedimentary coastal belt and the Pre-Cambrian complex roughly bisects the volcanic area, although in the north the lavas are more abundant on the western side of the fault. The lava-flows are everywhere horizontal, and are clearly the result of fissure-eruptions, no traces of pyroclastic ejecta having been anywhere encountered.

The flows are now restricted to innumerable small outcrops surrounded, according to the locality, by gneiss and granite, by Cretaceous or Tertiary sediments, or by more recent lateritic earths and alluvium. Small dykes and sills, representing the feeders through which the magmas reached the surface, penetrate the underlying rocks, and are exposed in many places between the much dissected lava-flows. On the accompanying sketch-map (fig. 1), it has been possible to express only the broader outlines of the various formations which enter into this complicated patchwork. No pretence is made to detailed accuracy, for the inherent difficulties of pioneer mapping, topographical as well as geological, were considerably increased by widespread sheets of superficial débris, and in places by a dense undergrowth of tropical vegetation.

Throughout the area the prevailing lavas are basalts of a remarkably uniform type. All are vesicular, and most of them are coarsely amygdaloidal. That similar flows of amygdaloid originally extended northwards as far as Fernão Velloso Harbour is made clear by the presence of abundant pebbles of agate and jasper around the Nakalla River and along the western shores of the Harbour. Pebbles of agate and jasper are still being derived from the amygdaloids, and naturally they occur in great abundance on the coastal side of the exposures, particularly along the lower reaches of the Mitikiti, Monapo, Mikati, and Sanhuti Rivers. Similar pebbles, however, also occur to the west of the exposures, especially in the Monapo district, where the flows appear to have been laterally more extensive than elsewhere. The existence of these relics in places (such as Mitikiti) to which they could not have been transported by the present drainage, makes it certain that the lavas flooded a strip of country from 5 to 10 miles broad, and at least 50 miles long.

Beyond Mitikiti's Kraal, a solitary basaltic dyke, well encrusted with laterite, was met with in Maravi's carefully guarded country. Its position, near Nashologoto, is marked on the map. In a line with this dyke, a few miles away to the south, a series of hot springs breaks through the gneissic surface, providing the Mitikiti River with a small but permanent tributary. We encountered the steaming waters in a dense forest during the dry season, when all the neighbouring gullies were empty. This fact, together with the comparatively high temperature (about 60° C.), suggests that the springs may be of juvenile origin, representing the last flicker of expiring activity on the border of a volcanic field already much reduced by erosion. Nearly a gallon of the water was evaporated to dryness in a clean prospecting-pan, in order that the residue might be tested by blowpipe reactions. Carbon dioxide was present in just sufficient abundance to be recognized. The residue was very small, and only soda and silica could be detected.

The rocks described in the present paper are confined to a district rather more than 30 miles in length, extending from the Mitikiti River to beyond the Sanhuti River. Amygdaloidal and vesicular basalts are not the only types of lava represented. In the neighbourhood of the Monapo River—2 miles north-west of Mochelia—a narrow dyke of hornblende-andesite penetrates a sheet of amygdaloid (H.A. in fig. 1, p. 226), and Mr. Wayland found pebbles of pyroxene-andesite on the débris-strewn flats of the same district. Here also fragments of tephritic pumice are found, though again not *in situ*. This rock clearly indicates another line of variation which is more strongly represented in the north, for the late Mr. R. L. Reid discovered an interesting occurrence of phonolite associated with basalt and picrite-basalt in the neighbourhood of the Sanhuti River. Other rocks not found *in situ* are sölvsbergite and ægirine-trachyte. Thus, there occur together, within the limits of what is a comparatively small volcanic field, lavas of both alkali and calc-alkali types.

Fig. 4.—*Specimen of amygdaloidal basalt from the Sanhuti-River district. (Photograph by Mr. D. A. Wray.)*

VI. Period of Eruption.

The period of eruption of the amygdaloids cannot be definitely ascertained, but three lines of evidence point to their Tertiary, and almost certainly post-Oligocene, age.

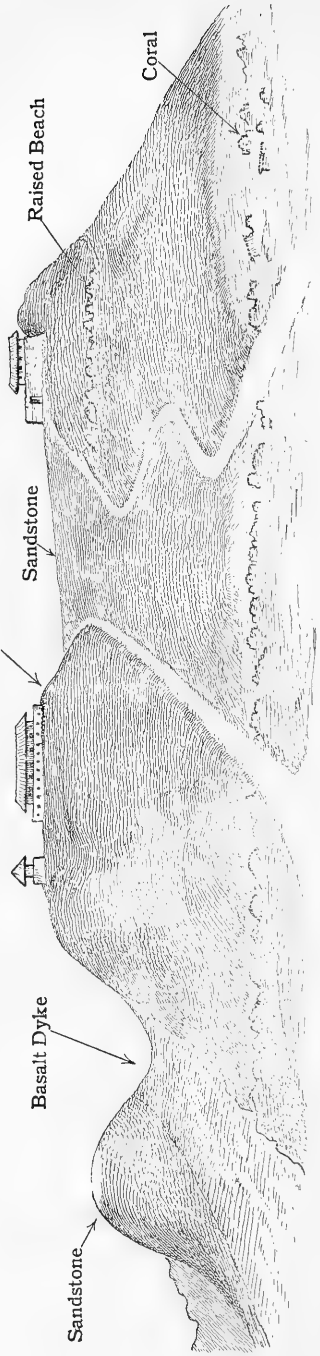


Fig. 5.—*Sketch of the Mochelia Dyke penetrating Tertiary sandstones, by E. J. Wayland: (for diagrammatic purposes vegetation is omitted).*

(*a*) Evidence from Faulting.

In the district north of Mokambo Bay, between the Monapo and Mitikiti Rivers, sheets of amygdaloid are seen to lie successively on a surface of Cretaceous sandstones and limestones, and on far older crystalline rocks. At Mitikiti's Kraal, only occasional pebbles of agate and jasper remain to prove the former extension of the flows. The junctions between sandstone and limestone and between limestone and gneiss are faulted, and it is evident that denudation kept pace with the movement and reduced the various formations to a nearly plane surface before volcanic activity commenced. Unfortunately, it is not easy to determine the period of faulting. The Oligocene deposits of Lumbo, on the southern shore of Mosuril Bay, are probably faulted down against the Cretaceous sandstone, but the movement there may not have been simultaneous with that within the Cretaceous sediments, nor with that between the latter and the Pre-Cambrian complex. If it be conceded that all the faulting is of approximately the same period, the time of extrusion could not be earlier than the Oligocene; but, as this assumption is itself not securely founded, the evidence points to a period no more definite than post-Cretaceous.

(*b*) Evidence from the Age of Intruded Sediments.

The phonolite of the Sanhuti River and the amygdaloids throughout the area are necessarily post-Cretaceous, since they lie partly on a base-levelled Cretaceous platform. At Mochelia, however, Mr. Wayland found a number of dykes intrusive through sandstone and conglomerate, which he interpreted a the shore-facies of the Oligocene deposits of Lumbo and Mozambique Island (fig. 5). From this more detailed evidence, a lower limit may be assigned to the period of vulcanicity, determining the age of the vulcanism as late Oligocene or post-Oligocene.

(*c*) Evidence from the Composition of the Oligocene Limestones.

In the Oligocene deposits of Mozambique Island and Lumbo, fragments of Cretaceous limestone occur that may be easily identified, although their size is small compared with the similar contained fragments in the Mochelia conglomerate. Now, if the conditions of denudation and deposition were such that pebbles of limestone were preserved, it seems reasonable to suppose that, if the amygdaloids had existed at that time, they would also have played some part in building up the Oligocene formations. At the present day, the rock-detritus that is distributed over the littoral plains at high-water level, invariably contains large numbers of agate- and jasper-pebbles; and similar, though less abundant, relics of igneous activity are found among the gravels of the numerous raised beaches which fringe the shore from point to point. Hence, since no trace of basalt nor of its siliceous amygdales have been detected in any of the Tertiary sediments, one may conclude with some confidence that the basalts had not then been extruded, and consequently that the period of their extrusion was late Oligocene or, more probably, post-Oligocene.

The phonolite and associated lavas from the Sanhuti district lie across the boundary between Cretaceous and Archæan rocks. Their age is, therefore, post-Cretaceous; but their relations to the far more abundant amygdaloids are as yet entirely unknown.

VII. Order of Eruption, and Classification.

The lavas from the Sanhuti mentioned above were collected by Mr. Reid during a journey to Mount Meza. In the case of three of his specimens, the order of eruption can be definitely stated. Near the base of the volcanic series, lying on a floor hidden by lateritic earth and gneissic débris, is a dark compact basalt containing rusty amygdales partly occupied by calcite. Both in the composition of the amygdale minerals and in its microscopical aspect, the rock differs conspicuously from all the other basalts of Mozambique. At a higher level a lava of lighter colour was met with. This is the phonolite, and it also contains calcite as the chief occupant of the vesicles. At the top of the series a black vesicular basalt was found. Owing to its extremely mafic character, it is here designated a picrite-basalt (see § XIII, p. 244). The specimens next collected include a fragment of amygdaloidal basalt rich in chalcedony and heulandite. This rock is identical with the amygdaloidal basalts occurring elsewhere in the volcanic area, and was found *in situ* on a sedimentary basement.

It is interesting to notice that, in Abyssinia, W. T. Blanford found two equally contrasted series of lavas. The lower consisted of amygdaloidal basalts remarkably similar to those of Mozambique, while the upper included extensive flows of trachyte and phonolite.[1] Thus in Abyssinia the evidence that the amygdaloids preceded a series of alkali-lavas is complete. Unfortunately, in Mozambique the observations hitherto made do not admit of so definite a deduction.

Of the remaining alkali-lavas described in this paper, none were found *in situ*.

South of the Monapo, the occurrence of a narrow dyke of andesite cutting a flow of amygdaloid leaves no doubt as to the succession.

A complete statement of the sequence of igneous rocks throughout the district cannot be given, but in the following synopsis the associations in three representative districts are enumerated. Names marked with an asterisk are of lavas not yet known *in situ* :—

	Sanhuti District.	*Sokoto District.*	*Monapo District.*
A.	Sölvsbergite.*	Ægirine-trachyte.*	Tephritic pumice.*
	Picrite-basalt.		
	Phonolite.		
	Basalt.		
B.			Pyroxene-andesite.*
			Hornblende-andesite.
	Amygdaloidal and vesicular basalts.	Amygdaloidal and vesicular basalts.	Amygdaloidal and vesicular basalts.
		Basalt sills and dykes.	Basalt sills and dykes.

The amygdaloidal and vesicular basalts (which extend throughout the area) vary but little in respect of their basaltic framework. Such differences as have been noted depend on the proportion of brown glass, the sizes of crystals, and the degree of vesicularity. The amygdales are occupied by agate, jasper, and quartz, and by a variety of zeolites ; moreover, the composition and the relative abundance of the amygdale-minerals constitute a second line of variation.

With the exception of the dyke of andesite already mentioned, all the dykes and sills encountered in the volcanic area are basaltic, and can be closely matched by rocks occurring as surface-flows. The reason for this is clear : the dykes and sills in most cases are exceedingly narrow, and they appear not to have been long separated by erosion from the overlying lava-sheets to which they served as feeders. The larger Mochelia dykes are free from vesicles; but all the other specimens collected contain a residuum of glass, and are minutely vesicular and amygdaloidal. A noteworthy feature is the general absence of zeolites from these small intrusions. Taking the basalts as a whole, a continuous series can be arranged, starting with the compact Mochelia basalt, passing through various vesicular and amygdaloidal types, and finishing with glassy scoriaceous basalts.

The lavas fall naturally into two main groups, designated as A & B in the list of types given below (p. 233). For petrographic description the following order will be adopted. In the cases

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[1] 'Observations on the Geology & Zoology of Abyssinia' 1870, p. 182.

determined, the position and symbol of each rock in the quantitative (C. I. P. W.) system of classification is added :—

Rocks of Group A. (Alkali series and associated basalts).

Sölvsbergite	Nordmarkose	I, 5, 1, 4.
Ægirine-trachyte	n. d.	
Trachytoid-phonolite	Umptekose	II, 5, 1, 4.
Tephritic pumice	Akerose	II, 5, 2, 4.
Basalt	Camptonose	III, 5, 3, 4.
Picrite-basalt	Auvergnose	III, 5, 4, 4.

Rocks of Group B. (Calc-alkali series).

Basalts : sills and dykes	Hessose	II, 5, 4, 4.
Basalts : lava-flows	Tonalose-bandose.	II, 4, 3–4, 4.
Hornblende-andesite	Bandose	II, 4, 3, 4.
Ground-mass	Lassenose	I, 4, 2, 4.
Pyroxene-andesite	n. d.	

Petrographic Descriptions and Analyses.

Rocks of Group A.

VIII. SÖLVSBERGITE. (Pl. XX, fig. 1.)

Two specimens (153[1] & 154) of sölvsbergite were collected by the late Mr. R. L. Reid, between Miali and the Sanhuti River; but their source, which was possibly a dyke penetrating gneiss, was not discovered.

The rock has a mottled appearance in the hand-specimen, due to the alternation in ill-defined layers of dark-grey and straw-coloured patches. In this respect it bears a close resemblance to the type-rock of Gran, but it is heavier, darker, and more finely-grained than the latter. Small tabular phenocrysts of clear glassy anorthoclase are sparsely scattered through the rock, reaching 1 cm. in their largest dimension. Under the microscope the following minerals can be distinguished. Their approximate proportions by weight, measured by the Rosiwal micrometric method, are added :—

Minerals.	*Estimated Percentage by weight.*
Anorthoclase	77
Cossyrite (accompanied in small amount by katoforite and arfvedsonite)	13
Ægirine and ægirine-augite	8
Magnetite (and ilmenite ?)	2
Hæmatite ?	n. d.
Zircon	n. d.
Total	100

Anorthoclase determines the texture of the rock, which is trachytic. The crystals are clear and unaltered, and have a

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[1] These numbers in parentheses refer to specimens in the collection of Mozambique rocks studied by the author. The collection is at present in the Geological Department of the Imperial College of Science & Technology. When its investigation is completed, it is proposed to present the collection to the Mineralogical Department of the British Museum (Natural History).

prismatic habit, elongated parallel to the a axis. The three refractive indices are respectively slightly above, equal to, and slightly below 1·526 (monochlor benzol) according to the direction. Carlsbad twinning is common, but the fine striations due to albite twinning often seen in anorthoclase have not been detected. The extinction, however, is mottled and undulose. Small inclusions are present, frequently with a peripheral arrangement. Most of them are minute prisms of ægirine, but a few highly refractive blebs, which exhibit high polarization-colours, are probably zircon.

Cossyrite occurs in ragged patches, and in thin wedges occupying the angles between adjacent felspars. Except in especially thin sections and near the edges, when the deep-red and brown pleochroism becomes visible, the mineral is practically opaque. Small grains of katoforite and arfvedsonite are associated with the more absorbent amphibole.

Ægirine and ægirine-augite lie among the felspars in shreds and granular aggregates. The pleochroic scheme of the ægirine is as follows:—

x (nearly $=c$)......	blue-green.
$y=b$	yellow-green.
z (nearly $=a$) ...	yellow-brown.

Magnetite, probably titaniferous, is present in masses of about the same size as those of cossyrite. It can readily be distinguished from the latter by observation in reflected light. Red ferruginous stains accompany the amphiboles in some cases, and probably represent an excess of ferric oxide over that required for their crystallization.[1]

Chemical Composition.

Analysis of a perfectly fresh specimen (153) gave the following results:—

	Percentages.	*Molecular Proportions.*
SiO_2	61·02	1·017
Al_2O_3	17·11	·168
Fe_2O_3	4·37	·027
FeO	3·42	·047
MgO	0·63	·016
CaO	1·20	·021
Na_2O	6·51	·105
K_2O	4·47	·048
H_2O+ ...	0·31	...
H_2O- ...	0·33	...
TiO_2	0·59	·007
MnO	0·34	·005
Total	100·30	

Mineral Composition (Norm).		
Quartz	1·74	Salic =87·62.
Orthoclase	26·69	
Albite	55·02	
Anorthite	4·17	
Diopside	1·40	Femic =12·00.
Hypersthene ...	3·28	
Magnetite	6·26	
Ilmenite	1·06	
	99·62	
Water	0·64	
Total	100·26	

$Ra=2{\cdot}26\times10^{-12}$ grms. per grm.
Specific gravity$=2{\cdot}58$.

Class I......	Persalane.
Order 5 ...	Canadare.
Rang 1 ...	Nordmarkase.
Subrang 4	Nordmarkose.

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[1] For the primary character of hæmatite and limonite in certain igneous rocks, see G. M. Murgoci, Amer. Journ. Sci. ser. 4, vol. xx (1905) p. 145.

Several analyses of sölvsbergite from other localities are tabulated below for comparison with the Mozambique example. All the analyses bear a close family resemblance, indicated in the quantitative classification by their falling into divisions I, 5, 1, 4. or II, 5, 1, 4. The Mozambique sölvsbergite is richer in iron-oxides, both ferric and ferrous, than any other hitherto analysed. The abundance of ferrous iron, which is the more noteworthy, is clearly related to the dominance of cossyrite over the more usual ægirine, and in part to the presence of magnetite :—

	A.	B.	C.	D.	E.	F.
SiO_2 ……	61·02	63·74	65·46	64·28	64·92	58·90
Al_2O_3 ……	17·11	17·86	17·40	15·97	16·30	17·70
Fe_2O_3 ……	4·37	4·27	3·00	2·91	3·62	3·94
FeO ……	3·42	0·30	1·60	3·18	0·84	2·37
MgO ……	0·63	0·10	0·09	0·03	0·22	0·54
CaO ……	1·20	0·83	0·76	0·85	1·20	1·05
Na_2O ……	6·51	7·23	6·51	7·28	6·62	7·39
K_2O ……	4·47	5·19	4·74	5·07	4·98	5·59
H_2O ……	0·64	0·83	0·87	0·20	0·50	1·90
TiO_2 ……	0·59	tr.	0·24	0·50	…	0·40
P_2O_5 ……	n. d.	…	…	0·08	…	…
MnO ……	0·34	0·19	…	tr.	0·40	0·55
Totals……	100·30	100·54	100·67	100·35	99·60	100·33

A. Between Miali and the Sanhuti River, Mozambique (an. Holmes).
B. Edda Gijorgis, Abyssinia (an. Prior).
C. Camel's Hump, Victoria, Australia (an. Bailey, Lewis, & Hall).
D. Andrews Point, Essex County, Mass., U.S.A. (an. Washington).
E. Sölvsberget, Gran, Norway (an. Schmelck).
F. Kjose, Aklungen, Norway (an. Schmelck).

IX. Ægirine-Trachyte. (Pl. XX, fig. 2.)

Fragments of a porous lava with small phenocrysts of felspar (anorthoclase) and strongly developed flow-structure were found north of Sokoto Hill (151 & 152). Mr. Starey and I worked in the district for several weeks, but failed to discover the rock *in situ*. The weathered surface of the specimens collected has a rusty-red colour, broken by white-lined vesicles, the contents of which prove to be opal (refractive index between 1·446 = chloroform, and 1·472 = nut-oil). Within, the rock presents a mottled appearance, similar to, but more finely granular than, that of the sölvsbergite just described. Specific gravity = 2·33.

Under the microscope the minerals that can be distinguished are anorthoclase, ægirine, cossyrite, magnetite, and opal. In addition, a great deal of an obscure brown alteration-product is present; similar material in the trachytes of the Great Rift Valley has been called 'ferrite' by Dr. G. T. Prior. As in the Rift-Valley rocks, so here, the 'ferrite' seems to be an alteration-product of cossyrite and other soda-amphiboles, for its mode of occurrence is exactly paralleled by that of the soda-amphiboles in the other rocks of Group A.

Flow-structure is of two kinds, which merge one into the other. The first is determined by parallel laths of anorthoclase accompanied by radial growths of that mineral with ægirine, cossyrite, and 'ferrite,' occupying the wedge-shaped interstices. The second type of flow-structure is that which imparts to the rock its megascopic aspect. It is determined by the alternation of bands rich in prisms of ægirine, with bands containing long drawn-out vesicles now occupied by opal. The opalized bands are further characterized by abundant 'ferrite.' A subsidiary type of band is mainly composed of parallel laths of anorthoclase with cossyrite. Elsewhere the laths of anorthoclase, while presenting a general trachytic aspect, have crystallized in radial aggregates. The lava bears a close resemblance to the phonolitic trachyte from Lake Baringo described by Dr. G. T. Prior in 1903.[1]

The radium-content of the rock was determined in 1913, and proved to be $2{\cdot}83 \times 10^{-12}$ grms. per grm. The silica percentage was found by the late Lieut. G. Kirby to be 64·51.

X. TRACHYTOID-PHONOLITE. (Pl. XX, fig. 3.)

The phonolites of the Sanhuti-River district (149 & 150) differ from the other lavas of Mozambique in two noteworthy respects. Large phenocrysts of clear glassy anorthoclase, an inch or more in length, are distributed through a grey ground-mass somewhat coarse in grain for a phonolite. Amygdales, averaging half an inch in diameter, are also scattered through the rock, and these are occupied by natrolite and calcite. The former mineral lines the cavities in aggregates of white fibres, leaving the bulk of the interior partly or wholly filled with calcite.

Under the microscope, the minerals recognized and their approximate percentages, determined by the Rosiwal micrometric method, are as follows:—

Minerals.	*Estimated Percentage by weight.*
Anorthoclase	33·8
Natrolite and isotropic material	24·7
Nepheline	6·6
Ægirine and ægirine-augite	15·1
Katoforite Arfvedsonite Barkevikite	11·5
Cossyrite	4·3
Calcite	2·0
Magnetite and ilmenite	2·0
Apatite	n. d.
Total	100·0

The phenocrysts of anorthoclase are prismatic, elongated

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[1] Min. Mag. vol. xiii (1903) p. 241.

along the *a* axis. Carlsbad twinning is common, but no twin striations can be detected. The refractive indices are the same as those of the sölvsbergite felspars. Small inclusions of the ground-mass are present, in which ægirine and magnetite can be seen. An analysis of the mineral for alkalies, made by Lieut. Angus McIntyre in 1913, yielded the following results:—soda = 6·68 per cent.; potash = 4·51 per cent.

The phenocrysts are surrounded by a narrow zone of kaolinization, which in places penetrates the interior along cleavage-cracks. Wherever kaolin is present, calcite is also found, sometimes in granular crystals, sometimes in cryptocrystalline aggregates with kaolin.

In the ground-mass small laths of anorthoclase are distributed in a mesh, which in texture falls between the trachytic and the intersertal types. Prisms of nepheline of similar dimensions are also present.

Soda-pyroxenes and amphiboles occupy the wedge-shaped spaces between the felspars, but not completely. The ultimate base of the rock is a mineral, the refractive index of which lies between 1·482 and 1·478, and is identical with that of the natrolite found in the vesicles. Associated with this interstitial natrolite is an obscure isotropic substance. Its refractive index approximates to, but is higher than, that of the natrolite: it contains no chlorine, and is probably analcime or glass.

With the exception of cossyrite, which forms occasional small phenocrysts, the coloured minerals are all of later crystallization than the anorthoclase and nepheline. Grass-green ægirine is very abundant; but in most cases the colour is patchy, indicating association with ægirine-augite, which is pale green and gives a high extinction-angle. A few grains of augite, sometimes zoned, are also present. The pyroxenes are frequently included in the monoclinic amphiboles. Cossyrite, however, itself containing inclusions of ilmenite and apatite, is often surrounded by ægirine.

The pleochroism of katoforite, as exhibited in this rock, is variable; but the following scheme represents the usual distribution of colour (and also the maximum extinction-angle):—

$X \wedge a = 33^\circ$ ...... straw-yellow to colourless.
$Y = b$ .... smoky red to purple-brown.
$Z \wedge c = 33^\circ$ ...... greenish-yellow.

The birefringence is very low, and the refractive index is approximately that of monobrom-naphthalin, 1·66. Some of the grains and wedges of katoforite pass into arfvedsonite, orientated in parallel growth. Its pleochroism is in tints of lavender-grey X; violet Y; and yellow-green Z. The extinction-angle 16° differs markedly from that of katoforite, while the birefringence remains about the same. A few individuals that look like katoforite in ordinary light are probably barkevikite, for their polarization-colours are high. The extinction-angle could not be measured, but the refractive index was found to lie between those of monobrom-naphthalin = 1·66 and methylene iodide = 1·74.

Owing to the smallness of the grains and the lack of cleavage, the optical orientation of cossyrite could not be determined. The refractive index is near 1·66, but slightly higher. Pleochroism is in tints of deep brown, reddish-brown, and lighter brown, and can only be observed in a very thin section.

The first minerals to crystallize out were magnetite, ilmenite, and apatite, followed by phenocrysts of anorthoclase and cossyrite. After partial resorption of the phenocrysts, during which the anorthoclase suffered peripheral alteration to kaolin, the crystallization of the groundmass began. Nepheline and anorthoclase were followed in order by cossyrite, ægirine, katoforite, and arfvedsonite. Finally, natrolite, a little calcite, and an obscure isotropic substance filled up the still-unoccupied spaces; also natrolite and calcite were deposited in the vesicles.

Chemical Composition.

An analysis of fresh portions of No. 149, free from visible amygdales, gave the following results:—

	Percentages.	*Molecular Proportions.*	*Mineral Composition (Norm).*		
SiO_2	56·34	·939	Orthoclase	27·80	Salic =84·38.
Al_2O_3	17·86	·175	Albite	46 11	
Fe_2O_3	4·43	·028	Nepheline	8·52	
FeO	3·81	·053	Anorthite	1·95	
MgO	0·52	·013			
CaO	1·97	·036	Diopside	3·07	Femic =14·28.
Na_2O	7·33	·118	Olivine	1·89	
K_2O	4·72	·050	Magnetite	6·50	
H_2O+	1·22	...	Ilmenite	1·22	
H_2O-	0·82	...	Calcite	1·60	
CO_2	0·71	·016			
TiO_2	0·67	·008		98·66	
P_2O_5	tr.	...			
MnO	0·28	·004	Water	2·04	
Total	100·68		Total	100·70	

Ra$=4·10 \times 10^{-12}$ grms. per grm.
Specific gravity=2·47.

Class II	Dosalane.
Order 5	Germanare.
Rang 1	Umptekase.
Subrang 4	Umptekose.

Analyses of similar rocks from neighbouring regions are quoted below for comparison. The Mozambique example is almost identical with the phonolite from Mount Kenya analysed by Dr. G. T. Prior. The similarity extends equally to the mineral composition. Dr. Prior has kindly allowed me to examine the phonolites from British East Africa in the Natural History Museum, and, except in texture, they bear a striking resemblance to the phonolite from the Sanhuti River. The latter rock, like the associated sölvsbergite, is unusually rich in iron-oxides, this being due to the presence of magnetite as an accessory.

	A.	B.	C.	D.	E.	F.
SiO_2	56·34	54·94	58·37	57·81	58·62	61·49
Al_2O_3	17·86	19·34	16·65	18·74	21·50	18·25
Fe_2O_3	4·43	1·80	4·09	5·76	0·47	1·77
FeO	3·81	4·52	3·03	0·42	3·65	3·13
MgO	0·52	1·11	0·37	tr.	0·56	0·41
CaO	1·97	2·05	1·66	1·28	0·88	1·65
Na_2O	7·33	8·39	7·28	9·35	7·95	6·78
K_2O	4·72	5·93	5·46	4·52	5·47	5·47
H_2O	2·04	0·32	2·36	1·50	1·12	0·26
TiO_2	0·67	0·67	0·21	...	0·06	0·51
CO_2	0·71	...	...	...	...	...
P_2O_5	tr.	0·18	0·08	...	...	0·09
MnO	0·28	tr.	0·43	tr.	...	...
Totals	100·68	99·90[1]	99·99	99·38	100·28	99·81

[1] Including $ZrO_2 = 0{\cdot}38$, and $SO_3 = 0{\cdot}27$ per cent.

A. Phonolite. Near the Sanhuti River, Mozambique (an. Holmes).
B. Glassy katoforite-phonolite. W. Kibo, B.E. Africa (an. Eyme).
C. Phonolite. Base of Mount Hohnel, Mount Kenya, B.E. Africa (an. Prior).
D. Tinguaite. Edda Gijorgis, Abyssinia (an. Prior).
E. Phonolite. Nosy Komba, Madagascar (an. Pisani).
F. Phonolitic trachyte. Ravin des Fleurs Jaunes, Réunion (an. Boiteau).

XI. Tephritic Pumice.

Among the detritus that litters the northern bank of the Monapo, near its entry into Mokambo Bay, numerous fragments of dark-grey pumice occur. Unfortunately the rock has nowhere been seen *in situ*, although it may be traced for a few miles along the northern bank of the river. It must, therefore, have come from the district between the Monapo and Murimatigri—an area originally covered by flows of amygdaloid, but now greatly dissected by erosion.

In chemical composition, the rock differs strikingly from the basalts and andesites of the neighbourhood, whereas it appears to be closely related to the alkali and associated lavas of the Sanhuti-River district.

Under the microscope, the rock is seen to be made up of a dense brown glass containing in places irregular patches of less intense colour, in which crystallization had just made a beginning. Within these local clearings, very minute crystals of magnetite or ilmenite and microlites of felspar can just be seen under a quarter-inch objective. The felspar shows no trace of twinning, but a maximum extinction-angle of 25° points to its identity as andesine. This result suggested that the rock might be an andesite-pumice. Against this view, however, was the fact that the radium-content of the lava was $2{\cdot}59 \times 10^{-12}$ grms. per grm., a figure which would be surprisingly large for a rock of andesitic composition. In these circumstances it was thought desirable to have the rock analysed. With the exception of the alkali determinations the analysis was made by my friend Dr. H. F. Harwood (Chemical Department, Imperial College of Science & Technology), and for his assistance I wish to express my grateful thanks.

Chemical Composition.

	Percentages.	*Molecular Proportions.*
SiO_2	52·27	·871
Al_2O_3	17·70	·174
Fe_2O_3	7·01	·044
FeO	4·48	·063
MgO	1·79	·045
CaO	5·93	·105
Na_2O	5·95	·096
K_2O	3·20	·034
H_2O+	0·37	...
H_2O-	0·43	...
CO_2	0·51	·012
TiO_2	0·56	·007
MnO	tr.	...
Total	100·20	

	Mineral Composition (Norm).	
Orthoclase	18·90	Salic =75·42.
Albite	37·31	
Nepheline	6·98	
Anorthite	12·23	
Diopside	10·90	Femic =23·99.
Olivine	0·62	
Magnetite	10·21	
Ilmenite	1·06	
Calcite	1·20	
	99·41	
Water	0·80	
Total	100·21	

$Ra = 2{\cdot}59 \times 10^{-12}$ grms. per grm.
Specific gravity = 2·55.

Class II	Dosalane.
Order 5	Germanare.
Rang 2	Monzonase.
Subrang 4	Akerose.

	A.	B.	C.	D.
SiO_2	52·27	52·78	51·80	53·04
Al_2O_3	17·70	19·08	17·90	17·34
Fe_2O_3	7·01	3·63	3·10	2·12
FeO	4·48	3·79	4·36	6·96
MgO	1·79	1·58	3·72	2·49
CaO	5·93	5·09	6·59	5·86
Na_2O	5·95	7·95	4·74	5·61
K_2O	3·20	3·85	3·65	3·00
H_2O	0·80	0·44	2·87	0·37
CO_2	0·51	0·10	...	...
TiO_2	0·56	1·50	1·41	2·12
P_2O_5	n. d.	0·63	...	0·83
MnO	tr.	tr.	...	...
Totals	100·20	100·75[1]	100·14	99·74

[1] Including 0·33 per cent. of chlorine.

A. Tephritic pumice, Monapo River, Mozambique (an. Harwood & Holmes).
B. Trachydolerite, Mount Meru, British East Africa (an. Maritz).
C. Essexite, Bekinkina, Madagascar (an. Pisani).
D. Olivine-trachyandesite, Vellouve, Réunion (an. Boiteau).

The most notable feature indicated by the analysis is the high percentage of iron, and especially of ferric oxide. This characteristic distinguishes the rock from the trachyandesites and trachydolerites, and suggests that the name tephrite would be somewhat more appropriate. According to Dr. H. S. Washington,[1] the name trachydolerite should be restricted to rocks containing labradorite or a more basic plagioclase, as well as alkali-felspars; and the name trachyandesite to rocks containing andesine in addition to alkali-felspars: both types of rock, moreover, should be rather rich in potash. But for the high iron-content, the composition of the rock now described would fulfil moderately well the conditions for a trachyandesite. Its close similarity to the trachyandesite from Réunion (analysis D) bears out this opinion, but the chemical characters of the rock are probably expressed more accurately if it be named a tephritic pumice.

XII. BASALT. (Pl. XX, fig. 4.)

The lava-flow represented by specimen 156 was found by Mr. R. L. Reid at the base of the volcanic succession in the Sanhuti-River district. It is exposed on the north side of the river near the boundary-fault, where it lies on a basement of gneiss, and probably extends to the Cretaceous sediments on the east. The basalt is a dense dark-grey rock holding rusty amygdales that average $\frac{1}{8}$ inch in diameter. The amygdales are lined and sometimes entirely filled by palagonite, which in thin section varies in colour from yellowish green to reddish brown, though in the hand-specimen, beneath the rusty shell of iron-oxides, it is nearly black. The specific gravity is about 2·42, thus agreeing closely with that of the palagonite from Cape Flora (Franz Josef Land) examined by Sir Jethro Teall.[2] The same material occurs in the main body of the rock, wedged in the crystalline network of the ground-mass.

The only other minerals found in the amygdales are thomsonite, easily recognizable by its moderately-high double refraction, and calcite. Thomsonite occurs in radiating aggregates, each acicular crystal giving straight extinction. The refractive index, about 1·52, is low for thomsonite, and points to a high content of soda.

Excluding the amygdales, the mineral composition of the rock, determined by the Rosiwal method, is approximately as follows:—

Minerals.	*Estimated percentage by weight.*
Labradorite	56
Augite	24
Palagonite	15
Magnetite, ilmenite,[3] and decomposition-products	5
Total	100

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[1] Journ. Geol. Chicago, vol. v (1897) pp. 366–68.

[2] Q. J. G. S. vol. liii (1897) p. 486.

[3] The percentage of these minerals is greater than 5, for only a few of the inclusions in felspar and augite could be measured.

The rock is for the greater part very fine-grained, but in places small ophitic patches occur, never more than $\frac{1}{4}$ inch long, in which the texture is much coarser (see Pl. XX, fig. 4). On an average, two of these patches may be seen in a section of half a square inch. In the direction of the greatest extension the ophitic texture seems to have been broken up, perhaps by flow, for porphyritic crystals of labradorite and augite stream away into the fine ground-mass. At right angles to this direction similar porphyritic crystals occur, but less abundantly. In the ophitic patches, as usual, the felspar was the first mineral to crystallize (except for a few skeleton-crystals of magnetite or ilmenite which form rare inclusions). The porphyritic crystals are sometimes composite, and here too the felspar preceded the augite. In the ground-mass, on the contrary, the augite began its crystallization before the felspar (and continued beyond the latter), and the texture is minutely intersertal. It is clear, therefore, that two distinct periods of crystallization are represented, and that these took place under conditions sufficiently different to affect not only the grain and texture, but also the order of crystallization of the two chief minerals.

The felspar of each generation is labradorite, but the early crystals are richer in the anorthite molecule than the later. In the former, which are characterized by broad albite twinning and absence of zoning, the average refractive index is 1·57. All the felspars are clear and glassy, and are nearly free from inclusions except around the borders of the smaller laths, where innumerable dark globules associated with tiny green blebs of augite obscure the edges. Only in the neighbourhood of the inclusions is there any trace of alteration, the body of the felspars being perfectly fresh.

Augite also shows a slight difference in composition, according to the time of its crystallization. The ophitic plates and larger crystals are grey-green, while the small granules of the ground-mass frequently exhibit a brown or even a purple madder tint.

Magnetite and ilmenite began to crystallize before the other minerals of the rock, but continued beyond them. They occur in skeleton-crystals and in small irregular masses, and probably the dark globules that border the felspars and fringe the edges of the palagonite wedges represent the final attempts of the same minerals to crystallize: for, where they occur in palagonite, the colour of the latter is paler than elsewhere.

Besides palagonite, there is a small amount of obscure interstitial matter, some of which is colourless and feebly birefringent, thus suggesting that it may be a zeolite or possibly orthoclase. A green alteration-product also occurs, and may be serpentine or chlorite.

There is nothing to suggest that palagonite has been produced by the weathering of an original glass. Glass does not occur in this rock; but, in many of the vesicular basalts belonging to the second stage of eruption, glass occurs abundantly, and when it weathers it changes in the direction of laterite, not of palagonite. The latter substance appears generally to be associated with amygdaloidal basalts, not with vesicular types. The formation of palagonite, like that of amygdaloidal infillings, is therefore to be ascribed to a concentration of water (and possibly of other volatile fluxes) in the residual liquors left in the crystal network of the nearly consolidated rock. In the present case, the occurrence of thomsonite with palagonite is significant, on account of the light that it throws on the origin of the alkali rocks which succeeded the basalt. Thomsonite may contain as much as 7 or 8 per cent. of soda, and the low refractive index of the present example suggests that it is a soda-rich variety. Moreover, palagonite often contains 4 per cent. of soda or more. In contrast with these figures, the rock itself (including a certain amount of interstititial palagonite) contains only 3·29 per cent. of soda, showing that the progress of crystallization led to an enrichment of the residual liquors in soda. The same conclusion would be deduced from the characters of the two generations of plagioclase. Thus, even within the limits of a lava-flow that has rapidly cooled, it is possible to discern a process of differentiation which, on a larger scale and with slower cooling, should result in the production of a magma relatively rich in soda. It is, surely, more than a mere coincidence that the magma erupted next in succession was that which crystallized as the phonolite already described.

Chemical Composition.

Portions of specimen 156, visibly free from amygdales and weathered crust, were crushed and analysed. The results obtained are as follows:—

	Percentages.	*Molecular Proportions.*
SiO_2	48·82	·814
Al_2O_3	15·93	·156
Fe_2O_3	7·18	·045
FeO	6·63	·092
MgO	6·02	·151
CaO	8·67	·155
Na_2O	3·29	·053
K_2O	1·41	·015
H_2O+	0·98	...
H_2O-	0·54	...
TiO_2	0·83	·010
MnO	0·32	·004
Total	100·62	

	Mineral Composition (Norm).	
Orthoclase	8·34	Salic =60·57.
Albite	27·77	
Anorthite	24·46	
Diopside	13·79	Femic =38·38.
Hypersthene	7·84	
Olivine	4·79	
Magnetite	10·44	
Ilmenite	1·52	
	98·95	
Water	1·52	
Total	100·47	

Ra $=1·38\times10^{-12}$ grms. per grm.
Specific gravity $=2·78$.

Class III	Dosalane.
Order 5	Gallare.
Rang 3	Camptonase.
Subrang	Camptonose.

	A.	B.	C.	D.	E.
SiO_2	48·82	47·20	46·36	50·22	49·43
Al_2O_3	15·93	15·29	16·70	16·20	12·73
Fe_2O_3	7·18	9·57	7·53	3·13	5·06
FeO	6·63	6·13	6·23	8·07	8·47
MgO	6·02	5·90	5·84	7·54	6·96
CaO	8·67	8·93	9·77	8·57	8·59
Na_2O	3·29	3·61	3·22	3·36	3·50
K_2O	1·41	0·85	1·12	1·38	1·21
H_2O	1·52	1·12	0·35	0·22	1·84
CO_2.........	...	...	...	...	0·28
TiO_2	0·83	1·14	1·88	1·95	2·26
MnO	0·32	...	...	...	0·08
P_2O_5	...	0·46	0·58	...	0·49
Totals......	100·62	100·20	99·58	100·64	100·90

A. Basalt, Sanhuti River, Mozambique (an. Holmes).
B. Basalt, Philippi Lake, Kerguelen Island, South Indian Ocean.
C. Basalt, Mount Drygalski, Heard Island, South Indian Ocean.
D. Basalt, Glass, Cockburn Is., Louis-Philippe Land, Antarctica (an. Prior).
E. Basalt, Yandina, Queensland (an. Jensen).

The composition of the basalt is in no way abnormal, and can be closely matched by that of other basalts from many other localities. Some of these are cited above for comparison with the Sanhuti example. The closest resemblance is found in the case of basalts from the islands of the South Indian Ocean.

XIII. Picrite-Basalt. (Pl. XX, fig. 5.)

Overlying the phonolite, described above, is a nearly black vesicular rock. Most of the vesicles are empty, but a few are occupied by a powdery form of phillipsite. The refractive index of the mineral is 1·53, its double refraction is very low, and the cleavage is good.

In thin section the minerals present and their relative proportions, determined by the Rosiwal method, are as follows:—

	Minerals.	*Percentage by volume.*
Phenocrysts	Titaniferous augite	21
	Olivine	14
Ground-mass	Labradorite	65
	Titaniferous augite	
	Magnetite and ilmenite	
	Isotropic base	
	Total	100

The rock is conspicuously porphyritic, though augite alone is represented in two generations. Olivine, in clear colourless crystals, which have suffered some resorption but practically no serpentinization, is present only as phenocrysts. Labradorite, on the contrary, occurs only in tiny laths distributed sparsely through the ground-mass. Purple-brown augite is the most abundant mineral present, and bears a close resemblance to the augite described by Dr. A. Scott[1] from the Arenig augite-andesites of Bail Hill (Dumfries-shire). The crystals have a tendency to group together in a roughly radial fashion about a central nucleus of olivine. In the ground-mass small grains of deep-purple augite are very abundant. Whether the purple coloration of certain augites is due to the presence of titanium or manganese cannot yet be definitely stated. The usual belief that it is due to the former element is supported by the analyses tabulated in this paper, but the subject is one that still awaits systematic investigation. The ground-mass is very fine-grained, and dark owing to the abundance of magnetite and ilmenite, which are present in well-shaped crystals and in a dendritic network of branching rods. Iron-ores, titaniferous augite, and a sprinkling of labradorite-laths are crowded together in a residuum of grey-brown glass. In sporadic patches labradorite becomes sufficiently abundant to control the texture, which is then not unlike that of the intersertal basalts described below.

Chemical Composition.

Portions of specimen 155, free from phillipsite, were analysed with the following results:—

	Percentages.	*Molecular Proportions.*	*Mineral Composition (Norm).*		
SiO_2	44·05	·734	Orthoclase	4·00	Salic =46·27.
Al_2O_3	13·39	·131	Albite	16·83	
Fe_2O_3	7·64	·048	Anorthite	25·44	
FeO	8·42	·117			
MgO	10·51	·263	Diopside	21·06	Femic =53·10.
CaO	10·46	·187	Hypersthene	3·79	
Na_2O	2·01	·032	Olivine	13·46	
K_2O	0·67	·007	Magnetite	11·14	
H_2O+	0·44	...	Ilmenite	3·65	
H_2O-	0·47	...			
TiO_2	1·93	·024		99·37	
MnO	0·25	·003	Water	0·91	
Total	100·24		Total	100·28	

$Ra=0{\cdot}47\times10^{-12}$ grms. per grm.
Specific gravity=2·78.

Class III ... Salfemane.
Order 5 ...... Gallare.
Rang 4 ...... Auvergnase.
Subrang 4 ... Auvergnose.

The rock is similar, both chemically and mineralogically, to the Hillhouse or picrite type of the Scottish Carboniferous basalts.[2] Chemically, it bears some resemblance to the camptonite of Kjose Aklungen (Norway),[3] and this is the more interesting because the

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[1] Min. Mag. vol. xvii (1914) p. 100.

[2] G. W. Tyrrell, Trans. Geol. Soc. Glasgow, vol. xiv (1912) p. 228 (Analysis II, p. 250).

[3] W. C. Brögger, 'Eruptivgesteine des Kristianiagebietes: III' 1899, p. 51.

frequent association of camptonite and bostonite is in the Sanhuti-River district paralleled by the association of picrite-basalt and sölvsbergite. The rock is also very similar to the limburgites of the Macedon District, Victoria[1] (Tertiary alkali series), which, like the Mozambique picrite-basalt, are associated with anorthoclase-bearing rocks. The main outstanding feature of the analysis is the high percentage (for this class of rock) of ferric oxide. This is due to the preponderance in the rock of augite, and to the abundance of magnetite. Titaniferous augites frequently show an excess of ferric over ferrous iron; the Bail-Hill example is a case in point.

Rocks of Group B.

XIV. Basalts: Sills and Dykes.
(Pl. XX, fig. 6 & Pl. XXI, fig. 1.)

The specimens collected[2] are slightly vesicular rocks from the following localities:—

128, 129, 130.	Sill, west side of Sokoto Hill, at the base.	Dark grey.
142.	Dyke, near Ibrahimo.	
141.	Dyke, Mochelia (reddish brown).	

These rocks are of even grain and fine texture, and consist essentially of a mesh of lath-shaped felspars, between which groups of granular augites are contained. Olivine has in all cases been altered to serpentine, and the latter is only a minor constituent. Filling up the interstices of the crystalline network is a grey-brown glass swarming with dark globulites, or with branching sprays of magnetite. Examined closely, specimens from Sokoto Hill and Ibrahimo are seen to be pitted with minute green-lined vesicles or amygdales. The first stage in the infilling of the latter is represented by a fibrous green mineral. The same mineral occurs in greater quantity in the amygdaloids; and, since it contains alumina and has a refractive index greater than 1·576, it may be referred to one of the chlorites. The main body of the amygdale occasionally consists of brown or greenish-brown palagonite; but more usually it is occupied by chalcedony, with which opal is sometimes associated. The minute amygdales of the Mochelia dyke appear to be free from a chloritic lining.

The felspar occurs chiefly in small tabular crystals accompanied by a sprinkling of larger individuals, indicating an approach to porphyritic texture. This appearance is intensified by the bunching together of some of the smaller crystals in parallel or divergent series. Extinction-angles, twinning, and refractive index (1·560) show that the species is labradorite. Many of the larger crystals enclose patches and shreds of chlorite, and lines of globulitic glass-inclusions immediately within their outer borders

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[1] H. S. Summers, Proc. Roy. Soc. Vict. n. s vol. xxvi (1914) p. 278.

[2] A number of dark compact dyke-rocks collected by Mr. Wray (from the district of Fernão Vellosa Harbour and from Makulia farther north) were lost during transit to England.

are common. Otherwise, the felspars are clear and glassy, and show no traces of alteration.

While most of the felspar came early in the order of crystallization, there is another member of the felspar family which is allotriomorphic, and was the last of the minerals to crystallize. It is free from twin lamellæ, exhibits lower polarization-colours than labradorite, and has a refractive index of 1·522. Its identity is thus determined as orthoclase, which is further verified by the relatively high percentage of potash contained in the rocks.

Augite is pale yellowish-green (iron-stained round the borders in the Mochelia rock), and exists in rounded grains or sharply-defined wedges determined by the disposition of the felspar-laths. It is probably a member of the enstatite-augite series. The intersertal texture thus produced is a marked characteristic of nearly all the Mozambique rocks.

Magnetite, perhaps accompanied by ilmenite, is evenly distributed in small octahedra, irregular grains, and skeleton-crystals. It tends to cling round the augite-crystals, but rarely forms inclusions in them, and never does so in the labradorite. In the Mochelia rock, magnetite is very abundant inside dark patches of glass or palagonite. The mineral certainly belongs to a late stage in the crystallization of the rock.

Dark interstitial matter occupies nearly a quarter of the volume of the rocks, being, however, much less abundant than in the lava-flows. Some of this material is an isotropic glass packed with globulites, or penetrated by a network of iron-ores. In other cases, microlites of felspar and obscure aggregates of dark augite are buried in a pale glass. Palagonite is also present in deep-brown or greenish patches, which under crossed nicols are seen to have a fibrous cryptocrystalline texture.

By means of a diffusion-column of methylene iodide and benzine, the constituents of the Sokoto-Hill rock (128) were separated into the following groups. The approximate proportions of each mineral, measured by micrometric analysis, are added:—

Mineral Composition of No. 128.

Specific Gravity.	*Mineral.*	*Percentage by weight.*
2·20	Opal	3
2·35 2·45	Glass and palagonite	20
2·56	Orthoclase	6
2·62 2·65	Chalcedony and chlorite	7
2·68 2·70	Labradorite	40
3·10 3·20	Enstatite-augite	18
Sank	Magnetite and ilmenite with glass	6
	Total	100

Taking the specific gravity of the material that sank as 5, the specific gravity of the rock should be 2·74. The actual value, 2·70, corresponds with the slightly vesicular character of the rock.

Chemical Composition.

The Sokoto-Hill and Mochelia basalts were analysed with the results tabulated below. The analysis of the former rock was made under my direction by my former students, Lieut. J. L. Harris, M.C., the late Lieut. G. Kirby, and Mr. E. Spencer:—

Sokoto Hill, 128.

	Percentages.	*Molecular Proportions.*		*Mineral Composition (Norm).*	
SiO_2	52·42	·874	Quartz	3·75	Salic =66·87.
Al_2O_3	17·40	·171	Orthoclase	10·01	
Fe_2O_3	4·21	·026	Albite	22·53	
FeO	5·16	·072	Anorthite	30·58	
MgO	5·30	·132	Diopside	12·10	Femic =32·03.
CaO	9·08	·163	Hypersthene	12·66	
Na_2O	2·65	·043	Magnetite	6·05	
K_2O	1·77	·018	Ilmenite	1·22	
H_2O	1·26	...			
TiO_2	0·67	·008		98·90	
MnO	0·24	·003	Water	1·26	
Total	100·16		Total	100·16	

Ra=$0·98 \times 10^{-12}$ grms. per grm.
Specific gravity=2·70.

Class II ...... Dosalane.
Order 5 ...... Germanare.
Rang 4 ...... Hessase.
Subrang 4 ... Hessose.

Mochelia, 141.

	Percentages.	*Molecular Proportions.*		*Mineral Composition (Norm).*	
SiO_2	51·21	·854	Quartz	0·99	Salic =64·54.
Al_2O_3	17·99	·176	Orthoclase	6·12	
Fe_2O_3	4·63	·029	Albite	24·63	
FeO	5·81	·081	Anorthite	32·80	
MgO	6·11	·153			
CaO	9·36	·167	Diopside	10·96	Femic =35·20.
Na_2O	2·92	·047	Hypersthene	16·75	
K_2O	1·03	·011	Magnetite	6·73	
H_2O+	0·32	...	Ilmenite	0·76	
H_2O-	0·72	...			
TiO_2	0·42	·005		99·74	
P_2O_5	tr.	...			
MnO	0·27	·004	Water	1·04	
Total	100·79		Total	100·78	

Ra=$0·85 \times 10^{-12}$ grms. per grm.
Specific gravity=2·72.

Class II ...... Dosalane.
Order 5 ...... Germanare.
Rang 4 ...... Hessase.
Subrang 4 ... Hessose.

For comparison, the analyses are repeated below with others of the same type. The occurrence of a similar basalt in Somaliland [1] is interesting, for it preceded the eruption of a series of alkali

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[1] A. de Gennes & A. Bonard, C. R. Acad. Sci. Paris, vol. cxxxi (1900) p. 196.

rocks of the same type as those found in the north of the Mozambique area. Microscopically, the east-and-west dykes of Northumberland—Crookdene, Collywell, and Tynemouth [1]—are very similar to those described here.

	A.	B.	C.	D.	E.
SiO_2 ……	51·21	52·42	49·47	51·31	51·20
Al_2O_3 ……	17·99	17·40	18·70	14·55	18·89
Fe_2O_3 ……	4·63	4·21	15·05	…	7·57
FeO ……	5·81	5·16	…	9·02	…
MgO ……	6·11	5·30	5·34	6·85	6·75
CaO ……	9·36	9·08	8·90	11·61	10·52
Na_2O ……	2·92	2·65	2·87	1·79	1·71
K_2O ……	1·03	1·77	0·79	0·60	0·51
H_2O ……	1·04	1·26	0·81	1·41	1·70
TiO_2 ……	0·42	0·67	…	1·00	1·14
P_2O_5 ……	tr.	…	…	…	…
MnO ……	0·27	0·24	…	0·47	…
CO_2………	…	…	…	1·47	…
Totals……	100·79	100·16	101·93	100·08	99·99

A. Dyke, Mochelia (an. Holmes).
B. Sill, Sokoto Hill (an. Harris, Kirby, & Spencer).
C. Basalt, Kallele River, 56 miles from coast, Somaliland.
D. Crookdene Dyke, Northumberland (an. Smythe).
E. Tynemouth Dyke, Northumberland (an. Stead).

Contact-Metamorphism.

The metamorphism of the sediments through which the dykes and sills intrude is everywhere of a simple character. Usually, the changes are restricted to bands extending only a few inches on each side of the contact. Limestones are recrystallized to granular calcite, and in places crystals of quartz are developed, indicating the percolation of silica-bearing solutions from the lavas. Mr. Wayland found that the upper part of a dyke, intrusive into calcareous sandstone near Mochelia, had been removed by weathering, thus exposing the sandstone walls which had enclosed it. Upon these well-marked hexagonal jointing had been superinduced.

Near the contact of this dyke steam-holes have been developed in the sandstone, and these are now filled with opal and chalcedony, the latter being pale brown owing to the incorporation of limonite which was present in the original cement. Examination of the unaltered sandstone in thin section shows that it consists of slightly rounded grains of quartz, orthoclase, and microcline, cemented together by calcite and limonite. Small nummulites are found embedded in the cement. Near the dyke, calcite is replaced by opal, the metasomatism having equally affected the nummulites. In the amygdales of the sandstone, opal was first deposited, chalcedony followed, and the infilling was completed by a clear mosaic of quartz. (See Pl. XXI, fig. 2.)

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[1] M. K. Heslop & J. A. Smythe, Q. J. G. S. vol. lxvi (1910) p. 3.

XV. Basalts: Lava-Flows. (Pl. XXI, fig. 3.)

The specimens collected include the following:—

124. Brown amygdaloidal basalt, near the bend of the Monapo River, south side.
125. Red amygdaloidal basalt, between Mochelia and Mitikiti (penetrated by an andesite dyke).
131. Purple vesicular amygdaloidal basalt; half a mile south of Sokoto Hill.
132. Purple vesicular basalt; three-quarters of a mile west of Sokoto Hill.
133. 134. 135. } Brown amygdaloidal basalt; south-east of Ibrahimo.
136. Purple vesicular amygdaloidal basalt; east of Murimatigri.
145. Purple-brown amygdaloidal basalt; near the Sanhuti River.
146. Grey-black vesicular basalt; near the Sanhuti River.

One of the best and most continuous exposures of amygdaloidal and vesicular basalts is to be found between the Monapo and Mitikiti Rivers. Numerous small streams and long alluvial flats, connected with the sea by way of mangrove swamps, cut up the flows, and sometimes expose the underlying floor of shale or limestone. In places, hard dykes stand out in ridges running nearly due north and south. The basalt is a rough purplish-grey rock, sometimes dull and earthy at the surface, but often glazed by the deposition of a thin film of lateritic constituents. Along the military road (made in 1910) which skirts the northern shore of Mokambo Bay, the freshly-broken rocks could be admirably seen *in situ*. The colour of the unweathered rock is there purple or reddish-brown, variegated by the green linings of the amygdales and brightened by the sparkling cleavage-surfaces of innumerable crystals of zeolites, such as heulandite. Similar exposures were examined east of the forts at Murimatigri and Ibrahimo, and in the Sokoto-Hill district. The thickness of the flows is now very variable and much reduced by erosion, but it was nowhere seen to exceed about 40 feet.

The lavas are characterized by a high proportion of glass—dark red-brown to black—and by a strong development of vesicles and amygdales. The chief minerals present in the latter are chlorite, zeolites, and various forms of silica. It is noteworthy that calcite is extremely rare. Chalcedony is very abundant, and occurs in a great variety of forms including waxy carnelian, red and green jaspers and bloodstones, and beautifully banded agates. The interior of many of the siliceous amygdales is occupied by a mosaic of quartz. In other cases, where a hollow cavity has been left, well-formed crystals of quartz, or zeolites, project from the sides. Among the agates and jaspers found in the alluvium flanking the Monapo, Mr. Wayland discovered a number of worked stones and implements. These are figured and described in an interesting paper, published in 'Man,' July 1915, p. 57.

Under the microscope the minerals seen are identical with those of the dyke-rocks already described. The felspars in some specimens are microporphyritic, and the smaller crystals are frequently grouped together in glomeroporphyritic clusters. Where individuals of markedly different size come into contact in parallel positions, the Becke test indicates that the larger crystals possess a slightly higher refractive index than their smaller neighbours. This evidence, implying that crystals of the second crop are slightly richer in the albite-molecule than those of the first, is interesting, in view of the fact that the zeolites of the amygdales are predominantly lime-bearing varieties. Some of the larger crystals of labradorite—especially in the neighbourhood of well-filled amygdales—are replaced by chalcedony, and veined and streaked with chlorite. Signs of weathering, however, are rarely met with.

Augite is present in colourless or yellowish-green grains and aggregates, the colour tending to deepen towards the outer borders, which are often ill-defined and merge imperceptibly into the surrounding glass. In the dark reddish- or greenish-brown glass that occupies the interstices of the crystal network, minute dendritic sprays of magnetite and innumerable globulites are present, particularly around the borders of ill-defined felspar- and augite-crystals. It is worthy of notice that the glass around the larger vesicles is frequently very dense and undifferentiated. This effect is doubtless due to the local cooling set up by the sudden expansion of the volatile constituents of the erupted magma.

Only the amygdale minerals remain to be considered. The vesicles in which they occur are of two strongly-contrasted types :—

(*a*) Well-shaped and smoothly-lined spaces easily visible to the naked eye in thin sections (Pl. XXI, fig. 4), and in hand-specimens extending in dimensions up to the size of the closed fist.

(*b*) Minute branching interspaces with obscure and irregular borders, connecting sometimes with the larger vesicles, and sometimes with small cracks and fissures that cut abruptly across the texture of the rock.

The minerals found in the amygdales are chlorite, heulandite, laumontite, natrolite, opal, chalcedony, quartz, calcite, and gypsum. In good exposures, such as that on the Mochelia road, it can be seen almost at a glance that zeolites are by far the most abundant of the amygdale minerals, and that of the zeolites heulandite is the chief member. In the associated surface-débris, the zeolites must soon fall a prey to decomposition, and consequently forms of silica greatly predominate, giving the erroneous impression that the parent amygdales were mainly siliceous. In hand-specimens the order of infilling is found to be (1) chlorite (which appears also in later stages), (2) zeolites, and (3) silica.

Palagonite sometimes occurs in minute vesicles; but, with the exception that it is occasionally replaced by chalcedony, it is unaccompanied by zeolites or other minerals. Chlorite is the usual lining material, and in vermicular aggregates it is often present in heulandite and chalcedony.

Heulandite ($CaAl_2Si_6O_{16}5H_2O$), with its bright cleavage-surfaces and pearly lustre, occurs in great abundance throughout the area, from Mokambo Bay to the Sanhuti River. Cleavage-flakes give good biaxial figures, which are optically positive. The refractive index is 1·5 and the extinction-angle practically straight. Heulandite is frequently followed (for instance in 125*a*) by downy sheaves and radiating granules of yellow laumontite ($CaAl_2Si_4O_{12}4H_2O$). Individual crystals are so small that a qualitative analysis was necessary to complete the identification. The mineral gelatinizes with hydrochloric acid, and contains alumina, iron-oxide, lime, and much water. The refractive index averages 1·52.

In one specimen divergent aggregates of stilbite were found on heulandite, and were distinguished from the latter by the larger extinction-angle, and by the fact that cleavage-flakes do not show a complete biaxial figure. All the zeolites were carefully tested for soda, but of the three already mentioned it was detected only in stilbite; natrolite ($Na_2Al_2Si_3O_{10}+2H_2O$), on the other hand, is free from lime. Slender needle-like crystals of this mineral are found on heulandite, and in No. 136 *b* radiating sheaves of natrolite complete the filling of vesicles already lined with heulandite. The refractive index is 1·47, and the extinction is straight.

Heulandite is frequently replaced by opal, chalcedony, and quartz, and in some sections (as, for example, in 136, Pl. XXI, fig. 4) it is clear that the change began at the walls of the amygdales and developed inwards. There is no evidence that the other zeolites have been similarly replaced, but both laumontite and natrolite are sometimes succeeded by chalcedony and quartz. Calcite is exceedingly rare, and it has only been found in one specimen (No. 136 *b*), in which it was deposited in minute crystals on quartz. Gypsum is also rare, but was met with in some of the sections in narrow veins cutting through everything from heulandite to quartz. The order of deposition in the vesicles may now be stated for a number of typical cases. Chlorite is omitted, as it is liable to appear at any or every stage up to quartz.

No. 125 a.	*No. 133.*	*No. 136 a.*	*No. 136 b.*	*No. 125 b.*
Heulandite.	Heulandite.	Heulandite.	Heulandite.	
Laumontite.	Stilbite.		Natrolite,	
		Opal.		Opal.
Chalcedony.			Chalcedony.	Chalcedony.
Quartz.			Quartz.	Quartz.
Gypsum.			Calcite.	Gypsum.

The most striking feature of this suite of minerals is the predominance of lime and silica, and the rarity of alkali and carbonate minerals. The sequence in No. 136 *b* is significant, for natrolite free from lime follows heulandite free from soda, while finally calcite appears. In the Sanhuti basalt (p. 241), thomsonite rich in soda is followed by calcite. In the phonolite from the Sanhuti district, natrolite is followed by calcite. There is thus a notable difference, which may be of great significance, between the vesicle-minerals of the Sanhuti lavas and those of the amygdaloids. On the one hand, is a series of lavas including types rich in alkalies in which soda-zeolites and calcite occupy the vesicles; on the other, is a series of typically calc-alkali lavas in which the vesicles are occupied by lime-zeolites and forms of silica. These two associations, which can be matched in other regions, seem to indicate that among the volatile fluxes of the alkali series carbon dioxide was a dominant member, whereas among those of the calc-alkali series water was the chief constituent, carbon dioxide being absent, or of minor importance.

The order of infilling is closely parallel to that determined in many other localities where the same minerals are represented. As long ago as 1849 Breithaupt[1] recognized the sequence from heulandite to stilbite (given in the original nomenclature as stilbit to desmin). In the Watching basalt, New Jersey, C. N. Fenner[2] shows that heulandite may be followed by laumontite, stilbite, or natrolite. At the well-known locality of Carnmoney Neck (Antrim), the order of infilling is given by J. Strachan[3] as (*a*) hullite and dellesite, (*b*) zeolites, (*c*) chalcedony and quartz.

The circulating solutions of the Mozambique amygdaloids appear to have become saturated in alkaline constituents only towards the end of the period of zeolite deposition. C. Dœlter has shown[4] that natrolite is deposited from solutions of soda, alumina, silica, and water at temperatures below 190° C. Above that temperature analcime is formed. The presence of gypsum among the end-products gives another point on the temperature-scale. Van't Hoff[5] investigated the relations of gypsum and anhydrite, and found that the latter mineral is deposited in place of gypsum if the temperature exceeds 63·5° C. In the presence of alkali salts the temperature of the transition-point is lowered. The stage of silica deposition falls between those of natrolite and gypsum, and at such low temperatures it is difficult to understand why the silica was not all deposited as opal, unless it is assumed that alkalies were present. G. Spezia[6] has shown that opal is deposited at moderately low temperatures from siliceous solutions, but that, when alkalies are present, quartz forms instead. Opal already deposited may be transformed into quartz by the action of a hot solution of sodium silicate. The order commonly observed in siliceous amygdales (opal—chalcedony—quartz) seems, therefore, to imply a growing concentration of soda in the percolating waters. Interesting in this connection is the composition of the hot springs at Nashologoto, for they may be regarded as a feeble

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[1] 'Die Paragenesis der Mineralien' Freiberg, 1849, p. 105.

[2] Ann. N.Y. Acad. Sci. vol. xx (1910) p. 169.

[3] Proc. Belfast Nat. Field Club, vol. ii (1906) App. vii & viii.

[4] Tschermak's Min. Petr. Mitth. vol. xxv (1906) pp. 99, 102.

[5] Zeitschr. Phys. Chem. vol. xlv (1903) p. 257.

[6] Atti Accad. Sci. Torino, vol. xxxiii (1898) pp. 289, 876, & Journ. Chem. Soc. vol. lxxvi, pt. 2 (1899) p. 300 (abstract).

solution containing soda and silica in water charged with carbon-dioxide.

In explaining the origin of amygdale minerals, appeal has been made to two chief processes. By some writers they have been regarded as decomposition-products due to weathering; by others they are regarded as hydrothermal products of the final stages of consolidation. The view is now gaining favour that these minerals represent, not the first stage of destruction of the lavas in which they occur, but the last stage in their construction.[1] C. N. Fenner[2] takes an intermediate position: for, although he concludes that the vesicles of the Watchung basalt were filled while it cooled, he thinks that the water concerned in the process was drawn from the underlying sediments.

In Mozambique the amygdale minerals are clearly not the result of weathering. In the freshly exposed surfaces on the Mochelia road and on the Ibrahimo road, weathering products are typically absent. The felspars are generally fresh, and, where altered, they are replaced by chalcedony and penetrated by streaks of chlorite—a change clearly to be correlated with the replacement of heulandite by silica and chlorite. If due to atmospheric weathering, the distribution of zeolites and agate should be uniform: on the contrary, it is very irregular. In some localities the basalts are vesicular and free from infillings; in others the walls of the vesicles are lined to a varying depth, while along certain belts the vesicles are all tightly packed. The view suggested by Fenner cannot be adopted, for the amygdales occur as abundantly when the basalts lie on a platform of granite and gneiss as when they cover a sedimentary basement. There seem to be, however, no objections to regarding the minerals and the water that accompanied them as the last products of consolidation. The regular sequence which, so far as can be seen, is one of decreasing temperature and of increasing concentration of soda and silica; the instability of heulandite towards silica; the absence of zeolites from the sills and dykes (because the material that would have formed zeolites was enabled to crystallize as plagioclase); the general absence of calcite, limonite, and other weathering products; the conspicuous freshness of the pyrogenetic minerals; and, finally, the occurrence of hot springs on the border of the volcanic field—all favour the hydrothermal or late magmatic origin of the amygdale minerals.

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[1] For a recent discussion and references to many other localities, see W. F. P. McLintock 'On the Zeolites & Associated Minerals from the Tertiary Lavas around Ben More, Mull' Trans. Roy. Soc. Edin. vol. li, pt. 1 (1915) p. 13.

[2] Ann. N.Y. Acad. Sci. vol. xx (1910) p. 106.

Chemical Composition of the Sokoto Vesicular Basalt (No. 132).

	Percentages.	*Molecular Proportions.*	*Mineral Composition (Norm).*		
SiO_2	56·42	·943	Quartz	8·97	Salic =73·19.
Al_2O_3	17·33	·170	Orthoclase	9·45	
Fe_2O_3	2·78	·018	Albite	24·89	
FeO	3·23	·044	Anorthite	29·88	
MgO	4·67	·117			
CaO	8·61	·154	Diopside	10·30	Femic =25·03.
Na_2O	2·95	·047	Hypersthene	10·09	
K_2O	1·58	·017	Magnetite	4·18	
H_2O+	1·32	...	Ilmenite	0·46	
H_2O-	0·44	...			
TiO_2	0·25	·003	Total	98·22	
MnO	0·17	·002	Water	1·76	
Total	99·75		Total	99·98	

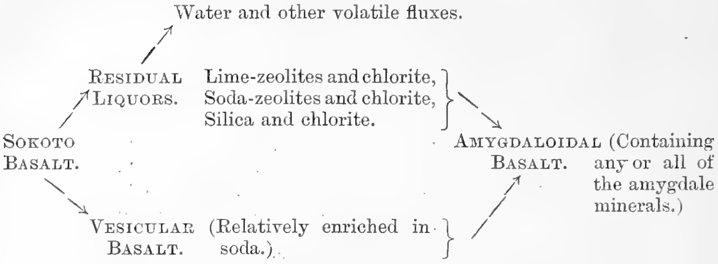
Ra $=0{\cdot}94\times10^{-12}$ grms. per grm.
Specific gravity $=2{\cdot}43$.

Class II	Persalane.
Order 4	Austrare.
Rang 3–4	Tonalase-Bandase.
Subrang 4	Tonalose-Bandose.

Comparing this analysis with that of the Sokoto sill, the most striking difference lies in the excess of silica in the vesicular lava. This is clearly referable to the presence of chalcedony in the microscopic vesicles of the latter. However, even if free silica be subtracted from the analysis, and the remaining figures recalculated to 100, there still remain noteworthy differences. The lava contains a smaller relative proportion of iron-oxides and magnesia than the sill, and the compositions of the normative plagioclase in the two rocks are :—

Sokoto sill	An_{58}
Sokoto vesicular lava	An_{55}

It thus appears that the lava is deficient in the constituents of chlorite and of lime-zeolites. The absence of these amygdale minerals from the rock analysed and their abundance in the neighbouring lavas confirm this result. If we regard the Sokoto sill as representing an approximation to the parent magma of the surrounding flows of vesicular and amygdaloidal basalt, then we may follow the progress of differentiation (controlled by the presence of abundant water and perhaps of other volatile fluxes) and reconstruction through various stages that may be represented as follows :—



XVI. HORNBLENDE-ANDESITE. (Pl. XXI, fig. 5.)

The specimen (No. 126) was collected from a small dyke penetrating a flow of amygdaloid on the south side of the Monapo, about 2½ miles north-west of Mochelia. In the hand-specimen white phenocrysts of felspar (averaging 4 mm. × 2 mm.) are seen distributed in a dark-grey ground-mass. Smaller crystals of hornblende and flakes of biotite can also be distinguished. The rock is compact, but a few very small amygdales containing well-crystallized quartz are present.

Under the microscope the chief minerals seen and their approximate proportions by weight, determined by the Rosiwal method, are as follows:—

Minerals.	*Estimated Percentage by weight.*	
Andesine and inclusions	26	Phenocrysts =40.
Hornblende	9	
Biotite	5	
Plagioclase	not determined separately	Ground-mass =60.
Orthoclase		
Quartz		
Biotite		
Hornblende		
Total		100

Part of the rock was crushed, and by means of bromoform, subsequently diluted with benzine, three groups of minerals were separated:—

(*a*) Hornblende and biotite sank in bromoform; in Thoulet solution diluted with water, the average specific gravity of the crop was found to be 2·97.
(*b*) Plagioclase sank in bromoform diluted with benzine at 2·67.
(*c*) The remaining material—mainly ground-mass—was collected for analysis. Its average specific gravity was found to be 2·61.

Mineral Group.	*Percentage by weight.*	*Specific Gravity.*
Andesine and inclusions	26	2·67
Hornblende and biotite	14	2·97
Ground-mass	60	2·61
Average specific gravity		2·67

With the data thus ascertained the specific gravity of the rock is calculated to be 2·67. The value actually found was 2·68.

The phenocrysts of plagioclase average andesine in composition. They are often strongly zoned, and the interior is, as is usual, richer in the anorthite molecule than the outer zones. Inclusions are rare, except for occasional wisps of chlorite. Alteration is common to a microcrystalline aggregation in which kaolin, perhaps sericite, epidote, and a very little calcite can be distinguished. Green hornblende is present in good idiomorphic crystals modified by slight resorption. Patches of ground-mass, shreds of biotite, grains of magnetite, and small crystals of apatite are found as inclusions, and in one case a rounded crystal of zircon. Biotite also exhibits slight resorption, and its fibrous texture suggests a certain degree of alteration. Magnetite and apatite are present sparingly as inclusions. The ground-mass contains small laths of andesine or oligoclase surrounded by fan-like intergrowths of colourless minerals having refractive indices respectively above and below that of Canada balsam. The minerals in question are probably quartz and orthoclase: for the intergrowths exhibit an approach to micrographyric texture, and the chemical composition of the ground-mass (tabulated below) leads to the same conclusion. Wisps of biotite largely altered to chlorite are distributed through the ground-mass, and irregular grains of hornblende are also present.

Chemical Composition (Hornblende-Andesite).

An analysis of part of specimen 126 was made, with the following results:—

	Percentages.	*Molecular Proportions.*	*Mineral Composition (Norm).*		
SiO_2	60·76	1·013	Quartz	14·16	Salic =80·30.
Al_2O_3	16·81	·165	Orthoclase	14·46	
Fe_2O_3	2·07	·013	Albite	27·77	
FeO	2·34	·032	Anorthite	23·91	
MgO	3·27	·082			
CaO	6·57	·117	Diopside	6·89	Femic =17·80.
Na_2O	3·32	·053	Hypersthene	7·28	
K_2O	2·42	·026	Magnetite	3·02	
Loss above 110° C.	1·19	...	Ilmenite	0·61	
Loss at 110° C.	0·48	...			
TiO_2	0·31	·004	Total	98·10	
MnO	0·22	·004	Loss on ignition	1·67	
Total	99·76		Total	99·77	

Specific gravity = 2·68.

Class II	Persalane.
Order 4	Austrare.
Rang 3	Tonalase.
Subrang 4	Tonalose.

The analyses of some other andesites from other East African localities are quoted below (B, C, D, E) for comparison with the

Mozambique example. The high silica-percentage of the latter is probably due to the presence in the specimen analysed of small quartz-bearing amygdales, and also to the presence of quartz in the micrographic groundmass :—

	A.	B.	C.	D.	E.	F.	G.	H.
SiO_2	60·76	51·32	56·65	51·97	56·14	65·32	66·40	62·07
Al_2O_3	16·81	16·62	22·11	16·21	17·81	16·08	12·91	17·15
Fe_2O_3	2·07	9·28	3·31	3·37	2·69	2·89	3·87	1·87
FeO	2·34			9·51	4·67		2·56	3·57
MgO	3·27	5·36	3·42	3·68	4·15	2·13	0·53	2·39
CaO	6·57	9·62	6·67	7·67	6·81	3·47	2·32	4·84
Na_2O	3·32	2·15	1·86	3·41	3·59	4·33	3·30	4·75
K_2O	2·42	2·96	4·10	1·75	1·63	3·62	3·09	2·15
H_2O	1·67	2·60	2·20	1·97	1·16	1·06	4·25	1·18
TiO_2	0·31	n. d.	n. d.	0·22	1·23	0·17	0·54	0·21
MnO	0·22	0·55	0·16	n. d.	0·08	n. d.	0·09	0·26
P_2O_5	n. d.	0·25	tr.	n. d.	0·12	n. d.	0·16	tr.
Totals......	99·76	100·71	100·48	99·76	100·13[1]	99·07	100·02	100·44

[1] Including 0·01 per cent. SrO and 0·04 per cent. BaO.

A. Hornblende-andesite, Monapo River (an. Holmes).
B. Olivine-augite-andesite,[1] Mount Meru.
C. Amphibole-biotite-andesite,[2] Mount Meru.
D. Andesite, Kordofan[3] (an. Linck).
E. Andesite, near the Lucalla River, Angola[4] (an. Harwood).
F. Base of hornblende-andesite, Monapo River (an. Holmes).
G. Toscanite, Indulawane Hill, Zululand (an. Prior).
H. Quartz-porphyry, Kadero, Kordofan[3] (an. Linck).

Chemical Composition of the Ground-mass.

The heavy-liquid separation of the ground-mass already mentioned was not quite clean, for a greater proportion of biotite and andesine accompanied the residue than appeared to be visible in thin section. However, it was thought advisable to analyse the material thus obtained, on account of the light that it might throw on problems of differentiation.[5] The ground-mass would be expected to have the composition of a latite or rhyolite, and although in Mozambique no such rocks have been discovered in association with the basalts, corresponding dyke-rocks are known to exist at Sinjal in the extreme west of Zambesia, among the volcanic rocks south of the Zambesi and the Lebombo, and in Uganda and Kordofan.

The separated material was air-dried at 110° C. Owing to

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[1] E. Pinkert, Földt. Közl. vol. xxxvii (1907) p. 292.

[2] *Id. ibid.* p. 296.

[3] Neues Jahrb. Beilage-Band xvii (1903) p. 428.

[4] A. Holmes & H. F. Harwood, Min. Mag. vol. xviii (1916) p. 69.

[5] See Sir Jethro Teall, Q. J. G. S. vol. lvii (1901) p. lxxxii, for the application of this method to the rocks of the Cheviots.

the lack of material, ferrous oxide was not separately determined, nor were several important minor constituents. The analysis gives a low summation, but is sufficiently full for the immediate purpose.

	Percentages.	*Molecular Proportions.*
SiO_2	65·32	1·089
Al_2O_3	16·08	·158
Fe_2O_3	2·89	·018
FeO	n. d.	...
MgO	2·13	·053
CaO	3·47	·062
Na_2O	4·33	·069
K_2O	3·62	·038
Loss on ignition	1·06	...
TiO_2	0·17	·002
Total	99·07	

Mineral Composition (Norm).		
Quartz	16·86	Salic =88·32.
Orthoclase	21·13	
Albite	36·15	
Anorthite	14·18	
Diopside	2·38	Femic =9·60.
Hypersthene	4·20	
Hæmatite	2·72	
Ilmenite	0·30	
Total	97·92	
Loss on ignition	1·06	
Total	98·98	

Specific gravity $=2{\cdot}61$.

Class I	Persalane.
Order 4	Brittanare.
Rang 2	Toscanase.
Subrang 4	Lassenose.

Analyses of African rocks of similar composition and associated in the field with andesites are quoted on the preceding page (G & H).

XVII. PYROXENE-ANDESITE. (Pl. XXI, fig. 6.)

Pebbles of pyroxene-andesite (No. 144) were found by Mr. Wayland in the bed of the Monapo River and on the alluvial flats to the south, at distances of 3 to 4 miles from the mouth of the river. The rock is dark grey in colour, and is speckled with phenocrysts of felspar, some of which are transparent, others being opaque. It lacks the prevailing reddish tints of the basalts, but weathers to a dark brown. The rock is singularly compact and free from vesicles—a feature suggesting that, like the neighbouring hornblende-andesite, it may be derived from a dyke. No known lava from the Mozambique volcanic area is entirely free from vesicles or amygdales. The specific gravity is 2·72.

Under the microscope the rock presents no unusual features. It consists essentially of phenocrysts of andesine, augite, and hypersthene, and occasional pseudomorphs of serpentine after olivine, embedded in a fine-grained ground-mass of hyalopilitic texture, in which tiny laths of oligoclase, shreds of biotite, grains of pyroxene and iron-ores, together with a little interstitial glass, are the chief constituents.

The phenocrysts of plagioclase are generally clear glassy andesine, with characteristic twinning and zoning, and an average refractive index of about 1·556. The opaque felspars of the hand-specimen owe their colour to the presence of large inclusions of biscuit-coloured glass or of innumerable blebs that suggest a frozen emulsion of felspar and glass. Large pyroxenes are also wholly or partly included by the larger felspars, and apatite, magnetite, and serpentine are accessory inclusions. The glass-filled felspars are surrounded by a clear mantle of oligoclase, which may represent a final period of growth simultaneous with that of the ground-mass. The average refractive index of the outer borders is approximately 1·545; that of the laths in the ground-mass appears to be a little less.

Hypersthene and augite occur in somewhat rounded forms, having rarely retained their idiomorphic outlines. Hypersthene, which is beautifully pleochroic, frequently acts as a nucleus around which augite crystals are built. Both pyroxenes contain magnetite, serpentine, and glass as inclusions. Peripheral wisps of biotite occur around many of the rhombic pyroxenes, and also disseminated sparsely through the ground-mass. In several cases the change from hypersthene to biotite is gradual and continuous, but against felspars the biotite always terminates sharply. Serpentine is not abundant, and is present as pseudomorphs after idiomorphic phenocrysts of olivine, and as confused aggregates in the ground-mass. It is of the golden-yellow variety found in the basalts. Like hypersthene, it is bordered with wisps of biotite which have clearly grown at the expense either of the serpentine or of the olivine which preceded it. The potash-bearing molecules of the magma seem to have reacted with the ferromagnesian silicates already precipitated—hypersthene, olivine, or serpentine—in such a way as to produce biotite.[1]

The order of crystallization is as follows:—apatite and magnetite, olivine, hypersthene, augite, andesine, oligoclase, biotite, and, finally, interstitial glass.

Relationships and Origin of the Volcanic Rocks.

XVIII. DISTRIBUTION OF SIMILAR LAVAS IN EASTERN AFRICA.

The outstanding feature of the volcanic district of Mozambique is the development of two strongly-contrasted series of rocks—one mainly composed of amygdaloidal basalts and including andesites, the other including alkali-trachytes and phonolites.

Amygdaloidal basalts similar to those of Mozambique are found in many localities of South and Central Africa, but nowhere else south of Mozambique are they known to be of Tertiary age. At Sinjal, near the border of Nyasaland and Portuguese East Africa, Dr. A. R. Andrew and Mr. T. E. G. Bailey[2] found basalts, associated with andesites and rhyolites, which they refer to the close of the Karoo Epoch. Dr. Prior has kindly allowed me to see the specimens from this locality (now deposited in the Natural History

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[1] N. L. Bowen, Journ. Geol. Chicago, Supplem. to vol. xxiii (1915) p. 46.

[2] Q. J. G. S. vol. lxvi (1910) p. 220.

Museum), and it is clear that in no essential respect do they differ from the Mozambique examples; even the amygdale minerals and the order of their deposition are the same.

South of the Zambesi, basalts, largely amygdaloidal, are found associated with late Karoo sediments, flanking the plateau of crystalline rocks for hundreds of miles. In the north they have been mapped by Dr. E. O. Teale & Mr. R. C. Wilson.[1] Between the Pungwe and the Sabi (Save) rivers they were traced by Col. A. Freire d'Andrade.[2] Some 50 miles west of the mouth of the Busi, he collected melaphyres in which chlorite-lined amygdales containing zeolites and chalcedony and quartz are abundant. Similar flows of melaphyre occur in Lourenço Marques. I have examined specimens from the Komati River that appeared to be identical with the basalt of the Sokoto sill. The Lebombo amygdaloids of Swaziland and Zululand are associated with andesites and rhyolites, and some of these have been analysed.[3]

Occurring farther from the coast, the Drakensbergen lavas,[4] the Bushveldt amygdaloid of the Transvaal,[5] the Tuli lavas of Southern Rhodesia,[6] the Batoka basalts of the Zambesi,[7] the basalts of the Forest Vale between Bulawayo and the Zambesi,[8] and the Ngami amygdaloids of the Kalahari,[9] all show a marked likeness one to the other and to the Mozambique lavas. Towards the south the resemblances become less marked, though the differences are limited to the incoming of olivine (generally serpentinized) among the pyrogenetic constituents, and of calcite among the amygdale minerals.[10] Throughout this vast region, west and south-west of Mozambique, no alkali series of rocks is known to occur in association with the late Karoo amygdaloids (except doubtfully those of the Bushveldt complex, where the age of the intrusions that preceded the amygdaloids is still uncertain). It seems, however, worthy of remark that the igneous rocks that followed the Upper Karoo amygdaloids and the later dolerites of South Africa are generally melilite-basalt, alnoite, or kimberlite. These rocks occur in the Cape Province, the Orange Free State, the Transvaal, Southern Rhodesia, Northern Rhodesia, and Katanga.

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[1] Geogr. Journ. vol. xlv (1915) p. 29.

[2] P. Choffat, 'Contributions à la Connaissance Géologique des Colonies Portugaises d'Afrique' Comm. Geol. Portugal, ii (1905) p. 33.

[3] J. McC. Henderson, Trans. Geol. Soc. S. Africa, vol. xii (1910) p. 24.

[4] A. W. Rogers & A. L. Du Toit, 'The Geology of Cape Colony' 1909, p. 225.

[5] E. T. Mellor, Ann. Rep. Geol. Surv. Transvaal, 1901, p. 31.

[6] A. J. C. Molyneux, Q. J. G. S. vol. lix (1903) p. 266.

[7] G. W. Lamplugh, *ibid.* vol. lxiii (1907) p. 162.

[8] F. P. Mennell, *ibid.* vol. lxvi (1910) p. 369; and Spec. Rep. 2, Rhodesia Museum, 1904, p. 15.

[9] S. Passarge, Zeitschr. Gesellsch. für Erdkunde, Berlin (1904) no. 3, p. 179.

[10] A. W. Rogers & A. L. Du Toit, 'The Geology of Cape Colony' 1909, p. 226; see also P. A. Wagner, 'The Diamond-Fields of South Africa' 1914, p. 99.

Melilite-basalt also occurs among the alkali rocks of the Great Rift Valley, where it appears to stand towards them in a complementary relation, as a mafic end-product of differentiation specially rich in lime and magnesia. In South Africa the 'alkaline affinities' of melilite-basalt and kimberlite have been noted,[1] and it is interesting to find that the amygdale minerals of these rocks include zeolites and calcite, but never chalcedony or quartz.[2]

Although the lavas of Mozambique, and of the greater part of Africa south of that latitude, are predominantly amygdaloidal basalts characterized by siliceous and lime-zeolite amygdales, the lavas known in the north are not commonly of this type, except in Abyssinia. The majority of the lavas belong to an alkali series (accompanied by mafic complementary types), to which those of Mozambique bear a close resemblance.[3] The distribution of the various types has been well summarized by Prof. J. P. Iddings in his 'Igneous Rocks,' vol. ii (1913) p. 576 *et seq.*, with references to the literature, and therefore the details need not be repeated here. It will be sufficient to draw attention, as Rosiwal did many years ago,[4] to the frequent association of a calc-alkali series (including amygdaloidal basalts, andesites, and rhyolites) with a more strongly-developed alkali series.

North of the Songwe River in German East Africa, Bornhardt found basalts, andesites, and trachytes, while south of the river, in the extreme north of Nyasaland, A. R. Andrew & T. E. G. Bailey discovered tuffs containing trachyte and phonolite.[5] In Masailand, along the Uganda Railway towards Victoria Nyanza, in the Kavirondo country[6] adjoining the Nyanza, in the islands of Lake Rudolf, in Kordofan, and especially in Abyssinia and Somaliland,[7] the two series are well represented. Wherever the succession has been noted[8] the alkali series, often accompanied by normal basalts, is the later. In the islands of Lake Rudolf, in Italian Somaliland, and in Abyssinia, the amygdale minerals of the earlier series are chiefly quartz, chalcedony, and opal, accompanied by heulandite and other lime-zeolites. Blanford draws attention to the striking similarity between the amygdaloids of Abyssinia and those of Southern Arabia and the Deccan. In each of the two last-named regions an alkali series is also present.[9] No detailed petrographic account of the Deccan traps has yet been published,

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[1] P. A. Wagner, 'The Diamond-Fields of South Africa' 1914, p. 106.

[2] A. W. Rogers & A. L. Du Toit, 'The Geology of Cape Colony' 1909, p. 348.

[3] Especially in the presence of such soda-amphiboles as katoforite and cossyrite.

[4] Denkschr. K. Akad. Wissensch. Wien, vol. lviii (1891) p. 465.

[5] Q. J. G. S. vol. lxv (1910) p. 222.

[6] F. Oswald, Q. J. G. S. vol. lxx (1914) p. 140 *et seq.*

[7] W. T. Blanford, 'Observations on the Geology & Zoology of Abyssinia' London, 1870, p. 180.

[8] As, for example, in Abyssinia, Lake Rudolf, and the Kavirondo country.

[9] See J. W. Evans, Q. J. G. S. vol. lvii (1901) p. 38. In Kathiawar the nepheline-bearing rocks appear to be intrusive into the Deccan traps, and therefore of later age.

but several specimens in my possession bear the most detailed resemblance to the basaltic dyke-rocks of Mozambique.

In the adjoining table, the distribution of the two series of lavas is tabulated in as complete a form as the present state

District.	*'Calc-Alkali' Series.*			*'Alkali' Series.*			
	Amygdaloidal basalt.	Andesite.	Rhyolite.	Alkali-rhyolite.	Alkali-trachyte.	Nepheline-bearing lavas.	Melilite-basalt.*
Deccan	×	×	×	...	...	×	...
Southern Arabia	×	...	...	×	×	...	...
Somaliland	×	...	...	×	×	×	...
Abyssinia	×	×	...	×	×	×	...
Kordofan	×	×	×	...	...	×	...
Lake Rudolf	×	×	...	×	×	×	...
Kavirondo	×	×	×	...	...	×	...
Uganda Railway	×	×	...	×	×	×	...
Elgon	...	...	...	...	...	×	×
Kenya	...	...	...	...	×	×	...
Naivasha	...	...	...	×	...	...	...
Masailand	×	×	...	×	×	×	...
Kilima Njaro	...	×	...	...	×	...	×
Meru	...	×	...	...	×	×	...
Songwe River	×	×	...	...	×	×	...
Mozambique	×	×	...	...	×	×	...
Katanga	×	...	×	...	...	...	×
Sinjal	×	×	×	...	...	...	...
Batoka	×	...	...	...	...	...	...
Forest Vale	×	...	...	...	...	...	...
Southern Rhodesia	×	...	...	...	...	...	×
Zambesia-Pungwe	×	×	×	...	...	...	×[1]
Lebombo	×	×	×	...	...	...	[2]
Zululand	×	×	×	...	...	...	[2]
Drakensbergen	×	×	...	...	...	...	[2]
Chief amygdale-minerals.	Quartz, chalcedony, opal, and lime-zeolites. (Calcite not common, but becoming more abundant south of Mozambique.)			Soda-zeolites and calcite. (Silica absent, except in the rhyolites and more acid trachytes.)			

* Melilite-basalt is included here, not because of any inherent richness in alkalies, but because it seems often to be a complementary end-product of an alkali series.

1. Southern Rhodesia.
2. Melilite-basalts and kimberlites (of later age than the amygdaloids) occur west of these localities in the Transvaal, the Orange Free State, and Griqualand West. See map in P. A. Wagner's 'Diamond-Fields of South Africa' 1914.

of exploration renders possible. The 'amygdaloidal basalts' of the second column are those in which siliceous amygdales are abundant. Normal basalts are not tabulated, for they appear, in various degrees of abundance, to be common to both series. The table brings out the fact that the association in Mozambique of two contrasted series of lavas is not exceptional, although it is the southernmost locality in Eastern Africa in which that association has yet been noted. The weighty problems that centre about the origin of the Mozambique lavas thus become common to all the African occurrences on the north.

The alkali series of Mozambique can be closely matched by the lavas of Réunion, and by those of the Mid-Atlantic islands.[1] In Angola, near Cambambe, trachytes containing katoforite and cossyrite are associated with augite-andesite.[2] In none of these localities are amygdaloidal basalts like those of Mozambique known to occur.

XIX. Variation-Diagrams.

In the preceding sections, ten analyses have been recorded. These analyses fall naturally into two series (belonging respectively to Groups A & B) characterized in each case by a well-marked serial relationship. The variation-diagram adopted for a graphical comparison of the analyses is that in which silica percentages are taken as abscissæ, and the other oxides plotted as ordinates.[3] In order to render the comparison as faithful as possible, the total of the two iron-oxides is expressed as ferrous oxide, and to this manganous oxide is added. The analyses are then recalculated to 100, water and carbon dioxide being omitted (figs. 6 & 7, pp. 266–67).[4]

It will be noticed that the two series of curves are distinctly different, and that no analysis belonging to one series would fit the curves connecting the other series.

Series A is based on analyses of the rocks from the Sanhuti district. The curves were drawn before the tephritic pumice of the Monapo was analysed, but when the analysis was made it fell naturally into its place between those of basalt and phonolite, and very little modification of the curves was found necessary. This seems to indicate that the lava in question belongs to the same series as the Sanhuti rocks, and that it is not immediately related to the amygdaloids of the district in which it was found.

The series is characterized throughout by a high percentage of iron-oxides, and by an excess of soda over potash with a marked parallelism of the two alkali curves. Lime and magnesia occupy a low position on the right (that is, beyond 55 per cent. of silica), but rise rapidly on the left, in antipathy to the alkalies which fall towards the left. It is, therefore, difficult to regard the whole

[1] G. T. Prior, Min. Mag. vol. xiii (1903) p. 254.

[2] A. Holmes & H. F. Harwood, Min. Mag. vol. xviii (1916) p. 58.

[3] A. Harker, 'Natural History of the Igneous Rocks' 1909, p. 118.

[4] To avoid confusion, the values for titanium dioxide are not plotted.

series as 'alkaline,' for the high alkalies on the right are compensated on the left by high lime and magnesia. In each direction the curves have been continued beyond the extreme analyses by what seemed to be a natural extrapolation. At the mafic end, the potash-curve meets the base at $SiO_2 = 38$ per cent. The composition of this mafic limit of the series is that of a melilite-basalt. At the felsic end the lime and magnesia curves meet the base at $SiO_2 = 70·6$ per cent., and the corresponding composition of the acid limit of differentiation is that of an alkali-rhyolite. Although these two limiting rocks have not been found in Mozambique, they both occur in quite similar series of rocks in British East Africa, and are evidently natural members of the series, although occurring only where differentiation has proceeded to its extreme limits.

In order to demonstrate the similarity of this series of Mozambique rocks to those of other areas, variation-diagrams have been made for the lavas of Abyssinia, British East Africa, Réunion, and Teneriffe (fig. 8, pp. 268–69). Most of the analyses on which these are based can be found in Iddings's 'Igneous Rocks,'[1] or in papers to which references are there given, and in Dr. H. S. Washington's well-known tables.[2] The curves for each constituent have a strong family likeness throughout. The chief points of dissimilarity are found in British East Africa, where, as Dr. Harker has already pointed out,[3] alumina falls rapidly in the more siliceous rocks, and iron-oxide (largely ferric) instead of gradually declining, compensates for the low alumina by ascending. The magnesia-curve for the rocks of British East Africa also differs from those of other localities in its slow ascent towards a mafic limit. The discrepancy is, however, due to subsidiary differentiation among the basic rocks, for melilite-basalts and picrite-basalts occur in British East Africa, which (if analysed) should provide a normal magnesia-curve. The resemblances of the curves for Abyssinia, Mozambique, and Teneriffe are the most perfect, and indicate that similar processes must have been at work on similar deep-seated materials in each of those regions, these conditions being the controlling factors in the development of a petrographic province or of a number of similar provinces in widely-separated regions. Analyses of the alkali-rocks of Madagascar, the Transvaal, Angola, and the Los Islands were also plotted, but in none of these cases was there any resemblance to the Mozambique curves, probably on account of the existence of more than one series of differentiates in those districts.[4]

Series B is based on analyses of rocks from the Monapo-River and Sokoto-Hill districts. The analysis of the ground-mass of hornblende-andesite is included, for it provides a good indication of the course of differentiation towards the felsic end of the series.

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[1] Vol. ii (1913) pp. 576–90.

[2] U.S. Geol. Surv. Prof. Paper 14 (1903).

[3] 'Natural History of the Igneous Rocks' 1909, p. 124.

[4] Such, for example, as occur in the Christiania district; see A. Harker, *op. cit.* p. 123.

Fig. 6.—*Variation-diagram of the Tertiary volcanic rocks of Mozambique: Series A.*

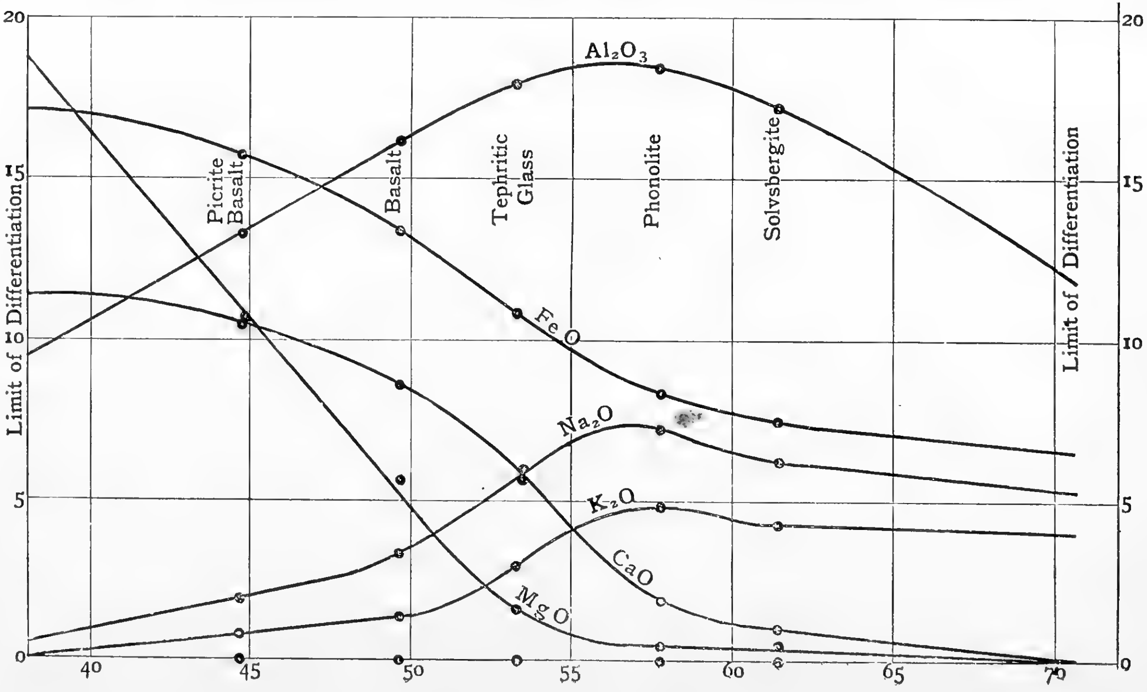


Fig. 7.—*Variation-diagram of the Tertiary volcanic rocks of Mozambique: Series B.*

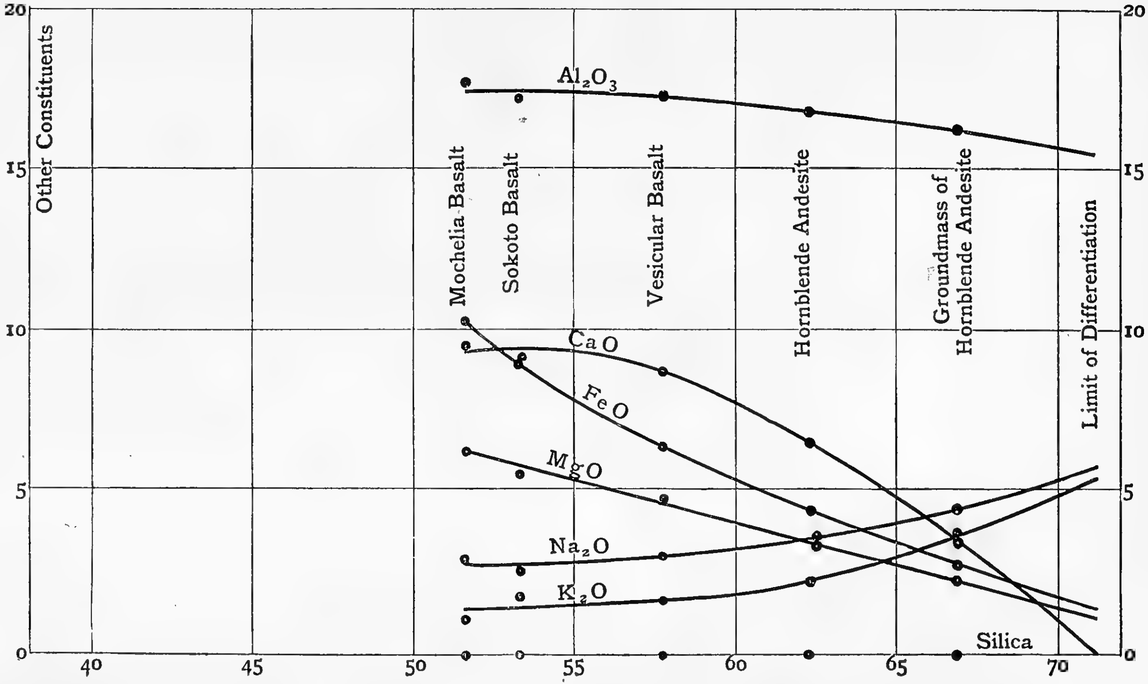
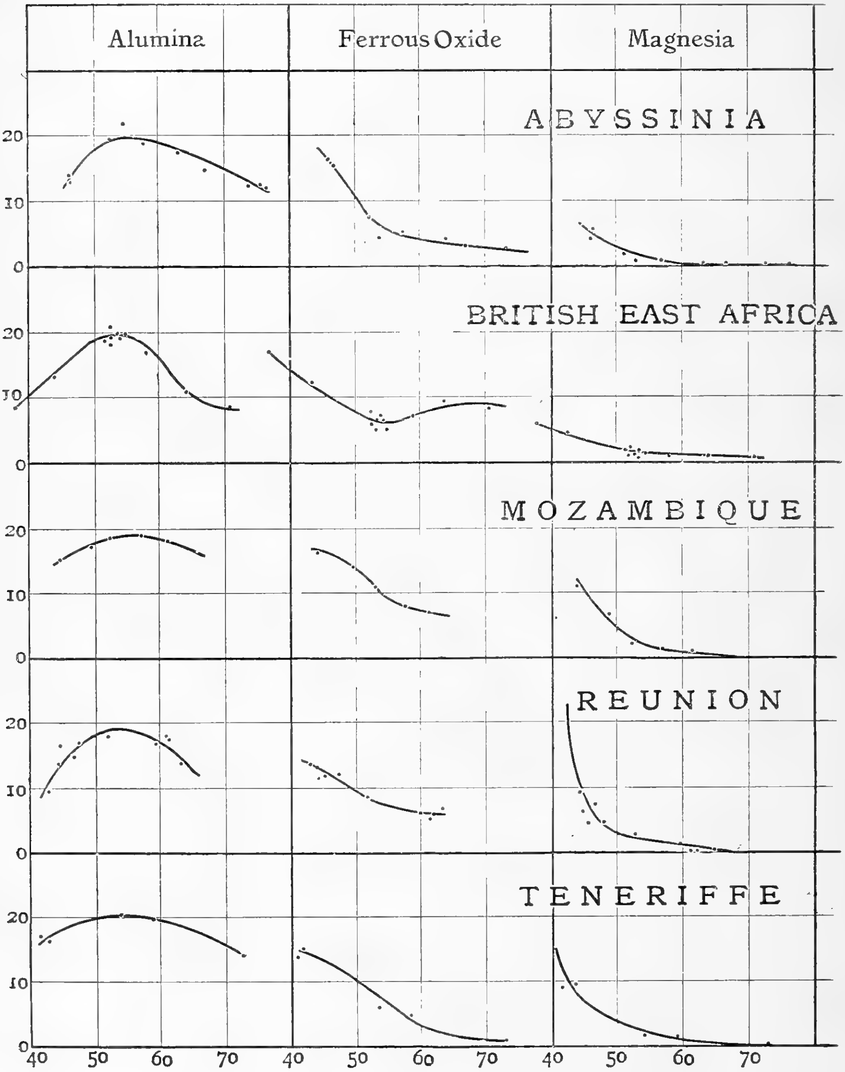
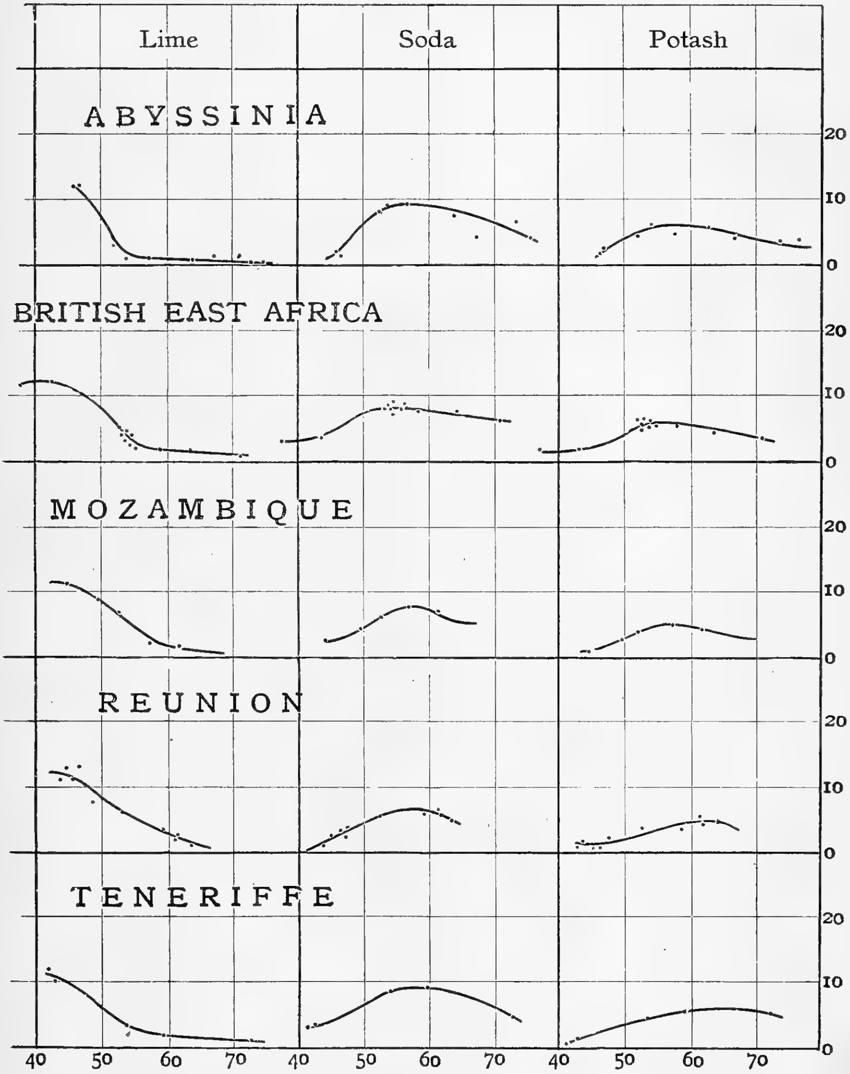


Fig. 8.—*Variation-diagrams of the post-Cretaceous volcanic* *Mozambique, Réunion,*



rocks ('alkali' series) of Abyssinia, British East Africa, and Teneriffe.



A felsic limit is reached at $SiO_2=71\cdot2$, where the lime-curve meets the base-line. The composition of the limit is that of a rhyolite. Alumina is much higher and ferrous oxide much lower than in the corresponding felsic limit of Series A. This contrast is in accordance with the mineralogical characteristics of the rocks of Series A, soda-pyroxenes and amphiboles being present, whereas in Series B the ferromagnesian minerals are augite, hornblende, and biotite. No attempt was made to find a mafic limit to Series B, for the curves do not reach even the ordinate corresponding to 50 per cent. of silica.

Soda is again in excess of potash and the two curves are nearly parallel, but converge as silica increases. The lime-curve is everywhere at a higher level than in the corresponding range of Series A. The iron-oxide curves are similar in the two series, but that of Series B is at a lower level throughout and declines more rapidly. The alumina-curve of Series B is much flatter than that of Series A, because in the latter the place of alumina is partly taken by ferric oxide in the soda-amphiboles and pyroxenes. The general form of the curves in Series B is very similar to those of the volcanic rocks of Lassen Peak (California),[1] and of the San Francisco district of Arizona.[2]

Regarding each of the series as a whole, it seems doubtful—in the absence of any knowledge of the relative volume of each rock species—whether one can be regarded as more alkaline than the other. The main distinction is that in Series A the antipathy of lime and magnesia to the alkalies is much more marked than in Series B, the separation of these two groups of constituents taking place much sooner and much more completely in Series A than in Series B. Each of the alkalies begins to exceed lime in Series A at about 54 per cent. of silica, whereas in Series B this does not occur until silica has reached 66 per cent.

There seems to be no justification for supposing that the two series of rocks are the result of different processes acting on similar deep-seated materials, for they are both associated with the same meridional system of faulting. We are, therefore, driven to consider the two series as the consequence of similar processes acting on different materials, those materials being in the one case under-saturated with silica, relatively deficient in water,[3] and rich in carbon dioxide, and in the other case over-saturated with silica, rich in water, and practically free from carbon dioxide. Whether these two groups of parent materials were derived from a pre-existing common source, is a problem that cannot yet be definitely solved.[4]

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[1] A. Harker, 'Natural History of the Igneous Rocks' 1909, p. 126.

[2] H. H. Robinson, U.S. Geol. Surv. Prof. Paper 76 (1913) p. 181.

[3] N. L. Bowen writes: 'It may well be . . . . . that volatile substances are as abundant in magmas of this [alkali] series as in any others, but that water is relatively an unimportant fraction' Journ. Geol. Chicago, Suppl. to vol. xxiii (1915) footnote 2, p. 78.

[4] For a suggestion that may apply here, see J. W. Evans, Geol. Mag. dec. 6, vol. iii (1916) p. 189.

XX. Origin of the Lavas.

Four problems, or groups of problems, present themselves for discussion in this section:—

(*a*) The differentiation of the alkali-lavas and their associates, Series A.
(*b*) The origin of the parent magma of Series A.
(*c*) The differentiation of the amygdaloidal basalts and their associates, Series B.
(*d*) The origin of the parent magma of Series B.

(*a*) The serial relationships of the lavas of Series A, disclosed by their variation-diagram, point to some continuous process of differentiation acting on a common parent magma. The sequence of lavas in the Sanhuti district—(1) basalt, (2) phonolite, (3) picrite-basalt—suggests that the first lava to be erupted most nearly approaches the composition of the parent magma, and that the lavas that succeeded it stand in a complementary relation one to the other, the one being rich in alkalies, the other in lime and magnesia. The order of crystallization of the more significant minerals in the series regarded as a whole is approximately as follows: olivine, titaniferous augite, labradorite, diopside, augite, less calcic labradorite (andesine in tephritic pumice?), anorthoclase and nepheline, soda-pyroxenes, soda-amphiboles, and opal (in the ground-mass of ægirine-trachyte). It thus appears that magnesia was the first of the main constituents to commence its withdrawal from the parent magma, and that it was closely followed by lime. A concentration of alkali alumino-silicates and of soda ferro-silicates accompanied by increasing quantities of the volatile fluxes thus became possible. Towards the close, water began to exert a controlling influence, shown by the formation of soda-amphiboles and still later by the deposition of natrolite. The close genetic association of rocks like ægirine-trachyte with free silica (opal) and of phonolite with deficient silica (nepheline) may also be due to the high-temperature activity of water. Describing the history of a magma gradually modified by crystallization, Dr. N. L. Bowen[1] says

> 'For any given concentration of the molecules $KAlSi_3O_8$ and $NaAlSi_3O_8$, however small, there is a certain corresponding concentration of $KAlSiO_4$, $NaAlSiO_4$, and SiO_2,'

the polysilicate molecules being broken down in the presence of water. Later, he says (*op. cit.* p. 56):

> 'The precipitation of $KAlSi_3O_8$, $NaAlSi_3O_8$, $KAlSiO_4$ in mica, and SiO_2 as quartz, means the concentration in the liquid of all the other molecules,'

among which nepheline and the volatile fluxes are important members. In preference to supposing that silica can be removed from a magma by crystallization in the presence of water and other

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[1] 'The Later Stages of the Evolution of the Igneous Rocks' Journ. Geol. Chicago, Suppl. to vol. xxiii (1915) p. 45.

fluxes, even at moderately high temperatures, two suggestions may be made:—

(i) that the portion of a magma specially rich in water and free silica—and therefore light—tends to move upwards, crystallizing only when water begins to escape, and leaving a desilicated portion in which the crystallization of nepheline would then naturally proceed; or

(ii) that in the presence of water, nepheline and alkali-felspar could crystallize, leaving free silica in solution, the ratio between nepheline and alkali-felspar depending on temperature and pressure and on the concentration of water in the magma.

For the reasons stated above, it is considered that the various rock-types of Series A could be evolved by a process of crystallization accompanied by a gravitational settling of the heavier crystals and an upward separation of the lighter residual magmas. At intervals the process would be locally brought to an end by the eruption of lavas.[1]

(*b*) Except at the close of the magmatic history described above, the rocks produced were under-saturated with silica. The parent magma must also have shared this characteristic, and other features to be explained (in contrast with the magmas concerned in the production of the amygdaloids) are the comparative poverty in water and the presence of carbon dioxide.

The well-known theory of Prof. R. A. Daly,[2] who ascribes alkali rocks to the desilication of basaltic magma by absorption of carbonate sediments, is quite inapplicable to the present case. Certainly calcareous bands occur in the Cretaceous rocks of the Sanhuti district, but these are merely a thin veneer on a Pre-Cambrian basement, and can have had no effect on the composition of the lavas. Crystalline limestones occur in narrow bands interfoliated with the gneisses of the basement rocks, but in such small quantity that, if any part of them had been absorbed, a much greater proportion of granite and gneiss would also have been taken up, and the desired effect would thus have been nullified. In one respect only is there a point of contact between Daly's theory and the view here adopted: namely, the belief that carbon dioxide was an important member of the volatile fluxes belonging to the magma from which the alkali lavas were derived.[3] Under high pressures calcite and magnesite can exist in the presence of silicate minerals without dissociation if the temperature be not too high. It is therefore possible that at very great depths, and among rocks

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[1] The process here suggested is, in principle, not unlike that advocated by Dr. N. L. Bowen (*op. cit.* 1915), except as regards the relationships of silica, nepheline, alkali-felspars, and water.

[2] Bull. Geol. Soc. Am. vol. xxi (1910) p. 115; and 'Igneous Rocks & their Origin' 1914, chap. xx.

[3] Prof. C. N. Smyth has recently discussed the genesis of alkali rocks on the hypothesis that they are segregated from 'normal' magmas by the action of special pneumatolytic agents, Am. Journ. Sci. ser. 4, vol. xxxvi (1913) p. 33.

presumably of basic composition, carbon dioxide may be present in primary calcite and other carbonate minerals. If this were so, then a sufficient relief of pressure, such as may have initiated the Tertiary volcanic activity of East Africa, would inevitably bring about reaction between natural carbonate and silicate minerals—reactions which, if they were of the kind described by Daly, would lead on to the evolution of an alkali series of rocks accompanied by a cafemic complementary series.

Methods of desilication by water and by natural carbonates have now been considered,[1] but there remains a third possibility that has not been previously suggested. There is reason to believe that below the granites and gneisses of the continents rocks of basaltic composition fall naturally into place, and that below these occur rocks of peridotitic composition.[2] If igneous activity in any region were initiated, at or through such a depth that the magmas formed included one of peridotitic composition, it seems likely that during the upward progress of the latter it would interact with basaltic material, taking up silica to form enstatite or hypersthene, and abstracting lime to form monoclinic pyroxenes. Such minerals, being heavy, would tend to sink (or at least not to rise) leaving above a magma relatively impoverished in silica, but enriched in alkalies and perhaps in a new series of volatile fluxes.

The occurrence of kimberlite pipes in South and Central Africa favours the view that igneous activity may begin in a zone of peridotitic composition; but, as it stands, the theory still throws no light on the origin of the associated melilite-basalts. On the other hand, if melilite-basalt is always a cafemic complement to an alkali series, it is remarkable that no alkali rocks should have been discovered in South Africa. The calciferous dykes of the Premier Mine,[3] and the great abundance of calcite in many kimberlite pipes[4] and in melilite-basalt, again suggest that carbon-dioxide was an important constituent of the deep-seated materials whence these rocks came.[5] It is difficult to explain the presence of so much calcite, either as an alteration-product or as an infiltration from surrounding sediments, and we are thus led from another point of view to consider the possibility of calcite being present as a primary constituent of very deep-seated rocks. A source for the high percentage of lime in melilite-basalts and of calcite in kimberlite pipes would thus be provided. Moreover, melilite-basalt could then be directly formed by the interaction of

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[1] Dr. H. I. Jensen's suggestion of desilication by Pre-Cambrian saline beds, Proc. Linn. Soc. N.S.W. vol. xxxiii (1908) p. 522, has obviously no application.

[2] A. Holmes, Geol. Mag. dec. 6, vol. ii (1915) pp. 63–64.

[3] P. A. Wagner, 'The Diamond-Fields of South Africa' 1914, p. 98.

[4] *Ibid.* p. 75.

[5] *Ibid.* p. 117. Wagner ascribes the initiation of the igneous activity represented by kimberlite pipes to the relief of pressure consequent upon the isostatic uplift of the continent that began in Upper Cretaceous times, and suggests that the rocks must have come from unusually great depths.

calcite and peridotite without necessarily implying the concomitant formation of complementary alkali rocks.

(*c*) As in Series A, the serial relationships between the rocks of Series B point to a process of differentiation acting on a basaltic magma. In this case, however, the magma must have been well provided with water and over-saturated with silica. Given a magma of the kind suggested, a process of differentiation towards andesite is not difficult to understand. By the sinking of some of the crystals first formed—olivine, labradorite, and augite—the residual magmas would have the composition appropriate to pyroxene- and hornblende-andesites. In turn, the sinking of the phenocrysts of hornblende-andesite would leave a magma having the composition of latite or rhyolite, according to the time during which the process was able to continue. For rocks of this series our knowledge of the kind of differentiation concerned in their genesis has been greatly advanced by recent freezing experiments made in the Carnegie Institution of Washington, and particularly by those of Dr. N. L. Bowen.[1] Prof. Daly has summarized the field evidence in favour of the generally accepted hypothesis that andesite is an early differentiate from basaltic magma.[2]

The Mozambique lavas suggest that in the presence of water not only silica is held in solution by the magma, but also that calcium silicate is retained, its complete crystallization in plagioclase and, perhaps, in augite being deferred (relatively to increasing silica) to a much later stage than in magmas containing carbon-dioxide. The forms of the two lime-curves in the variation-diagrams demonstrate the later crystallization of lime minerals in Series B than in Series A, and the abundance of lime-zeolites in the amygdaloids points to water as the responsible agent. As soon as means are devised for experimenting with artificial magmas containing volatile fluxes under pressure, the suggestion here advanced could be directly tested. It would only be necessary to compare the course of crystallization in two melts of similar composition, one charged with water, the other with carbon-dioxide.

(*d*) The question of the origin of the parent magma of Series B is probably one that could be solved only with a complete knowledge of the preceding igneous history of Mozambique. There is no reason to suppose that the excess of silica is due to the absorption of granite and gneiss by an ascending basaltic magma, for the percentage of potash in the lavas is quite normal. Moreover, as will be pointed out more particularly later, the heat-supply can scarcely have been sufficient to allow a margin for the occurrence of any appreciable assimilation.

[1] Am. Journ. Sci. ser. 4, vol. xxxix (1915) p. 175; 'The Crystallization of Haplobasaltic, Haplodioritic, & Related Magmas' Am. Journ. Sci. ser. 4, vol. xl (1915) p. 161; and Journ. Geol. Chicago, Suppl. to vol. xxiii (1915).

[2] R. A. Daly, Journ. Geol. Chicago, vol. xvi (1908) p. 401; and 'Igneous Rocks & their Origin' 1914, p. 375.

Assimilation not being admitted, there are two ways in which the requisite magma may have been formed. There have been in Mozambique at least three successive periods of granitic intrusion, the first being by far the most extensive, the second and third being almost entirely restricted to small intrusions and pegmatite dykes respectively. It may be that the deep-seated differentiation that gave rise to the early granitic magmas was never quite clean, the result being that a considerable proportion of water accompanied by silica would be retained by the deeper basaltic magmas.[1]

On the other hand, even if there had been no free silica in the basaltic magma that formed in Tertiary times, a certain amount may have been liberated by the early crystallization of olivine, the olivine being afterwards separated from the residual liquor by sinking,[2] the liberated silica being maintained in solution by the activity of water and the crystallization of lime as silicate being deferred by the same agency. No olivine-rich lavas are associated with the basalts, but this may be due to the eruption of the lighter magmas in preference to the heavier crystal-charged differentiates.

XXI. The Radioactivity of the Lavas, and its Bearing on their Origin.

The radium-content of most of the lavas was estimated by Strutt's solution method.[3] In the case of the andesites from the Monapo River this could not be done, on account of lack of material. The results obtained, together with those for some other Mozambique rocks, are tabulated below:—

	Rock.	*Radium in grms. per grm. of rock.*
Series A.	Sölvsbergite	$2·26 \times 10^{-12}$
	Ægirine-trachyte	2·83 ,,
	Phonolite	4·10 ,,
	Tephritic pumice	2·59 ,,
	Basalt (Sanhuti River)	1·38 ,,
	Picrite-basalt	0·47 ,,
Series B.	Basalt sill (Sokoto Hill)	0·98 ,,
	Basalt dyke (Mochelia)	0·85 ,,
	Microvesicular basalt (Sokoto Hill)	0·94 ,,
	Amygdaloid (mean of four specimens)	0·76 ,,
Tertiary.	Sandstone (Mochelia Hill)	0·71 ,,
Cretaceous	Limestone (Sokoto Hill)	0·43 ,,
	Felspathic sandstone (Mount Mesa)	1·59 ,,
	Ferruginous sandstone (Mosuril)	1·18 ,,

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[1] The differentiation of granitic magma from basaltic magma has been fully dealt with by N. L. Bowen, Journ. Geol. Chicago, Supplem. to vol. xxiii (1915) p. 46.

[2] *Ibid.* p. 39.

[3] R. J. Strutt, Proc. Roy. Soc. ser. A, vol. lxxvii (1906) p. 472 & vol. lxxviii (1907) p. 150; A. Holmes, Sci. Progress, no. 33 (1914) p. 13; and 'The Age of the Earth' London, 1913, pp. 104–107.

These results correspond in a general way with those obtained by other observers for similar rocks from other parts of the world,[1] and they support two generalizations already admitted[2]:—

(a) That rocks belonging to an alkali series tend to be richer in radium than those of corresponding silica content belonging to a calc-alkali series.

(b) That in alkali rocks the radium-content is roughly proportional to the amount of alkalies and particularly to the amount of soda, rather than to the silica percentage.

In the absence of any knowledge of temperature-gradients in Mozambique, it is not possible to apply the results specifically in their relation to the thermal problems of vulcanism. The radium-content of the basalts (including that from the Sanhuti River) is about $1{\cdot}0 \times 10^{-12}$ grms. per grm., and, since this figure agrees closely with the average for other basaltic rocks, it is to be expected that the average thorium-content of the basalts is also normal. I have previously shown[3] that, if granite and gneiss continue downwards from the surface to a depth of about 6 kilometres, and if below that depth basaltic rock continues for 47 kilometres, then the temperature at the base of the 'radioactive layer' (about 33 miles below the surface) must be about 1000° C. This calculation assumes that all the earth's heat is maintained by the thermal energy liberated during the disintegration of uranium and thorium. If, on the other hand, part of the earth's heat (say, one quarter) is a remnant of its original thermal condition, then the temperature at the same depth may be a little above 1000° C.,[4] and the temperature will continue slowly to increase at greater depths. With a capping of granite and gneiss thicker than is assumed above, the basal temperature of the radioactive layer is (given the same temperature-gradient) reduced below 1000° C., whereas, if the thickness is less than 6 kilometres, the basal temperature becomes higher. With no granite and gneiss (that is, assuming the whole radioactive layer to be of basaltic material having a radium-content of $1{\cdot}0 \times 10^{-12}$ grms. per grm.) the temperature would be increased to a maximum of 1650° C. at a depth of about 44 miles.[5]

A temperature of 1000° C. at a depth of 33 miles would be barely sufficient to initiate volcanic activity, even if far-reaching relief of pressure by fissuring be admitted. A temperature of 1650° C. at a depth of 44 miles is in this case an impossible maximum, since there is a capping of granite and gneiss, though of unknown thickness. We may, therefore, conclude that the lavas came from depths between 33 and 44 miles. Even so, it is not likely that a basaltic magma could be formed by fusion unless

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[1] See, for example, J. Joly, Phil. Mag. vol. xxiv (1912) p. 694; and A. Holmes, Sci. Progress, no. 33 (1914) p. 15.

[2] *Ibid.* p. 17.

[3] Geol. Mag. ser. 6, vol. ii (1915) pp. 68–69.

[4] *Ibid.* p. 111.

[5] *Ibid.* p. 67.

there were a considerable relief of the pressure appropriate to such depths. In this connexion, the boundary-fault along which the lavas are aligned is of particular interest, for it seems to mark a zone along which pressure actually was relieved to an extent and depth sufficient to promote fusion.

The boundary-fault system is probably a consequence of isostatic readjustment between the uplifted mainland and the sunken region of Mozambique Channel. Long denudation of the crystalline plateau should, on the hypothesis of isostasy, naturally lead to its uplift, and that such a movement has taken place is demonstrated by the presence of a coastal belt of Cretaceous and Tertiary sediments, and by the existence of still more recent raised beaches at various levels along the coast (see fig. 5, p. 230). Moreover, the heavy denudation of the crystalline rocks implies the removal of an important section of the 'radioactive layer.' This process therefore leads, like uplift, to the cooling and contraction of the lithosphere, and thus additional tension-stresses are developed that can only find relief in fissures and faults. Doubtless the actual formation of fissures was helped by regional movements of a tensional character, associated in a complementary way with the compressive movements of Tertiary mountain-building elsewhere.

In conclusion, I wish to place on record the unfailing courtesy and hospitality with which we were everywhere received by the Portuguese officials in Mozambique, who were always ready to help us in every way that lay in their power. For permission to publish the geological observations made during the expedition, I owe my thanks to the Directors of the Memba Minerals Ltd.; in particular, I have to thank them for placing at my disposal a large collection of rock-specimens, including those collected in the Sanhuti-River district, and many of those collected by the staff of the Company during the 1910 season. From my friends and former colleagues Messrs. E. J. Starey, E. J. Wayland, and D. A. Wray, I have received notes and sketches referring to the districts in which they worked, and I desire to express my indebtedness to them for help thus afforded. In connexion with the investigation of the rocks in the laboratory, I wish to thank Prof. W. W. Watts for granting every possible facility for work at the Imperial College of Science & Technology; Prof. the Hon. R. J. Strutt for continuing to lend me his apparatus for determining radium in rocks and minerals; Prof. C. G. Cullis and Dr. J. W. Evans for examining many of my sections, and offering valuable suggestions; and Dr. G. T. Prior and Lieut. W. Campbell-Smith for looking through my sections, and allowing me to compare the Mozambique lavas with specimens of similar rocks in the Natural History Museum from British East Africa, Abyssinia, Nyasaland, and other African localities. In making the analyses published in this paper I received considerable help from Dr. H. F. Harwood, Lieut. J. L. Harris, M.C., the late Lieut. G. Kirby, Lieut. A. McIntyre, and Mr. E. Spencer, and for their assistance in an

arduous task I am particularly grateful. Finally, I owe my thanks to Mr. G. S. Sweeting, who kindly cooperated with me in the preparation of the photomicrographs reproduced in Plates XX & XXI.

EXPLANATION OF PLATES XX & XXI.

PLATE XX.

Fig. 1. Sölvsbergite (153) found between Miali and the Sanhuti River, Mozambique. Chief minerals: anorthoclase, cossyrite, and soda-pyroxenes. × 20. (See p. 233.)

2. Ægirine-trachyte (152) north of Sokoto Hill. Chief minerals: anorthoclase, cossyrite, and ægirine. × 20. (See p. 235.)

3. Phonolite (150) near the Sanhuti River. Chief minerals: anorthoclase, nepheline, natrolite, soda-pyroxenes, and amphiboles. The dark phenocryst is cossyrite surrounded by a green chlorite-like mineral. × 20. (See p. 236.)

4. Basalt with ophitic patches (156) near the Sanhuti River. Chief minerals: labradorite and augite, with some palagonite in the ground-mass. × 20. (See p. 241.)

5. Picrite-basalt (155) near the Sanhuti River. Chief minerals: purple augite and olivine; labradorite, purple augite, and glass in the ground-mass. × 20. (See p. 244.)

6. Micro-vesicular basalt (128) from a sill at the western base of Sokoto Hill. Chief minerals: labradorite and augite, in a base of dark-brown glass. The vesicles are occupied by chalcedony and chlorite. × 20.

PLATE XXI.

Fig. 1. Basalt (141) from the dyke at Mochelia. Chief minerals: labradorite and augite in a base of dark-brown glass. × 36. (See p. 246.)

2. Amygdaloidal sandstone (112) from contact with the Mochelia dyke (text-fig. 5). Grains of quartz, orthoclase, and microcline are present in the sandstone, cemented by calcite which is replaced near the dyke by opal. In the steam-holes opal, chalcedony, and quartz are present. × 12. (See p. 249.)

3. Amygdaloidal basalt (124) south of the Monapo River. Chief minerals: labradorite and augite in a base of dark-brown glass. × 20. (See p. 250.)

4. Amygdale in amygdaloidal basalt (136) east of Murimatigri Quartel. Illustrating the replacement of heulandite (dark areas) by chalcedony. × 20. (See p. 252.)

5. Hornblende-andesite (126) from a dyke penetrating amygdaloid south of the Monapo River. Chief minerals: andesine, hornblende, and biotite, in a ground-mass consisting of the same minerals, together with quartz and orthoclase. × 20. (See p. 256.)

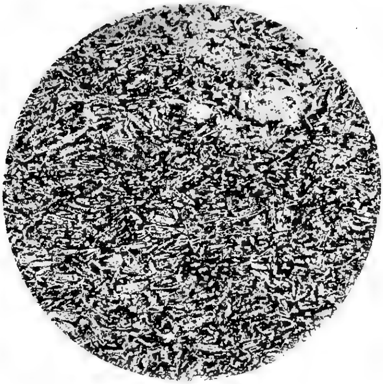
6. Pyroxene-andesite (144) found near the Monapo River. Chief minerals: andesite, augite, and hypersthene, in a ground-mass of hyalopilitic texture. × 20. (See p. 259.)

DISCUSSION.

Mr. F. P. MENNELL said that he had listened to the paper with the greater interest, in that he had spent more than ten years in a neighbouring part of Africa. He was quite in accord with

[November 23rd, 1917.]

1. × 20



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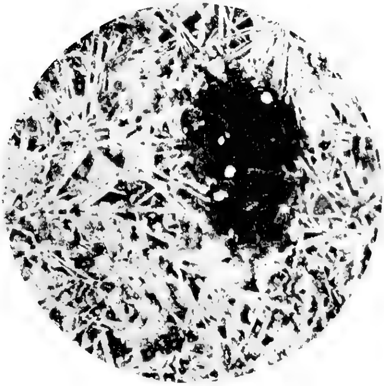

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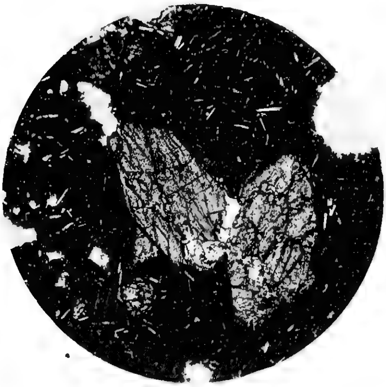

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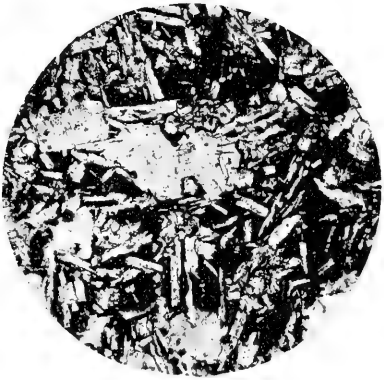

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VOLCANIC ROCKS OF THE DISTRICT OF MOZAMBIQUE.

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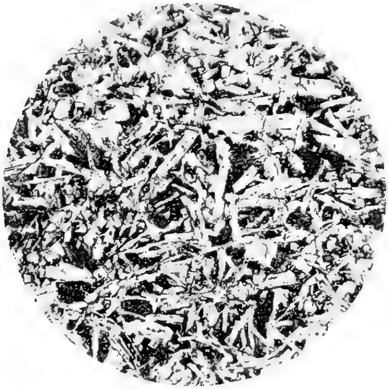

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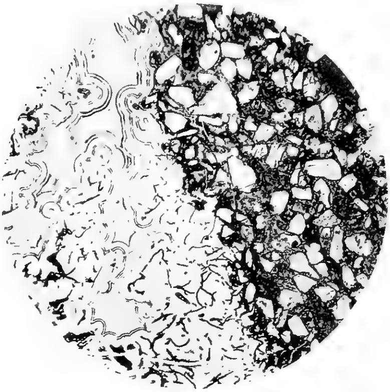
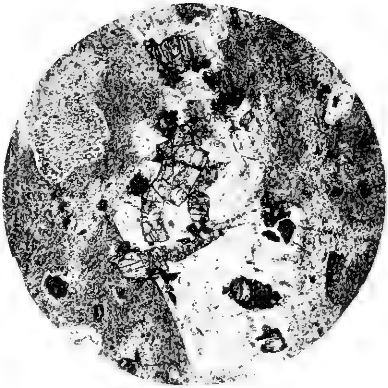


3. × 20

4. × 20

5. × 20

6. × 20



A.H. & G.S.S., Photomicro.

Bemrose, Collo., Derby

VOLCANIC ROCKS OF THE DISTRICT OF MOZAMBIQUE.

the Author, that alkaline and non-alkaline rocks were to be found along the African coast in intimate association. It was not clear, however, from what had been said, on what principle the Author separated the rocks that he put into his alkaline group from the others with which he had dealt, and it was not easy to see why they should be treated apart. It was interesting to note that, although alkaline volcanic rocks were so often found in the coastal regions, there were no occurrences known in the inland districts of this part of Africa.

Dr. J. W. EVANS congratulated the Author on his presentation of the results of several years' work on some very interesting rocks. He had not confined himself to simple descriptions of structures and minerals, but had endeavoured to ascertain what light the facts disclosed threw on the evolution of igneous rocks, especially those rich in alkalies. The speaker enquired whether there was any evidence that the alkali-rocks were later than those of normal types in this area.

Mr. A. E. KITSON congratulated the Author on the paper. He asked whether there was any general linear arrangement of the dykes, and if so, whether the lines were parallel with the coast. He said that on both sides of Africa, wherever late volcanic rocks occurred, it seemed that they had been extruded along lines of fracture roughly parallel with the coast, or in fracture-zones inland, and that on the Gold Coast volcanic necks and plugs occurred in several places along the Volta River; but he had not found similar evidence in that colony outside of zones of fracture.

The AUTHOR, in reply, thanked the Fellows for their kind reception of his paper, and stated that most of the points raised in the discussion were fully dealt with in the paper itself. Answering Mr. Mennell, he said that the division of the lavas into two series was based on analyses, variation-diagrams, the composition of the amygdale-minerals, and in part on the sequence, so far as this was known. In reply to Dr. Evans, he was sorry to say that there was no definite field-evidence from which the relations of the two series could be deduced. Referring to Mr. Kitson's remarks, he observed that, as in many other of the African coast-lands, the main faults were parallel to the prevailing trend of the coast, and most of the basaltic dykes followed the same direction.

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Vol. LXXII.
PART 4.

No. 288.

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

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[With Three Plates, illustrating Dr. Stanley Smith's Paper.]

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1918.

Wednesday, January	9*—23*
,, February (*Anniversary*, Friday, February 15th)	6*—20*
,, March	6—20*
,, April	17*
,, May	1—15*
,, June	5—19*

[*Business will commence at 5.30 p.m. precisely.*]

The asterisks denote the dates on which the Council will meet.

the Author, that alkaline and non-alkaline rocks were to be found along the African coast in intimate association. It was not clear, however, from what had been said, on what principle the Author separated the rocks that he put into his alkaline group from the others with which he had dealt, and it was not easy to see why they should be treated apart. It was interesting to note that, although alkaline volcanic rocks were so often found in the coastal regions, there were no occurrences known in the inland districts of this part of Africa.

Dr. J. W. Evans congratulated the Author on his presentation of the results of several years' work on some very interesting rocks. He had not confined himself to simple descriptions of structures and minerals, but had endeavoured to ascertain what light the facts disclosed threw on the evolution of igneous rocks, especially those rich in alkalies. The speaker enquired whether there was any evidence that the alkali-rocks were later than those of normal types in this area.

Mr. A. E. Kitson congratulated the Author on the paper. He asked whether there was any general linear arrangement of the dykes, and if so, whether the lines were parallel with the coast. He said that on both sides of Africa, wherever late volcanic rocks occurred, it seemed that they had been extruded along lines of fracture roughly parallel with the coast, or in fracture-zones inland, and that on the Gold Coast volcanic necks and plugs occurred in several places along the Volta River; but he had not found similar evidence in that colony outside of zones of fracture.

The Author, in reply, thanked the Fellows for their kind reception of his paper, and stated that most of the points raised in the discussion were fully dealt with in the paper itself. Answering Mr. Mennell, he said that the division of the lavas into two series was based on analyses, variation-diagrams, the composition of the amygdale-minerals, and in part on the sequence, so far as this was known. In reply to Dr. Evans, he was sorry to say that there was no definite field-evidence from which the relations of the two series could be deduced. Referring to Mr. Kitson's remarks, he observed that, as in many other of the African coastlands, the main faults were parallel to the prevailing trend of the coast, and most of the basaltic dykes followed the same direction.

12. *AULINA ROTIFORMIS*, gen. et sp. nov., *PHILLIPSASTRÆA HENNAHI* (Lonsdale), and *ORIONASTRÆA*, gen. nov. By STANLEY SMITH, B.A., D.Sc., F.G.S. (Read November 8th, 1916.)

[PLATES XXII–XXIV.]

CONTENTS.

I. INTRODUCTION.

PHILLIPSASTRÆA is a genus of Devonian Corals possessing certain well-marked characters. The genus *Orionastræa* has been established to include certain Carboniferous species very closely related to *Lithostrotion*, but which have been regarded by many writers as congeneric with those of *Phillipsastræa*. *O. phillipsi* (McCoy) is commonly known as *Ph. radiata* (Martin).

Aulina is a new genus, found at the horizon of the Millstone Grit. One species only has been recognized: this has been confused hitherto with *O. phillipsi*, and hence recorded as *Ph. radiata*. I regard *Phillipsastræa* as the ancestor of *Aulina*, but do not consider that these are related to *Orionastræa*.

All three genera, however, are colonial in habit, and possess a similar type of corallum: namely, that in which the individual corallites have lost their epitheca, and consequently are united by their dissepiments—a type of colony which may be termed 'astræiform.'[1]

The foregoing statements explain my reasons for including the history of the name *Phillipsastræa* and the description of its genotype in a communication primarily concerned with Carboniferous genera.

I am deeply indebted to the late Prof. T. McKenny Hughes, to Dr. A. Smith Woodward, Dr. F. L. Kitchin, Dr. W. G. Lee, and Mr. Peter MacNair for the loan of material (including various type-specimens) preserved in the Sedgwick Museum,

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[1] The term is frequently used by Edwards & Haime in their well-known Monograph, as also by other writers, to indicate the type of corallum in which the septa of the corallites are confluent, and does not in any way imply relationship to the Astræidæ. I here employ the word in a slightly more extended sense, so as to include any Madreporarian colony (Rugose or Aporose) in which the corallites are united as above described.

Cambridge, the British Museum (Natural History), the Museum of Practical Geology, the collection of the Geological Survey of Scotland, and the Glasgow Museum & Art Gallery; and to Mr. Charles Edmonds, Prof. E. J. Garwood, and Prof. T. F. Sibly for use of the specimens that they had collected.

My thanks and acknowledgment are also cordially extended to Dr. F. A. Bather, Mr. W. D. Lang, and Mr. C. D. Sherborn for their ever-ready advice and kindly assistance.

II. DEFINITION OF CERTAIN TERMS EMPLOYED.

On account of the unfortunate lack of uniformity in the nomenclature of Corals, it seems advisable, before proceeding farther, to define clearly certain terms here employed.

I denote the skeleton of a single individual, whether solitary or member of a colony, by the term 'corallite,' and use the term 'corallum' to mean the skeleton of the whole colony. In the case of solitary or 'simple' corals the terms are synonymous.

I divide the Rugose corallite into two regions: (1) the intrathecal region, which is built up of tabulæ or of tissue ontogenetically derived from tabulæ, and (2) the surrounding extrathecal tissue, which is built up of dissepiments. The junction of the tabular with the dissepimental tissue constitutes an annular wall—the theca. The corallite is usually clothed with an outer mural investment—the epitheca, the nature and development of which I have discussed in a previous publication.[1]

The terminology applied to the septa will be found in a paper by Mr. R. G. Carruthers,[2] or in my own paper 'On the Genus *Aulophyllum*.'[3]

III. THE ASTRÆIFORM CORALLUM.

Among the Rugose colonial corals there are certain genera, or certain species within a genus, in which the corallites have lost their epitheca, and are united by their dissepimental tissue.[4]

The septa of adjacent corallites in the 'astræiform' colony tend to become confluent; but all stages of this development, from that in which it is incipient to that of perfect confluence, are to be found. In some cases, on the other hand, the septa of one corallite do not extend to those of another, and leave an intervening space to the sole occupation of the dissepiments.

Astræiform colonies make their appearance in widely divergent stocks and at different periods of time: being, it would seem, the ultimate terms in a progressive development along a well-defined line. The steps towards this end are:—

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[1] Q. J. G. S. vol. lxxi (1915) pp. 228–29.

[2] Ann. & Mag. Nat. Hist. ser. 7, vol. xviii (1906) pp. 356–63.

[3] Q. J. G. S. vol. lxix (1913) pp. 60–62.

[4] An epithecal growth external to the whole corallum may, nevertheless, be retained in the astræiform colony.

1. The simple or solitary coral.
2. The fasciculate colony, in which the corallites are not contiguous or do not press on one another, and are therefore cylindrical in form, as (for example) *Lithostrotion martini*.
3. The basaltiform colony, in which the corallites are contiguous, and are prismatic through mutual pressure. Although the corallum is massive, the corallites are defined by an epitheca, as (for example) *Lithostrotion basaltiforme*. And, finally,
4. The astræiform colony: for instance, *Orionastræa*.

The examples quoted are from a single lineage.

The number of genera represented by the astræiform type of colony among the Rugosa does not appear to be numerous at any period, although the individuals may be extremely abundant.[1]

Strombodes is fairly common in the Upper Silurian; *Phillipsastræa* is very plentiful in the Upper Devonian; while, among the British Carboniferous Rugosa, the only examples of astræiform genera and species that have come under my notice are *Aulina* and *Orionastræa*, *Cyathophyllum regium* Phillips, and a species of *Koninckophyllum* (or *Diphyphyllum*). All these forms are from the uppermost part of the Carboniferous Limestone Series—D_2 and higher beds.

Certain Characters assumed by the Astræiform Corallum in the Rugosa, and Factors that have produced them.

The coralla of *Orionastræa* and of *Aulina* exhibit certain interesting characters—namely, a flattened form, an extensive development of extrathecal tissue, and epithecal growth external to the colony, even in cases where there is no trace of epitheca within it.

(i) The form of the corallum is correlated with the mode of growth of the corallites. These may arise at any point on the surface of the corallum, but the region of most active growth is the margin. The peripheral corallites at first grow outwards, away from the centre of the colony, and then bend upwards into a more vertical position, as is shown in fig. 1 (p. 283).

The extreme case of this form of colony is to be found, not in the Rugose but among the 'tabulate' corals—for example, *Heliolites*, where an almost horizontal base is often developed.

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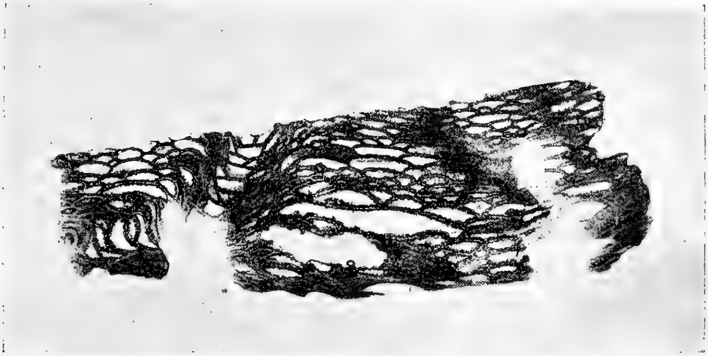
[1] This type of corallum, while exceptional in the Rugosa, is characteristic of the massive Aporose corals—in fact, exceptions are rare,—but it must be remembered that the epithecal covering to the skeleton (always present in Rugose simple corals) is often lacking in the case of Aporose simple corals. The mæandriform colony (due to repeated but incomplete fission so common among the Aporose stocks) is unknown in the Rugosa, and necessarily so, on the assumption that Rugose colonies increase by gemmation only, but never by fission. (See my notes on the subject in Q. J. G. S. vol. lxxi, 1915, p. 233, and W. D. Lang, 'Homœomorphy in Fossil Corals' Proc. Geol. Assoc. vol. xxviii, 1917, p. 90.)

Fig. 1.—*Longitudinal section of* Orionastræa placenta *(McCoy), holotype of* Sarcinula placenta, *showing the corallite in its earliest stage.* × *5 diameters.*

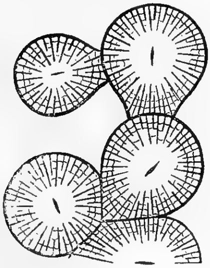


W. Tams photo.

(ii) The development of dissepimental tissue can be shown to be progressively greater, as we follow the passage of dendroid and fasciculate into basaltiform, and these into astræiform colonies.

The case is not merely one of phylogenetic change, but may be observed to take place wherever two or more corallites of a dendroid-fasciculate colony approach each other to the extent of contiguity. This is illustrated by the accompanying figure of a group of corallites of *Lithostrotion martini* Edwards & Haime.

Fig. 2.—*Group of corallites of* Lithostrotion martini. × *2 diameters.*



The phenomenon may be accounted for, by supposing that two neighbouring polyps mutually extend one towards the other until they are in contact. This results in a stretching of the area of dissepiment-secreting tissue where the two touch, and in a consequent widening of the dissepimental area of the skeleton when secreted.

(iii) The external epitheca, which stretches round the corallum as a continuous surface, usually displays pronounced rugosity.

It differs neither in its origin nor in character from the epitheca that clothes a simple coral or an individual corallite; yet its presence is often emphasized in descriptions of corals (especially if the corallum in question is discoid in form), and it is frequently defined as the 'basal epitheca.' It represents merely the epitheca of the outer side of the peripheral corallites.

IV. PHILLIPSASTRÆA d'Orbigny.

Summary of Research.

William Lonsdale (1840), in Sedgwick & Murchison's 'Physical Structure of Devonshire, & on the Subdivisions & Geological Relations of its older Stratified Deposits, etc.' Trans. Geol. Soc. ser. 2, vol. v, pt. 3, p. 697, pl. lviii, figs. 3, 3 *a*, & 3 *b*, described, under the name of '*Astrea* (*Siderastrea* de Blainville) *hennahii* (sp. n.),'[1] a type of colonial coral since proved very characteristic of the Upper Devonian. The specimen (or specimens) upon which the species was established was stated to have been found at Barton, north-west of St. Marychurch, and to have been in the collection of Daniel Sharpe.[2] This collection is now in the Museum of Practical Geology.

The specimen represented by fig. 3 can be recognized with absolute certainty in No. 6185; but the source of fig. 3 *a* is uncertain: it was probably another fossil. Edwards & Haime assumed such to be the case, although Lonsdale made no mention of there being two specimens.

John Phillips (1841), 'Figures & Descriptions of the Palæozoic Fossils of Cornwall, Devon, & West Somerset' p. 12, pl. vi, figs. 16 *α a*, 16 *β b*, 16 *β c*, & pl. vii, fig. 15 D, illustrated *A. hennahi* by a drawing (fig. 16 *α a*) clearly intended to represent the weathered surface of Lonsdale's actual specimen, and by two figures—16 *β b* (enlarged) & 16 *β c* (natural size)—of a polished specimen in his own possession. His description of the species does not differ materially from that given by Lonsdale—in fact, Phillips appended to it the following statement:—

> 'The above description is almost *verbatim* from Mr. Lonsdale. I have added the words in brackets, from a beautiful polished specimen in my possession (fig. 16 *c*), which may be distinct.'

Phillips's specimen unquestionably belongs to the same genus as Lonsdale's; but the figure is not sufficiently exact to enable one to pronounce a certain opinion as to the species. Pl. vii, fig. 15 D, is that of a specimen which Phillips found in the Carboniferous Limestone of Flintshire, and figured under the impression that it was allied to, if not identical with, *A. hennahi* Lonsdale. As a matter of fact, the species bears no relationship at all to the Devonian coral, but is the form that I here describe as *Orionastræa phillipsi* (McCoy). Unfortunately, this figure has been the cause of much subsequent confusion. It must be borne in

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[1] J. B. Lamarck, 'Système des Animaux sans Vertèbres' 1801, p. 371.

[2] Daniel Sharpe's Collection was presented to the Geological Society by Henry Sharpe, his brother, in 1856, and passed into the possession of the Museum of Practical Geology in 1911, when the Society divided its collection between that institution and the British Museum—the British material going to the former and the foreign to the latter.

mind, in connexion with the controversy which followed, that Phillips did not state that it was '*A. hennahii*,' but, in his own words, a 'specimen from Mountain Limestone much allied to *Astræa hennahii*.'

F. A. Rœmer (1843), 'Die Versteinerungen des Hartzgebirges' p. 5, pl. ii, figs. 13 *a*–13 *b*, & pl. iii, fig. 1, contributed to the literature of the genus a description and figures of two species allied to '*Astræa hennahii*,' both from the Devonian of the neighbourhood of Gründ in the Harz, namely '*Astræa hennahii*' Lonsdale? and '*Astræa parallela* N.':—

Astræa hennahii (pl. ii, figs. 13 *a* & 13 *b*).—The figure indicates a form differing from the type-specimen in regard to the smaller size of the corallites and the apparent presence of an epitheca. It suggests *Phillipsastræa pentagona* Goldfuss (*Acervularia pentagona* Goldfuss auctt.).

Astræa parallela (pl. iii, fig. 1).—In the figure of this species the intrathecal regions are very small and widely separated, and the septa are markedly confluent. Rœmer identified this species with Phillips's polished specimen, also with the coral from North Wales, for which he assumed a Devonian age.

Alcide d'Orbigny (1849), 'Note sur des Polypiers Fossiles' p. 12, introduced the generic name '*Phillipsastræa*,' and he defined the genus in the following words:—

> 'G. *Phillipsastrea*, d'Orb., 1847.[1] Le dessin qu'en a donné M. Phillips pourrait faire croire que ce sont des calices petits, à cloisons rayonnantes, entourées de cloisons costales communes. On en connaît deux espèces de l'étage dévonien. Ex.: *Astrea parallela* et *hennahii*, Phillips.'

In the 'Prodrome de Paléontologie' published the following year (1850), on pp. 106–107, he tabulated under various generic names most of the species that I have previously mentioned, namely:—

Lithostrotion hennahii (Lonsdale, pl. lviii, fig. 3).
Actinocyathus hennahii (Phillips, pl. vi, fig. 16 *a*).
Phillipsastræa parallela (Rœmer, pl. iii, fig. 1).
Phillipsastræa hennahii (Phillips, pl. vi, fig. 16 *β*, and pl. vii, fig. 15 D).

Furthermore, he re-defined the genus *Phillipsastræa* thus:—

> 'Ce sont des *Siderastræa* dont la columelle, au lieu d'être styliforme saillante, est large et divisée en cloisons rayonnantes, comme chez les *Columnastræa*.'

H. Milne Edwards & J. Haime, in 1850, in the Introduction to their monograph on 'British Fossil Corals' pp. lxx–lxxi, defined the genus *Phillipsastræa*, and quoted as the type-specimen '*Astrea hennahi*' Lonsdale.

Later, however (1851, 'Mon. Polypiers Fossiles' pp. 417 & 421; and again in 1852 & 1853, 'British Fossil Corals' pp. 203 & 240), they restricted the name *Phillipsastræa* to a genus represented by Phillips's Carboniferous species, which they identified with Martin's species *Erismatolithus radiatus* (see p. 296), and quoted

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[1] This date is untenable, since the tract was not published until October 10th, 1849, *fide* C. D. Sherborn.

'*A. hennahii* Lonsdale' fig. 3 (excluding fig. 3 *a*[1]) as the type of a new genus—*Smithia*. *Phillipsastræa*, they stated, possessed a columella, and *Smithia* did not.

While acknowledgment is due to the service rendered by these authors in separating the Devonian and Carboniferous forms, the legitimacy of their use of the name *Phillipsastrea* must be challenged: because, although the figure of the Carboniferous species was quoted by d'Orbigny, he clearly intended the name *Phillipsastræa* to be applied to the Devonian species, since he framed his definition of the genus upon the figures and descriptions of those corals. It is quite certain that, in quoting fig. 15 D, he did so under the impression that the species was identical with that represented by figs. 16 β *b* & *c*. It is also true that he mentions the presence of a columella as one of the generic characters of *Phillipsastræa*; but, here again, he was misled by the figures that he quoted, and interpreted as a coral structure the interstitial calcite which filled the intrathecal region and stood out from the weathered surface as a boss. The name *Phillipsastræa* must, therefore, be retained for the Devonian genus, and a new one given to the Carboniferous species. The actual genotype of *Phillipsastræa* is the species to which Phillips's specimen belonged, but there is nothing in the figures to warrant the assumption that it was not specifically identical with the type-specimen of *Astræa hennahi*—it may, or may not, have been. In either case the two specimens belong to the same genus, and, even supposing that they represented different species, Phillips's specimen is lost, and we are at liberty to close a neogenotype—besides, in so doing, we rectify an anomaly.

Edwards & Haime also described under the name *Acervularia*[2] ('Polypiers Fossiles' 1851, pp. 416, 421, and 'British Fossil Corals' 1853, pp. 236–41) certain species of Devonian corals, which differed from *Phillipsastræa* (*Smithia* of these authors) only in the presence of a thin but distinct epitheca.

I agree with Frech in regarding the two as congeneric—in fact, careful examination of material shows that certain species of the one are identical with certain 'species' of the other, and that the development (or, rather, loss) of the epitheca is one of degree only. Indeed, in a single corallum, epitheca may be present in one region and absent in another.

Frederick McCoy (1851), 'British Palæozoic Fossils' p. 72,

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[1] They founded upon this figure a new species, *Smithia pengellyi*, and thereby definitely fixed for us the type of *A. hennahi*.

[2] The genus *Acervularia* was founded by Schweigger, 'Handbuch der Naturgeschichte' &c., 1820, p. 418, upon the figure and description of a Silurian coral from Gothland by Henry Fougt, 'Corallia Baltica' in 'Amœnitates Academicæ' pp. 92–93, pl. iv, fig. ix and No. 2. Fig. ix bears a strong superficial resemblance to weathered specimens of the so-called Devonian *Acervularia*, but it is not at all likely that these are congeneric with the coral figured by Fougt. No. 2 (also fig. viii, referred to as a variety of the same 'madrepora composita') undoubtedly represents *Acervularia luxurians*.

assigned *Astrea hennahi* of Lonsdale to Dana's genus *Arachnophyllum.*

Fritz Frech (1885), 'Die Korallenfauna des Oberdevons in Deutschland' Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxvii, pp. 44 *et seqq.*, has anticipated me in merging *Smithia* and the Devonian species of '*Acervularia*'; he also questioned the right of including *Phillipsastræa radiata* in the same genus.

Rudolph Schäfer (1889), 'On *Phillipsastræa* d'Orb., with special reference to *Phillipsastræa radiata* S. Woodward sp. & *Phillipsastræa tuberosa* McCoy sp.' Geol. Mag. dec. 3, vol. vi, 1889, pp. 398–409, pl. xii, reviewed the literature of *Phillipsastræa*, and redescribed the species of *Orionastræa* mentioned in the title of his paper. He examined McCoy's types at Cambridge and specimens of *Orionastræa* in the British Museum, and came to the conclusion that these forms did not possess a columella, and therefore the basis upon which Edwards & Haime separated *Phillipsastræa* and *Smithia* had no real existence.

I must modify Schäfer's assertion, that the Carboniferous species do not possess a columella,[1] by the statement that a columella may be present or absent; although in most cases it is present, the columella is admittedly merely the dilated prolongation of the counter-septum, but in this origin it does not differ from the columella in other Rugose genera. Even if Schäfer had been correct in his statement concerning the absence of a columella in *Orionastræa*, there still remains the very striking character of *Phillipsastræa* that is not developed in the former: namely, the peculiar septal dilations already described.

Several other palæontologists have discussed the genera *Phillipsastræa* and *Smithia*; but, in every case, they have contented themselves with the question of the identity of the two 'genera,' and have neglected to inquire into the legitimate application of the names. In fairness to these authors, it must be stated that they decided that the genera were identical, and consequently the other question did not concern them.

Generic Characters.

The corallum is composite and massive; the corallites are united by their dissepimental tissue, or are separated by a thin epitheca only: in the former case the septa are often confluent. In the

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[1] It should be noted that some of Schäfer's own figures (5, 6, & 7) show the columella, and that, although in figs. 1 & 2 no columella is represented, yet in the actual specimens (R. 541 & 56740) the columella is prominent. Schäfer quoted Kunth (Zeitschr. Deutsch. Geol. Gesellsch. vol. xxii, pp. 30–37, pl. i, figs. 4*a*–4*d*) to support his contention that there was no fundamental difference between the Devonian and the Carboniferous species of *Phillipsastræa*; but, as a matter of fact, Kunth's figure of *Ph. hennahi* bears very little resemblance to the actual type, and may be dismissed from the argument. The major septa are shown in these figures to unite in the centre of the corallite, and so form a 'columellarian tubercle'; moreover, they do not appear to dilate at the theca.

mature corallite the septa assume a radial symmetry, although the bilateral symmetry of its early growth-stages is sometimes traceable in the adult state through the presence of a cardinal septum shorter than the rest, and is indicated in some species by a prolonged counter-septum. Both the major and the minor septa dilate at the theca, and the latter terminate there; but the major septa, in an attenuated form, advance into the intrathecal region, and frequently dilate again at their axial edge. The central part of the corallite is occupied solely by the tabulæ.

Confluence and dilatation of septa are characters comparatively rare in the Rugosa, but of very frequent occurrence in the Aporosa.

Genotype: *Phillipsastræa (Astræa) hennahi* (Lonsdale).

Type-specimen of *Ph. hennahi*: No. 6185, Museum of Practical Geology.

The type is possibly the holotype, but is much more probably one of two syntypes. Edwards & Haime assumed the latter to be the case, and chose it as the lectotype.

Description of Type-Specimen of *Phillipsastræa hennahi* (Lonsdale). (Pl. XXII, figs. 1–4.)

No. 6185 & Sections 28348–28349, Museum of Practical Geology ('Daniel Sharpe Collection'—part of the 'Geological Society Collection'). For literature and history, see p. 284.

The specimen is a weathered and rounded block measuring some 10 cm. along its greatest length and about 4 cm. through its thickest part. There are two plane polished surfaces, transverse and longitudinal respectively to the direction of growth. The material is translucent and of a grey colour, except near the surface, where it is bleached and opaque. Superficially, it is iron-stained. Weathering has reacted more vigorously upon the coral tissue than upon the interstitial calcite, and so has engraved the coral structures into the stone. The calcite occupying the interseptal spaces stands out from the surface, and counterfeits actual septa, while that filling up the intrathecal region projects as a central prominence.

External Characters.

None present.

Internal Characters. (Pl. XXII, figs. 2–4.)

Transverse section.—Epitheca almost but not entirely absent, weak traces being detectable here and there. Confluence on the part of the septa is not highly developed: the septa may be confluent; but, for the greater part, those of one corallite abut against those of another, or intermingle in a confused network. The thecæ are of uniform size, measuring 3 mm. in diameter;

but the extrathecal tissue is very unevenly developed, so that the intrathecal regions may lie closely together or widely apart.

There are twenty-six septa present in the majority of the corallites, and the dilation of these at the theca extends for a distance of about 1 mm. The dilation at the axial edge is but feebly developed in this specimen.

Longitudinal section.—The dissepiments are small and crowded; the tabulæ are closely set. Shallow concave tabulæ occupy the central part of the intrathecal region, and these are supplemented near the theca by smaller proximally-inclined plates. The figure should be compared with that of *Aulina*, p. 292. The peripheral plates do not appear to be present in all species of the genus.

Notes upon Lonsdale's Figures and Statements.

Fig. 3 combines a view of the weathered surface and the longitudinally-polished face of specimen No. 6185. The features displayed have been most accurately drawn,[1] and the portion included in the figure can be precisely defined by a line. It is evident that Lonsdale (and others after him) mistook the etched-out interstitial calcite of the surface for actual coral-tissue.

Fig. 3 *b* shows, on an enlarged scale, the longitudinal section through a few septa as seen in the polished surface. It supplies no useful information.

Fig. 3 *a* illustrates a transverse section, but, as has been previously mentioned, this figure has probably been supplied by another specimen. The corallites are represented as being larger, and the septa as being more numerous and more perfectly confluent, than those in the specimen figured in fig. 3 *a*—the type.

I have searched through the Daniel Sharpe Collection, and, among those examined, the specimen with which the figure most closely agrees is No. 6192, a thin polished slab of irregularly pentagonal shape. In this specimen the thecæ are larger (5 mm. in diameter) and the septa are more numerous (about 36) than in the type-specimen; and, furthermore, the dilation of the septa at the theca is less localized and consequently not so obvious. The characters displayed agree with Lonsdale's statements that there are 36 septa (or rays, as he termed them), 'unequal in length and breadth, and of a crenulated structure.' The last remark is of some importance in identifying the specimen: it refers to a feature not unfrequently found in mineralized corals, and is strongly shown in the present case—a feature due to the obliteration or partial obliteration of the dissepiments, except where these meet the septa. Despite his assertion that the number of septa is 36, Lonsdale only shows about 30 in this figure. The origin of his fig. 3 *a* must, nevertheless, remain uncertain.

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[1] The drawing is reversed on the plate, so that the right side in the original is the left in the figure—a common occurrence in plates of the period.

V. AULINA, gen. nov.

Family ? Phillipsastræidæ.

The structure of *Aulina* is in most respects similar to that of *Phillipsastræa*, but it appears to carry to a further stage of development the septal characters peculiar to the latter genus.

Generic Characters.

The corallum is massive, and the corallites are united by their extrathecal tissue. All the septa dilate at the theca, and those of the major cycle again dilate at their axial edges, in such a manner as to fuse together and so to form a cylindrical wall or tube within the theca (see fig. 4, p. 292).

Stability of character is a feature strongly maintained.

Genotype: *Aulina rotiformis* S. Smith.

Type-specimen of *A. rotiformis*. The holotype has been cut in two: one half is in the British Museum (R. 17497), and the other in the Sedgwick Museum, Cambridge.

AULINA ROTIFORMIS, sp. nov.

1910. *Phillipsastræa radiata* (Martin), S. Smith, Trans. Nat. Hist. Soc. Northumberland, &c. n. s. vol. iii, pt. 3, pp. 629–30.
1912. *Phillipsastræa radiata* (Martin), E. J. Garwood, Q. J. G. S. vol. lxviii, pp. 542–43.
1916. *Aulina rotiformis* S. Smith, Abs. Proc. Geol. Soc. No. 995, pp. 2, 3.

Aulina rotiformis was recorded as *Phillipsastræa radiata* from South Northumberland by myself and from Hurdorthwaite Moor (North Yorkshire), by Prof. E. J. Garwood, in the publications above cited. No description of the form was given in either paper. I remarked that the form was plentiful in and characteristic of the Fell Top Limestone around Harlow Hill, while Prof. Garwood stated that it was somewhat abundant in the Botany Beds on Hurdorthwaite Moor and that he had not found it *in situ* at any other horizon.[1]

External Characters.

The corallum is massive, and is typically depressed in form. The corallites are not defined by epitheca; consequently, the only epithecal development present is that external to the whole colony.

The upper or distal surface of the corallum is generally flattened and fairly uniform. The thecæ measure about 1·5 mm. in diameter; they are near together and regularly arranged, as compared with those of *Orionastræa*, lying 1 to 3 mm. apart.[2]

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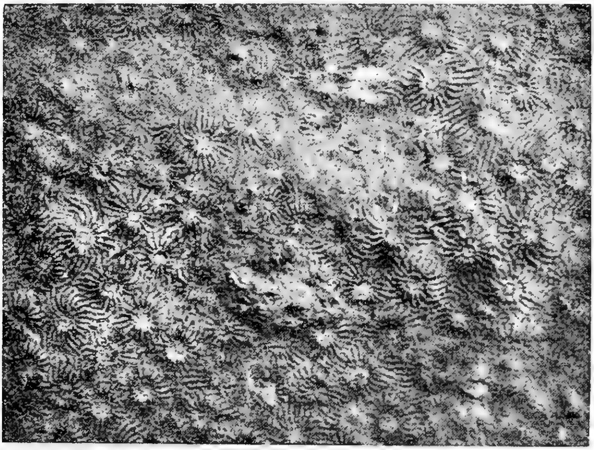
[1] He recorded the finding of an angular and unworn specimen of *Phillipsastræa radiata* resting upon the Tyne Bottom Limestone in High Cup Gill and of a cast of the same from the Drift of Ravenstonedale. The High-Cup Gill specimen was correctly identified, and therefore not *Aulina*, but *Orionastræa*.

[2] In one of the specimens collected from the Botany Beds the calices are larger and proportionately more widely separated, and the surface more mammiferous, than in the Harlow-Hill material.

The general surface of the corallum (as will be noticed in the text-figure) rises towards the thecæ, so as to form mound-like borders to the calicular depressions, suggesting the idea of minute craters. Within the calice the tubular wall terminates as an elevated ring, forming a hollow axis against which the major septa abut like the spokes of a wheel.

Fig. 3.—*Distal surface of the type-specimen of* Aulina rotiformis, *sp. nov.* × *2 diameters.*



A. H. Harrow photo.

[Fell Top Limestone, Harlow Hill (Northumberland). One half is in the British Museum (Natural History), R. 17497, and the other half in the Sedgwick Museum, Cambridge.]

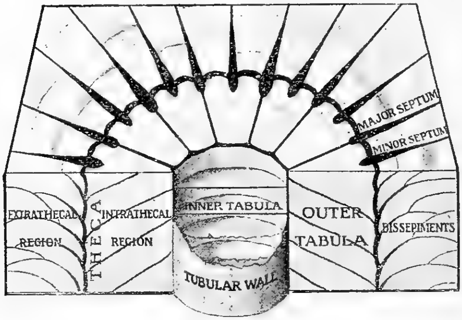
Internal Characters. (Pl. XXII, figs. 6–11, & text-fig. 4.)

The most distinctive feature is the tube traversing the tabular tissue. Within this tube the tabulæ are horizontally disposed, and are remarkably flat; externally to it, they take the form of cones perforated by this axial tube. The dissepiments are very small and regularly formed.

All the septa dilate at the theca, and there the minor series abruptly terminate. In these respects *Aulina* is similar to *Phillipsastræa.* The major septa, in an attenuated form, advance towards the tube, to which their axial edges appear to be fused. Actually, the septa dilate along their axial edges in such a way as to present in cross-section the letter T, and form the tube by the mutual fusion of these peculiar dilations into a perfect wall. Confluence of the septa is well developed.

Transverse section.—In this section the septa display the characters above mentioned, and the tube appears as a polygonal ring. The number of septa in each cycle is usually eleven; very rarely does it exceed twelve or is it less than ten. The theca is emphasized by a very slight secondary thickening of the dissepiments which form it. The diameter of the theca is about 1·5 mm., and the diameter of the tube about 0·5 mm. The dilation of the septa at the theca does not extend far in a peripheral direction (as indicated in the figure).

Fig. 4.—*Diagram combining a transverse and a longitudinal section of* Aulina rotiformis. × *about 18 diameters.*



Longitudinal section (Pl. XXII, fig. 8).—The tube is represented by two vertical walls limiting the horizontal tabulæ; the tabulæ external to these walls are seen as inclined plates.

Ontogeny.

In the earliest growth-stages observed in *Aulina* the septa then present meet in the centre of the corallites (Pl. XXII, figs. 9–11). Later, these leave the centre and form the initial stage of the tube, while new members are being added to their number.

Although, by the time that it reaches the adult stage, the form displays a radial symmetry, the insertion of septa follows the general rule appertaining to the Rugosa as a class. A cardinal fossula (in some cases very conspicuously, but in others less prominently displayed) and a distinct pinnate symmetry may be observed in the immature stage.

Phylogeny.

The morphology of *Aulina* clearly points to its derivation from *Phillipsastræa*: the axial tube in the former and the dilated edges of the septa in the latter are probable stages in a continuous line of development. The interval of time, however, separating the epochs in which the two genera lived respectively is considerable—practically the whole of the Lower Carboniferous Period, and no intermediate forms have as yet been recorded from the beds of that age.

Horizon and locality.—*Aulina* occurs abundantly in the Fell Top Limestone in the vicinity of Harlow Hill,[1] where the

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[1] Harlow Hill lies on the Newcastle and Carlisle Road, 11 miles west of the former city (Quarter Sheet 105 N.W. New Series 14).

outcrop of that limestone is exposed by a chain of old quarries extending from the south side of the village to Stob Hill, near Cheesburn Grange, some 2 miles in a north-easterly direction.

In that locality the Fell Top Limestone lies somewhere about 1000 feet above the Great Limestone, and is between 20 and 30 feet thick (I have not been able, however, to expose the actual base nor find the exact top). The lower portion consists of well-bedded crystalline limestone; the middle is much more argillaceous, and is divided up by bands and partings of shale; but the upper part, again, is more massive and more purely calcareous.

The fauna does not materially differ from that of the limestones between it and the Great Limestone, except in a few (but noteworthy) particulars—namely, the presence of *Aulina* and the abundance of *Lithostrotion* cf. *junceum* (but approaching *L. irregulare*), which occurs as small stunted colonies of tortuous growth-habit. These colonies form in places a band at the top of the lower and more massive portion, and appear to have been buried as they lived by the overlying silt (now calcareous shale). *Dibunophyllum* near ψ Vaughan (small, conical and often twisted forms) is plentiful, and *Lithostrotion portlocki* is common. The most striking feature of the brachiopod-fauna is the great abundance of *Productus latissimus*. *Fenestella* is present in large quantity.

The other locality in which *Aulina* has been found is Hurdorthwaite Moor, from a thin series of limestones and shales intercalated in the Millstone Grit, to which series Prof. E. J. Garwood has given the name of Botany Beds,[1] after the farm north of their outcrops.

Prof. Garwood[2] defines the stratigraphical position and geographical situation of the beds, and describes their character in the following passages:—

> 'The beds lie some distance [200 feet or so] above the base of this series [the Millstone Grit], 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 limestone at the base, which is overlain by some 10 to 15 feet of impure calcareous and ferruginous shales' [and I may add—especially towards the top—limestone-bands].

The sequence suggests at once the Fell Top Limestone, and the resemblance is still further strengthened by the characteristic appearance of the pale crumbly shale packed with *Fenestella*. Faunistically also the two series bear a striking similarity, since, in addition to *Aulina*, the Botany Beds have yielded the same

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[1] Botany Farm lies 2½ miles west-south-west of Romaldkirk, and about half a mile north of the Reservoir (Quarter Sheet 102 S.E. New Series 31).

[2] Q. J. G. S. vol. lxviii (1912) p. 542.

stunted and twisted forms of *Lithostrotion junceum*, the same dwarfed and conical forms of *Dibunophyllum*, and also *Lithostrotion portlocki*.[1] The list of fossils from these beds published by Prof. Garwood[2] is very similar to that of the Fell Top Limestone which I previously published.[3]

Thus, in their agreement in faunal contents, lithological character, and stratigraphical position there is strong evidence for correlating the Botany Beds with the Fell Top Limestone.[4] This correlation being accepted, the bed represents the highest known limestone of standard conditions[5] occurring at a horizon occupied in most places by arenaceous deposits ('Millstone Grit') or argillaceous beds ('Pendleside Series'). Assuming that subsequent investigation does not discover *Aulina* in beds lower than those which it is known to occupy, I suggest that the horizon in which it occurs be removed from the *Dibunophyllum* Zone to constitute a new zone—the *Aulina* Zone, which, in accordance with Vaughan's system, would be indicated by the initial letter A: a definite limit would thus be given to the *Dibunophyllum* Zone, which at present tends to extend indefinitely upwards. The *Posidonomya* Zone[6] in Gower and elsewhere is approximately equivalent to the *Aulina* Zone, but represents a shallow-water phase, and, appearing earlier in time in some localities than in others, must also represent beds belonging to 'D_3' as well as 'A.'

The question as to whether the Avonian Stage should include the *Aulina* Zone, or be restricted so as to end with the *Dibunophyllum* Zone, is worthy of future consideration, but cannot be discussed here.

VI. ORIONASTRÆA, gen. nov.

Family: LITHOSTROTIONTIDÆ.

Species.—*O. phillipsi* (McCoy). Genotype.
O. placenta (McCoy).
O. ensifer (Edwards & Haime).

The species grouped together under the name *Orionastræa* are closely allied to the species of *Lithostrotion*, and appear to

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[1] Although I paid a visit to these beds in the summer of 1915, in company with Mr. C. T. Trechmann and Dr. D. Woolacott, and found *Aulina* and other forms, the principal source of information for the above facts was the material collected by Prof. Garwood, which he kindly allowed me to examine.

[2] Q. J. G. S. vol. lxviii (1912) p. 542.

[3] Trans. Nat. Hist. Soc. Northumberland, n. s. vol. iii, pp. 630–31.

[4] The identity of the two limestones was suggested long ago by J. G. Goodchild, but he does not appear to have ever published these views—*fide* Prof. G. A. Lebour.

[5] Standard conditions as opposed to a phase: that is, any interruption in a sequence of deposits formed under conditions which have been fixed for the purpose of zoning. See A. Vaughan, Proc. Bristol Nat. Soc. ser. 4, vol. i (1906) p. 79.

[6] E. E. L. Dixon & A. Vaughan, Q. J. G. S. vol. lxvii (1911) p. 494.

represent the phylogerontic (or senile) stage in the history of that stock. The separation of *Lithostrotion ensifer* from the other species of that genus and its inclusion here may encounter reasonable objection, since the differences that it exhibits are certainly not great; but, as it possesses (although in a less-developed condition) those features which distinguish the genotype of *Orionastræa*, I believe that the step is justifiable.

Generic Characters.

The corallum is composite and massive, and the corallites are either defined by a thin epitheca, or, in the more typical forms, by no epitheca at all; in this latter case the corallites are united by the dissepimental tissue, and the septa are confluent. Both major and minor septa are well developed, and a columella is present (except in *O. placenta*).

The characters of *Orionastræa* are essentially those of *Lithostrotion*, but in a modified form, and their structures are more unstable and variable. Even in the same corallum the difference between the corallites is often very marked, as in Pl. XXIV, fig. 2.

From a large quantity of material examined three distinct types of *Orionastræa* can be readily isolated, represented respectively by the three species here described; but a large proportion of the specimens falls between two species rather than within one of them, and might, therefore, be ascribed to the one species equally as well as to the other.

To *O. ensifer* specific rank can with little hesitation be accorded, and it is easily distinguished from *O. phillipsi* and *O. placenta*. Furthermore, it represents almost exclusively the genus in the Bristol area, whereas it is very rare in North Wales, where *O. phillipsi* is so abundant and where *O. placenta* also occurs.

I have considerable doubt as to whether, in the strict zoological sense, it is correct to regard *O. phillipsi* and *O. placenta* as separate species: both occur together, and the difference may be nothing more than that between individual colonies of the same species. Since, however, in the absence of sufficient evidence this question cannot be settled, and since it may prove useful to have separate names for the two types, it seems permissible and even desirable to recognize McCoy's species rather than keep them merged under Martin's name '*radiata*.'

Genotype: *O. phillipsi* (McCoy). Type-specimen of *O. phillipsi*: No. 213 *a*, Sedgwick Museum, Cambridge. (Lectotype chosen from two syntypes.)

Summary of Research.

The earliest figures of *Orionastræa* are those of a highly siliceous specimen from Winster (Derbyshire), published by William Martin in 1809, 'Petrificata Derbiensia' pl. xviii, figs. 2 & 3.

Martin described the specimen under the name '*Erismatolithus tubiporites (radiatus*[1]*)*', and stated that the coral was built up of 'straight tubes connected by transverse dissepiments or partitions . . . embedded in a calcareous cellular mass.' From his fig. 2 these 'tubes' can be readily recognized as cherty casts of the intrathecal region of corallites, and the 'transverse dissepiments' as silicified layers in the extrathecal tissue.

The confluent character of the septa is mentioned by Martin, and is well shown in the figure.

John Fleming (1828), in 'A History of British Animals' p. 529, recorded Martin's species as '*Tubipora radiata*.' This citation appears to have been overlooked hitherto, and those palæontologists who refuse to acknowledge Martin's claim to the authorship of the species which he named, on the grounds that his terminology did not conform to the laws of Linnæan nomenclature, credit the trivial name '*radiata*' to Samuel Woodward, 'Synoptical Table of British Organic Remains' p. 5 (1830).

John Phillips's 'Figures & Descriptions of the Palæozoic Fossils of Cornwall, Devon, & West Somerset' (1841) contained the figure (pl. vii, fig. 15 D) of the coral from the Carboniferous Limestone of Flintshire which Phillips believed to be allied to '*Astræa hennahii*' (see p. 284), but which actually belonged to the same genus as Martin's '*Erismatolithus tubiporites (radiatus)*.' The form is common, and very characteristic of the Lower Carboniferous of North Wales.

Frederick McCoy, in 1849, 'On some New Genera & Species of Palæozoic Corals & Foraminifera' Ann. & Mag. Nat. Hist. ser. 2, vol. iii, pp. 124–25, and in 1852, 'A Systematic Description of the British Palæozoic Fossils in the Geological Museum of the University of Cambridge' p. 110, pl. iii B, figs. 8 & 9, described, under the generic name *Sarcinula*,[2] three 'species' of *Orionastræa*, namely, *S. tuberosa*, *S. placenta*, and *S. phillipsi*. The last he rightly identified with the coral from North Wales figured by J. Phillips. Brief notes upon the type-specimens will be found on pp. 299–300.

H. Milne Edwards & J. Haime, 'Monographie des Polypiers Fossiles' 1851, pp. 448 & 449 and 'A Monograph of the British Fossil Corals' 1852, pp. 203–204, pl. xxxvii, fig. 2, merged *S. phillipsi* and *S. placenta*, and identified these with Martin's coral, but retained as a separate species *S. tuberosa*. Now that I have cut the type-specimens, I consider it more desirable to recognize *S. phillipsi* and *S. placenta* as distinct species, and to merge *S. tuberosa*[3] with the former. Moreover, on grounds

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[1] The name '*radiatus*' has not been retained, for reasons subsequently explained.

[2] J. B. Lamarck, 'Histoire Naturelle des Animaux sans Vertèbres' vol. ii (1816) p. 222 (for two recent forms, one of which he confuses with a Silurian fossil).

[3] H. M. Edwards & J. Haime, 'Polypiers Fossiles des Terrains Paléozoïques' p. 447, include an American species, *P. verneuili* in the same genus; but, arguing from the species so named in the British Museum, I do not consider the form congeneric with the British species.

already adduced (pp. 285 *et seqq.*), these authors restricted the use of A. d'Orbigny's generic name *Phillipsastræa* to these species—by which name they have since been known.

In the same works (pp. 442–43 and p. 193 respectively) Edwards & Haime described a new species of *Lithostrotion (L. ensifer)*, which I propose to include in the genus *Orionastræa*, although acknowledging its equal claim for inclusion in either genus: it constitutes, in fact, the link connecting *Orionastræa phillipsi* with the typical forms of *Lithostrotion*.

James Thomson, in 1883, 'On the Development & Generic Relation of the Corals of the Carboniferous System of Scotland' Proc. Phil. Soc. Glasgow, vol. xiv, pp. 394–96, pl. iv, figs. 1, 1 *a*, 1 *b*, 1 *c*, & 2, recorded *Orionastræa* (as '*Phillipsastræa*') from Blackridge (Linlithgowshire), and thus widened its known area of distribution to include Scotland. Moreover, he demonstrated its instability of character by enumerating the varieties that he obtained from a very limited horizon at that locality, which he stated was the only one in Scotland where the genus had been found.

He specified four varieties, distinguished by the following characters:—

1st variety. Columella absent, tabulæ regular.
2nd do. do. do. do. irregular.
3rd do. do. present.
4th do. do. do. mammilliform surface (=*S. tuberosa* (McCoy)).

He illustrated his description by figures of:

(*a*) a form in which the counter-septum alone invades the intrathecal region, and constitutes a slender and inconstant columella;
(*b*) a form in which several septa unite in the centre of the intrathecal region.

I consider it probable that his varieties 1 & 2 are *O. placenta*, and that 3 & 4 are *O. phillipsi*.

Rudolph Schäfer's (1889) contribution to the literature, 'On *Phillipsastræa* d'Orb., with especial reference to *Phillipsastræa radiata* S. Woodward sp. and *Phillipsastræa tuberosa* McCoy sp.' Geol. Mag. dec. 3, vol. vi, pp. 398–409, pl. xii, has already been discussed (p. 287); wherefore here I merely desire to draw attention to the text-figures on p. 403, representing calices over the floors of which a number of septa have straggled: the figures are intended to demonstrate the absence of a columella. I admit the accuracy of the figures; but unfortunately they illustrate selected calices, while others of the same specimens in which the columella can be detected have been overlooked. Schäfer followed Edwards & Haime in merging McCoy's species *S. phillipsi* and *S. placenta*, and retaining his *S. tuberosa*.

A. Vaughan (1903), 'Notes on the Corals & Brachiopods obtained from the Avon Section & preserved in the Stoddart Collection' Proc. Bristol Nat. Soc. n. s. vol. x, pp. 109–10, included remarks on *Lithostrotion ensifer* Edwards & Haime; and in 1905, in 'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area' Q. J. G. S. vol. lxi, p. 199, he stated the exact palæontological horizon at which the species occurs—namely, the upper part of the *Dibunophyllum* Zone: that is, Subzone of *Lonsdaleia floriformis* (D_2).

ORIONASTRÆA PHILLIPSI (McCoy).

? 1809. *Erismatolithus tubiporites (radiatus)* W. Martin, 'Petrificata Derbiensia' pl. xviii, figs. 2 & 3. [*O. phillipsi* or *O. placenta.*]
? 1828. *Tubipora radiata* (Martin), J. Fleming, 'A History of British Animals' p. 529. [*O. phillipsi* or *O. placenta.*]
? 1830. *Tubipora radiata* (Martin), S. Woodward, 'A Synoptical Table of British Organic Remains' p. 5. [*O. phillipsi* or *O. placenta.*]
1841. 'Specimen from the Mountain Limestone much allied to *Astræa hennahii* Lonsdale' J. Phillips, 'Palæozoic Fossils, &c.' p. 12 & pl. vii, fig. 15 D.
1849. *Sarcinula phillipsi* F. McCoy, Ann. & Mag. Nat. Hist. ser. 2, vol. iii. p. 125.
Sarcinula tuberosa. *Id. ibid.* p. 124.
1850. *Phillipsastræa hennahii* Lonsdale, *partim* A. d'Orbigny, 'Prodrome de Paléontologie' vol. i, p. 107.
1851. *Phillipsastrea radiata* (Martin), H. Milne Edwards & J. Haime, 'Polypiers Fossiles des Terrains Paléozoïques' p. 448.
Phillipsastrea tuberosa (McCoy). *Id. ibid.* p. 449.
1851. *Sarcinula phillipsi* F. McCoy, 'British Palæozoic Fossils' p. 110.
Sarcinula tuberosa. *Id. ibid.* p. 110, pl. iii B, figs. 8 & 8 *a*.
1852. *Phillipsastræa radiata* (Martin), H. Milne Edwards & J. Haime, 'Monograph of the British Fossil Corals' Pal. Soc. p. 203, pl. xxxvii, figs. 2 & 2 *a*.
Phillipsastræa tuberosa (McCoy). *Id. ibid.* p. 204.
1883. *Phillipsastræa radiata* (Martin), J. Thomson, Proc. Phil. Soc. Glasgow, vol. xiv, p. 394, pl. iv. figs. 1, 1 *a*, 1 *b*, & 2.
1885. *Phillipsastræa radiata* (Martin), F. Frech, Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxvii, p. 48.
Phillipsastræa tuberosa (McCoy). *Id. ibid.* p. 48.
1889. *Phillipsastræa radiata* Martin, *partim* R. Schäfer, Geol. Mag. dec. 3, vol. vi, p. 401, pl. xii, figs. 1, 3, 4, 7, 8, & 9, text-figs. 1–3 (p. 403).
Phillipsastræa tuberosa (McCoy). *Id. ibid.* p. 407, text-figs. 4–6 (p. 403).

Phillipsastræa radiata (Martin) includes, in all cases quoted, *Sarcinula phillipsi* and *S. placenta*.

External Characters. (Pl. XXIII, figs. 1, 3, & 4; Pl. XXIV, fig. 2.)

The corallum is typically depressed, and the distal surface is usually flat. Nevertheless, the species occurs in more tumular masses, and may display a mammillate surface (see Pl. XXIII, fig. 4).

The dissepimental tissue, which constitutes the greater part of the skeleton, is often unevenly developed; consequently, the calicular depressions may be near together, or widely separate: these depressions are not infrequently bounded by a sharply-elevated border (Pl. XXIII, fig. 1). A columella is present, and is often prominent.

Epitheca clothes the lower surface of the corallum.

Internal Characters. (Pl. XXIII, figs. 2 & 5; Pl. XXIV, fig. 1.)

Transverse section.—The septa are confluent; the inequality between the minor and the greater number of the major septa is not marked, since only a few of the latter advance far into the intrathecal region; but these longer major septa may extend to the columella. The counter-septum is prolonged into the centre of the corallite, and there dilates to form a conspicuous columella: the swollen axial portion often becomes isolated from the rest of the septum in the ephebic stage. (Many of these features are displayed equally well in the calices as in section.)

The number of septa present ranges from 30 to 40 in all, 15 to 20 in each cycle, and the thecæ, although varying in size, measure on the average 2·5 mm. in diameter.

Longitudinal section.—The tabulæ are conical in form, the columella is persistent, and the dissepiments are fine. The absence of the epithecal boundary to the corallites, and perhaps to a small extent the less uniform disposition of the tabulæ, distinguishes the species from those of *Lithostrotion*.

The foregoing description applies only to more typical examples. The characters enumerated are subject to much variation: a less well-developed axis leads to convergence with *O. placenta*, and less perfect confluence on the part of the septa merges the members of this species with those of *O. ensifer*.

Notes upon the Type-Specimens of *Sarcinula phillipsi* McCoy (genotype) and *S. tuberosa* McCoy in the Sedgwick Museum, Cambridge.

1. Sarcinula phillipsi: Specimens 213*a* & 213*b*; from Corwen, Merionethshire. (Pl. XXIII, figs. 1–3.)

The species was described, but not figured, by McCoy. There are two syntypes mounted on the same tablet, and of these I have chosen the first (213 *a*, Pl. XXIII, fig. 1) as the lectotype. Photographs of both specimens are reproduced in Pl. XXIII, which illustrate sufficiently well the external characters to obviate the necessity of detailed description. The two types of calices present in the specimens should be observed, namely, those in which the theca is marked by a raised border (fig. 1) and those in which the extrathecal region simply rounds off at the intrathecal depression (fig. 3, and certain calices in fig. 1). In the case of 213 *b* (fig. 3) the intrathecal depressions are filled with matrix. The internal characters of the lectotype agree with the general description, and need not here be repeated. The number of septa present ranges from 32 to 40.

2. SARCINULA TUBEROSA: Specimen 212; found in Derbyshire, and presented by W. Hopkins. (Pl. XXIII, figs. 4 & 5.)

The holotype is a silicified specimen, perforated by several large drusy cavities. The coral structures are nevertheless well preserved, and the interstices are but incompletely filled with mineral deposit. The distal surface, which is in a fair state of preservation, displays in a somewhat exaggerated form a mammillate development. The thecæ are slightly larger than usually observed, and the columella is not very prominently shown in the transverse section (Pl. XXIII, fig. 5). The number of septa present is smaller than is generally the case, being only about 30: otherwise the characters of this form are in agreement with those of *O. phillipsi*.

Its one pronounced and distinguishing feature—the mammilliform calices—may be found associated in a single corallum with calices of the types illustrated as typical of *O. phillipsi*. It seems therefore inadvisable to regard the form, simply because of its external characters, as a separate and distinct species.

McCoy illustrated (from a fragment of the type) what he conceived to be the internal characters of the species ('British Palæozoic Fossils' pl. iii B, fig. 8 *a*), but he omitted the columella, and showed the tabulæ as concave—an idea probably due to the tangential nature of the sections, which missed the former, and incompletely displayed the character of the latter.

ORIONASTRÆA PLACENTA (McCoy).

1849. *Sarcinula placenta* F. McCoy, Ann. & Mag. Nat. Hist. ser. 2, vol. iii, p. 124.

1851. *Sarcinula placenta* F. McCoy, 'British Palæozoic Fossils' p. 110 & pl. iii B, figs. 9, 9 *a*, 9 *b*.

See also synonymy and notes on *O. phillipsi*.

O. placenta differs from *O. phillipsi* solely in the absence of a columella, and consequently in the form of the tabulæ, which, deprived of their axial support, are concave instead of being conical. The major and the minor septa are almost equal in length, the former advancing very little farther beyond the theca than do the latter.

O. placenta bears the same relationship to *O. phillipsi* as the non-columellate forms of *Lithostrotion* (*Diphyphyllum* and *Stylastræa*)[1] do to the columellate forms.

At certain horizons (for example, at the base of the Great Limestone around Chollerford, South Northumberland) '*Diphyphyllum*' not infrequently occurs to the exclusion of *Lithostrotion* locally. It is conceivable that similarly *O. placenta* may subsequently be found, to the exclusion of *O. phillipsi*, at some particular place or level.

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[1] See W. Lonsdale, in R. I. Murchison's 'Geology of Russia, &c.' vol. i (1845) pp. 619 & 624: *Diphyphyllum* refers to the fasciculate, and *Stylastræa* to the massive, variety.

Notes upon the Holotype of the Species in the Sedgwick Museum, Cambridge, No. 211, presented to the Collection by W. Hopkins. (Pl. XXIII, figs. 6 & 7.)

The type-specimen of *Sarcinula placenta* McCoy is part of a depressed corallum measuring some 6 by 4 cm., and is about 2 cm. thick. Both the upper and the lower surfaces are remarkably flat. For the greater part, the coral interstices are free from mineral deposit, and consequently the material is very friable. Along certain planes, however, it is highly silicified, being then converted into thin bands of chert. Superficially, the fossil is stained a deep red.

The thecæ measure about 2 mm. in diameter, and are fairly regularly spaced, the interval between them averaging 4 to 5 mm. None of the septa invade the intrathecal region, and there is no columella. In consequence of the absence of a columella, the tabulæ are concave, but are somewhat irregular in habit.

In this specimen it may be observed that the thecæ are somewhat smaller than in the average examples, and the number of septa correspondingly less—about 25.

Attention must be drawn to the striking resemblance of this type to Martin's figure of *Erismatolithus radiatus.* In mode of preservation it would seem identical with the specimen illustrated in 'Petrificata Derbiensia.' Unfortunately, since we know nothing of the intrathecal character of Martin's coral, it is impossible to identify McCoy's type with Martin's figure, although the presumption is that they are the same.

ORIONASTRÆA ENSIFER (Edwards & Haime).

1851. *Lithostrotion ensifer* H. Milne Edwards & J. Haime, 'Polypiers Fossiles des Terrains Paléozoïques' p. 442.
1852. *Lithostrotion ensifer* H. Milne Edwards & J. Haime, 'Monograph of the British Fossil Corals' Pal. Soc. p. 193 & pl. xxxvii, figs. 2, 2 *a*.
1889. *Phillipsastræa radiata* (Martin), *partim* R. Schäfer, Geol. Mag. dec. 3, vol. vi, pp. 401–407 & pl. xii, figs. 2, 5, ? 6.
1903. *Lithostrotion ensifer* Edwards & Haime, A. Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x, p. 109.
1905. *Lithostrotion ensifer* Edwards & Haime, A. Vaughan, Q. J. G. S. vol. lxi, p. 199.

The specimens upon which Edwards & Haime established the species came from Bristol, and were preserved in the British Museum. The identification of these is not possible; nevertheless, there are several specimens which were in that collection at the time when these authors were engaged upon their researches. The figures and descriptions given by them leave no room for doubt as to the identity of the species. They drew attention to its resemblance to '*Phillipsastræa*' (that is, *Orionastræa*), and remarked that 'in this fossil the columella is more prominent than in any other species of the same genus, and the walls much thinner.' I cannot quite agree with the statement concerning the columella, although

I admit that the prominence of this axis is a characteristic feature of the species.

The material examined by Schäfer included specimens of *Orionastræa ensifer* from Bristol, as well as of *O. phillipsi* and *O. placenta* from North Wales and Derbyshire. The Bristol specimen (No. 56740, British Museum), which he figured as '*P. radiata*,' could be referred almost equally as well to *O. phillipsi* as to *O. ensifer*; but I consider it to belong to the latter, rather than to the former species.

O. ensifer is considerably less differentiated from the species of *Lithostrotion* than is the genotype *O. phillipsi*, and constitutes, as previously suggested, the passage-form between *Lithostrotion* and *Orionastræa*. Characters not described here may be taken to be in agreement with those of the genotype.

External Characters. (Pl. XXIV, fig. 5.)

The corallum has the same general form and characters as *O. phillipsi*, except in regard to the distal surface; in this it differs very slightly from *Lithostrotion basaltiforme*. The individual calices are clearly defined, and each is divisible into an intrathecal depression and an extrathecal platform. The latter is broad and sloping, and meets that of the contiguous corallites in a sharp ridge.

In *Lithostrotion* this ridge is surmounted by a distinct wall of epitheca, and it is in the absence or weak development of this that *O. ensifer* is distinguished from the massive forms of *Lithostrotion*. Calices of the two genera are figured in juxtaposition for the purpose of comparison (Pl. XXIV, figs. 5 & 6).

Internal Characters. (Pl. XXIV, figs. 3 & 4.)

A thin epitheca may divide the corallites; but, if present at all, it is usually reduced to a palisading of isolated rods which in transverse section present a line of dots. The septa never attain a confluent condition. The number of septa present is a fairly constant character: the number, including both series, closely approximates to 36. The major septa extend farther into the intrathecal region than those of *O. phillipsi* generally do, and are much more uniform in their length. The minor septa, on the other hand, are but feebly developed. The columella is persistent and stoutly built, but this axis is not found swollen to the extent sometimes observed in *O. phillipsi*. The thecæ usually measure about 2·5 mm. in diameter, but I have examined a specimen in which this measurement attained 4 mm. and in which the extrathecal region was proportionately wide, yet the number of septa present was the same as in the forms of more usual size.

Summary of Specific Characters, and Table showing the Distribution of the Genus *Urionastræa*.

The distinguishing characters of the three species may be summarized as follows:—

1. *O. ensifer* .... Septa not confluent; columella present.
2. *O. phillipsi* .... Septa confluent; columella present.
3. *O. placenta* .... Septa confluent; columella absent.

Table.

Horizon.	*Locality.*	*Species.*	*Remarks.*	*Material examined or sources of information.*
D_2	Bristol and neighbourhood (Avon Gorge). Wrington, Wick, etc.	*O. ensifer.* *O. phillipsi.*	Plentiful. Much rarer.	Specimens in the British Museum, largely the gift of Mr. Swinfen Jordan and Mr. S. G. Perceval, but they include some collected by Dr. A. Vaughan, Prof. T. F. Sibly, and others.
D_2 or D_3 ...... Upper Grey Limestone.	North Wales, principally Hafod-y-Calch, Corwen, but also Llangollen, Mold, and Minera.	*O. phillipsi.* *O. placenta.* *O. ensifer.* Most specimens must be ascribed to *O. phillipsi*, a few to *O. placenta*, and one or two to *O. ensifer.*	Plentiful. Rare. Rare.	Specimens in the British Museum, mainly collected by Mr. G. H. Morton; others in the Sedgwick Museum, Cambridge, the Museum of Practical Geology, and elsewhere.
D_2 or D_3	Derbyshire. Locality unknown.	*O. phillipsi.* *O. placenta.*	Rare.	One specimen only. One specimen only. Both in the Sedgwick Museum, Cambridge, presented by Mr. W. Hopkins.
	Winster.	*Orionastræa* sp.		Specimen figured by W. Martin, the whereabouts of which is not known.
D_2 .... 'Fourth Limestone.'	Cumberland. Salter Hall, Egremont.	*O. ensifer.*	Rare.	One specimen collected by Mr. Charles Edmonds.
D_2 .... 'Tyne Bottom Limestone.'	Westmorland. High Cup Gill.	*O. phillipsi.*	Rare.	One specimen collected by Prof. E. J. Garwood, but not found *in situ.*
D_3	Scotland. Blackridge (Linlithgowshire).	*O. phillipsi, O. placenta* and intermediate forms.	Plentiful.	Specimens in the Collection of the Geological Survey of Scotland. Information supplied by the record and descriptions of the forms, as given by James Thomson.
	Kirtlebridge, south-east of Lockerbie (Dumfries-shire).	*Orionastræa* sp.		Single (poor) section in the Glasgow Museum.

VII. NOTES ON *CYATHOPHYLLUM REGIUM* AND ON *KONINCKOPHYLLUM* SP.

For description and figures of *Cyathophyllum regium* Phillips, the 'Monograph on British Fossil Corals,' by Edwards & Haime, may be consulted, p. 180, pl. xxxii. It is merely necessary here to point out one or two features of special interest in connexion with the present discussion, some of which are not mentioned by those authors.

Although a thin wall of epitheca may separate the corallites, this mural development is more often absent than present, and the corallites are then united by their dissepimental tissue; in some cases, where there is no epitheca, the septa of one corallite do not reach those of their neighbours.

The coralla of *C. regium* are, like those of *Aulina* and *Orionastræa*, characteristically depressed; but to these there are some interesting exceptions: attenuated cylindrical corallites are found attached together into small groups of twos and threes, but otherwise identical with *C. murchisoni* or *C. stutchburyi* (denoting by these names the smaller and larger varieties of the solitary forms); these link *C. regium* with the solitary 'species.' Even in such forms as these the epitheca is generally absent at the junction of two individuals. These Carboniferous species of *Cyathophyllum* are distinguished by the great number and the correspondingly slender nature of their septa; and the epitheca, even in the simple forms, is very thin. It is not surprising that it should disappear altogether between contiguous corallites.

[It may be observed that, in corals in which the number of septa is small, these are stout, and the corallite is clothed by a thick epitheca (as, for example, *Zaphrentis*); but, where they are numerous (as, for example, in *Cyathophyllum murchisoni*), they are slender, and the epitheca is lightly developed.]

The form *Koninckophyllum* sp. was obtained by Mr. S. C. Perceval from beds exposed in Rhododendron Walk, Blaize-Castle Wood, Henbury, north of Bristol, the horizon of which was determined by Vaughan as the Subzone of *Lonsdaleia floriformis*, D_2. The specimens now in the British Museum (Natural History)—R 16985–88, R 16991, and R 17066—are in a very poor state of preservation, and it is therefore advisable to defer the attribution of a name to the species, or even a detailed description of it, until more perfect material is forthcoming.

The corallites measure about 1·5 cm. in diameter; the septa are numerous, but the minor series are much shorter than the major. The tabulæ are shallow concave diaphragms. Although the corallites are not separated by epitheca, the septa are not confluent, and the individual calices are distinct.

EXPLANATION OF PLATES XXII–XXIV.

Plate XXII.

Phillipsastræa and *Aulina*.

Figs. 1–4. *Phillipsastræa hennahi* (Lonsdale). Holotype of *Astræa hennahi*. Upper Devonian. Barton (Devon). Museum of Practical Geology, Jermyn Street, London. No. 6185 and Sections 28348–28349. (See p. 288.)

Fig. 1. External surface of No. 6185. Natural size.
2. Transverse section (28348). Natural size.
3. The same. × 6.
4. Longitudinal section (28349). × 2·5.

Fig. 5. *Phillipsastræa* sp. (cf. *Acervularia coronata* Edwards & Haime, 'British Fossil Corals' Monogr. Pal. Soc. pl. liii, fig. 4 *b*). Transverse section showing dilatation of the axial edges of the septa. ×4. Upper Devonian. Devon. British Museum (Natural History), R 5632 (Vicary Collection). (See p. 286.)

6. *Aulina rotiformis*, sp. nov. Paratype. Transverse section. × 5. Fell Top Limestone. Harlow Hill (Northumberland). British Museum (Natural History), R 17714. Collected by the Author. (See p. 291.)

7. The same. Natural size.

8. *Aulina rotiformis*, sp. nov. Longitudinal section. × 2. Botany Beds, Hurdorthwaite Moor. British Museum (Natural History), R 17716. Collected by Prof. E. J. Garwood.

Figs. 9–11. *Aulina rotiformis*, sp. nov. Showing earliest growth-stages of the corallite. × 5. (Same section as figs. 6 & 7.)

Plate XXIII.

Orionastræa.

All forms are from the upper part of the *Dibunophyllum* Zone.

Fig. 1. *Orionastræa phillipsi* (McCoy). Lectotype. Distal surface. Natural size. Hafod-y-Calch, Corwen. Sedgwick Museum, Cambridge, No. 213 *a*. (See p. 298.)

2. Transverse section of the above. Natural size.

3. *Orionastræa phillipsi* (McCoy). Distal surface. Hafod-y-Calch, Corwen. Natural size. Sedgwick Museum, Cambridge, No. 213 *b*. Specimen labelled as having been figured by Edwards & Haime, in 'British Fossil Corals' Monogr. Pal. Soc. pl. xxxvii, fig. 2. Nos. 213 *a* & 213 *b* (two specimens mounted on the same tablet) are the type-specimens of *Sarcinula phillipsi* McCoy, but the species was not figured by him.

4. *Orionastræa phillipsi* (McCoy). Type-specimen of *Sarcinula tuberosa* McCoy. Distal surface. Natural size. Derbyshire. Sedgwick Museum, Cambridge, No. 212. (Presented by W. Hopkins.)

5. Transverse section of the above. Natural size. (See p. 300.)

6. *Orionastræa placenta* (McCoy). Holotype of *Sarcinula placenta* McCoy. Distal surface. Natural size. Derbyshire. Sedgwick Museum, Cambridge, No. 211. (Presented by W. Hopkins.)

7. Transverse section of the same. × 3. (See p. 301.)

8. *Orionastræa placenta* (McCoy). Transverse section. × 2. Upper Grey Limestone. Llangollen. British Museum, R 4412 (G. H. Morton Collection).

9. Longitudinal section of the same specimen. × 2.

PLATE XXIV.

Orionastræa and *Lithostrotion.*

All forms are from the upper part of the *Dibunophyllum* Zone.

Fig. 1. *Orionastræa phillipsi* (McCoy). Transverse section. × 2. Upper Grey Limestone. Hafod-y-Calch, Corwen. British Museum (Natural History), R 4510 (G. H. Morton Collection). A typical section of the species. (See p. 299.)

2. *Orionastræa phillipsi* (McCoy). Distal surface. Natural size. Hafod-y-Calch, Corwen. British Museum (Natural History), R 4575 (G. H. Morton Collection). This specimen illustrates the variability of distal characters. (See p. 298.)

3. *Orionastræa ensifer* (Edwards & Haime). Neotype. Transverse section. × 2. Clifton, Bristol. British Museum (Natural History), R 17084 (S. G. Perceval Collection). (See p. 302.)

4. *Orionastræa ensifer* (Edwards & Haime). Longitudinal section. × 2. South-West of England. British Museum (Natural History), R 17087 (S. G. Perceval Collection).

This also illustrates a characteristic longitudinal section of *O. phillipsi.* (On account of their tortuous mode of growth, great difficulty has been encountered in obtaining an accurate medial section through the corallites of the corals for more than a short distance, as seen in the present case.)

5. *Orionastræa ensifer* (Edwards & Haime). Distal surface of the neotype (R 17084). Natural size. (See p. 302.)

6. *Lithostrotion basaltiforme* auctt. Distal surface. Clifton, Bristol. Natural size. British Museum (Natural History), R 4547 (G. H. Morton Collection). (See p. 302.)

The figure is here included, in order to illustrate the difference between *Lithostrotion,* with its well-developed epitheca separating the individual calices, and *Orionastræa ensifer,* in which the calices merely meet in a sharp ridge.

DISCUSSION.

Prof. E. J. GARWOOD congratulated the Author on a further contribution to the good work that he had already done in revising different groups of Lower Carboniferous corals. He quite agreed with him that the form, generally known as '*Phillipsastræa*' *radiata*, which occurs in the Botany Beds in Yorkshire and also in the Fell Top Limestone of Northumberland, was a distinct form apparently limited to a high horizon in the Yorkshire beds, and he had himself used it as a zonal index for this horizon. He pointed out that at Botany the beds still contain abundant examples of Dibunophyllids and other well-known marine Lower Carboniferous forms, although they occur some 200 feet above the base of the Millstone Grit Series of the Geological Survey maps. It was obvious, therefore, that, however useful it might be for economic purposes to represent the arenaceous occurrences by a special colour, this sandy episode entered in different districts at different periods, and could not be used as a definite stratigraphical horizon dividing the Lower from the Upper Carboniferous rocks.

Prof. T. F. SIBLY wished to compliment the Author on the completion of yet another excellent palæontological investigation, and

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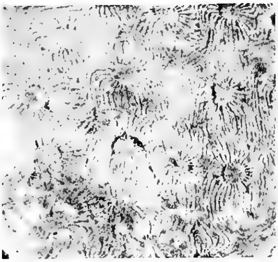

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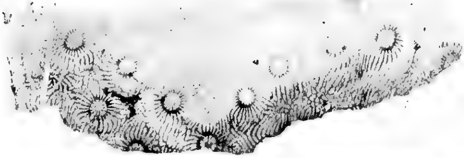

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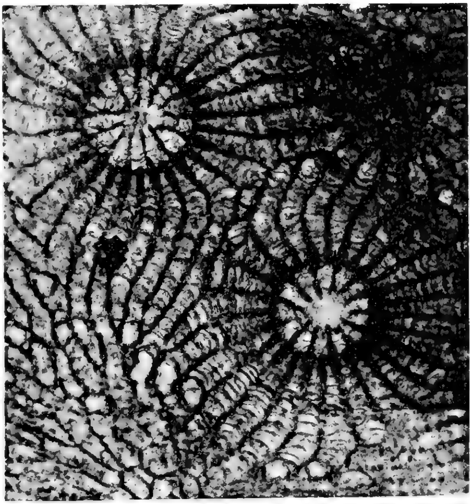

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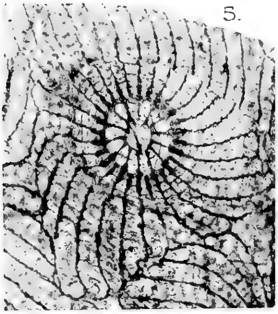

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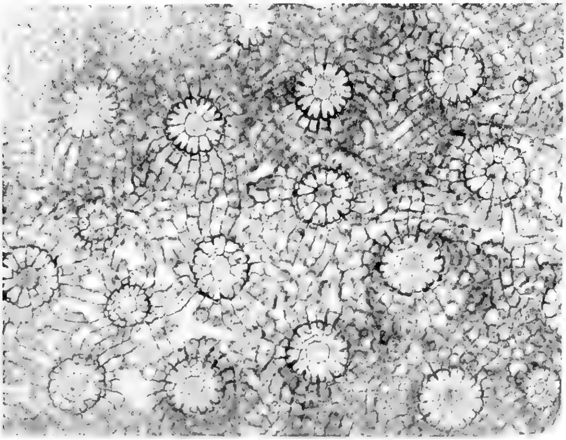

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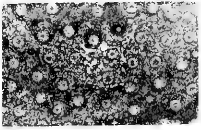

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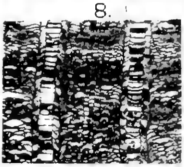

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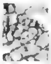

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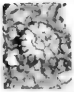

W. Tams, Photo. [exc. fig I].

Bemrose, Collo., Derby

PHILLIPSASTRÆA AND AULINA.

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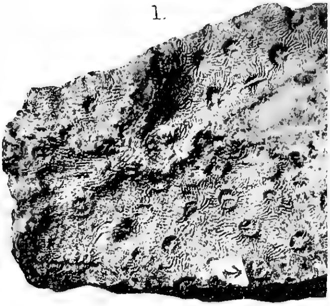

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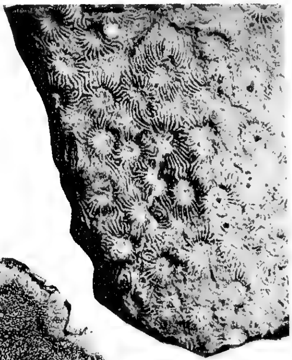

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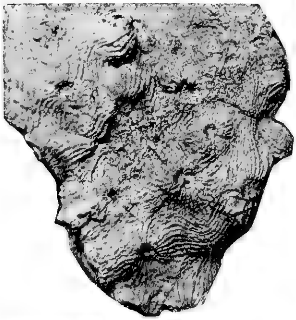

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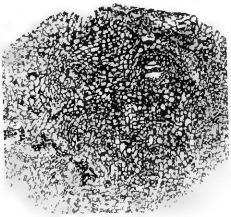

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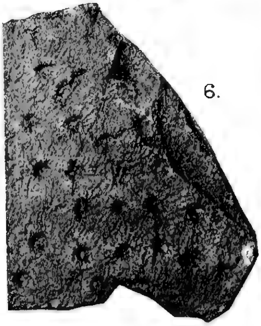

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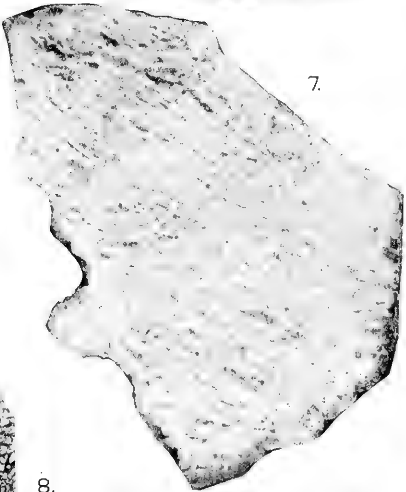

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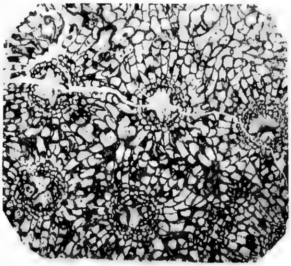

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W. Tams, Photo. [exc. fig. 7].

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ORIONASTRÆA.

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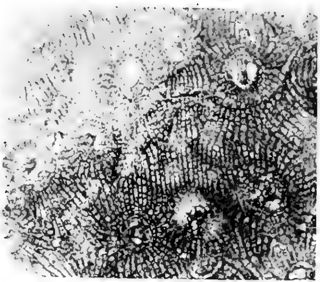

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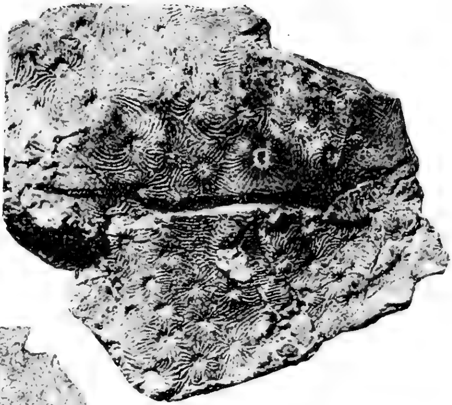

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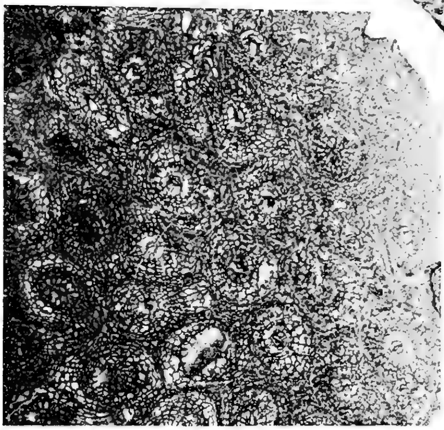

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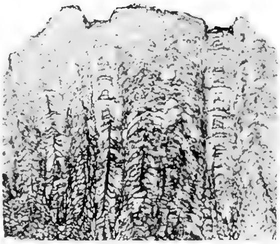

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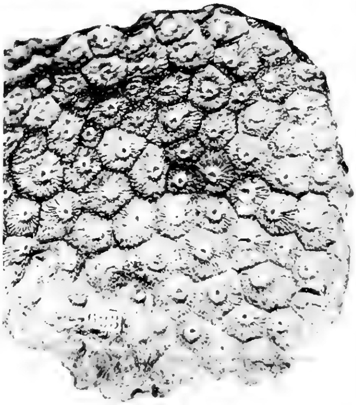

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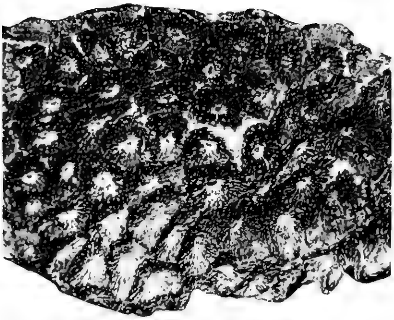

W. Tams, Photo.

Bemrose, Collo. Derby.

ORIONASTRÆA AND LITHOSTROTION.

to take the opportunity of expressing his appreciation of the high value of the Author's researches to the stratigrapher as well as to the palæontologist. It seemed not unlikely that the species of *Orionastræa* and *Aulina* described by the Author would provide a means of more precise subdivision and correlation of the highest beds of the Lower Carboniferous, and the speaker would be glad to hear more about the distribution of these corals. He hoped that the Author's researches would be continued, and extended to Devonian corals as well as to other Carboniferous types.

Mr. C. B. WEDD remarked upon the interest of these corals as appearing at very high horizons of the Carboniferous Limestone Series, and presumably at the highest coralliferous horizon in the Carboniferous of this country. He compared the coral-sequence suggested by these forms to that of Central Russia, where the lower limestones overlying the coal-bearing strata show an unmistakable *Dibunophyllum* fauna, while higher limestones contain quite a different coral-assemblage, including several species assigned to *Phillipsastræa*.

Dr. F. A. BATHER asked whether the inner tube of *Aulina* could be explained as an adaptive character due to the environment, or whether it was purely an increase of calcification, inevitable with the passage of time. Only in the latter aspect could it safely be regarded as a certain guide to the correlation of previously uncorrelated beds.

Dr. F. L. KITCHIN also spoke.

The AUTHOR, in reply to Dr. Kitchin, stated that all the species of *Orionastræa* occurred at the same horizon—the upper part of the *Dibunophyllum* Zone. *O. ensifer* is the characteristic form of the South-Western Province, whereas *O. phillipsi* and *O. placenta* occur associated together in North Wales and other regions of the more northern province, almost to the exclusion of *O. ensifer*.

Answering Dr. Bather, he said that the internal structure of *Aulina* points to evolution from a simpler Phillipsastræid type, but in the general form and character of the colonies of *Aulina*, *Orionastræa*, and *Cyathophyllum regium* there is evidence of environmental influences affecting several stocks similarly.

He thanked the Fellows for their kind reception of his paper, and for the remarks that had been made by Prof. Garwood, Prof. Sibly, and other speakers.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXXII.

[December 31st, 1917.]

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

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CONTENTS.

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